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JOURNAL OF
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CAPTAIN FRANCIS W. H. PETRIE, F.G.S., &c.

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ORDINARY MEETING.*

REV. PREBENDARY R. THORNTON, D.D., V.P., IN THE CHAIR.

The Minutes of the last Meeting were read and confirmed, and the following Election took place :—

MEMBER :—Peter F. Wood, Esq., Kent.

The following paper was then read by the author :—

HOW THE WATERS OF THE OCEAN BECAME SALT.

By Prof. EDWARD HULL, LL.D., F.R.S., F.G.S.

THERE are many things in the world around us to which we are so accustomed from childhood that we never stop to enquire why they should be so. That rivers and lakes should consist of fresh water, and that the sea should be formed of salt water, seems so natural that we consider them as not only matters of course, but essential to the physical economy of the world; and if perchance our attention is called to the fact that some inland lakes are formed of salt water we proceed to investigate the cause of so unusual an occurrence— one which being exceptional requires special explanation. But how few of the thousands and millions who traverse the ocean or dwell upon its shores put to themselves the question “Why are its waters salt?” And this, notwithstanding that it is daily receiving supplies of fresh water both from the rain which falls upon its surface and from the rivers which empty themselves into it. Clearly there is something here which *does* require special investigation, a question which *does* need solution, because, as far as the sup-

* 3rd of 28th Session.

plies afforded by the rain and rivers are concerned, the ocean waters ought apparently to be fresh rather than salt.

² In using the terms "fresh" and "salt" here, and in the following pages, I do so in the popular sense of the words. Scarcely any natural water, except rain, is absolutely free from dissolved salts. All rivers contain them to a greater or less extent, as do also the waters derived from wells and springs. Such waters, however, are called (and properly called) "fresh," which does not necessarily mean water absolutely devoid of salts in solution; but when the proportion of salts is so great as to cause the water in which they are dissolved to appear "salt" to the taste, then the term salt water or brine is applied to them. The varieties of saline waters and the degrees of salinity are innumerable, and their properties and uses vary accordingly. There are the salt waters of the Dead Sea—so acrid as to be nauseous to the taste; there are those of the ocean, not so acrid: there are the varieties of mineral waters, and the brine springs highly impregnated with sodium chloride. But it is not necessary to go further into this branch of the subject; all that is necessary is to understand clearly the meaning of the terms we employ, and in the following essay I shall use the words fresh, brackish, and salt as applied to water in the sense they are popularly understood.

³ But before entering upon the discussion regarding the cause or origin of the saltiness of the oceanic waters we may endeavour to ascertain whether this highly saline character has characterised these waters throughout a very long period of geological time. Now the evidence we can safely rely upon in this part of our enquiry is mainly derived from the character and affinities of the organic forms of past geological ages. At the present day the molluscan and other forms which inhabit the ocean waters are distinguishable from those which inhabit fresh water lakes and rivers, while there are numerous others, such as the *Actinozoa* or corals, starfishes, crinoids, sea-urchins, and echinoderms, exclusively confined to oceanic waters at the present day. Amongst the molluscs the Brachiopods (molluscoidea) and the Cephalopods are specially characteristic of oceanic waters of the present day, and are therefore of special value in the attempt to determine the character of the waters which they inhabited in past geological times.

⁴ Now representatives of all these forms are found not only in Tertiary, Secondary, but even in early Primary or

Palæozoic strata. Not only in the Cretaceous and the Jurassic strata, but also in the Carboniferous, Devonian, and Lower Silurian (Ordovician) formations do we find corals, crinoids, starfishes, sea-urchins, various forms of Brachiopods and Cephalopods, differing indeed specifically from, but sometimes generically related to, those of the present day. The forms which are thus preserved to us in a fossil state are only those which were furnished with a stony or horny skeleton or integument. Many other forms there were which had no calcareous skeleton, and consequently have not been preserved in a fossil state, but which are represented in the ocean waters of the present day; and if these be allowed for, it becomes clear that amongst the invertebrate forms of marine life, those of the present day were largely represented in very early geological periods.

⁵ Such being the case we are justified in coming to the conclusion that the waters of the ocean must have been salt from very early geological times; but it by no means follows that they were fully as saline as those of the present day.

The forms of life which require the high salinity of existing ocean waters were possibly represented by others capable of sustaining life when the salinity was only half as great as it is now. We know that some forms, such as those of the oyster, cockle, &c., are capable of surviving in the Baltic, or of ascending estuaries, where the water is almost brackish. Degrees of temperature, purity (or freedom from sediment), and other conditions were probably of greater importance in determining the existence of life than degrees of salinity. Adaptability to the conditions of environment has doubtless been a law of nature amongst marine forms as well as those of the air and the land throughout all past time.

⁶ It is scarcely necessary to state here that the occurrence of beds of rock salt in several formations, especially in the Trias of the British Isles and of Europe, affords no evidence as regards the degree of salinity of the sea water in geological times. At no period have the waters of the ocean been so saturated with saline matters as to admit of the deposition of beds of rock salt. It has sometimes been suggested that such deposits may have been formed by the accidental accumulation of sand bars, owing to which portions of the ocean have been cut off from the main mass and the salts have been deposited as the waters have decreased and become supersaturated by evaporation. But the mode of

occurrence of the known beds of rock salt lend little support to this view; and recent investigations have led to the conclusion that deposits of rock salt have been accumulated over the floors of inland salt lakes like that of the Dead Sea in Palestine, along whose banks such deposits occur in the form of terraces which once formed the bed of the inland lake itself, when at a higher level than at present, but owing to the lowering of its waters are now exposed along its western margin, as in the case of the terraced hill known as *Jebel Usdûm*. Another fatal objection to the view of the marine origin of salt rock is to be found in the fact that this rock generally consists of nearly pure chloride of sodium, while ocean water contains large proportions of the chlorides of calcium, magnesium, and potassium, the precipitation of which would result in a deposit very different from that of the rock salt of Cheshire and Worcestershire, which is composed of 98·30 per cent. of chloride of sodium and only small traces of other salts.

7 But in addition to the evidence derived from organic forms of the primæval ocean we apparently possess very remarkable direct evidence that the waters were highly saline. It is known that some strata of the Upper Silurian period in North America are saliferous, constituting the Onondaga salt group and the Trenton and Chazy limestone series.* These strata are characterised by large numbers of marine organisms, and there can be no doubt that they were formed in the waters of the Silurian seas. They also yield large quantities of saline waters which are used in commerce, and in which chloride of sodium predominates; and as the strata are often in the condition of basins below the level of the outer ocean, Dr. Sterry Hunt has inferred that the waters with which they are saturated were originally those of the Palæozoic ocean in which the strata were deposited. In other cases, however, where the strata are upraised above the ocean level and highly inclined, the same author considers that surface waters have gradually replaced those originally contained in the strata.† Thus we are justified in inferring, not only from organic, but from direct physical evidence, that the waters of the early Silurian oceans were salt.

8 On examining samples of water taken from the open

* Dana states that in the State of New York the salt is made from strong brine by sinking wells varying from 150 to 340 feet in depth. It takes from 35 to 45 gallons of this water to make a bushel of salt, whereas it takes 350 gallons of sea water for the same result.

† *Chemical and Geological Essays*, p. 104.

ocean of various regions and far from land, it has been found that the proportions of salts and carbonates do not much vary. This is doubtless owing to that wonderful system of currents by which the waters are kept in a state of perpetual movement, and owing to which there is a constant interchange of the warmer waters of the equatorial regions with the colder of the polar. Sea water is essentially a chlorinated alkaline mineral water, the saline contents of which consist chiefly of sodic, magnesian, potassic, and calcic chlorides and sulphates; together with a number of other substances in much smaller proportion. The total amount of dissolved contents in the water of the open ocean varies from about 28 to 39 grammes per litre. Forchhammer fixes the mean amount of such contents at 34.404 grammes per litre,* and the mean proportions of the constituent substances to each other and 100 parts of chlorine are as follows†:—

Sodium.	Magnesium.	Calcium.	Chlorine.	Total saline constituents.
14.26	6.642	3.114	100	181.10

⁹ What is most striking in this analysis is the large proportion of chlorine, and the greatest difficulty we are met with in order to account for the salts of sea water is the abundance of this gas. Recollecting that chloride of sodium is the most abundant salt both in most salt lakes and in sea water, we are justified in seeking for a solution to our problem by an examination into the mode of origin of salt lakes.

¹⁰ Now there is one peculiarity which characterises all salt lakes over the surface of the globe, namely—that they have no outlet; they are closed lakes. Whether we take the case of the salt lakes of Western America, those of Central Asia and the Dead Sea, we shall find that they are not drained by rivers.

¹¹ In such cases the lakes are constantly receiving supplies of water from streams and springs, but do not give it off in the same manner, inasmuch as it is evaporated into the air as fast

* *Phil. Trans.*, civ, 303 *et seq.*

† *Watt's Dict. Chem.*, Vol. v, 1019.

as it falls. In the case of fresh water lakes it is otherwise. Here the water of the streams which enter the lake is at least partially discharged by means of rivers flowing out, in consequence of which the water remains fresh, as the saline ingredients are carried away as fast as they are delivered. Of these two varieties of inland lakes we have remarkable examples in the case of the Dead Sea and the Sea of Galilee. In the former case the river Jordan entering at the northern end keeps up a constant supply, but this lake, which is about 1,292 feet below the level of the Mediterranean, has no outlet, in consequence of which the water supplied by the Jordan passes away into the atmosphere in the state of vapour. In the case of the Sea of Galilee it is otherwise. The river which enters at the north passes out again at the south; hence the water of the lake is fresh and supports an abundant fauna of fishes and molluscs, while the waters of the Dead Sea are (as the name indicates) absolutely destitute of living beings, and fish entering it from the Jordan immediately perish. If there had been an outlet to the southwards from the Dead Sea into the Gulf of Akabah, and a continuous stream had been flowing from the time the depression was formed, the waters of the Dead Sea would have only differed from those of the Sea of Galilee by a somewhat greater proportion of salts and carbonates. Several other examples might be cited, but those of the Sea of Galilee and the Dead Sea are the most familiar and striking.

¹² There are two ways by which we may account for the salinity of the ocean waters from very early periods of geological time. First, by supposing that the primæval waters were saturated with acid gases which were held in suspension in the vapour surrounding the incandescent globe; or secondly, that the salinity resulted from a process resembling that by which salt lakes of the present day have been formed.*

* Of the former method Dr. Sterry Hunt may be considered the chief exponent, and in order that I may not unintentionally misrepresent his views I will give them here in nearly his own words. Referring to that period in the physical history of our globe in which it may be presumed to have been in a molten state surrounded by an atmosphere and an envelope of vapour of water, he says:—"There would be the conversion of all the carbonates, chlorides and sulphates into silicates, and the separation of the carbon, chlorine and sulphur in the form of acid gases which, with nitrogen, vapour of water, and a probable excess of oxygen could form the dense primæval atmosphere. The resulting fused mass would contain all the bases as silicates, and must have resembled (when consoli-

13 We must, I think, concur with Dr. Hunt that from some cause or other, chlorine largely abounded in the waters of the primæval ocean, as by far the greater proportion of the salts are chlorides, and chlorine is but very slightly represented in river waters at the present day.

14 In contrast to the above, which may be called "the chemical theory," we may now consider that which may be called "the geological theory," though it very much depends upon certain chemical processes.

15 If we compare the analyses of waters brought down by rivers into the ocean at various parts of the globe we shall find that the matters in solution are very much the same as those which we find dissolved in oceanic waters; the proportions are doubtless immensely different, but the ingredients are essentially similar. Now, what are the dissolved ingredients of river waters? They are calcium, magnesium, sodium, potassium, a little iron, silica, alumina, and other matters, in combination with carbon-dioxide (carbonic acid gas), sulphuric acid, hydrochloric acid. Of these the carbonates of lime and magnesia are the most abundant, but chlorides of sodium and magnesium are almost always present even in waters where there can be no suspicion that they have been introduced by any artificial means. These constituents are also found in even larger proportions in the waters of natural springs; and in such chlorine occurs, sometimes in considerable quantity, in combination with sodium, magnesium, and potassium. Spring water coming as it does directly from the strata, or from rocks of various kinds, is

dated?) certain furnace slags or volcanic glasses. The atmosphere charged with acid gases which surrounded this primitive rock must have been of great density. Under the pressure of a high barometric column condensation could take place at a temperature much above the present boiling point of water, and the depressed portions of the half-cooled crust would be flooded with a highly heated solution of hydrochloric and sulphuric acids, whose action in decomposing the silicates can easily be understood. The formation of the chlorides and sulphates of the various bases and the separation of silica would go on until the affinities of the acids were satisfied, and there would be a separation of silica taking the form of quartz, and the production of sea-water holding in solution, besides the chlorides and the sulphates of sodium, calcium, and magnesium, salts of aluminium and other metallic bases. The atmosphere being thus deprived of its volatile chlorine and sulphur compounds, would gradually approximate to that of our own time, but would differ in the greater amount of carbonic acid gas." *Chemical and Geological Essays*, p. 40 (1875).

generally free from any external or artificial ingredients, hence it may be regarded as the chief source of supply of the carbonates and salts found in streams and rivers. If we enquire what is the origin of spring water, the reply is simple. It is water which originally falling on the surface as rain or snow has percolated downwards into the rocky crust, and taking up the soluble matters with which it comes in contact, bursts forth at the surface along lines of fault, fissure, or other natural ducts. The relative proportions of the ingredients of sea water and of rivers or lakes may be gathered from the following selected examples:—

PROPORTION OF SOLUBLE INGREDIENTS IN THE WATERS OF THE OCEAN AND SPECIAL LAKES AND RIVERS.
Parts in 1,000,000.

	Total Solid Contents.	Ca.	Mg.	Na.	K.	CO ₂ .	SO ₄ .	Cl.	Br.	SiO ₂ .	Fe.	Authority.
Atlantic Ocean (41° 18' N., 36° 28' W.) ..	38,400	556	1,198	11,719	668	..	3,029	20,839	387	..	..	Von Bibra.
Caspian Sea (2 versts S.W. of Pischnoi) ..	6,296	191	409	1,444	139	77	1,337	2,737	..	..	40	Göbel.
Dead Sea.. ..	240,483	9,000	19,883	47,918	6,385	..	497	154,442	2,176	..	11	Herapath.
Rhine at Basle	169	55	4·8	0·6	..	86	15·4	1·5	..	2·1	..	Pagenstecher.
Aar, near Berne	216	66	10·0	0·3	..	103·3	33·7	0·3	..	2·7	..	„
Severn, Wales	38·7	3·0	2·0	6·1	1·2	2·0	12·8	8·2	..	2·0	..	Frankland and Odling.
Thames at Twickenham	321	83·8	4·7	9·2	4·2	119·9	31·4	14·2	..	3·9	..	Clark.
Thirlmere	51·5	4·3	1·2	4·9	..	10·9	7·5	11·0	..	0·7	..	Way.
Bala Lake	27·9	1·5	0·8	3·9	0·9	1·9	3·5	7·3	..	0·3	..	Frankland.

Decimals are omitted in the case of sea waters.

16 From the above results of the analysis of various waters, it will be seen that there is no essential difference between the waters of the ocean and those of lakes and rivers except in the proportions of the dissolved ingredients. There are, of course, occasionally substances specially abundant, as is the case with bromine in the waters of the Dead Sea, probably derived from the volcanic district on its borders; on the other hand, silica (Si O_2), which is not mentioned in the waters of the Atlantic Ocean in the analysis of Von Bibra, is certainly present in those waters, and supplies the material from which sponges, diatoms, and radiolaria build up their skeletons. It will be observed also that chlorine and sulphuric acid is present in all the waters, and these gases uniting with the alkalis, give rise to the salts which are so abundant in the waters of the ocean and of closed lakes.

17 In considering the manner in which springs and surface waters have become impregnated with salts and carbonates, we have to recollect that all rocks decompose in presence of the atmosphere. This is mainly due to the carbonic acid (carbon-dioxide) contained in the air and rain water, which acts upon felspathic rocks, composed, as we have seen, of double silicates of alumina, potash, and soda. Ebelman has well explained the process by which basaltic and similar rocks are decomposed under the influence of the atmosphere. The carbonic acid (carbon-dioxide) combines with the lime and magnesia, while the silica is liberated in a soluble form. The felspar is more stable than the pyroxene and hornblende, but it ultimately gives way, forming a hydrous silicate of alumina. Thus we can account for the presence of carbonates of lime and magnesia, free silica, and by a further process in presence of sulphuric acid and chlorine of the various sulphates and chlorides.

18 Now, as bearing on the fact of sodium chloride (or common salt) being the chief ingredient in oceanic waters, as well as in those of the Dead Sea and most salt lakes, we must recollect that the soda-felspars are much more soluble than the potash-felspars, and on this account we have probably a true cause of the predominance of sodium chloride. The rocks composed in the main of such felspars as labradorite, albite, oligoclase, and andesine, were therefore more powerfully acted upon than those composed of orthoclase and sanidine; but even in these cases many orthoclase granites contain proportionate quantities of the soda felspars

such as oligoclase and albite, and the decomposition of these components would hasten that of the less soluble varieties.

19 It seems not improbable from certain considerations connected with the organic structures of the ancient world, that carbon-dioxide was more abundant in the atmosphere of Palæozoic times than at present. The enormous quantity of carbon which must have been extracted from the air during the Carboniferous period in order to the formation of the beds of coal at intervals all over the world, seems to favour this view; and if this be so, then we may suppose that previous to the Carboniferous period, the air was highly charged with carbon-dioxide, and the process of decomposition on the land surface was carried on with even greater rapidity than at the present day; but even had this not been the case, it only requires a sufficiently long period in order to bring about the chemical reactions necessary to the salinification of the oceanic waters.

20 We are now approaching the conclusion of our enquiry. From the examples of closed lakes we can determine the process of salinification with the utmost certainty. Throughout greater or shorter periods, these lakes have been receiving the waters of rivers bringing down, both mechanically suspended sediments and chemically dissolved salts, silicates and carbonates. The sediments are precipitated over the bottom of the lakes, and the water being carried off into the atmosphere in the form of vapour as fast as it enters, leaves behind the dissolved ingredients. These necessarily augment in quantity, and ultimately the waters of the lakes become saturated with salts and carbonates, which are then deposited.

21 Now the ocean is a closed lake of enormous magnitude. Throughout all geological time it has been receiving continual supplies from rivers bringing down not only sediment, but salts and carbonates, together with free silica, in solution. The sediment is deposited over the ocean floor, and generally not far from the lands, while the dissolved ingredients are carried by the currents into all parts. Meanwhile the ocean surface is constantly giving off, particularly over the equatorial regions, enormous quantities of vapour which are carried into the higher regions of the atmosphere, and are precipitated in the form of rain and snow over the lands. Part of course falls on the sea again, but the greater quantity falls on the land surfaces, and is returned to the

ocean in streams charged with a fresh supply of the salts and carbonates it had left behind in the ocean.* The consequence of this process must clearly be that the saline ingredients have been increasing in the oceanic waters from the earliest periods down to the present day. As regards the carbonates of lime and magnesia, and the silica which are being carried into the ocean by the rivers, we have no difficulty in accounting for their uses. Of these materials, the shells and skeletons of the molluscs, echinoderms, reef-building corals, foraminifera, sponges, radiolarians and diatoms and other forms are built up, and as these structures are continually being formed, and the materials solidified as fast as they enter the oceans, there is no reason why they should augment. Hence the proportion of carbonates of lime and magnesia in the ocean waters may be very much the same now as it was in Silurian and Carboniferous times.

22 We are thus brought to the conclusion that the saltness of the sea may have originated in very much the same way as has that of the Dead Sea, Lake Oroomiah, or the Great Salt Lake of Utah, or many others which might be named, and which possess in common the characteristic of having no outlet. When the great envelope of vapour which surrounded the incandescent globe began to condense upon its cooling surface, the resulting waters, though containing, as Dr. Sterry Hunt supposes, acid gases, were destitute of saline ingredients. The process of salinification began with the first streams which entered the seas from the bordering uplands, and this process carried on throughout the long ages preceding the Silurian period brought the waters to a condition suited to sustain the life of forms of inhabitants representative of those which inhabit the ocean at the present day. These long ages may be supposed to include, not only the Archæan and Azoic periods, but that during which the first crust was in course of formation over the incandescent globe.

* This process of evaporation and supply by rivers is accurately described in the Book of Ecclesiastes i, 7.

The CHAIRMAN (the Venerable Archdeacon ROBINSON THORNTON, D.D., V.P.)—I am sure all have listened to this paper with much interest and desire to return the author their hearty thanks.

Captain F. PETRIE (Hon. Sec.)—Some communications have been sent by those unable to be present to-day. The first is from Professor JOHN TYNDALL, F.R.S. :—

“ Hind Head House, Haslemere.

“ DEAR SIR,

“ I have read with interest the paper by Professor Hull which you have been kind enough to send to me.

“ The theory which he enunciates is set forth with lucidity and scientific truth.

“ Yours very faithfully,

“ JOHN TYNDALL.

“ To Captain F. Petrie.”

The next is from Professor JOSEPH PRESTWICH, D.C.L., F.R.S. :—

“ There is one point in the interesting address of Professor Hull in which I cannot agree. Speaking of the great deposits of salt in the Triassic and other strata, he says: ‘ Another fatal objection to the view of the marine origin of rock-salt is to be found in the fact that this rock generally consists of nearly pure chloride of sodium, while ocean water contains large proportions of the chlorides of calcium, magnesium, and potassium, the precipitation of which would result in a deposit very different from that of the rock-salt of Cheshire and Worcestershire, which is composed of 98·30 per cent. of chloride of sodium and only small traces of other salts.’ As I have explained elsewhere (*Geology*, vol. ii, p. 160) it seems to me on the contrary probable that these salt beds were formed by the deposition on the evaporation of sea water in lagoons or inland lakes, the cause of the difference of composition being the different solubility of the various salts existing in sea water. Thus the sulphate of lime, which is the most insoluble, is deposited first, and this substance is always found associated with rock-salt, while the more soluble salts of potash and magnesia, which require a greater degree of concentration than the chloride of sodium (rock-salt), resist deposition till the last. Thus in the salterns on the coasts of the Channel the sea water let in first deposits the more insoluble sulphate, and then, when removed to other pans, deposits its chloride of sodium with but traces of the other ingredients, whilst in the mother

liquor which remains are to be found the more soluble bromides and chlorides of potassium, &c. The result is that the salt obtained in this manner direct from sea water corresponds almost exactly in composition with the rock-salt of Cheshire, as the following table will show:—

	Salt from salterns.	Rock-salt, Cheshire.
Chloride of sodium	98·80	98·32
Other chlorides	0·50	0·39
Bromides	none	none
Sulphates	0·70	0·62
Other ingredients	none	0·67
	100·00	100·00

“Thus, while sea water contains about 78 parts in 100 of chloride of sodium or common salt, the salt procured from it by evaporation consists of 98·80 parts in 100, which corresponds within a fraction with the proportion (98·32) existing in rock-salt.”

The third is from Mr. J. POSTLETHWAITE, F.G.S. :—

“I have read Professor Hull’s paper on ‘How the Waters of the Ocean became salt,’ with much interest, chiefly because my attention had been directed to the subject whilst endeavouring to investigate the source of certain mineral springs, near Keswick, for the purpose of laying the results of such investigation before the members of the Cumberland and Westmorland Association for the Advancement of Literature and Science, at their Annual Meeting in 1886. (See *Trans. C. and W. Assoc.*, vol. xi, p. 142.)

“The existence of those springs is a further confirmation of Professor Hull’s statement that ‘from direct physical evidence the waters of the early Silurian oceans were salt’ (sec. 7). The salt spring at Brandley Mine, on the margin of Derwentwater, issues from the Skiddaw Slate, in the lower part of the Ordovician (Lower Silurian) System; it contains a large amount of mineral matter in solution, namely, 203·78 grains per imperial pint, consisting of:—

Chloride of calcium	...	...	87·67 grains per pint.
” ” magnesium	...	...	1·53 ” ”
” ” sodium	...	...	110·23 ” ”
Sulphate of magnesia	...	...	4·35 ” ”

Total 203·78

“The large amount of chloride of sodium proves that a large bed of this rock salt exists beneath Catbells and Maiden Moor, and this bed must have been formed in the early part of the Ordovician Age. The quantity of water issuing from this spring is, on the most moderate computation, about 150 gallons per minute, and the quantity of salt (chloride of sodium) contained in it amounts to about $18\frac{1}{4}$ lbs., which gives a total of 12 tons 3 cwt. every twenty-four hours, 4·434 tons every year, or 443·400 tons in 100 years, and this has been going on for ages. Moreover, there is another spring at Saltwell Park, about three-quarters of a mile south of Brandley Mine, precisely the same in quality, but the quantity of water issuing from this spring is probably not more than one-third of that issuing from Brandley Mine. (When the mine was being worked it was found sometimes necessary in dry seasons to use the salt water, for a short time, for supplying the engine boiler, and I have seen cartloads of salt taken out of the boiler on these occasions.) The quantity of salt which is being continually conveyed away by these springs shows that the bed from which it is obtained must be very extensive.

“The presence of chlorine in these springs is also a confirmation of the opinion quoted from Dr. Hunt’s essay, to the effect that ‘chlorine largely abounded in the waters of the primeval ocean.’”

Mr. DAVID HOWARD, F.C.S.—I am sure all those who have paid attention to this subject must feel a great debt of gratitude to the author of the paper for the very careful research he has given to it. Of course it is not an easy subject, it is rather readily assumed either that the beds of rock salt are the source of the saltiness of the ocean or *vice versa*, and yet what seems so simple a thing is not really easy to understand. To begin with it is a puzzle for chemists to make from sea water salt of the marvellous purity of some beds of rock salt which are almost absolutely pure, and it is a remarkable fact that they are free from those elements which adhere most persistently to salt made from sea water. On the other hand, if one studies formations which undoubtedly are the result of the drying up of portions of sea or inland lakes, one is struck by the excessively mixed character of the resulting beds—as for instance in the nitre beds of South America, which are evidently the result of drying up—the different strata are formed of different substances which follow one another as you would expect from their solubilities, and very remarkable substances some of them seem. They are very difficult to make artificially,

and yet it is clearly seen how they are formed. It is very easy to find that some of the very substances obtained from these beds are obtained from sea water. Undoubtedly there are very minute traces in all sea water of boron components, which is found crystallised in the form of boro natro calcite in these nitre beds. You must evaporate an enormous quantity of sea water to get evidence of these substances. Boron you can find with the aid of the spectroscope, but iodine, which also abounds in these beds, is extremely difficult to obtain from salt water; but the processes of certain sea weeds, of obtaining it, for the physical requirements of the plant come to our aid, and it was first discovered from the ashes of these sea weeds, which contain a considerable quantity. I believe the more you study the chemistry of sea weeds the more confidence you will have in the value of this admirable paper.

Rev. F. A. WALKER, D.D., F.L.S.—There are two points upon which I should be glad to be permitted to ask for information. First:—Is it not a fact that certain seas do very greatly differ from one another in amount of salinity? the waters round the Channel Islands are said to be very salt. Secondly:—Is it the case that waters at a great depth down, say one mile or more, differ in their respective degree of salinity from the surface waters? would their smaller proportion of salinity tend to account for the total absence or great scarcity of organic life at a considerable depth, or is this absence or scarcity solely attributable to the absence of light at a great depth?

The CHAIRMAN.—There is a theory that the globe was once incandescent and probably surrounded by a quantity of acid vapour called carbon-dioxide, and chlorine vapour especially; if that theory be true does not Professor Hull think that the chlorine vapour and the sodium vapour would have been present and have united themselves, and to the union of these two vapours the immense supply which we have of chloride vapour may be due.

The AUTHOR.—Although the speakers are few they have given me enough to do if I am to answer their questions. But I am rather disappointed that I have had no what I may call downright opponent to meet.

The CHAIRMAN.—I think you cannot expect anybody to criticise so convincing a paper.

The AUTHOR.—Then I will, with the best grace I can, give my

replies. With regard to Mr. David Howard's remarks, he referred to the nitre beds of Western America. I have not seen those, they are very exceptional and very valuable; but I think he will, perhaps, find they are exceptional in this respect, viz., that they are all situated in volcanic regions, and nitre, as we know, is a volcanic product, and these are probably laid down in inland lake beds which have derived their supply of that salt from volcanic sources. It is quite true what he said about the possible existence of substances in such small quantities that in an ordinary—or indeed more than ordinary—chemical analysis they might be passed over; and I have referred in my paper to the case of free silica in solution in the waters of the ocean, which we know must be there, because from that the silicious sponges, diatoms, and other forms have built up their skeletons. Dr. Walker has given me some questions to answer, but I am afraid if I entered into them exhaustively I should keep you here too long. I will endeavour, therefore, to reply as shortly as possible. I think the first question is whether the salinity of the different parts of the ocean varies? No doubt it does to a certain extent. The surface portions of the ocean are not so saline as those of deep water; and, of course, waters which are in proximity to the outlets of large rivers are necessarily less saline than those which are in mid-ocean; but as regards the absence or prevalence of marine life in the ocean it is probably much more due to the difference of temperature than to salinity. Now the "Challenger" and other expeditions in their soundings over almost all parts of the ocean, adduced this remarkable and interesting fact—that the very deep parts of the ocean, even under the equator and the tropics, are intensely cold—almost as cold as the Arctic waters;—differing very slightly from the freezing point of water, viz., 32° F. In consequence of that, temperature is, as we know, the main factor in determining the presence or absence of animal forms in the ocean. There are many forms which will survive and flourish in warm water and will not do so in temperate water—much less will they do so in cold water; and after going down, say 3,000 fathoms, the temperature of the ocean does not vary much in any part of its floor area from the freezing point of water. Dr. Carpenter, we know, founded on that the very beautiful theory with regard to oceanic circulation which seems to be borne out by this fact. He showed that not only is there a surface circulation—the currents with which we are familiar, which

circulate over the surface of the ocean—but a vertical circulation. As the waters of the Arctic and Antarctic regions pass down—at a very slow rate it is true, but still they do pass down—along the bed of the ocean towards the equator; those on either hand gradually rise and replace the warm water which is constantly given off by the surface currents in the equatorial regions. As to the theory which the Chairman has mentioned that sodium may have been in a gaseous condition in the original highly heated circumincumbent air surrounding the incandescent globe—sodium gives a very marked line indeed in the spectroscopic analysis of the sun and of many of the heavenly bodies. But my paper refers to a more advanced stage in its course of consolidation, and I start from the period in which sodium and calcium would have entered into combination in the formation of rocks during the cooling of the crust owing to the radiation of the original heat into space. Crystalline rocks of the granitic or volcanic type may have been thus formed, and then the sodium would of course be in a combined state. It is the reaction of the supposed highly saline waters, which would still have remained as an envelope outside the incandescent globe, which, according to the view I have advanced, would result in the formation of various salts—sodium chloride being the principal and the most abundant.

I will now refer to the communications that have been received.

Let me say how much gratified I feel by Professor Tyndall's approval of my views. As regards Professor Prestwich's communication, which gives what may be considered the alternative theory regarding the origin of oceanic salinity, there is much to be said. But I have for a long time regarded it as an insufficient hypothesis; and as regards the statement that gypsum (sulphate of lime) "was deposited first," this is not generally the case; at least not in Worcestershire where the gypsum lies above the rock salt, nor can I admit that the Triassic strata are of marine origin in England.

Mr. Postlethwaite's letter is of very great interest to me, because it is the first case in which I have heard in the British Isles of such highly saline water as he describes being found in strata of the lower Silurian age. I do not know of any case in England, Ireland, Wales, or Scotland where these old rocks have yielded such highly saline waters as he describes. They seem to represent those which have been worked for so long a period

for chemical purposes in the United States, and this occurrence in Cumberland is very interesting, for it seems to show, as he concludes, that the waters of the lower Silurian period were really highly saline.

In conclusion I beg to thank all for the kind manner in which my paper has been received.

The Meeting was then adjourned.

A NOTE ON THE FOREGOING PAPER.

D. BIDDLE, Esq., M.R.C.S.E., writes :—

I feel sure that on consideration of the facts, Professor Hull's view as to the cause of the saltiness of the ocean will be found to be untenable. Although the first chapter of Genesis does not lend much countenance to the nebular hypothesis, yet in effect it states that the whole surface of the earth was fluid before the dry land appeared. Science has confirmed this testimony, and has thus assigned to the ocean the first place in mundane existence. Such being the case, it is scarcely too much to assume that the original liquid forming the ocean was capable of holding (and, in fact, did hold) in solution all those salts which are found in the ocean of the present day. It possibly held many more when its temperature was higher; and some geologists have gone so far as to assert that the solid crust of the earth is wholly a precipitate from the ocean, the stratified appearance of many rocks giving support to this hypothesis. But, be that as it may, it is not unreasonable to believe that the ocean originally held in solution all the sodium chloride entering into the earth's composition, and that so far from the land having given salt to the ocean, the reverse has been the case, the ocean having given salt to the land. One way in which this has been effected is by alterations of the earth's surface (at the first appearing of dry land and subsequently), whereby portions of the ocean have been imprisoned in basins, from which there has been no outlet except by evaporation. The salt left behind then forms part of the land, and by further alterations of the earth's surface may be overlaid, as in Worcestershire and Cheshire, or be upheaved, as in the Kalabagh Mountains of India.

Another argument against Professor Hull's view is to be found in the fact that at least one-fortieth of the ocean consists of sodium chloride, that the geographical area of the ocean is about three times that of the land, and its mean depth far greater than the mean height of the land above sea-level. Thus the salt at present in the ocean is fully equal to one-tenth of all the land from which, by gravitation, it could have been discharged, if Professor Hull's

view held good. This is, indeed, a prodigious proportion of soluble material to be even temporarily withheld from an almost omnipresent solvent. Is it not much more reasonable to believe that the ocean, as it receded from the upheaved land, took its salt with it?

The following is the author's reply :—

I do not think there is any discrepancy between my views and those of the creation of land and ocean in Genesis: on the contrary I venture to maintain they are quite consistent. Nor can I see how Dr. Biddle is to account for the sodium of the sodium chloride unless it was derived from the decomposition of the rocks by the chlorine which (I assume) existed in the original aqueous atmosphere. His statement that "it is not unreasonable to believe, &c.," is not scientific induction, but only mere assumption. As for the beds of salt in the strata of Cheshire and Worcestershire, the opinions of geologists are almost unanimous that they were formed on the beds of inland lakes like those of the Dead Sea, of Utah and of Central Asia; though, I admit, that there are instances of their formation in the way Dr. Biddle describes.

ORDINARY MEETING.*

PROFESSOR E. HULL, LL.D., F.R.S., IN THE CHAIR.

The Minutes of the last Meeting were read and confirmed, and the following Elections were announced :—

ASSOCIATES :—Rev. C. W. A. Clarke, M.A., India; Rev. J. P. Clark, M.A., London; Rev. H. D. Buswell, Mauritius; Rev. H. J. Hoare, India.

A lecture entitled "Primitive Indian Philosophy, with some Modern Parallels," was given by Mr. W. H. Robinson.

* 8th of 28th Session.
