PROCEEDINGS

OF THE

LIVERPOOL GEOLOGICAL SOCIETY.

SESSION EIGHTEENTH.

OCTOBER 10TH, 1876.

THE PRESIDENT, T. MELLARD READE, C.E., F.G.S., in the Chair.

JOSEPH T. STOWELL was elected an Ordinary Member.

The President read the Annual Address.

PRESIDENT'S ADDRESS.

SINCE the time when Hutton laid the foundation of our present knowledge of Physical Geology, our acquaintance with the structure of the Earth has advanced with rapid strides. The various formations have been reduced to order and sequence through the combined influence of Palæontology and careful Stratigraphical Surveying. But to make Geology essentially a science, the mathematical method must step in to measure, balance, and accurately estimate.

Though fully recognising that there still remain vast and varied unexplored fields for original research, the direction of advancement will be towards reducing those comprehensive generalisations for which we have to thank the old generation of Geologists—now almost passed away—and their rough though wonderful approximations to truth, to careful and accurate measurement.

Instead of giving you, as is usual on these occasions, a *resumé* of geological progress during the year, I purpose devoting the time to what I trust will prove in my case more valuable, viz., an investigation of the nature and amount of the solvent action of rain-water upon the crust of the earth, and its influence in that direction as an agent of denudation.

There have, as you know, been various estimates made of the amount of mechanical denudation caused by rain, calculated upon the amount of mud held in suspension and carried annually to the ocean by our great rivers; and all of us who prize Lyell's Principles will remember the masterly manner in which he treats the question in the case of the Mississippi and the Ganges, with the Brahmapootra. Other geologists have also calculated from the same data and the area of the river basins, the amount of time it takes to reduce the whole of these river basins one foot in depth; the result being in the case of the Mississippi 6,000 years, and the Ganges 2,300 years.

There have also been estimates of the amount of carbonate of lime carried into the sea annually by the Thames and other rivers draining calcareous districts; but, even if they exist, I am not aware of any attempt having been made to estimate as a whole the soluble constituents removed annually from the varied formations which constitute the crust of the earth. Most of you, no doubt, are aware of the valuable information contained in the Sixth Report of the Rivers Pollution Commission, and the wonderful elaboration and accuracy of all the information relating to the potable waters of Great Britain.

When first I turned over its pages, it at once occurred to me that here is the very thing which a geologist wants for the solution of several interesting problems. I made up my mind that I would use it on the very first opportunity. The present I consider a suitable occasion. In page 131 of the report is a table of the average composition of unpolluted potable waters, commencing with rain water, but it is chiefly the upland surface waters that I purpose dealing with to-night. In the first column we get the "total solid impurity," which means the total ingredients held in solution, consisting practically of the *soluble inorganic ingredients*, as the proportion of organic constituents is almost invariably very weak. For an explanation of the other columns I quote from a letter Dr. Frankland kindly sent me, and without which I could have made but a limited use of the stores of information collected, through the analyses having been made in a form suited to the immediate object of the Commission. He says:

. . "'*Ammonia*' is generally present in very small quantity, and may be left out of consideration. It is probably always present as Carbonate of Ammonia, and is therefore an *in*organic constituent.

'*Nitrogen*' as nitrates and nitrites means almost invariably nitrogen as nitrates, since the occurrence of nitrites in any but shallow well water is exceedingly rare. If you multiply the numbers in this column by six, you will obtain with close approximation the weight of nitrates in the water.

'*Chlorine*.'—This exists practically as 'chloride of sodium,' and if you multiply the numbers in the chlorine column by 1·65, you will get approximately the proportion of common salt. 'Temporary hardness' means in most cases (except water from Dolomite or Coal-measures, in which there is a good deal of carbonate of magnesia) carbonate of lime, with a little carbonate of magnesia.

'*Permanent hardness*' means, except as aforesaid, hardness produced by sulphate of lime; and if you multiply the numbers in the column by 1·36, you will get approximately the proportion of *sulphate of lime,* with a little sulphate of magnesia.

Of ingredients of any importance there only remain: Alkaline sulphates—that is, sulphate of soda and sulphate of potash.

Carbonate of Soda.

Silica.

Iron.

Of these, the last two are rarely present in any but very small proportion—about 1 part of silica and 0·1 part of peroxide of iron in 100,000 parts of water."

With this preliminary information I proceed to explain my application of the data for a solution of the problem before us—that is, the estimation of the total solids annually removed by the solvent action of rain from the surface of England and Wales.

To have guaged every river and stream delivering into the sea during a period of say ten years, and to have analysed the water in each case from day to day under the varying circumstances of the dry weather and flood flow, would no doubt have been the most accurate way of determining the question. It is needless to say such a course is fraught with too much labour and expense to be practicable to any individual. There is, however, another method used by engineers, accustomed to design water-works, for estimating, in the absence of gaugings, the flow off the land which gives us what we want with sufficiently close approximation.

By taking the mean rainfall over a given area, and then allowing a certain depth for evaporation and absorption, with judgment, the flow off the land can be arrived at with tolerable accuracy. In the case of several rivers, through elaborate gaugings and observations of the mean rainfall of the basin, it is known with certainty what the proportion is. In the Thames basin, for instance, with a mean rainfall estimated at 27 inches, only 8 inches reaches the sea; whereas in the basin of Loch Katrine, in the area of rainfall exceeding 75 inches of Symons' Hyetographical map, 81·7 inches, according to Bateman, and at Rivington Pike, in the area of between 40 and 50 inches of the same map, according to Stephenson, 39·8 inches runs off the ground. The yield of a gathering-ground is in all cases determined by the total rainfall, the nature of the rocks, and the steepness of the land surface.

In a porous area and small rainfall, like the Thames basin, the maximum of loss takes place, measuring in that case 19 inches per annum; while in the mountainous tracts of siliceous rocks in Wales and Cumberland it is doubtful if more than 10 inches is lost.

My method of procedure thus has been to take out the areas of rainfall from Symons' Hyetographical map attached to the report, to allow to the best of my judgment for evaporation, and then, grouping the formations together in each rainfall area, to estimate the number of tons of water yielded by each gathering-ground annually. Instead of, however, taking out each group exactly as given in Dr. Frankland's table referred to, I have roughly divided them where it could readily be done; and in other cases, judging their relative proportions, I have added up the figures opposite the "Total solids in solution" given for surface water off each formation, and then averaged the results before multiplying the total yield of water by the fraction of 100,000 in that way obtained. I consider that this method is more likely to be near the truth than a more minute analysis. A reference to the table prepared will, however, explain the operation better than any description by me. I have exercised very considerable care in the calculations, so I trust they may be relied upon as close approximations.

As there is a certain amount of chloride of sodium in most rain water, due to the spray of the sea being carried inland, I have deducted the average amount from the "Total solid impurity," as not being a product of denudation; but I have not deducted the other solids in solution in the rain, for primarily they must emanate from the land itself. This, however, is but a small fraction of the whole.

Looking at the more remarkable features developed by this analysis, perhaps the one I was least prepared for is the curious way in which the smallest percentages of solids in solution, such as is contained in water from granitic and metamorphic rocks, rise in the aggregate, through the greater rainfall on these formations, to the total solids in solution from such specially soluble rocks as constitute the Thames basin.

With few exceptions, in England the greatest rainfall follows the older formations, whether as cause or effect it is difficult to say; but the older formations constituting the higher grounds they collect more rain, while the denudation being so much greater has no doubt had a tendency to cut down the rocks formerly overlying them so as to expose the old rocks forming the core beneath. Will not this help us to understand those grand examples of denudation in Wales so forcibly shown by Ramsay to have taken place, and which I called your attention to in my last address.

Is it not strikingly apparent from this what a leveller the rain is? Certainly it was never brought to my mind so vividly before.

A reference to the Geological and to the Rainfall maps of England, and a comparison of them, shows that the mountainous districts, generally composed of rocks from the Cambrian to the Carboniferous, being situated on the west coast intercept the greatest rain, which is from the south and north-west, and that here in Devon, Wales, and the Lake district of Cumberland and Westmoreland, the rainfall ranges from 50 to over 75 inches.

The extremes of rainfall in 1874 were at five stations in the Lake district, from 107·53 at Little Langdale to 148·79 at Seathwaite; while in Wales, at three stations, it was from 116·56 to 149·00 inches. The smallest, as might be expected, was on the east coast, ranging from 12·85 at Chatteris, in the Isle of Ely, to 14·97 at Ipswich; and in Wales from 22·33 at Holywell, to 27·96 at St. Asaph.

The rainfall, expressed in inches, if distributed evenly over England and Wales, would have been for 1874, 34·02, or 1·50 below the average from 1860 to 1865, if we take the mean of all the stations. Estimated, however, by areas, as given in Symons' map, the mean rainfall of England and Wales, is 31.988 or say 32 inches.*

Dividing the country in sections, as shown in the table, and estimating each separately, gives a total of 68,450,936,960 tons of water run off the area of England and Wales annually, equal to 18·3 inches in depth, which leaves 13·7 inches for evaporation.† The total solids in

* The difference arises from the fall at some of the mountain stations being much in excess of the average; and the areas of this excessive fall being restricted, the mean of all the principal stations naturally gives the excess we see. Mr. Symons, in a letter to me, says he has never worked out the mean rainfall, but is "under the impression it would come out about 35 inches."

† It must not be lost sight of that it is the *evaporation* only that affects our calculations. Water that *percolates* will find its way eventually into the river system, or directly by springs into the sea itself. This water is, of course, more highly charged with mineral matter than surface water, and may help to balance flood surface water, which often contains less than the mean quantity of soluble mineral matter. On the whole, it will be seen that the figures work out fairly in unison with each other.

solution amount to 8,370,630 tons, or 12·23 parts in every 100,000 of water. This total includes, calculating on the method pointed out by Dr. Frankland, and on the averages of the samples 9·50 parts of the carbonates and the sulphates of lime and magnesia, the sulphates predominating in the averages of the water from all the rocks below the New Red and the carbonates in those above the Permian, reaching its maximum in the cretaceous. The average amount of chloride of sodium, deducting ·36 as that contained in the rain, is 1·66 for the upland waters. The nitrates amount to ·08.*

There is now left ·99 for the alkaline sulphates and carbonates of soda, silica, and peroxide of iron.

I have intentionally taken the upland surface water as a Geological basis to work upon, for in consequence of drainage works, artificial manures, and other disturbing causes incidental to a thickly populated country, the primitive denudation of the world is not accurately represented by the constituents held in solution in most of our river waters far down their course. The chloride of sodium in the Thames water, for instance, as supplied by five different companies, averaged in 1873 3·1 parts in 100,000, and most of this is no doubt of artificial origin. In the Mersey at its junction with the Irwell the chloride of sodium is 4·12, and in the Irwell at its junction with the Mersey it reaches the enormous amount of 21·28 per 100,000.

Again, the drainage and culture of calcareous soils adds considerably to the amount of the carbonates and sulphates of lime held in solution, and these disturbing

* The averages of all the samples of upland water give 12·66 as the total solids in solution, which is a very close approximation to the 12·23 estimated in the totals as before described, and is calculated to verify the accuracy of the method I have adopted.

causes I have endeavoured to eliminate from my calculations.

If we may estimate the various solids held in solution at 15 feet to the ton, the weight of limestone,* the amount of denudation if distributed equally over the area of England and Wales reckoned at 58,300 square miles would be .0077 of a foot per century, that is it would take 12,978 years to reduce it one foot.

It is certainly a rather remarkable coincidence of figures that Professor Prestwich, I find, in his address to the Geological Society of London, 1872, calculates that the Thames removes from the Chalk, Upper Greensand, Oolitic strata and Marlstone, carbonate of lime alone to the extent of 1 foot over its basin in 13,200 years. This he arrives at by referring 10 grains to the gallon on the total discharge at Kingston to these strata, estimated at 2072 square miles. The total denudation due to solids in solution over the whole area is, as will be seen further on, 149 tons per square mile per annum, as against 140 tons of carbonate of lime alone removed from the restricted area calculated by Professor Prestwich.

Taking the carbonates and sulphates of lime and magnesium at 9·5 and 15 feet to the ton, that would represent the removal of those substances in solution at the rate of 1 foot in 16,707 years.

The Chloride of Sodium estimated at 1·66 would represent the removal of 1 foot in thickness (16 feet to the ton) of Rock Salt in 89,640 years.

The remaining portions consisting of Silica, Alkaline Sulphates, Peroxide of Iron, &c., have not been directly determined by analysis, and are therefore only very

* Some very compact limestones only contain 13 feet to the ton.

rough approximations. The analyses of river waters by Bischof* shew these ingredients to be very variable, even in the same river at different times. If we estimate them at 12 feet to the ton, ·99 parts per 100,000, would give 200,405 years to remove 1 foot in thickness.

After very carefully reviewing my data and calculations, I am of opinion that these figures in the main represent very nearly what would be the denudation of England and Wales in their primitive condition, before the hand of man had interfered much with the surface.

If, however, we desire to know what is now being removed, I think we must increase this estimate by one-fifth, as Dr. Frankland's analyses clearly shew that cultivation of the land, and drainage especially in calcareous districts, increases the soluble substances in the water to a very considerable extent.

It would have been impossible to rely upon the data had not a very great number of samples been analysed, taken, be it observed, at all seasons of the year, for we find these averages tend to correct one another, and to give a very close approximation to the aggregate result.

Stated simply, this then, is the result. If we imagine the area of England and Wales, consisting of 58,300 square miles, to form one river basin, the delivery of water by such river would be 68,450,936,960 tons, or 18·3 inches per annum, containing a total of 8,370,630 tons of solids in solution, representing a general lowering of the surface from that cause alone of ·0077 of a foot per century, or one foot in 12,978 years.

Thus far we have got with our geological modulus of time; but before attempting to apply it to the solution of the larger problems of Geology, let us see if we can

* Chemical and Physical Geology, Vol. 1, p. 76.

institute a comparison between England and the other parts of the world best known and Geologically surveyed.

A reference to the Geological Map of the world, constructed by Jules Marcou, shews that in the continent of Europe the principal difference from the Geology of England is the much greater development of what in his classification are Crystalline Rocks, consisting of gneiss, metamorphic rocks, granite, porphyries and trappean rocks, principally situated in Norway and Sweden, and the Tertiaries in mid-Europe, between the Baltic and the Black Seas. Roughly speaking it is easy to see that in England and Wales a line may be drawn, dividing them into two nearly equal halves, on the western side of which are the rocks from the New Red downwards, and on the eastern the rocks from the lias upwards, including the Tertiaries. I have, at considerable trouble, calculated the areas of the several formations of Europe from Jules Marcou's Map.

They are approximately as follows:—

	English Square Miles.
Modern Rocks	468,277.
Tertiary do.	613,043.
Cretaceous Rocks	552,282.
Jurassic do.	246,983.
New Red Sandstone	466,292.
Carboniferous Rocks	181,940.
Paleozoic or Grauwacke	463,661.
Crystalline Rocks	714,960.
Volcanoes and Basalt	13,062.
Total	3,720,500.

It will thus be seen that the formations from the base of the Jurassic up to the Modern Rocks constitute almost exactly half of the continent, and those from the New

Red downwards, inclusive of the Volcanoes and Basalt, the other half; consequently the dividing line is nearly the same in the Continent as in England and Wales. The Geological structure of England is almost an epitome of that of Europe, excepting that in the Continent the Carboniferious rocks are in less force, and the Tertiary and Metamorphic in greater.

The average solubility of the rocks, I suspect, is not very different on the Continent from that of England, but the rainfall is less, averaging, according to Sir John Herschell,* 23 inches for the *non*mountainous districts, and 42 inches for the mountainous ones.

We may, therefore, assume that the total solids in solution removed annually are proportionately not so great as in England, excepting in the Swiss mountains, where, no doubt the denudation is more rapid than in any area in England or Wales.

As bearing upon this comparison, I have collected all the available information I could as to the discharge of several of the principal rivers of Europe; and, though the data is imperfect in many particulars, the facts bear out the views I have just stated.

The Rhine, the Rhone, and the Danube all rise in the Alpine district, and flow to the west, the south, and the east, through formations of which the basin of the Thames and the Severn would form, perhaps, the nearest English equivalents. The basin of the Rhine is rather more than the area of England and Wales; so we may readily institute a comparison between the country drained by the Rhine and England. Above Lauterbourg, its area is 63,000 square miles, and the annual discharge of the river is 34,216,560,000 tons, equal to a depth of 8·53

* Physical Geography, 4th Edition, p. 241.

inches.* The rainfall is from 16·4 inches at Frankfort-on-the-Main to 26·3 at Bonn; but, of course, it is also fed by the Alpine snows through the Lake of Constance. The mean of the analyses of solids in solution, as given by Bischof, is 17·1, say 17 in 100,000, this gives 5,816,805 tons per annum, or 92·3 tons per square mile.

The Rhone at Avignon has an area of 35,745 square miles, and an annual discharge of 53,144,040,600 tons, equal to 22·86 inches in depth. The mean of four analyses given by Bischof is 15·6, which will give 8,290,464 tons of solids removed per annum in solution, or 232 tons per square mile.

The Danube has an area of 310,000 square miles, and the mean discharge into the Black Sea, from ten years' observation is, according to Sir C. A. Hartley, M.I.C.E.,† 207,000 cubic feet per second, equal to 181,332,000,000 tons per annum.

The discharge appears, however, to be very variable, the maximum being 383,000 cubic feet per second in 1871, and the minimum 125,000 cubic feet per second in the years 1863 and 1866.

The rainfall at Sulina also varies from 10·03 inches to 34·28; but whether it is as variable over the whole basin I cannot say.

This discharge equals a depth of 6·8 inches run off the ground, or one-third of the mean rainfall at Sulina. The amount of solids in solution was 12·42 at Vienna. Bischof, however, only gives the one analysis. If this is an average quantity, the total solids in solution would amount to 22,521,434 tons per annum, or 72·7 tons per square mile, or as nearly as possible one-third of the

* Beardmore's "Manual of Hydrology."

† "Minutes of Proceedings of the Institution of Civil Engineers," vol. xxxvi, p. 224.

average amount of matter held in suspension, which is given as 67,760,000 tons, estimated from surface samples.

The total drainage area of these three great rivers is, therefore, 408,745 square English miles, their annual discharge 268,692,600,600 tons, and the total solids in solution 36,628,703 tons.

Comparing this with the calculated denudation of England, it amounts in England to 143·5 tons per square mile and 90 tons per square mile in the three European river basins.

The data for these latter calculations are, indeed, insufficient, more especially as regards the Danube, from the absence of analyses at more points than Vienna. I think it extremely probable that the estimate should be increased, as the direct determination of the solids in solution amounts to 14·14.

The result is, however, in accordance with what we should *a priori* expect; the greater rainfall on the western coast produces its effect upon the land, not only in removing detritus mechanically, but in its solvent action upon the rocks. It works more quickly.

The Garronne removes 142 tons per square mile.

The Seine contains, according to two analyses by Bischof, 21·72 parts per 100,000. The drainage area is at Paris 17,111 square miles, and the discharge equals 6·98 inches per annum; it therefore removes about 97 tons of solids in solution per square mile.

The Thames, estimating the discharge at eight inches per annum and the total solids in solution at 29·26, as given by Prestwich, removes 149 tons per square mile per annum.

It is thus seen that there is much less variation than one would have expected between the soluble constituents removed by one river and another; for if we compare the maximum of our examples, which is the Rhone at 232 tons per square mile per annum, with the minimum, the Danube at 72·7 tons, we find there is only about the same difference between them as there is between the maximum and minimum annual discharge of water of the Danube itself! If, on the other hand, we compare the quantity of solids in solution removed to the solids in suspension, we find that the former is a much more constant quantity. The detritus carried down to the Black Sea by the Danube was, in 1866, 12,500,000 tons, and in 1871 it rose to 154,000,000.

It is also evident that the character of the solids in solution is determined by the nature of the rocks the water flows over. On the western half of England the sulphates of lime in the upland waters predominate over the carbonates in the proportion of 7·15 to 2·9; while in the Thames area the carbonate of lime is in excess of the sulphate in the proportion of about two to one. It is extremely probable, therefore, that over the whole area of England and Wales the carbonates and sulphates of lime are about equal.

On taking the mean of eighteen analyses of water from European rivers, given by Bischof, I find the carbonates in excess of the sulphates of lime in the proportion of 9·32 to 1·79. Bischof, himself, says, "Among the mineral substances in these rivers, carbonate of lime is always in the largest quantity." The basins of these rivers are, however, composed nearly wholly of the strata above the New Red Sandstone, excepting as regards the Crystalline rocks. The Volga is a river flowing through the New Red; of this water I have no analysis, but, as might be expected, the sulphates of lime predominate over the carbonates in the Caspian

Sea, which receives its waters. The mean of two analyses, one by Göbel, the other by H. Rose, gives 89·6 parts per 100,000 of sulphate of lime to 18·9 of bicarbonate of lime.

It is evident, therefore, that, estimated over the whole Continent of Europe, and taking into consideration the proportions of the various rocks, the carbonates of lime will still be in excess of the sulphates.

The extensive development of Carboniferous strata in England, together with the New Red, to a large extent accounts for this diversity between England and the Continent; but the proportional excess of sulphates of lime in the Thames water over the Continental European river waters may perhaps be partly traced to the more artificial state of the Thames basin. If the information we require is limited with respect to Europe, it is still more restricted in relation to the rest of the world. Of the geology of Asia our knowledge is very partial and very indefinite, as a glance at Jules Marcou's map will show. To calculate the proportion of the various formations would be impossible, with the accuracy required for our purpose. Dr. Frankland has, however, kindly supplied me with several unpublished analyses of water in various parts of the world, and among them is one of Tienshan Lake, in China, in which the total solids in solution are 13·10 per 100,000. Of these 5·31 are due to carbonate of lime and 1·91 to sulphate of lime. The River Wangpoo, above the influence of ordinary tides, has 10·46 per 100,000 of solids in solution, of which 4·14 are carbonates and 1·57 sulphates of lime.

Above the bridge at Wangdoo the water holds 21·54 of solids in solution, of which 9·31 are carbonates and 1·65 sulphates of lime; at Tyking 30·52 of total solids in solution, of which 11·30 are carbonates and 3·88 sulphates of lime.* The chloride of sodium in Tienshan Lake amounted to 1·71, and in the Wangpoo to 1·48. The Tisai (Tienshan) Lake, according to another analysis, holds 10·90 solids in solution, of which 5·31 are carbonate and 2·32 sulphate of lime, while the chloride of sodium is 1·73.

There are other analyses by Dr. Frankland, but I cannot make any deductions from them, as the samples were apparently taken within the influence of the tides.

In South America an analysis of the Parana in front of Carabelos gives 10·08 of total solids in solution, of which ·28 was carbonate of lime and 3·03 sulphate, and 2·97 chloride of sodium, the nitrates amounting to ·42.

It is rather a pity this analysis did not determine the separate amount of each constituent, as there is a large balance to be accounted for, viz., 3·38 to be divided between the alkaline sulphates, carbonate of soda, silica, and iron.

I have now pretty nearly exhausted all the information I can bring to bear on what, for brevity, I shall call "*Soluble Denudation.*"

The rainfall is so variable in different parts of the world, that it is difficult to make an estimate of the average "Soluble Denudation" of the globe; but we find that Nature, on the whole, averages the results; and, though there is as much as 300 inches of annual rainfall in some places in the Tropics, and 600 inches, or 50 feet, on the Khāsi Hills at Cherra Poonjee, on the other hand we have great rainless districts in the interior of Africa and Asia. The River Nile, with a basin of 600,000 miles, above Cairo, according to Girard, runs off only 3·78 inches per annum; but this, if the data of my calcula-

* Probably affected by the tide.

tions are reliable, must be in excess of the actual depth.*

The Ganges at Sikreegulee, with a basin of 330,000 English square miles, runs off 20·51 inches per annum; while if we take the Ganges and Brahmapootra together as having a joint basin of 432,000 geographical miles,† equal to 570,240 English square miles, and the joint discharge at 12,736,154,880 cubic feet per annum, according to Lyell's statement, based on Mr. Everest's calculation,‡ the amount run off the ground per annum will be 50·8 inches.

This tremendous depth is due to the rainfall on the Himalayas, and is greater than the Rhone at Geneva, which is 48·20. The Mississippi and Missouri have a basin of 1,300,000 English square miles; and according to Messrs. Humphreys and Abbott, as quoted by Lyell, 132·36 cubic miles of water are discharged annually, equal to 8.19 inches in depth over the whole area.§

Keeping the above facts in view, and seeing how constant a quantity the solids in solution are, for when the rainfall is small the river water as a rule holds a larger proportionate quantity of dissolved matter; and taking into consideration what we know of the geology of the world, I think we have sufficient grounds for a provisional assumption that about 100 tons of rocky matter is dissolved by rain per English square mile per annum.

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* The mean annual delivery of the Nile is calculated by M. Talabot at 101,000 cubic feet per second, and its supposed drainage area, according to Herschell, 520,000 square geographical, or 686,400 statute miles. This would give only 2·01 inches run off the ground. (See Herschell's "Physical Geography," p. 210, 4th Edition.)

† Herschell's "Physical Geography."

‡ "Principles of Geology," 10th Ed., pp. 481–3.

§ This is arrived at by dividing the cubic quantity of sediment by the fraction representing the proportion it bears to the water, that is $\frac{1}{1321}$ Beardmore calculates the depth run off the ground at 8·40 inches.—"Manual of Hydrology."

Of this total, if we allot 50 tons to carbonate of lime, 20 tons to sulphate of lime, 7 to silica, 4 to carbonate of magnesia, 4 to sulphate of magnesia, 1 to peroxide of iron, 8 to chloride of sodium, and 6 to the alkaline carbonates and sulphates, we shall probably be as near the truth as present data will allow us to come.

Before leaving the subject, let us now see what light, if any, these figures throw upon geological time.

How can we approach the question? If, as is generally supposed, the sea contains only what is washed into it from the land,* and we can estimate its mineral contents in tons, we at once get a minimum measure of the age of the Earth; whether it will be possible to arrive at a maximum we shall see further on. According to Herschell, the ocean contains 2,494,500 billions of tons of water; and the mean of Dr. Frankland's analyses of sea water gives 48·9 tons of carbonate of lime and magnesia, and 1017 tons of sulphate of lime and magnesia in 100,000 tons. Taking the area of all the land in the world at 51 millions of English square miles, there is in the ocean, in round numbers, 1,222 billions of tons of carbonate of lime and magnesia, or sufficient to cover the whole of it at 15 feet to the ton 12·9 feet thick; and of sulphate of lime and magnesia 25,369 billions of tons, or sufficient to cover it 267·6 feet thick. If, then, we reckon the whole of the sulphates removed from the land at 20 tons per square mile per annum, it would take in round numbers 25

* Herschell says. "Physical Geography," p. 21. As the sea continually receives the drainage of all the land, besides having in the course of countless ages, washed over and over again the disintegrated materials of successive continents, it must of course hold in solution all the saline ingredients capable of being separated and taken up by such lixiviation in cold water; in fact, in greater or less quantity, every soluble substance in nature—such, at least, whose existence in extremely dilute solution are not incompatible.

millions of years to accumulate the quantity of sulphate of lime and magnesia contained in sea water, but only 480,000 years to renew the carbonate of lime and magnesia, at the rate of 50 tons per square mile of land surface per annum. We know, however, that the carbonate of lime is constantly being removed by testaceous animals, corals and foraminifera.

There is also good reason to suppose that the sulphates of lime are also decomposed by decaying organic matter, and we know from numberless analyses that there is always present in sea water a large quantity of free carbonic acid,* which the result of the "Challenger" expedition proves is sufficient to entirely dissolve the calcareous portions of the dead foraminifera before they in sinking reach the bottom of the greater ocean depths.

The quantity of sulphuric acid in sea water also varies considerably. It is probable, also, that marine organisms can in some way directly utilise the sulphate of lime. Bischof shows very beautifully and clearly that the amount of carbonic acid in sea water is subject to very little variation, and that it is present in sufficient quantity to dissolve five times as much of the earthy carbonates as are actually dissolved, and "that the sea water is so far below its point of saturation as regards carbonate of lime, can only depend upon the constant separation of this carbonate by testaceous animals. By this separation, however, the carbonic acid which had dissolved this carbonate always returns again into the sea water. In the sea, therefore, the solution of carbonates and their separation by organic agency go on constantly, no addition of carbonic acid from without being required." He also shows that the carbonic acid which has been

* Bischof, "Chemical Geology," vol. i, p. 103.

removed in the vapour of water returns to the sea by the rivers.

If we turn to the chlorides consisting principally of chloride of sodium, we find the mean of Dr. Frankland's analyses to be 3,259 parts in every 100,000, which gives 81,295 billions of tons; or, at 16 feet to the ton, sufficient to cover the whole of the land 914·9 feet deep! * This is certainly a startling result. Reckoning all the chlorides brought into the sea by the rivers annually at 8 tons to the square mile, it would take, in even numbers, 200 millions of years to renew the chlorides of the sea. I have now, I hope, enabled you to form a quantitative idea of the soluble constituents of the globe, so far as we can measure them in water.

The greater portion of the land of the globe is composed of sedimentary rocks, themselves laid down in the sea, lakes, inland seas, or estuaries.

The constituents of the crust of the earth have been again and again dissolved, carried into the sea, separated therefrom by organisms, or by evaporation from portions that have from time to time been cut off from the general ocean, or in that minute chloride dust Dr. Frankland so beautifully shews is constantly being carried into the air through the spray of every wave. What a lengthened vista does not this disclose?

We cannot see the beginning, all that is plain to us is the sequence, the circulation.

The matter of the world is continually changing place —its solvent is the rain, its carrier the river, its receiver and distributor the ocean. How many times

* As shewing the necessity to the Geologist of a quantatitive knowledge of the constituents of the Earth, even so great a reasoner as Lyell imagines it possible that all the salt in the sea could, during a subsidence of the land, be evaporated in the Runn of Cutch.—See "Principles."

the matter of this solid land on which we stand has been in solution, suspension, or moving to and fro on the shore or the sea bottom, it is impossible to say. In the present state of science it defies calculation to reach a maximum beyond which we can say the age of the earth does not extend, for the calculations based upon the form of the earth and tidal retardation * are fallacious, through leaving out agencies that we know are at work, and which the calculations I have to-night submitted to you bring out in greater force.

I have said nothing as yet of the comparative potency of mechanical erosion as compared with chemical in reducing the crust of the earth. Strictly speaking, one, however, is the complement of the other. The chemical agency decomposes the matrix, and separates the particles, which the mechanical force of the river in flood carries to the sea. The actual degradation of the rocks by mechanical movement of water containing stones, is a very small matter. The effect of tidal action I have before dwelt upon and explained.

The ocean, I consider, acts merely as a mechanical distributer of matter, which has been introduced from the land; and though tidal action has the power in certain cases of excavating very wide, deep, and long gullies in the shallow seas, its effect is limited by the force and direction of the current, so that it cannot work out its hollows beyond a certain depth below the general floor of the sea. The action of subaërial denudation is on the other hand unlimited, except by the sea-level. It can degrade, excavate, and deepen, so long as anything is left above the water.

The amount of matter brought down mechanically into the sea, in the case of the Danube, we see was

* Sir William Thompson.

$\frac{1}{3060}$ of the water, or about three times the calculated solids in solution. The maximum amount being $\frac{1}{465}$, and the minimum $\frac{1}{73000}$. The solids in solution come down constantly; the mud is pushed along in times of flood. According to Messrs. Humphreys and Abbott the solids in suspension in the Mississippi are $\frac{1}{1321}$ of the water. If we were to take the solids removed mechanically and in solution at six times those in solution, which is a very high estimate, we should have over the whole of the globe 600 tons of denuded matter annually per square mile. Taking the sedimentary crust of the earth at ten miles thick throughout—a moderate estimate—and allowing for the denudation of the sea and the amount added to sediments by volcanic ejections, matter equal to one-third that which is denuded from the land, we should have annually removed and deposited matter equal to 800 tons per square mile of land surface, or 40,800 million tons annually. The total surface of the globe is 197 millions of English square miles. A cubic mile of rock at 13½ feet to the ton would weigh 10,903,552,000 tons, so that to cover the whole surface of the globe one mile deep with sediment from the land at the rate of 800 tons per square mile of land surface, would take 52,647,052 years, or 526 million years in round numbers for ten miles deep.*

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*It is not necessary for the accuracy of this calculation that the sedimentary crust of the earth should everywhere now measure 10 miles thick, or even that it should average that thickness, indeed if it were so the estimate of time would have to be enormously increased, because the rocks of one formation are largely derived from the sediments of preceding formations, therefore it is probable that the *maximum* thickness of the whole of the sedimentary deposits is a true guage of the average thickness of rock which has been removed by denudation from the entire surface of the globe. The maximum thickness of the whole of the known sedimentary formations is variously estimated at from 14 to 17 miles.

At $13\frac{1}{2}$ feet to the ton, 800 tons per annum would give one foot of denudation of the land each 2,581 years; so it will be seen, that the above is a very moderate estimate of the time which has elapsed since the first of the sedimentary rocks, we are acquainted with, were laid down, on the hypothesis that the denuding agencies had the same average potency as now, and that the area of land surface has been constant.

But it will be said—What proof have we that the denuding agencies were not formerly much greater and more active than now? I reply with Lyell: We have no evidence that such was the case.

It is true that, according to fossil evidence in the earlier periods, the earth appeared to be of a more uniform temperature than now.*

This, it seems to me, would act in the contrary direction, and tend to reduce the rainfall, as it is the mixing of air of different temperatures that produces rain. Again, if we assume the land surface to have been proportionately to the sea greater than it is at present, the evaporating surface would have been lessened; in fact, the forces of nature in this, as in other cases, tend to equalise themselves.

In opposition, therefore, to astronomical calculations, I am prepared to maintain the position of Hutton and Lyell. We may speculate on a beginning, but we can find no trace of it by geological methods, for in no respect do these earlier sediments, so far as they have yet been investigated, lead us up to a particular rock from which the first sediments were derived. The beginning may be a logical necessity, and astronomical and mathematical reasoning may eventually throw some

*See Hooker on Carboniferous plants, Memoirs of the Geological Survey, Vol. II. Also papers by Nordenskiöld and Judd in Geological Magazine and Dana's Manual of Geology.

light upon it, but before then a multitude of circumstances will have to be considered by the mathematician, which he often ignores, through unfamiliarity with geological reasoning.

The calculations I have had the pleasure of laying before you have been laborious, but they have given proportion and definiteness to my ideas of geological cause and effect, and their relations to time. Probably I have dealt too much in figures to make my address as interesting in its delivery as the subject will be found on closer study. It is so vast and complicated that I cannot hope to have given you more than a faint outline of the whole picture as it presents itself to my mind. The value of figures is best seen by those who work them out; but if I have succeeded in demonstrating that the views of geology taken by our greatest masters come out with greater force and truth, the more they are put to the test of calculation—then I have achieved quite as much as I can expect to do, or could hope that you would patiently listen to.

In resigning the Chair of the Society, I can only express to you the satisfaction it has been to me to meet you all from year to year since I first joined the Society, and during the term of my Presidentship, and to thank you for the uniform consideration and courtesy with which all, I have said, has been treated. In welcoming my successor to the chair, I can only say that we shall all extend to him the same feeling of good fellowship, begotten of kindred pursuits, which will enable him to perform his duties in the satisfactory manner we know he is capable of, and assist him in upholding the dignity of the science we all love.