VI. "Preliminary Report to Professor Wyville Thomson, F.R.S., Director of the Civilian Scientific Staff, on Work (Chemical and Geological) done on board H.M.S. 'Challenger.' By J. Y. Buchanan, Chemist and Physicist to the Expedition. Communicated by Professor Wyville Thomson, F.R.S. Received March 7, 1876. Read March 16.

The following Preliminary Report on my work on board the 'Challenger' during the last three years has been drawn up in compliance with a request on the part of Professor Wyville Thomson, which was communicated to me on the 23rd June, 1875. As my time at sea is fully occupied with the daily laboratory work, I was obliged to postpone preparation of the report until our arrival at Valparaiso, where the whole of my time was devoted to it. Three weeks, however, is too short a time to prepare even a preliminary report with satisfaction, and there are doubtless many things in the present one for which I must crave indulgence. In venturing to publish the few geological notes which I have embodied, I feel that a special apology is required, as my knowledge of rocks is, at best, but superficial. I was emboldened to do so, however, by considering that the islands to which the notes refer are principally such as are but seldom visited by any one, and that, as it was my good fortune to be able to visit them, it was right that I should make what observations I could and record them, in case amongst them there might be some which would be of value to the geologist.

Observations on the Specific Gravity of Sea-water.

As the value of these results depends to a great extent on the nature of the means taken to collect the water, and on the delicacy of the instrument used for determining its specific gravity, I shall shortly describe them both.

The samples of water are collected either in an ordinary canvas bucket, or in one of two kinds of metal "water-bottle," according as it is to be taken from the surface or from depths below it. The use of the ordinary hand-bucket needs no explanation. When water is to be obtained from the bottom, the "slip" water-bottle is used. This instrument is a Swedish invention, improved by Dr. Meyer, of Kiel, who without doubt has described it, and by Messrs. Milne, of Edinburgh, who furnished those on board the 'Challenger.'

Water from intermediate depths is obtained in a much lighter instrument, which, with a drawing and the method of using it, is fully described in a paper presented to the Royal Society in the early part of 1875, of which an abstract has been published in the 'Proceedings,' No. 160. It consists of a metal cylinder furnished with stopcocks at both ends. The levers by which these stopcocks are turned are con-

nected by a straight rod, so that they are simultaneously either open or shut, or at least at the same phase of being open or shut. When water is to be collected by its means, the stopcocks are opened and the instrument sunk to the required depth, having been previously securely fastened to a sounding-line. The operation of sinking must be carried on without a check, owing to the peculiarity of the closing-apparatus. When the required depth has been reached, the line is checked, hauled in a few fathoms, let go again, and finally brought to the surface by means of a donkey-engine. The rod connecting the stopcocks is furnished with a metal plate, which, during the descent, is retained in a vertical position by the passage of the water on both sides of it. When, however, the direction of motion is reversed, the plate falls down into a horizontal position, when, by its passage through the water, it exercises such a downward pressure on the rod that the stopcocks are closed. Arrived at the surface, it contains the water which it had enclosed at the depth in question. A small safety-valve allows of the escape of the surplus water, which, owing to the greater density of the water below the surface, it has enclosed in excess of what it can hold at atmospheric temperature and pressure. The apertures of the stopcocks being necessarily smaller than the diameter of the cylinder, the efficiency of the instrument in really changing the water as it descends was tested before leaving England in a freshwater lake, the water with which it was filled at the surface containing some yellow prussiate of potash. It was found that the water fetched, under these circumstances, from depths over $1\frac{1}{2}$ fathom was unacted upon by solution of perchloride of iron. The rate, therefore, of change of water is satisfactory, as we can be certain of obtaining an average sample of the last two fathoms passed through by the instrument.

Representing the specific gravity of distilled water at 4° C. by 100,000, I found that of ocean water at 15°·56 C. to vary between the extremes of 102780 and 102400; so that, to be of any value at all, the possible error in the results must not exceed 10. The hydrometer used for these observations is fully described in the paper above referred to. Its description is briefly as follows:—

The stem, which carries a millimetre-scale 10 centimetres long, has an outside diameter of about 3 millimetres, the external volume of the divided portion being 0·8607 cubic centimetre; the mean volume of the body is 160·15 cubic centimetres, and the weight of the glass instrument is 160·0405 grammes. With this volume and weight it floats in distilled water of 16° C., at about the lowest division (100) of the scale. In order to make it serviceable for heavier waters, a small brass table is made to rest on the top of the stem, of such a weight that it depresses the instrument in distilled water of 16° C. to about the topmost division (0) of the scale. By means of a series of six weights, multiples by 1, 2, 3, 4, 5, and 6 of the weight of the table, specific gravities between

1·00000 and 1·03400 can be observed. It is not necessary that these weights should be accurate multiples of the weight of the table; it is sufficient if they approach it within a centigramme, and their actual weight be known with accuracy. The weights of the table and weights in actual use are:—

Weight of table	0·8360	gramme.
Weight of weight No. I.	0·8560	"
" " II.	1·6010	"
" " III.	2·4225	grammes.
" " IV.	3·1245	"
" " V.	4·0710	"
" " VI.	4·8245	"

For oceanic waters the hydrometer is always used with the table and either No. IV. or No. V. weight.

When the mechanical part of the construction of the instrument was finished, with the exception of the closing of the top of the stem (which instead was widened into a funnel-shape large enough to receive the ordinary decigramme weights), the calibration of the stem was effected by loading the stem with successive weights, and observing the consequent depressions in distilled water of known temperature. This done, the top was sealed up and the instrument carefully weighed. The expansion of the body with temperature was determined in a similar manner by reading the instrument in distilled water of various temperatures. The coefficient of expansion of the glass was then found to be 0·000029 per degree Centigrade.

For using this instrument at sea about 900 cub. centimetres of sea-water are taken, and the containing cylinder placed on a swinging table in a position as near the centre of the ship as possible. The observation with the hydrometer, loaded with the necessary table and weight, is then effected in the ordinary way, the accuracy of the readings being but little affected by rolling; pitching, however, is found to have a distinctly disturbing effect; and when it is in any way violent, it is advisable to store the specimen of water till the weather improves.

The temperature of the water at the time of observation is determined by one of Geissler's "normal" or standard thermometers, graduated into tenths of a degree Centigrade; and it is essential for the accuracy of the results that the water, during the observation of the hydrometer, should be sensibly at the same temperature as the atmosphere, otherwise the changing temperature of the water makes the readings of both the hydrometer and the thermometer uncertain. At low temperatures (below 10° or 12° C.) a tenth of a degree makes no sensible difference in the resulting specific gravity; but at the high temperatures always found at the surface of tropical seas, rising sometimes to 30° C., the same difference of temperature may make a difference of 3 to 4 in the resulting specific gravity.

Having obtained the specific gravity of the water in question at a temperature which depends upon that of the air at the time, it is necessary, in order that the results may be comparable, to reduce them to their values at one common temperature. For this purpose a knowledge of the law of expansion of sea-water with temperature is necessary. This had been determined with sufficient accuracy for low temperatures by Despretz and others; but as the temperatures at which specific-gravity observations are usually made are comparatively high, their results were of but little use, directed as they were chiefly to the determination of the freezing and maximum-density points. When the late Captain Maury was developing his theory of oceanic circulation, owing to difference of density of the water in its different parts, he found the want of information on this important subject. At his request the late Professor Hubbard, of the National Observatory, U.S., instituted a series of experiments, from which he was enabled to lay down a curve of the volumes of sea-water at all temperatures from considerably below the freezing-point to much above what obtains even in the hottest seas. The results are published in Maury's 'Sailing Directions,' 1858, vol. i. p. 237, and have evidently been carried out with great care. The composition of different oceanic waters varies, even in extreme cases, within such close limits, that the law of thermal expansion is sensibly the same for all of them; of this Hubbard's experiments afford satisfactory proof. In the Table which gives the results of all his experiments he takes the volume of water at 60° F. as his unit. In order to avoid much useless calculation, I have been in the habit of reducing my results to the same temperature (15°·56 C.), while, for a like reason, I have retained the specific gravity of distilled water at 4° C. as the unit. The choice of a common temperature to which the results should be reduced, and of a unit of specific gravities, is a purely conventional matter; and in choosing the above-mentioned ones, in the first instance, I was moved solely by a desire to save calculation. For every water, however, there is one temperature to which it would be *natural* to reduce its specific gravity, namely, the temperature which the water had when in its place in the ocean; and in this sense all my results during the cruise have been reduced. Hubbard's Table of the change of volume of a mass of sea-water with change of temperature enables us very easily to reduce any observed specific gravity from the temperature of observation to any other temperature, say 15°·56 C. In the paper it is transcribed from the 'Sailing Directions.'

In the following Table the volumes for every Centigrade degree from $-1°$ C. to $+30°$ C. are given:—

Temp. ° C.	Volume.	Temp. ° C.	Volume.	Temp. ° C.	Volume.	Temp. ° C.	Volume.
−1	0·99792	+7	0·99853	+15	0·99987	+23	1·00194
0	795	8	866	16	1·00010	24	224
+1	799	9	878	17	034	25	256
2	804	10	893	18	059	26	288
3	812	11	910	19	086	27	320
4	820	12	927	20	111	28	352
5	830	13	947	21	137	29	385
6	840	14	967	22	164	30	420

By means of the results given in this Table a chart of isothermals was constructed, giving by inspection, as soon as the specific gravity at any one temperature is known, its reduced values at any other. In this way the specific gravity of every water has been reduced to its value at 15°·56 C. and at the temperature which it possessed when in its place in the sea.

The results obtained since leaving Teneriffe on 15th February, 1873, are given in a series of Tables, in which those relating to surface-water are collected together and grouped in sections, as Teneriffe to St. Thomas's, St. Thomas's *viâ* Halifax to Bermuda, and so on. Those relating to bottom-water are collected in larger groups—the first containing all those observed in the Atlantic, the second those in the Southern, the third thôse on the western side of the Pacific Ocean, and the fourth those observed between Japan and Valparaiso. Where series of observations on waters from intermediate depths have been obtained, each series is given by itself. By far the greater number of the observations relate to surface-water, the specific gravity of which was, as a rule, taken once a day when at sea, the temperature of the water being at the same time observed with the standard thermometer above mentioned.

With a single exception, off the coast of Brazil, the densest water which we have met with in the ocean was found on the section from Teneriffe to St. Thomas's in the heart of the north-east trade-wind territory, where, from the strength and dryness of the wind, the amount of evaporation must be very large. Round about the Canary Islands the mean specific gravity was found to be 1·02730; to the westward it rises steadily until in longitude 28° W. it has reached 1·02762. Between longitude 28° W. and 54° W. the mean specific gravity is 1·02773, the maximum being 1·02781. On approaching the West Indies it rapidly falls off to an average of 1·02719 in the neighbourhood of St. Thomas's; and if we take into account all the observations made on the western side of the Atlantic, from St. Thomas's northward to the edge of the cold

water which separates the Gulf-stream from the coast of America, we obtain the same average, 1·02719. Between Bermuda and the Azores an almost perfectly uniform specific gravity was observed, the mean being 1·02713, and the extremes 1·02694 and 1·02727. As Madeira is approached the specific gravity rises until it reaches 1·02746 close to the island itself. The mean specific gravity on the eastern side of the North Atlantic, between the latitude of St. Thomas's and that of the Azores, is 1·02727, or slightly higher than that of the water on the western side.

After leaving the Cape-Verd Islands, the ship's course lay almost parallel to the African coast, and at an average distance of about 200 miles from it. Proceeding thus in a south-easterly direction, the specific gravity fell rapidly from 1·02692 off St. Iago on the 10th August, to 1·02632 on the 12th, after which it retained the low mean specific gravity of 1·02627 until the 21st August, when the course was changed to a westerly one along the equator. The specific gravity of the water on this day was the lowest hitherto registered for a surface-water; it was 1·02601, in lat. 3° 8′ N., and on the boundary line between the equatorial and Guinea currents. The same low specific gravity was observed in following the equatorial current as far as St. Paul's rocks, after which it quickly rose as the Brazilian coast was approached; and the maximum of 1·02786 was obtained on the 26th September, when off the entrance to Bahia, in latitude 13° 4′ S.

The observations in the South Atlantic were limited to a line down the western side as far as the Abrolhos Bank, and thence across to the Cape of Good Hope. In the region of the south-east trade-wind, therefore, we have only a few observations close to the coast; and as we have seen in the North Atlantic, on the voyage from Teneriffe to St. Thomas's, the specific gravity is higher in mid-ocean than either on the east or the west side, so in the South Atlantic it is possible that the same may hold good. From the Abrolhos Bank to Tristan d'Acunha the specific gravity sinks steadily from 1·02785 to 1·02606, and from Tristan to the Cape of Good Hope, along a course lying between the 35th and the 37th parallels of south latitude, the mean specific gravity was 1·02624. Between the same parallels of north latitude the mean specific gravity was 1·02713.

It must be remembered that the results obtained can only be held good for the season of the year in which they were observed, and that the observations in different latitudes were made in different seasons, and, further, that all the observations north of the line as far as 20° N. were obtained on the eastern side, and those to the southward of it as far as 30° S. were obtained on the western side of the ocean; so that it would be unwise to attempt to draw any general conclusions from such imperfect data. Considering, however, our four parallel sections, we have at least this positive result—that in the month of June and mean latitude 36° N. the surface-water in mid-ocean has a

mean specific gravity of 1·02713, that in the months of February and March and mean latitude 22° N. the mean surface specific gravity is 1·02773, that in the month of August and mean latitude 2° N. it is 1·02624, and that in the month of October in mean latitude 36° S. it is 1·02621.

On the way to and from Halifax in the month of May some observations were obtained in the cold water with which the north-eastern coast of America is surrounded, the mean specific gravity being 1·02463. On the 1st May in the Gulf-stream the specific gravity of the water was 1·02675, and its temperature 23°·9 C.; and the next day it was 1·02538, and the temperature 13°·3 C. If the results be reduced to their values at the respective temperatures of the different waters, we have for the specific gravity of the Gulf-stream water 1·02445, and of Labrador-current water 1·02584; so that the fall of temperature very much more than counterbalances the want of salt in the water. In the same way we find the mean specific gravity of the water referred to the temperature which it has in the ocean to be—in latitude 36° N. and month of June 1·02548, in 22° N. and months of February and March 1·02592, in 2° N. and month of August 1·02335, and in 36° S. and month of October 1·02659.

Leaving Simon's Bay on the 17th December, 1873, the ship proceeded in the direction of the Marion Islands. Immediately outside the Cape the warm water of the Agulhas current was met with, which possessed a comparatively high specific gravity, averaging on the 18th, 19th, and 20th December 1·02657 at 15°·56 C., and 1·02477 at the average temperature (21°·9 C.) of the water. As we advanced in a southerly direction, the specific gravity as well as the temperature sank rapidly; and on the 26th, when off the misty and snow-capped islands of Marion and Prince Edward, the surface was 5°·3 C. and the sp. gr. 1·02518. After leaving these islands, and until on the way northward to Australia we had passed the 50th parallel of south latitude, the specific gravity of the surface remained remarkably uniform. Between the Marion Islands and Kerguelen's Land the average specific gravity was 1·02512, between Kerguelen's and the edge of the pack-ice it was 1·02506, along the verge of the pack-ice it was 1·02476, and between the pack-ice and the 50th parallel it was 1·02514; thence to the Australian coast it rose daily, reaching 1·02638 off Cape Otway. Except when amongst loose ice, there was hardly any variation at all in the specific gravity all the way between Marion Island and the 50th parallel; when amongst the ice the specific gravity was liable to sudden and considerable fluctuations, going down on the 14th February to 1·02419, and on the 18th to 1·02418, the ship being on both occasions surrounded by broken pack-ice. During the same trip the specific gravity at the temperature of the water was also very uniform, the mean being 1·02690.

Leaving Sydney a loop-like course was made, by way of New Zealand,

Tongatabu, and the Fiji Islands, back to the Australian coast at its northernmost point, Cape York. The mean specific gravity of the western part of the sea between Australia and New Zealand was 1·02647, and that of the eastern part 1·02622, while in Cook's Strait itself it was only 1·02593. Between New Zealand and the Kermadecs the average specific gravity was 1·02630, and between the Kermadec Islands and Tongatabu it was 102651; round the Fijis it was 1·02661; and between the Fijis and Cape York a very uniform specific gravity was maintained, the mean being 1·02643. We thus see that in the western part of the Southern Pacific the specific gravity of the surface-water is very uniform, varying but little with latitude, showing a very marked difference from the Atlantic Ocean, a difference which was observed to obtain in all parts of the Pacific.

From Cape York to Hong Kong the course lay through the remarkable series of so-called enclosed seas. The mean surface specific gravities in these seas were as follows:—In and around Torres Straits, 1·02655; in the Arafura Sea, 1·02549; in the Banda Sea, 1·02603; in the Molucca Passage, 1·02517; in the Celebes Sea, 1·02562; in the Sulu Sea, 1·02496; in the sea enclosed by the Philippine Islands, 1·02532; and in the China Sea, 1·02518. On the way to Hong Kong we traversed the Sulu and China seas just at the time when the south-west monsoon had ceased and the north-east one began to blow. When we returned by the same route as far as the south point of Mindanao, the north-east monsoon had already persisted for more than two months; and the effect of the comparative dryness of this wind is very evident in the surface specific gravities. The following average values were found:—In the China Sea, 1·02534; in the Philippine Sea, 1·02532; and in the Sulu Sea, 1·02570. On the other hand, the few observations made in the northern part of the Celebes Sea showed a diminution of specific gravity, the average being 1·02496. Outside the south point of Mindanao a strong and steady north-easterly wind was met with, and for the next ten degrees in longitude the mean specific gravity was 1·02596. On nearing the coast of New Guinea the specific gravity went down rapidly, averaging for a few days before our arrival at Humboldt Bay 1·02519. That a very large river must here empty itself into the sea was evident from the amount of drift-wood with which the sea was covered, and from the superficial distribution of the light water. The specific gravity of water at 50 fathoms below the surface was almost perfectly uniform, varying from 1·02611 to 1·02636 during the whole cruise from Mindanao to Admiralty Island. When about twenty miles off Humboldt Bay the specific gravity of the water fell as low as 1·02420. Between Humboldt Bay and the Admiralty Island the surface specific gravity was very uniform, varying from 1·02583 to 1·02600, except in one position (lat. 2° 30′ S., long. 144° 7′ E.), where it fell to 1·02554; but a series of observations on waters taken from different depths at this position showed at once the

superficial nature of the variation; the water at 10 fathoms from the surface had a specific gravity of 1·02580. Although there was here no drift-wood to be seen, I have little doubt that we had to do with warm water, although the nearest point of New Guinea was at least 80 miles distant; and indeed Capt. Scoresby, who sailed along this coast much closer in shore, observed in this part large quantities of drift-wood, and inferred the existence of a large river in the neighbourhood.

North of Admiralty Island the specific gravity is somewhat higher; between the equator and 3° north latitude the mean is 1·02648; thence all the way north to Japan it remains very uniform, the mean being about 1·02600.

Leaving Japan in the month of June, the course lay entirely between the parallels of 34° and 40° N. as far as the meridian of 155° W. The specific gravity was slightly greater on the western side of the ocean than on the eastern. The following mean specific gravities were observed for every ten degrees of longitude:—

140° to 150° E.	1·02586.
150 to 160	1·02574.
160 to 170	1·02585.
170 to 180	1·02568.
180 to 170 W.	1·02569.
170 to 160	1·02544.
160 to 155	1·02532.

Arrived at 155° W. longitude, a southerly course was pursued by way of the Sandwich Islands and Tahiti, when the following mean specific gravities were observed:—

35° to 25° N.	1·02618.
25 to 15	1·02593.
15 to 5	1·02574.
5 N. to 5 S.	1·02649.
5 S. to 15	1·02658.
15 to 25	1·02699.
25 to 35	1·02620.

Whence it will be seen that the minimum value is reached between 15° and 5° N. latitude, the lowest value actually observed having been 1·02488 in latitude 7° 26′ N. The maximum to the south between 15° and 25° is very much more pronounced than that to the north of it; in fact round about Tahiti is the only spot in the Pacific where I have observed the specific gravity reaching 1·02700; the actually highest observed value was 1·02728 on the 3rd October, when the ship was being swung a few miles off Papeete Harbour.

The easterly course to Valparaiso was made principally between the parallels of 35° and 40° S. latitude. From 125° W. longitude to Valparaiso the mean specific gravity was 1·02534, the maximum being 1·02552 and the minimum 1·02513.

A large number of observations on the specific gravity of the waters at the bottom and intermediate depths have been made. In a preliminary report like the present it would be out of place to enter upon the discussion of so extensive a subject, even did the time at my disposal admit of my attempting it. I therefore content myself with giving the numerical results. It is to be hoped that in the homeward cruise through the Atlantic a more complete series of observations in this direction may be obtained, as those obtained on the way out were only sufficient to show that this ocean, and especially its northern part, differs greatly from the rest of the world-sea in density, as it does in temperature and in many other particulars. As a general rule, in both oceans between the parallels of 40° N. and 40° S. the specific gravity (reduced to 15°·56 C.) is greatest at or near the surface, and decreases more or less regularly until a minimum is reached, generally about 400 fathoms from the surface, when there is a slow rise, the bottom-water being rather heavier. This general law obtains in the Pacific and in the South Atlantic; but from the few observations obtained in the North Atlantic, there are indications of a departure from it. Although in the case of surface-water the variations of specific gravity with latitude are very considerable, more especially in the Atlantic, the water below 200 fathoms presents great constancy, the variations being comparable with those of the temperature at the same depths. In intertropical regions, and generally where there exist alternating wet and dry seasons, there are usually more than one maximum and minimum in the series between the surface and the bottom. How long it takes in quiet seas for fresh water to diffuse downwards in the sea, will be seen by inspection of the results obtained on the 22nd February, 1875, above referred to, when about 80 miles off the mouth of one of the large rivers of New Guinea, and the sea covered with driftwood. The specific gravity was at the surface 1·02537; at 10 fathoms, 1·02578; at 20 fathoms, 1·02584; at 40 fathoms, 1·02594; at 50 fathoms, 1·02636; and at 100 fathoms, 1·02658, where it obtained its maximum, the temperature being sensibly the same down to 50 fathoms, namely from 28° C. to 28°·4 C.

Observations on the Carbonic Acid contained in Sea-water.

The carbonic acid when boiled out of the water is received by baryta-water of known strength; its consequent loss of alkalinity is measured by hydrochloric acid of corresponding strength. Having observed that the presence of sulphates in sea-water is one of the potent agents in the retention of the carbonic acid*, I always add 10 cub. centims. of a saturated solution of chloride of barium to the water before commencing the operation. This facilitates greatly the liberation of the carbonic acid, and also causes the water to boil tranquilly, even to dryness, without showing any tendency towards bumping. The

* Proc. Roy. Soc. 1874, vol. xxii. pp. 483–495.

quantity of water used has been almost invariably 225 cub. centims., and the property possessed by sea-water of retaining its carbonic acid with great vigour makes it possible to perform the determination of it even a couple of days after its collection. As a proof of this, on the 10th July, 1875, the surface-water was found when freshly drawn to contain 0·0291 gramme carbonic acid per litre. A quantity likewise of the freshly drawn water was boiled *in vacuo* for an hour and fifty minutes in order to collect the oxygen and nitrogen, and then allowed to cool protected from the air. One portion of this water was exposed to the air in a flat dish outside the port for three hours, and in another portion the carbonic acid was at once determined. It contained 0·274 gramme per litre, whilst the water exposed to the air contained 0·6273 gramme. The effect, then, of boiling *in vacuo* was only to remove about 5 per cent. of the whole amount, whilst free exposure to the air had no effect whatever. As the determination of the carbonic acid takes a considerable time, it is only by taking advantage of this property that I have been able to determine it in samples from depths in the same locality; for where boiling *in vacuo* has so little effect, there is no danger of losing carbonic acid when the water is carefully decanted.

As in the great majority of cases, where the carbonic acid has been determined, the oxygen and nitrogen have also been collected, and are being preserved until our return home, when they will be analyzed: it would be useless to attempt to discuss the results of the carbonic-acid determinations at present, and before these analyses have been made, especially as there is likely to be some relation between the amounts of oxygen and of carbonic acid. Independently, however, of the relations which may subsist between the two bodies, it may be gathered from the inspection of the accompanying Table that, taking surface-waters alone, the amount of carbonic acid present is many times greater than would be contained in the same volume of distilled water under the same circumstances. I have again and again exposed distilled water, surcharged with carbonic acid, to the air, and after even a very few minutes the carbonic acid was completely gone; on adding to 225 cub. centims. of it 5 cub. centims. baryta-water, the mixture remained perfectly clear; and on titrating with hydrochloric acid there was no diminution of alkalinity.

The temperature of the water on this occasion was 18°·3 C. On that particular day, namely the 8th July, 1875, when in the middle of the North Pacific, there was no determination made of the carbonic acid in the surface-water; but two days later, when the temperature of the surface-water was 18°·9 C., 225 cub. centims. of it contained 0·0066 gramme carbonic acid. Had there been 0·002 gramme CO_2 in the 225 cub. centims. distilled water, it must have been detected and determined. Hence, under the same circumstances, this particular sea-water, whose specific gravity was 1·02528 (at 15°·56 C., water at 4° = 1), contained at least thirty times as much

carbonic acid as an equal bulk of fresh water would have done. Further, as might have been expected from the above observations, the amount of carbonic acid contained by surface-waters of the same temperatures increases with the density, and consequently is greater in the surface-water of the Atlantic than in that of the Pacific, the two oceans being very markedly distinguished from one another by the different densities of their surface-waters. Thus we have a mean of 0·0466 gramme CO_2 per litre in Atlantic surface-water of temperature between 20° and 25° C. and mean density 1·02727; whilst in the Pacific the mean is 0·0268 gramme in water of 1·02594 mean density; and the mean amount of carbonic acid in Atlantic water of temperature above 25° C. and mean density 1·02659 is 0·0409, whilst in the Pacific the corresponding water is of mean density 1·02593, and contains 0·0332 gramme CO_2 per litre. As a rule, other things being equal, the amount of carbonic acid diminishes as the temperature increases; thus the mean amount of carbonic acid in waters whose temperature was between 15° and 20° was found to be 0·0446 gramme per litre, the mean density being 1·02642, whilst we have seen that in the Atlantic the surface-water of temperature above 25° C. and of mean density 1·02659 contains 0·0409 gramme per litre. Also there is usually more carbonic acid in waters taken from the bottom and intermediate depths than in surface-water; but if regard be had to the temperature of the water, it will be seen that there is but little difference in the amount in waters of the same temperature from whatever depth they may have been derived. This seems to indicate that the animal life at the bottom and at great depths cannot be very abundant, otherwise there could hardly fail to be a decided excess of carbonic acid in the deep water, owing to constant production and want of the means of elimination of the gas. On this subject, however, it would be premature to speculate before the determination of the oxygen, from which we may hope for much information.

I have made a number of experiments to detect the presence of carbonates in sea-water. If any were present, they should be found in the residues from the determination of the carbonic acid; and I had been in the habit of testing by adding a little acid to them, and invariably with the same result—that carbonates were not present; at the same time it appeared to me to be very unlikely that such should be the case, when there is plenty of carbonate of lime in the shells of the animals living and dying in it, and also plenty of carbonic acid in the water to dissolve it. It was also not improbable that the very considerable amount of sulphate of baryta in the residues might disguise the effervescence. I therefore evaporated a separate portion (about 150 cub. centims.) of the water in a platinum dish to dryness, removed the soluble salts with a little water, and added a few drops of strong hydrochloric acid, which was allowed to flow slowly over the inner surface of the dish, when even the smallest trace of carbonates could be detected by the appearance of minute bubbles on the

platinum surface. In this way I have examined a number of waters between Tahiti and Valparaiso, and with the general result that in ocean-water carbonates are never present except in small quantities, and in many samples they have been absent altogether. They are generally present in waters at or near the surface, disappearing, however, as the depth from which the water has been taken increases. They are generally, though not invariably, absent in waters from greater depths than 400 fathoms. They are present or absent in bottom-water according to their occurrence in the bottom; although here also there appears to be exceptions, as I have observed water taken from a "*Globigerina*-ooze" bottom which contained no carbonate.

In connexion with carbonic acid I may mention that I have frequently tested waters, and especially bottom-waters, for organic matter. None of the methods in use for determining this substance in drinking-water giving satisfaction when applied to sea-water, I had to content myself with endeavouring to detect its presence. If the jelly-like organism which had been seen by some eminent naturalists in specimens of ocean bottom and called *Bathybius* really formed, as was believed, an all-pervading organic covering of the sea-bottom, it could hardly fail to show itself when the bottom-water was evaporated to dryness and the residue heated. In the numerous samples of bottom-water which I have so examined, there never was sufficient organic matter to give more than a just perceptible greyish tinge to the residue, without any other signs of carbonization or burning. Meantime my colleague, Mr. Murray, who had been working according to the directions given by the discoverers of *Bathybius*, had actually observed a substance like "coagulated mucus," which answered in every particular, except the want of motion, to the description of the organism; and he found it in such quantity that, if it were really of the supposed organic nature, it must necessarily render the bottom-water so rich in organic matter that its presence would be abundantly evident when the water was treated as above described. There remained, then, but one conclusion, namely, that the body which Mr. Murray had observed was not an organic body at all; and on examining it and its mode of preparation I determined it to be sulphate of lime, which had been eliminated from the sea-water, always present in the mud, as an amorphous precipitate on the addition of spirit of wine. The substance when analyzed consisted of sulphuric acid and lime; and when dissolved in water and the solution allowed to evaporate, it crystallized in the well-known form of gypsum, the crystals being all alike, and there being no amorphous matter amongst them.

These observations were made chiefly on the voyage from Hong Kong to Yokohama in the first quarter of the year 1875; and it subsequently occurred to me that an approximate determination of the organic substance in sea-water might be effected in the following way:—Supposing the amount of carbonic acid in the water to be known, let a little per-

manganate of potash be added to a sample of it, and let the carbonic acid be determined in the usual way by boiling the solution. If the water contained any easily oxidizable carbon compound, we should obtain more carbonic acid in the second than in the first determination, and the difference would correspond approximately to the amount of organic carbon present. In several waters which I have treated according to this principle, I have found from two to five milligrammes of carbon per litre.

Observations on the occurrence of Manganese Nodules on the Sea-bottom.

Occasionally pieces of stone of a black colour have been brought up, and been found to consist of peroxide of manganese mainly. Several interesting specimens were obtained between Bermuda and the Azores, which were apparently steps in the formation of the black substance out of concretions of the bottom at the place in question. They were obtained on the 17th and 27th June, and may be divided into four classes :—1st, those which contain no manganese at all; 2nd, those where the manganese formation has commenced; 3rd, those where it is well advanced; and 4th, those where the bulk of the substance is peroxide of manganese. Those of the first class are, as far as can be learned from qualitative analysis and microscopical examination, merely mechanical aggregations of the bottom existing at the place in question. Of a white colour, and generally the same appearance, are those of the second class; they contain, however, numerous perforations, whose walls are lined with a very thin black film peculiarly striped. On treating with dilute hydrochloric acid, the mass is found to consist chiefly of carbonate of lime with a considerable quantity of clay. Strong hydrochloric acid decomposes the latter, when a certain amount of chlorine is given off. In another concretion, belonging to the same class, the manganese is seen forming in minute mammillary concretions on the outside surface, as well as on the tube linings. Belonging to the third class is one (also brought up on the 27th June) where the outside is wholly covered with oxide of manganese; and in cutting through the substance of the stone, the layer is seen to be of a sensible thickness; also all the worm-holes are seen to be completely coated; and numerous more minute holes are found, all of which are coated in the same way. A very considerable percentage of the whole mass has thus become manganese. On the face of a fresh cutting the interior of the mass may be seen to preserve its white colour. From the edge of the black layer inwards, however, the mass is stained of a brownish colour, which gradually disappears towards the centre. Blackish brown veins are also seen to traverse the whole mass. Pulverized, it effervesces strongly with dilute hydrochloric acid. The residue is easily decomposed by strong acid, evolving large quantities of chlorine; silica is left undissolved with a little sand. In the hydrochloric-acid solution there was found, besides alumina, manganese, and a little iron, a certain quantity of nickel and cobalt. A concretion of the fourth class

came up on the 17th June. It is an irregular nodule, about 1½ inch long, of a brownish-black colour, having its outside surface mammillated all over. This mammillated surface is so peculiar that, by its means, the manganese may be at once recognized. When broken it is found to consist of irregularly concentric layers of peroxide of manganese, alternating with fine seams of calcareous and earthy matter. It contains a small, white, earthy nucleus. The broken surface resembles the figuring of polished walnut wood. It consists of peroxide of manganese, alumina, iron, silica, small quantity of lime, magnesia, cobalt, and phosphoric acid. Heated in the tube it gives out, like all these concretions, water with a strong alkaline reaction.

The most remarkable occurrence of peroxide of manganese on the bottom was met with on the 18th February, in latitude 35° 45′ N. and longitude 20° 12′ W. The dredge was put over in 1500 fathoms, and came up full of dead coral of a jet-black colour on the surface. Some of the sticks adhered to large black masses, and on breaking them the inside was seen to be perfectly white, the black substance forming merely a very thin rind which cracked off easily on receiving a smart blow. This black rind, as well as the masses to which some of the sticks were attached, consisted of peroxide of manganese, the white part or inside having the composition of ordinary coral (chiefly carbonate of lime). The black masses to which some of the sticks were attached present, like the concretions already described, a minutely mammillated appearance on the outside, and when broken across are seen to consist of concentric layers, blacker and more compact towards the outside, and browner and more earthy towards the inside. The layers are separated from each other by numerous very fine layers of mud, chiefly carbonate of lime. They increase in number towards the inside, and in some instances can be seen to be composed in part of fragments of foraminiferous shells. The black mass was found on analysis to consist of peroxide of manganese, alumina, oxide of iron, silica, small quantities of lime and magnesia, and traces of copper, cobalt, and phosphate of lime. Compared with the manganese concretions already described, they appear to have the same chemical composition, and their internal structure in layers points to a similar mechanical origin; in fact they differ from the others only in being fragments of much larger concretions. Where the coral sticks adhere, they do not penetrate into the mass at all, but their flat roots are as sharply divided from the black mass as the black rind is from the inside coral.

On the 27th June, amongst the concretions, a fragment of slate, coated on the outside with mammillated peroxide of manganese, was brought up.

The preceding notes on the occurrence of the manganese nodules was written at the Cape of Good Hope, and sums up our knowledge of the subject at the close of the Atlantic cruise. In the Antarctic Ocean the soundings obtained showed in a remarkable manner the general com-

parative shallowness, the depth being in general under 2000 fathoms. Whenever the dredge or trawl was used in that ocean it brought up large quantities of stones; but they were invariably fragments, more or less rounded, of granitic and igneous rocks, and I did not notice any manganese. On the 13th of March, however, when approaching Australia, the depth increased to 2600 fathoms; a very large haul of manganese nodules was obtained, presenting the same general characteristics as those in the Atlantic. In the Pacific the amount of manganese found has been immense, there being hardly a sounding where it could not be detected in small particles amongst the mud; and, indeed, in many parts the nodules occur in such quantity that the sounding-tube has brought them up in considerable numbers at one time; they have also frequently come up sticking to the bottom of the water-bottle. Here, however, they have chiefly come under the observation of my colleague Mr. Murray, and will be treated of in his Report. Chemically they are very much alike, as far as quantitative analysis can supply information. They all contain one of the higher oxides of manganese in preponderating amount, cobalt and nickel in notable quantity, and copper in traces, besides argillaceous and often sandy matter. I hope, when the cruise is over, to be able, by means of quantitative analysis, to render a detailed account of their nature, from which it may perhaps be possible to obtain some hints as to their origin and development.

Since the discovery of this most remarkable and unexpected occurrence of a mineral, having much resemblance to psilomelane, evidently forming at the bottom of the sea, I have taken every opportunity of examining specimens of peroxide of manganese from terrestrial sources; and in many cases I have found them to resemble the marine mineral in several points, especially in nodular structure and in giving off alkaline water when heated. Some peroxide of manganese which I got from the mines near Paarl, about thirty miles from Cape Town, had most perfectly nodular structure, but was extremely hard, whereas our nodules, when freshly brought up, can generally, although not invariably, be easily cut with a knife; but they increase very markedly in hardness when exposed to the air, even for only a few weeks. I do not attach very much importance to the fact of its giving out alkaline water, for this is a property which I have found to be very generally possessed by rocks and minerals. Of the zeolites, for instance, which were found in Kerguelen, there was not one which did not give out alkaline water with a very perceptible empyreumatic smell when heated.

It has been mentioned above that the dredge frequently brought up large quantities of stones in the Antarctic Ocean. Amongst them were almost invariably fragments of granite or syenite, as well as of both basalt and trachyte. On the 2nd February, 1874, when between Kerguelen and Heard Islands, a very large quantity of stones was brought up in the dredge from a depth of 150 fathoms. Amongst them were a

piece of granite, also two varieties of basalt, one coarse-grained with porphyritic olivine, and the other exceedingly fine-grained and compact, without any separate crystals being visible to the naked eye. It was chiefly remarkable from the fact that the stones, though fresh from the bottom and still quite wet outside, were, when broken, perfectly dry inside, the moisture not having penetrated beyond the thickness of a sheet of paper. The edges of these stones were less rounded than those of the other species which accompanied them. In order to be perfectly sure that there was no mistake, I broke about a dozen of them, the species being easily recognized by the edges of the stones being less rounded than those of the others, and always with the same result; while those of the other species were not only wet inside, but, especially in the trachytic ones, decomposition in concentric shells had made considerable advances. As a drop of water applied to the fractured face was readily and quickly absorbed, I can only account for the dryness inside by considering that the stones in question had passed but a very short time under water. As they were found in lat. 52° S., and the first iceberg was only met with in 60° S., it would be difficult to imagine that they had come ice-borne from the Antarctic land; at the same time it was equally difficult to imagine any other adequate means of conveyance than ice. I believe that they come from Heard Island, whose ice-bound shores are constantly despatching miniature bergs into the sea, which, from their insignificant size, would suffer rapid destruction alike from the violence of the seas and from the temperature of the water, which, on the occasion in question, was between 3° and 4° C. Many small ice-masses, such as I have supposed, were floating off the southern shore of Corinthian Bay, which on this side had a continuous icy coast-line formed by a glacier descending from the central high grounds which culminate in Kaiser Wilhelm Peak, and reaching the sea both on the west and on the east side of the inhabited isthmus, as I have described in my short note on the island. The position where the stones were dredged is within 100 miles of Heard Island, and through the above-mentioned agency there must be a constant conveyance of the *débris* of the island out to sea, which would account for the very stony character of the bottom found.

Observations on Sea-water Ice.

Many different opinions have been expressed as to the nature of ice resulting from the freezing of sea-water, all agreeing, however, in one point, that when melted the water is unfit to drink. During the Antarctic cruise I took an opportunity of examining some of the broken pack-ice, into which the ship made an excursion on the morning of the 25th of February, and also some ice which had formed over night in a bucket of sea-water left outside the laboratory port.

The piece of pack-ice which I examined was in substance clear, with many air-bells, most of them irregularly shaped. Two portions of this

ice were allowed to melt at the temperature of the laboratory, which ranged from 2° to 7° C. The melting thus took place very slowly, and made it possible to examine the water fractionally. My experiments consisted in determining the chlorine in the water by means of tenth-normal nitrate of silver solution, and observing the temperature of the ice when melting.

A lump, which when melted was found to measure 625 cub. centims., was allowed to melt gradually in a porcelain dish. When about 100 cub. centims. had melted, 50 cub. centims. were taken for the determination of the chlorine; they required 13·6 cub. centims. silver solution, corresponding to 0·0483 gramme chlorine. When 560 cub. centims. had melted, 50 cub. centims. were titrated, and required 1·6 cub. centim. silver solution, corresponding to 0·0057 gramme chlorine. The remainder (65 cub. centims.) of the ice was then melted and 60 cub. centims. titrated; they required 0·39 cub. centim. silver solution, corresponding to 0·0014 gramme chlorine. We have, then, in the first 50 cub. centims. 0·0483 gramme chorine, in the next 510 cub. centims. 0·0579 gramme chlorine, and in the last 65 cub. centims. 0·0015 gramme. Hence the whole lump (625 cub. centims.) contained 0·1077 gramme chlorine, or, on an average, 0·1723 gramme chlorine per litre. A qualitative analysis of the water showed lime, magnesia, and sulphuric acid to be present.

Another piece of the ice was pounded and allowed to melt in a beaker. When about half was melted, the water was poured off and found to measure 95 cub. centims.; 75 cub. centims. were titrated with silver solution, and required 1·9 cub. centim. The remainder, when melted, measured 130 cub. centims., and required 0·9 cub. centim. silver solution. Hence the first fraction of 95 cub. centims. contained 0·0085 gramme chlorine, and the second of 130 cub. centims. 0·0032 gramme chlorine. The whole quantity (225 cub. centims.) of ice, therefore, contained 0·0117 gramme chlorine, or, on an average, 0·0520 gramme per litre.

From these results it is evident that the ice under examination was very far from being an homogeneous body; and, indeed, nothing else could be expected, when it is borne in mind that the ice in question owes its existence, not only to the *bonâ fide* freezing of sea-water, but also to the snow which falls on its surface and is congealed into a compact mass by the salt-water spray freezing amongst it.

The ice formed by freezing sea-water in a bucket was found to have formed all round the bottom and sides of the bucket, and forming a pellicle on the surface, from which, and from the sides and bottom, the ice had formed in hexagonal planes, projecting edgewise into the water. The water was poured off, the crystals collected, washed with distilled water, pressed between filtering-paper, and one portion melted. It measured 9 cub. centims., and required 4 cub. centims. silver solution, corresponding to 0·0142 gramme chlorine, or 1·5780 gramme per litre. The other portion was used for determining the melting-point. The

thermometer used was one of Geissler's *normal* ones, divided into tenths of a degree Centigrade, whose zero had been verified the day before in melting snow. The melting-point of the ice-crystals was found to be $-1°\cdot3$. The temperature of the melting mass was observed to remain constant for twenty minutes, after which no further observations were made.

In the same way the melting-point of the pack-ice was determined. The fresh ice began to melt at $-1°$; after twenty minutes the thermometer had risen to $-0°\cdot9$, and two hours and a half afterwards it stood at $-0°\cdot3$, having remained constant for about an hour at $-0°\cdot4$. Another portion of the ice rose more rapidly; and when three fourths of the ice was melted, the thermometer stood at 0°.

These determinations of the temperature of melting sea-water ice show that the salt is not contained in it in the form of mechanically enclosed brine only, but exists in the solid form, either as a single crystalline substance, or as a mixture of ice and salt crystals. Common salt, when separating from solutions at temperatures below 0°, crystallizes in hexagonal planes; sea-water ice, therefore, may possibly have some analogy to the isomorphous mixtures occurring amongst minerals.

A very important practical consequence follows from these observations, namely, that pack-ice, though unfit to drink when a lump of it is melted as a whole, may serve as a source of fresh water if melted fractionally. As the melting-point of the salt ice is lower than that of pure ice, it melts first, and at the same time, by keeping down the temperature of the mass to its own melting-point, it prevents any of the fresh ice being wasted. When the salt ice has all been melted the brine may be thrown away, and the remainder of the ice will supply fresh water. If a thermometer be kept in the ice during the process of melting, it will indicate by its reading when drinkable water is being formed.

Observations made on Shore in some of the Islands visited.

Viewed from the sea, the island of St. Vincent, one of the Cape-Verd group, presents an extremely rugged and desert appearance, which it preserves even upon the closest inspection. The hills round the harbour consist of interbedded igneous rocks, the individual beds being seldom over three or four feet thick, and generally only about two feet, dipping at a gentle angle away from the centre of the harbour. These beds are much cut up by vertical dykes of basaltic rock running in two principal directions, namely, north and south and east and west. They frequently present an eminently columnar cleavage in the direction of their breadth. Many of the beds which form the mass of the hill are of similar nature and cleave in the same way. The rock on each side of these basaltic masses, whether beds or dykes, is generally much altered, and has suffered considerable disintegration and decomposition, being frequently transformed into a mass of kaolin in the neighbourhood of the basalt.

The effect of heat in rendering many minerals which occur in igneous rocks decomposable by acids is well known, and may furnish an explanation of the above-named phenomena. As the dykes extend to the very tops of the hills, and the adjacent rock is weathered away leaving them projecting, the outline of the hills gets a peculiar serrated appearance, which is very characteristic of the island. The spurs which project from the main ranges into the plains are always found to depend for their height and direction on one of these basaltic dykes, which can be followed all the way along their crest.

In many of the rocks, where their character is cellular, their cells are filled with geodes, in some cases of carbonate of lime, and in others of zeolite. The rocks are nearly all of a porphyritic character from crystals of augite separated out. The most common rock contains large augites in a light grey ground-mass. The crystals are frequently arranged in bands with their longer axes parallel to each other and in the direction of the bands. Nothing approaching to either obsidian or pumice was observed in any part of the island. Besides the igneous rocks, there is in the plain on which the town stands and to the south of it a calcareous formation consisting of shells, corals, and rounded pebbles of the neighbouring rocks, united by a firm paste of a white and sometimes of a reddish colour; also, from the constant prevalence of winds from one quarter, the sand from the beach has been distributed over the plains and in the valley. At the south side of the harbour there are dunes of blown sand, which in some places is consolidated into rocks similar to those of Bermuda. Here, however, the sand does not consist purely of carbonate of lime, but of the *débris* of shells and volcanic material mixed. Hence the consolidation of it into rock is not so easy, even if there was the quantity of rain to do it. On the sand hills the wind produces the usual beautiful ripple-mark, and the mixed character of the sand makes the levigating action of the wind very apparent, the light calcareous particles being swept into the eddies under the crest of the ripple, the heavy volcanic *débris* remaining on the surface. As the colour of the latter is generally black and that of the former white, a sand hill looks lighter or darker according as it is viewed from the weather or from the lee side.

We were told that on the other side of the island there were tolerably perfect craters; we were, however, unable to visit them. In the neighbourhood of the harbour there was no vestige of recent volcanic action. At St. Paul's rocks the ship was made fast to the rocks, and as we remained there over thirty-six hours we had ample time to thoroughly explore them. They were visited by Darwin in the 'Beagle,' and several times later by other ships. As the nature of the rocks appears to present some difficulty to geologists, I made as complete a collection of them as I could, and they will be sent home with the other collections from this place. The white enamel-like incrustation mentioned by

Darwin, I found only on the southern island. On the northern island the bulk is composed of what I take to be Darwin's "yellowish harsh stone, split up into numerous pseudo-fragments." These last have an appearance which recalls that of weathered orthoclase crystals. All of these rocks give off alkaline water when heated in the closed tube, and consist of hydrated silicate of magnesia with alumina and protoxide of iron in subordinate quantity. They may therefore, I think, be classed as serpentine; and the above-mentioned resemblance to orthoclase crystals may perhaps afford some indication of the parent rock. Of the more recent veins mentioned by Darwin, some are bordered on both sides by black bands. These bands consist of a hard infusible substance. The powder has a dirty greyish green colour, and effervesces with dilute hydrochloric acid, leaving a brown insoluble residue. In strong hydrochloric acid it dissolves with evolution of chlorine, and the colour phenomena of dissolving peroxide of manganese. It was found to consist of phosphate of lime, peroxide of manganese, a little carbonate of lime and magnesia, and traces of copper and iron. Like the other rocks it gives off alkaline water in the closed tube.

At Fernando Noronha some of the smaller islands at its N.E. extremity were visited. The highest of these, St. Michael's Mount, forms one of the prominent peaks which are characteristic of the group. It is very steep and formed entirely of phonolite, which occurs columnar at the base and massive towards the top. On the western side, where we landed, the columns are inclined to the horizon at an angle of about 30°. Their transverse section looks nearly square, the corners, however, being considerably rounded off. The columns are for the most part slender, and their mass is of a dirty green colour. In this the sanidin crystals are arranged with great regularity, with their broadest faces in a plane perpendicular to the length of the column. The sides of the mount are covered with loose blocks of massive phonolite fallen down from above, and retained in position on a very steep incline by the branches of most luxuriant creeping plants. On the weathered sides of these blocks the sanidin crystals, and also the hornblende ones, though in less degree, project sometimes as much as a quarter of an inch. This rock possesses also, in a most eminent degree, the characteristic property from which it has derived its name of phonolite; when struck with the hammer it rings like a bell. The mount is cleft from top to bottom in two places, nearly at right angles to each other. These clefts are filled up with a hard flinty looking substance, which appears from its structure to have been gradually deposited by water trickling down the sides. Its mass is concretionary and sometimes foliated; its colour is white, to yellowish white or brownish yellow. It scratches glass with ease, and does not effervesce with acid. Plates of 2 to 3 millims. thickness are quite translucent. Heated in the forceps it does not fuse, but turns perfectly white, and is then easily crumbled between the fingers. In the closed

tube it gives off alkaline-reacting and empyreumatic-smelling water. It was found to consist of phosphate of alumina and iron, with some silicate and sulphate of lime.

Besides St. Michael's Mount, Rat Island and Platform Island were landed upon. Rat Island is the largest of the secondary islands, and the one most distant from the main island. It is composed on the western side of massive basaltic rock, and on the eastern of sandstone. This latter probably overlies the basalt, as in its structure it bears the marks of having been deposited in drifts, and the sand is calcareous, consisting of shell *débris*. On our way to and from Rat Island we had to pass all along the western side of Booby Island. The wave-worn cliffs showed that the island was entirely formed of the above-mentioned calcareous sandstone. No igneous rock was visible at all; and as the peculiar wind-blown stratification marks are continued below the level of the sea, it is probable that the land here is sinking, or at least has sunk.

Platform Island consists of a mass of perfect basaltic columns rising out of the water, and supporting a covering of massive basalt, on which is spread out the platform of calcareous rock, on which are the ruins of an old fort, and from which the island doubtless takes its name.

A day was spent on each of the islands of the Tristan d'Acunha group. It consists of three :—Tristan, the largest, Inaccessible, and Nightingale. The last is more properly a group of islands studded all round with isolated rocks. The difficult nature of the ground in Inaccessible and Nightingale, and that combined with the uncertain state of the weather when at Tristan, rendered excursions to a distance from the landing-place impossible. The rock specimens, therefore, which have been collected are all from the neighbourhood of the landing-places. Each island has its distinctive features. Inaccessible is a raised plateau, bounded on all sides by cliffs over 1000 feet high, which plunge directly into the sea. Looked at from the sea, there is no appearance of a crater on the top, the only inequalities in the surface being apparently due to erosion. The waterfalls, which tumble from the cliffs, afford most picturesque proof of the abundance of water above. Tristan Island, like Inaccessible, consists of a very similar plateau, bounded by cliffs of about the same height and almost equally impracticable. This plateau, however, is surmounted by a lofty peak rising to the height of 8300 feet above the sea. Nightingale Island differs from the other two as much in geological structure as in outward appearance. The principal island rises from the sea in low cliffs, nowhere on the eastern side exceeding 30 or 40 feet, and generally lower. At the south end the ground rises from these cliffs by several steep ascents to the peak 1105 feet high, which on its northern side presents a nearly perpendicular face of about half its height from the sea. The rest of the island is more undulating, the light grey rocks appearing only here and there through the openings in the long tussac grass. Of recent volcanic action there appears to

be no trace. The shore cliffs consist of a conglomerate, or rather breccia, of generally light-coloured doleritic fragments in a white felspathic matrix. These are overlaid, in places, by a bed of old igneous rocks. The peak, which I did not reach, is composed of light grey subcolumnar rock. All along the top of the cliffs, and about 35 feet above the sea, an ancient beach is seen to run; and the huge caves, at a considerable height above high-water mark, afford additional evidence of the rising of the land. The middle island, which I explored, consisted entirely of the above-mentioned breccia, and even at its highest point (150 feet) it was much water-worn. Dykes are by no means so frequent in this as in the other islands. Where they occur penetrating the breccia, the latter appears to be rendered more easily decomposable, the result being that the dykes form the axes along which creeks or inlets indent the shore. In the island of Tristan, the gully behind the settlement, in the centre of which the spring rises which supplies the village brook, is formed in a similar way. It is backed by a vertical dyke (if a mass at least sixty yards wide can be called so) of rock similar to that observed on Nightingale, and, like it, it has altered the adjacent rock considerably; and, probably from the pressure of the sides during its injection, it has a most perfect, almost slaty cleavage, which renders it easily disintegrable, though it does not appear to decompose easily. Dykes of this description, but of usually not more than 1 or 2 feet in thickness, traverse the rocks, seen in section in the face of the cliff, both in Tristan and Inaccessible, in great numbers. Besides these, there are others of a very compact, fine-grained, basaltic rock intersecting the nearly horizontal layers, which form the cliff, in all directions, and showing very marked differences in texture at the sides, where the action on the contiguous rock is apparent. In one of the specimens collected the rock in the interior of the dyke is of the usual light colour, while the edge is marked by a black obsidian-like band of half an inch breadth, as sharply defined from the internal mass as if it had been painted.

The cliffs, being quite perpendicular and naked, give a good view of a vertical section of the island. At their base the rubbish fallen down from them has accumulated to a heap reaching sometimes quite 100 feet up the face. I had thus the opportunity of observing two sections of what had been valleys or hollows, but which were filled up with finely levigated volcanic material. From the arrangement of the material I should think that it had been erupted by a subaerial volcano and fallen into a bay, where it had gradually settled. If such has been the case, it furnishes additional evidence of the rising of the land in these parts.

During the cruise between the Cape of Good Hope and Melbourne three islands were landed on, namely, Marion, Kerguelen, and Heard islands. On the first of these a day was spent. The soft mossy nature of the ground made the walking very heavy, which, combined with the

necessity of being at any time prepared to join the ship in case of change of weather, rendered any expedition far from the coast impossible. Viewed from the sea, the rocky shores are seen to be surmounted by an undulating country covered with herbage, which, as the height increases, passes into a barren mountain cluster with many sharp and sometimes perfectly conical peaks. The highest of these were covered with snow, and for the greater part of the day enveloped in mist; the lower ones were mostly of a bright brick-red colour. Where the coast cliffs could be viewed they showed layers of compact and brecciated lavas of no great thickness. Having landed at the mouth of a watercourse, I traversed the beach to the westward until I reached the next stream, which I followed some distance inland. When the swampy moss-covered ground, whose uniformly dull green colour was relieved here and there by the snowy plumage of the nesting albatross, had been left behind, the stream was found to flow over an apparently very recent stream of black cellular lava, whose ripples and eddies were still perfectly fresh, except in the very centre, where they had suffered some slight abrasion; of any hollowing action on the part of the water, however, there was no trace, the windings and little waterfalls being still determined by the original inequalities of the solidifying rock. The lava was basaltic, containing much olivine. Close by the bed of the stream rose several of the abovementioned red conical hills. One of these, the highest within reach, and the only one I had time to ascend, consisted of a heap of loose scoriæ dipping away on all sides at a regular and very steep angle. Few of these pieces of scoriæ were more than six inches in diameter; and had it not been for the occasional clumps of moss, which alone afforded a sure footing, the ascent would have been a matter of considerable time. At the top was a perfectly conical pit, and slightly below the summit, on the north side, were three smaller and similar pits. The scoriæ of which the hill is made up consisted of a highly cellular red ground-mass, with indications of augite, without, however, any perfect crystals being discernible. Besides the red scoriæ, there were some of a chocolate-brown colour, with frothy exterior and compact kernel. The shape of some of them resembled the almond-shaped bombs found in many volcanic districts; but I did not notice any with the dense outside and highly cellular core so characteristic of the true volcanic bomb. Besides this hill there were five or six others precisely similar in appearance, and rising out of the same valley or depression in the ground. From the top of the hill this depression could be seen to be bounded, towards the interior, by a semicircular cliff of rock, in some parts columnar, and open towards the sea. Above this cliff rose the snow-covered cones and peaks of the interior, which, wherever the snow had been removed, showed the same red colour and steep sides, so that there can be little doubt of their being similarly formed to those on the lower ground. On leaving the streambed and returning to the eastward over the spur of the mountain, the

above-mentioned cliff had to be skirted, and it was found to consist of a light grey compact doleritic rock.

From these few observations it may be concluded that the island consists of a foundation of older igneous rock ruptured and surmounted by recent volcanoes. That these have been active at no very ancient date is, I think, rendered probable by the perfect preservation of the forms of the cones with their summit craters, and by the fact that the mossy vegetation so luxuriant at their base, and retaining this luxuriance on the certainly older mountain-spurs to an elevation at least equal to that of the top of the cone ascended, has as yet spread up their sides only in straggling isolated patches.

The evidence afforded by the want of erosion deserves all the more weight when the position of the island is remembered, where, of necessity, the rainfall must be considerable.

The island of Kerguelen was visited at various points on the north-eastern and south-eastern coasts. The first part touched at was Christmas Harbour, already visited by Cook, Ross, and other navigators. It is a deep inlet surrounded by high rocky banks, which are in many places quite precipitous. At the head of the bay there is an extensive sandy beach; and the ground behind it slopes at a tolerably easy gradient up to the top of the ridge, which is occupied by a large lake. From a ship anchored in the harbour an excellent general view of the arrangement of the rocks can be obtained; they are seen to be arranged in apparently perfectly horizontal beds, the separation lines of the different beds being easily traced all round the harbour. Where the sides are not precipitous the summit of the ridge is attained by a series of terraces, and the summit of the ridge is, as might have been expected, almost perfectly flat. The continuity of the flat-topped surfaces, both of the northern and of the southern ridges, is broken by the two most conspicuous objects in the landscape, namely, Table Mountain on the north, and one unnamed on the south. This rock-mass does not project above the horizontal hill-top, but rather appears to stand out from it like a huge boulder. The summit of the ridge has been called Mount Havergal; but it is formed of the ordinary bedded rock, this "neck" of conglomerate not reaching any greater height than that of the contiguous parts of the ridge. These hills belong to a class representatives of which were found again in the south in Greenland Harbour; and as they resemble each other closely they will be described together. In both places they protrude through the horizontal beds of basalt, differing from these and from each other in nature, and without having caused any apparent disturbance in the arrangement of the beds which surround them. The horizontal beds which form the mass of the land are basaltic, and vary from 10 to 20 feet in thickness, being generally compact; but in ascending the hill beds are met with frequently which contain large amygdaloidal cavities filled with zeolites, principally analcite and heu-

landite. These minerals are very plentiful in this part of the island; and when rounded by the action of water, they form remarkable white pebbles on the otherwise dark-coloured volcanic sand. Up to the summit the alternation of beds of compact subcolumnar rock of amygdaloid is pretty regular. The amygdaloid is of two kinds; in one the cells are small, very thickly disseminated, and completely filled up by a zeolitic mineral; the other has larger cavities, less thickly spread, and generally only coated with crystals, while seams filled with crystalline matter are also frequently met with. The cavities contain generally analcite, the seams heulandite. The ridge on the southern side is higher than that on the northern; and from it, on a clear day, a very extensive view of the island towards the southward can be obtained. The coast on this side being much indented by fiord-like inlets, the horizontal bedding of the rocks in which they are enclosed can be distinguished, even at great distances, by the consequent terracing of the hill-sides, which is especially conspicuous on the shoulders and promontories. It is worthy of remark that, to the eye viewing as above, the heights of the ridges appear to differ very little from each other, the effect produced being that of a vast tableland quarried into deep indentations running down to the sea. Out of this plateau rise many peaks of considerable altitude, and often so sharp and steep in outline that at first I never doubted they were recent volcanic mountains. A nearer view of them, however, showed them generally to consist of the same horizontally bedded rock found underneath; and it was impossible to avoid the impression that they might be the remnants of a higher plateau, of which all but these peaks had been removed by the rodent action of ice, of which there is abundant evidence.

After leaving Christmas Harbour anchor was dropped in Betsy Cove, a small bay near the eastern end of the island. Here the hills have exactly the same structure as in the north, consisting of horizontal layers; but they are further removed from the sea, and from their base to Point Digby stretches an expanse of almost perfectly level plain, broken only by the remarkable Mount Campbell, which I regret I was not able to visit.

Prince of Wales's Foreland is an elevation formed by slender basaltic columns, many of which were clustered together into what, if perfect, would have formed spherical agglomerations. The basalt contained large cavities filled with olivine. Behind this rocky point the usual flat-topped range of hills stretches inland, which consists of the same basalt with much olivine, only not columnar, but in tabular masses with almost slaty cleavage.

Nearly opposite Prince of Wales's Foreland, and on the other side of the entrance to Royal Sound, is a very remarkable hill of a castellated appearance; it was called "Cat's ears." I believe it belongs to the same class of hills as Table Mountain in Christmas Harbour. The ruggedly

worn rock at the crest, which gives it its castellated look, consists of a light-coloured ground, in which are enclosed pieces of the recent scoriaceous lava which occurs immediately beneath it and large crystals of augite. These crystals, though apparently perfect when imbedded in the rock, were not found otherwise than broken when weathered out; and in places inside these natural battlements, where there was free play for the usually boisterous wind, all the lighter sand had been blown away, leaving the ground covered by a jet-black gravel. Both these crystals and the rocks show the abrading effect of blown sand, the crystals having lost their regularity of form and the rocks having acquired a more definite shape than would have been the case had the weathering proceeded equally on all sides. Here, however, and still more remarkably so in Heard Island, the constant and violent westerly winds, wherever they have an opportunity of charging themselves with sand, sculpture the rocks into shapes of apparently unnatural regularity. From this hill another similar but smaller one could be seen close to the base of the "Sugar-loaf." It resembled more a circle of Druidical stones protruding through the moorland than a hill; my time, however, was too limited to admit of my visiting either it or the imposing Sugar-loaf, the structure of which appeared from a distance to be quite peculiar.

On entering Greenland Harbour, which at its head is only separated by a narrow neck of land from Royal Sound, the eye is at once struck by the strange protrusions of light grey rock through the ordinary horizontal basaltic beds which form the hill-ranges. The most extensive of them, which occurs on the summit of the range on the western side of the harbour, has at a distance a very strong resemblance to a ruined castle. I was able to examine two of them, one on the summit and one down nearer the landing-place, both on the west side of the harbour. The rock in both of them is identical, and consists of a light, greenish-white phonolite protruding through the horizontal beds of augitic rock. These cylindrical masses of phonolite are columnar at the outer edges, the columns lying horizontally and being arranged radially. This columnar structure, however, disappears a few feet from the outside, and the rock is simply massive. The effect of weathering has been to split it up into loose blocks, which lie thickly scattered over the ground enclosed. The whole outside line being constructed of horizontal columns, forms a sort of natural cyclopian wall, much more capable of resisting the degrading influence of the weather than the massive inside; hence we might expect that as they always protrude on a hill slope, the rock being disintegrated in the centre would slip down the hill, forming a heap or talus of rubbish below, and overwhelming the wall encircling the lower edge, but at the same time falling away from the wall of the upper edge, which, thanks to its artificial structure, is able to keep together its fragments; and, in fact, this is what we observe. The upper wall of the more distant one, which stands out a prominent object on the summit of the ridge, is over

50 feet high, and presents a perfectly smooth wall-face to the outside. As it stretches down the hill-slope, which here is very steep, its height diminishes irregularly until it is lost in the heap of loose stones which covers the lower wall and the whole inside.

The rock is hard and compact, of a light greenish grey colour, with much of the appearance, though none of the ring, of phonolite. Near the outside, or in the columnar part, the rock is closer-grained than in the centre, and has a distinct cleavage in a plane perpendicular to the length of the columns. It gelatinizes partially with hydrochloric acid, and the solution contains much soda and some sulphuric acid. It is therefore probable that both nepheline and nosean are present.

Another prominence on this side of the harbour is formed of precisely similar material. It is a round, greenish grey hill covered with phonolitic rock lying about in angular fragments, generally of a size to be easily lifted. The rock is very similar to that of the hills just described; and it seems to belong to the same class, differing from the others owing to the complete disappearance of the outside wall, large pieces of which lie scattered on the slope like portions of dislodged masonry.

It is to be remarked that in neither of these cases was there any distortion in the beds in which the phonolite occurred. The line of junction of the highest one with the augitic rock was very well shown, and I was enabled to get specimens from it. For some feet from the line of junction the basalt is considerably altered, the large crystals of augite and olivine disappearing as the line of junction is approached. This line is in general quite decided; there are many angular particles of the phonolite completely surrounded by the basalt, whereas basalt imbedded in phonolite was not observed. Further, the grain of this basalt, in immediate proximity to the junction, is very fine, becoming rapidly coarser till the basalt at 10 feet from the junction has the porphyritic appearance which it presents at other parts of the hill. These two facts appear to point to the phonolite as being the more ancient of the two, and to the basalt as having flowed round it. How the phonolite came to be sticking up in the pillar-like form which it must have had is very difficult to say; but the peak of Fernando Noronha, however it may have been formed, is always evidence of the possibility of such a thing. There is no necessity for supposing that the portions of these phonolitic masses which we see should be sections of cylinders: they may equally well be sections of domes. The other view that the phonolite had burst through the lava appears to me to be untenable in view of the facts above stated.

Of the similar hills in Christmas Harbour, Table Mountain consists of columnar basalt with large cavities filled with olivine. The columns starting normally to the cylindrical surface of the enclosing rock curve upwards, and, unlike the phonolite, are continued well into the mass of the hill. The top of this hill is covered with loose fragments of basaltic columns. I did not succeed in obtaining specimens from the junction

of the columnar with the bedded rock; in fact there appeared to have been next to no fusion between the two.

The corresponding hill on the south side of the harbour is formed entirely of volcanic conglomerate, intersected here and there by dykes, some of which show on the outside the obsidian-like bands produced by rapid cooling, which were observed in considerable abundance at Tristan d'Acunha.

Fossil wood is found on the south side of Christmas Harbour imbedded in the igneous rock. It occurs in stumps and smaller branches. The colour varies from yellowish white to chocolate-brown and black. Its hardness is also very variable. Even in the perfectly white pieces there is still much organic matter remaining. The bark has been transformed into a brown crystalline mass of greasy appearance, which effervesces with acid. The inside of one rather large trunk, the core of which had probably rotted away, was entirely filled up with a mass of igneous rock with elongated cavities filled with crystals. Iron pyrites was occasionally observed. Parts that internally consisted of nothing but trap-rock often presented on the outside the fibrous appearance of the simply silicified wood; the thickness of this rind, however, was insignificant.

A species of brown coal occurs on the south side of Christmas Harbour between two layers of basalt, and only a few feet above the sea. It is, practically, of no use, being too poor to burn at all alone.

Near the eastern point of Howe Island much amygdaloid was found, the geodes here consisting almost exclusively of agate. The tops of the hills were thickly strewed with such as, in the lapse of time, had been weathered out of the matrix. Many of these presented a very striking appearance, one of the corners of the cast of the cavity having been neatly planed off, and in some instances even highly polished, in others covered with a natural etching of great beauty. The occurrence of these abraded faces is, I think, a further evidence of the recent prevalence of ice-action over the whole island; and it must be remembered that glaciers actually do reach the sea-level in fiords on the main island not more than twenty miles distant.

It is worthy of remark that, although amygdaloids are common along the north-eastern side of the island, the nature of the geodes is different in different localities. In Christmas Harbour they are almost exclusively zeolites; in Cumberland Bay those who have visited it report numerous cavities in the rock filled with quartz crystals, and, indeed, one of the promontories in it is called Crystal Point; while at Howe Island the silica with which the cavities were filled occurred entirely in compact masses of agate or chalcedony. The cavities were usually quite full, the geodes being solid and forming an accurate cast of the cavity. Where this was not the case the interior presented a finely mammillated surface. I did not observe quartz crystals either here or at Christmas Harbour; nor did I observe the zeolites, so common in the last-named locality, either at Howe Island or Betsy Cove.

Scoriæ were only met with on one occasion, namely, on the hill called "Cat's ears," at the entrance to Royal Sound; but, as far as could be decided by a view from the sea, they seemed to be by no means rare on the southern coast, where the cliffs, worn by the violence of the south-westerly gales, show sections of what undoubtedly is red scoriaceous matter. The whalers who frequent the harbours of the island chiefly for sealing purposes, and from whom much valuable and reliable information was obtained, affirmed the existence of an active volcano on the western side of the island, as well as of springs of mineral water, both hot and cold, and of petroleum.

It is much to be regretted that our time was too limited to allow of our visiting the but little-known coast of the western side of the island.

The group of Heard and M'Donald islands was visited after leaving Kerguelen. M'Donald, the smaller of the two, is, I believe, quite inaccessible. The ship anchored in Corinthian Bay, Heard Island, on the afternoon of the 6th February, when I had the opportunity of spending about an hour and a half on shore. The landing-place was at the head of the bay on a flat sandy beach at the mouth of a river which comes out of one of the magnificent glaciers which form a continuous ice-wall along the south-western shores of the bay. Like all glacier-streams it was very muddy. The island here is very narrow, not more than a mile broad, and the sandy plain stretches from sea to sea; it, in fact, forms the heads of three bays, namely, Corinthian bay facing to the north-east, the open sea towards the south-west, and a narrow bay which runs in between two remarkable promontories on the north-east. The connexion of these two promontories with the main island by means of this sandy plain is so low that a depression of a few feet would suffice to separate them from each other and from the mainland. The sand is very dark-coloured and highly magnetic, and was being blown with such violence by the then prevailing south-west wind, that it was necessary, when exposed to it, to use some protection for the face. Nowhere have I seen the abrading power of blown sand better exemplified than on the isolated rocks which have rolled down from the heights above and remained fixed in the sandy plain, exposed to the constant strong south-westerly gales, driving the sharp volcanic sand against their sides. In this way they have frequently been cut and dressed as by a mason's chisel. It is, however, not the south-westerly winds alone which produce this effect; but from their great predominance they have given the rocks the peculiar "sheared" appearance, much resembling that assumed by the trees growing on a coast exposed to the trade-winds. If favourably placed rocks be carefully examined, the effect of every prevalent wind will be observed in the facets which it has produced on the surface. The largest facet, and the one which determines the general appearance of the rock, is the one turned towards the west; and I do not doubt that the areas of the others would afford useful information as to the relative prevalence of other winds.

Of the promontories above mentioned, the one which extends towards the west is a lofty mountain rising precipitously from the sea on the N.E. and S.W., and terminating in two peaks. Between these two peaks a glacier descends to the edge of the cliff overhanging the sea on the north-east side, over which the ice-masses fall with a thundering noise. The other promontory or peninsula is covered by a flow of very recent lava, the eddies and ripples on the surface being still quite fresh. This stream of lava proceeds from the base of a recent but much dilapidated crater, which having sprung up close to the sea could only have been preserved by renewing its substance with constant eruption. When this ceased, the degrading action of the waves began to tell; and at present it is worn into a group of fantastic-looking peaks, the vertical sides of which are marked by the layers of scoriæ dipping away from the centre. The lava-stream covers the whole of the peninsula, and from having been worn by the waves it forms a range of low black cliffs along the north side of Corinthian Bay. In the face of these cliffs many large cavities, bubbles in the once molten lava, had been opened, and were tenanted by the nesting Cape pigeon.

The glaciers which cover the whole of the southern side of Corinthian Bay have been prevented from encroaching on the beach at the head of it by a sharp conical hill of scoriæ, behind which the ice-covering stretches from sea to sea.

H.M.S. 'Challenger,'
December, 1875.

[The Tables which accompany this paper are preserved for reference in the Society's Archives.—Sec. R.S.]

VII. "Report to the Hydrographer of the Admiralty on the Voyage of the 'Challenger' from the Falkland Islands to Monte Video, and a Position in lat. 32° 24′ S., long. 13° 5′ W." By Prof. WYVILLE THOMSON, F.R.S., Director of the Civilian Scientific Staff on board. Received May 5, 1876. Read June 15.

[PLATES 25-33.]

H.M.S. 'Challenger,'
Ascension, March 1876.

SIR,—I have the honour to report that we left Stanley Harbour in East-Falkland Island for Monte Video on the afternoon of the 6th of February, and on the 8th we sounded in lat. 48° 37′ S., long. 55° 17′ W., about 200 miles to the N.E. of Stanley, in a depth of 1035 fathoms. The trawl was lowered, but it was unfortunately carried away, after the weights, which were at a distance of 300 fathoms in advance of the trawl, had been brought in board. The rope looked much chafed, as if it had been ground against rocks. The sounding-machine brought up no sample of the