ART. XL.—*Denudation of the two Americas* ;* by T. MELLARD READE, C.E., F.G.S.

INTRODUCTION.

WHEN in 1876 I had the honor to deliver a Presidential address to this Society I chose as its subject matter "Geological Time," I then had the pleasure to lay before you some calculations relating to "Chemical Denudation" which at the time possessed some little novelty. Since the information was published, it has to a certain extent been incorporated with geological literature. The subject was, however, far from being exhausted, nor is it likely to be so for many years yet to come.

In the meantime, having accumulated additional facts, it will be part of the object of this address to arrange and analyze them, so as to check the original generalizations and further to illustrate the value in geological speculation of an accurate knowledge of the relative magnitude of the various objects and things dealt with.

My former calculations dealt almost exclusively with the amount of matter annually removed in river water from the surface of England and Wales, and from some of the river basins of Europe. I now propose laying before you calculations of a similar nature relating to some of the larger rivers of the two Americas. This done we shall be able to take a wider survey of the subject, and to ascertain how far the provisional generalizations to which previous investigations led are confirmed or otherwise by the greater experience since gained.

THE MISSISSIPPI.

First then we will see what the Father of Waters, the Mississippi, tells us. I may observe that for a long while I found great difficulty in obtaining answers to my various questionings. Years elapsed and letters innumerable were written before I could alight upon any analyses of the waters of the Mississippi, reliable or otherwise. At last through the kindness of Prof. J. W. Spencer, of the State University of Missouri, I was supplied with the following analysis:

Analysis of Mississippi water near Carrolton, a few miles above New Orleans:†

* Substance of Presidential Address to the Liverpool Geological Society, Session 1884-5. Communicated by the author.

† Aveyquin, Journ. Pharm. [3], xxxvii, p. 258, 1857.

IN A GALLON (56,000 GRAINS).		
Potash sulphate, }	-----	Grains.
" chloride, }	-----	3·154
Calcium chloride, }	-----	
Silica, -----		2·455
Alumina, -----		1·753
Calcium carbonate, }	-----	
Magnesium " }	-----	7·307
Organic matter, -----		0·818
Total solid residue, -----		15·487

According to this analysis the proportion of total solids in solution is by weight $\frac{1}{3615}$. If we take the mean annual discharge of the Mississippi at 541,666,666,666 tons* in round figures, there are 150 million tons of solids in solution per annum poured into the Gulf of Mexico by the Mississippi, a truly remarkable quantity, which if reduced to rock at 15 feet to the ton is represented in round numbers by 80 square miles, 1 foot thick. According to Messrs. Humphreys and Abbot the proportion of sedimentary matter to the water by weight is $\frac{1}{1500}$ and the total discharge of matters in suspension excluding the three outlet bayous is according to them 362,723,214 tons.

The amount of matters in solution vary within certain limits in river water according to the time the samples are taken. There are in some rivers, the Nile for instance, seasonal variations, and doubtless a river with many affluents, traversing strata of various degrees of solubility, must vary in the chemical composition of its waters according as the flood may come from one or the other tributary basin.

If we take the drainage area of the Mississippi proper at 1,214,000 square miles, the calculated amount of solids in solution, according to the analysis, will be 120 tons, removed from each square mile of surface per annum. From the surface of England and Wales I have shown that 143·5 tons per annum are removed in solution† and from the Danube basin 90 tons,‡ so that this is a mean and probably correct.

It has been estimated that the basin of the Mississippi is lowered at the rate of one foot in 6,000† years, but this rate has been calculated from the removal of sediment alone; § if we add to the matter removed mechanically that in solution it will raise the rate to one foot in 4,500 years.¶ What stronger evi-

* Report of Humphreys and Abbott, (1876), p. 146, 19,500,000,000,000 cubic feet at 36 feet to the ton.

† Geikie, Text book of Geology, p. 444.

‡ Chemical Denudation, p. 20.

§ According to the figures I have taken it would be one foot in 6,375 years.

¶ This is estimated as follows: Drainage area 1,244,000 square miles, annual sedimentary discharge from the same area 362,723,214 tons, solids in solution 150,000,000 tons, the average rock estimated at 15 feet to the ton. Strictly speaking, to this should be added 750,000,000 cubic feet of matter, estimated to be pushed along the bottom and the discharge from the bayous. For simplicity's sake I omit these elements.

dence can we have of the importance of chemical action in geological investigation; an importance that has hitherto been strangely overlooked.

Not less surprising considering the apparent insolubility of silica by ordinary agencies* is the fact that in round numbers from 23,000,000 to 24,000,000 tons of silica are poured into the sea annually by this river, while there are 70,000,000 tons of carbonate of lime and magnesia. There is also an exceptional quantity of alumina and a low percentage of sulphates in this water.

THE RIVER PLATE OR RIO DE LA PLATA.

The next river I shall deal with is the Rio de la Plata—the second greatest river of the South American continent. I am indebted to the very exhaustive series of observations and analyses of the waters of the river contained in the report to the Commission of running waters of the City of Buenos Ayres by Juan J. J. Kyle in 1872 and 1874,† for most of the information relating to this river.

I find that the mean of 14 analyses of water taken at different times (April, May and June) in the neighborhood of and above the City of Buenos Ayres gives a proportion of $\frac{1}{8418}$ of solids in solution, which, taking the dry weather flow of the La Plata at 670,000 cubic feet per second‡ (Bateman), will equal 2·8886 tons per second or 91,000,000 tons per annum in round figures.

The dry weather flow of the La Plata equals the *mean* annual flow of the Mississippi. The mean annual flow of the La Plata is not known but it must be greatly in excess of the dry weather flow and sufficient to bring up the total amount of dissolved matter to above that of the Mississippi though it appears from the analysis to have a less percentage of mineral matters in its waters than has the Mississippi. It appears from the report of 1874 that in two analyses of the La Plata water in September 15th and 18th, the matter in solution reached a proportion of $\frac{1}{3125}$. According to an analysis of the waters of the Paraná supplied me by Dr. Frankland§ they contained a proportion of only $\frac{1}{9926}$ of solids in solution. Mr. Juan Kyle states that there is very little difference between the waters of the La Plata taken at 850 m. from the shore and the waters of the Paraná de los Palmas. As the Paraná supplied, according to careful measure-

* Mr. M. E. Wadsworth has shown that ordinary atmospheric agencies produce a greater effect upon rocks of a siliceous character than is generally believed. See this Journal. Dec. 1884, p. 466.

† I must here express my thanks to Mr. J. E. Hawkes for his valuable assistance in translating the pamphlet for me.

‡ See Chemical Denudation, p. 55.

§ See Chemical Denudation, p. 23. 10·08 parts per 100,000.

ment by Mr. Bateman, 520,000 cubic feet of water to the La Plata, while the Uruguay was estimated at only 150,000 cubic feet at the same time, it follows that the chemical constituents of the water of the La Plata must vary considerably at different times and seasons. Probably the analysis on which I have made my calculations will represent a fair annual mean of the solids in solution.

The estimated drainage area of these two rivers is 1,250,000 square miles, so that were the mean annual discharge known it would probably turn out that the greater discharge of the La Plata would more than compensate for the smaller rise per centage of dissolved matters in its waters and bring the chemical denudation per square mile of river basin up to or beyond that of the Mississippi.

The observations of Mr. Bateman were taken in the month of December, 1870, when the river was at its lowest state. "A continuous drought of six or seven months having diminished the ordinary sources of supply and the periodical rise from the Andes not having commenced." It is difficult, nay, impossible, to predict the mean delivery from the dry weather flow, but the mean flow of the Rhine is given by Beardmore as over twice, the Rhone at Avignon nearly three times, and the Nile at Cairo over seven times the ordinary summer flow.

The waters of the La Plata are distinguished by the fineness of the matter held in suspension; this consists, according to Mr. Kyle, principally of clay. This clay continues a long time in suspension even after filtering. It will pass through the pores of the best filtering papers, the water preserving its turbidity even after months of repose. This is a feature according to Mr. Kyle which is common to all waters that are weakly alkaline. Several chemicals added to the water will, however, precipitate the solid matter by making the muddy particles coagulate into larger compound particles. Chloride of calcium in the proportion of 1 to 5,000 parts will act in this manner. The analyses given by Mr. Kyle are of the water after 48 hours subsidence, so that the unprecipitated matter is included in the solids in solution. The matters in suspension, as is the case with other rivers, vary much according to the state of the river and the water is more impure near the shore than at 850 m. distant.

It is pretty well known that an admixture of seawater with turbid fresh water tends to hasten the precipitation of the solid matters* but it is very probable, as will be seen before I conclude, that the extremely divided solid matter will be carried far and wide by oceanic currents before it can settle to the bottom.

* See "precipitation of Clay in fresh and salt water." by D. Robertson, Trans. Glasgow Geol. Soc., vol. iv, Part III, page 257.

The annual amounts of solids in suspension in the La Plata waters has never to my knowledge been determined or even approximately estimated.

THE ST. LAWRENCE.

The next river on the American Continent of which we have any knowledge worth speaking of is the St. Lawrence. The elements for a calculation such as I wish to make are however unfortunately rather vague. Even the area of its basin is stated differently by different authors. According to Guyot* its basin, including, I presume, the area of its immense lakes, is two-fifths that of the Mississippi, while it is said to pour into the sea more than twice its volume. This must, however, be an error, for it would give 40 inches of rain run off the area per annum, whereas, according to the Rainfall Map of the World, prepared by Loomis (this Journal, vol. xxv, p. 88, January, 1883) the whole basin lies in the area of rainfall of from 25 to 50 inches. If we were to take it at 20 inches run off the ground per annum, or half the stated delivery, after deducting the area of the great lakes, the chemical denudation would still be enormously great. The only analysis I have met with gives the proportion of solids in solution at $\frac{1}{8230}$ † so that the denudation would amount to, at that rate, over 200 tons per square mile per annum. The one thing probable, however, is, that the matter removed in solution is more per square mile than in the Mississippi basin. The matter removed to the sea in suspension must be comparatively small from the clearness of the water due to its passing through the great lakes.

THE AMAZONS.

The River Amazons is compared by Agassiz in its main features to the Mississippi, inasmuch as it lies in a Cretaceous basin.‡ I think, however, the analogy is a fanciful one. The valley of the Amazons is distinguished from other river valleys by its immense extent, the drainage basin being estimated by Humboldt at over 3 million square miles. The basin appears to have existed much in its present form before it became partially filled with the remarkable deposits of red sandstones and clays covering an immense area which the river is now engaged in rapidly removing to the sea. The upland portions of the basin are largely composed of the granitic and crystalline rocks which are so prominent a feature in the Brazils. The sandstones and clays that have so large a development over the bottom of the basin appear to be Post-tertiary and laid down by the river itself in more ancient times. There are, however,

* Physical Geography. † 16.05 per 100,000 parts, Jahresbericht der Chemie.

‡ Geological sketches—Physical History of the Valley of the Amazons, p. 171.

Tertiary rocks in a part of the basin* possessing an estuarine character in addition to Cretaceous rocks, while on the flanks of the Andes draining into the river are found both Cretaceous and Carboniferous rocks. The larger area of the basin appears, however, to be occupied by crystalline rocks and the Post-tertiary sandstones and clays; but a very large part of the basin seems never to have been geologically explored. The basin of the Amazons has also the peculiarity of being situated both to the north and south of the equator and in an area of very heavy rainfall. The chart of mean annual rainfall by Loomis before referred to puts it at from 50 to 75 inches for about $\frac{2}{3}$ of its area, the remainder near the Andes being over 75 inches. The volume of water discharged by the river has been estimated at from 2,700,000 to 3,510,000 cubic feet per second. Taking the mean, this would give about 15 inches run off the ground, or 0.25 of the total rainfall if we take it at 60 inches, about the proportion that flows off the Mississippi basin. The mean rainfall of the Mississippi basin is estimated by Messrs. Humphreys and Abbot at 30.4 inches. Probably 60 inches, would represent the mean rainfall of the Amazons basin. For the purposes of this calculation I take the mean discharge at 3,105,000 cubic feet per second, or 86,250 tons=2,719,980,000, 000 tons per annum.†

Through the good offices of Mr. E. Edmondson of Messrs. Gunston & Co., of this city, I have obtained a sample of the water of the Amazons, taken in mid-stream between the Narrows and Santarem in June of this year. This sample I submitted to Dr. Pery I. Frankland for analysis with the following result :

PARTS IN 100,000.

Silica.....	0.98
Iron and alumina.....	0.38
Carbonate of lime.....	2.75
Carbonate of magnesia.....	0.22
Sulphate of magnesia.....	0.37
Chlorate of potassium.....	0.23
Chloride of sodium.....	0.15
Sulphate of soda.....	0.13
Organic matter.....	0.71
Total solids in solution.....	5.92

* See "On the Tertiary deposits on the Solimoes and Javury Rivers in Brazil by C. Barrington Brown, Quart. Journ. Geol. Soc., 1879," also "Ancient River Deposits of the Amazons," *ibid*.

† Bates, *Naturalist on the Amazons*, vol. i, page 237, says: Von Martius estimates the volume of water passing through the straits of Obydos at 499,584 cubic feet per second. He arrives at this result by taking the depth in the middle at 60 fathoms and at the sides 20 fathoms, the width is given at 1738 yards. Suspecting some error—as the volume of the La Plata in dry weather exceeds this estimated volume of the Amazons—I have re-calculated the delivery from these elements and find that it cannot be less than 3,000,000 cubic feet per second, but may be more according to the form of the bottom. Our gratitude is due to those who give us the means of checking their results.

This gives a proportion of total solids in solution of $\frac{1}{16.890}$ or 5.1 tons per second.

The total delivery of matters in solution will amount, according to these data, to 160,833,600 tons per annum, or, if we estimate the basin at 3,000,000 square miles, to 60 tons per square mile per annum.

It will be observed that the total amount delivered to the sea of solids in solution is not much greater than that we arrived at for the Mississippi. This is a fact worth knowing and due doubtless to the preponderance of gneissic rocks and sandstones and clays of an insoluble character. It is also worth noting that the proportion of silica to the total matter in solution corresponds very closely with that of the Mississippi, amounting to 26,624,481 tons per annum. It is also evident that the rocks and Pampean deposits* occupying the basin of the La Plata are also of a more calcareous and soluble character than the Amazonian Rocks. Not less interesting is it that the carbonate of lime, roughly speaking, is one half of the whole of the solids in solution.†

It follows from these data that the matter removed in suspension must bear an excessive proportion to those in solution as compared to other rivers. The deposits forming the banks of the river are of a loose and friable nature on which the river makes great inroads. The proportion of matters in suspension has never to my knowledge been estimated. Bates, comparing the Pará and the main Amazons, says, "In the former the flow of the tide always creates a strong current upwards, while in the Amazons the turbid flow of the mighty stream over-powers all tides, and produces a constant downward current. The color of the water is different, that of the Pará being of a dingy orange-brown, while that of the Amazons has an ochreous or yellowish clay tint," also "Indeed the fresh water tinges the sea along the shores of Guiana to a distance of nearly 200 miles from the mouth of the river."‡

INFERENCES AND GENERALIZATIONS.

In my former address I said, "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 are dissolved by rain per English square mile per annum."§ This at the time was considered a very bold statement, but from the data I have laid before you respecting the American continents I venture to think it will be now con-

* See Geological Observations, Darwin, Second Edition, pp. 313 to 369.

† See Chemical Denudation, p. 24. ‡ Naturalist on the Amazons, vol. i, p. 5.

§ Chemical Denudation, p. 24.

sidered as applied to the whole world a very fair approximation.

Let us pause to consider the meaning of all these figures, for unless they have a meaning which the mind and imagination can seize upon, the wearisome labors of collecting the data and making the computations were well nigh wasted.

First, as regards the Mississippi, of which we possess the most reliable particulars.—I have shown that the estimate of the rate of denudation of its basin must be increased in round figures from $\frac{1}{8000}$ to $\frac{1}{4500}$ of a foot per annum* in consequence of the solid matter which is removed in solution. Is it not a striking instance of the little importance attached to chemical denudation as a geological agent, when the matter removed in solution does not enter as an element into the calculations of such an observant reasoner as a Geikie or a Croll. Thus we arrive at the first and not unimportant result which I promised from quantitative examination. Now mark, it is not that geologists were unaware of the effect of chemical action on the rocks. Take up any text-book or manual and you will find a chapter devoted to it and the whole process correctly explained, nevertheless the quantity of matter removed was not realized and never could have been except through laborious calculations. That being done it is easy to see how these great results occur. Examine the hardest rock and you will find it weathered, you will find it coated over with a crust, of a thickness varying with the time its surface has been exposed. This crust is composed of the constituents of the rock that remain after part have been removed by chemical action.† Examine the waste talus from some of the old quarries at Penmaenmawr and you will see that atmospheric agents have in the space of 30 years perceptibly affected a felstone rock that seems at first sight absolutely indestructible.‡ How much more then must they affect rocks of a more friable and soluble nature. I have shown that $\frac{1}{12578}$ of a foot per annum is removed from the surface of England and Wales in a soluble form every year,§ say $\frac{1}{1081}$ of an inch, so that in 30 years it would amount to $\frac{1}{36}$ of an inch.

* This calculation as before explained takes no account of matters pushed along the bottom, they have not been determined with much accuracy and it is probable as Mr. A. Tylor has suggested there is more than has been estimated. This would further reduce the time.

† It is usual to refer this action entirely to the carbonic acid present in the rain water, but Mr. Alexis A. Julien has brought forward a great body of facts to prove that the solvents of the rocks are largely organic acids existing in decaying vegetable matter. "On the geological action of the Humous Acids." Proc. of the American Assoc. for the Advancement of Science, Saratoga meeting, 1879.

‡ This stone is largely used for making "setts" for street paving, sold under the name of "Welsh granite setts," and found to be the most lasting material for the purpose.

§ Chemical Denudation.

This is the mean denudation, but I have also shown that the denudation is very much equalized by the fact of the harder rocks usually occurring in areas of great rainfall.*

It is therefore not unlikely that, if we were to institute accurate experiments over a sufficiently long time, it would turn out that the calculation of the amount of matter removed in solution could be verified by direct tests, and that even these hard rocks would be found to waste at something near the indicated rate. It would appear from the examples of the Mississippi, the Nile and Danube that the matter brought down in solution and suspension is as 1 to 3.

These examples are of rivers where there have been the most accurate and fullest data to judge by. Whether the proportion would be borne out in other river basins we have no very good means of judging; but it would appear that in large rivers the nature of the rocks is so varied, the areas being so extensive, that the relation of the materials in solution to those in suspension have a tendency to keep very constant. It will be seen from a consideration of these facts that matters chemically dissolved in the water must play a much more important *role* in the reconstruction of the earth than was formerly suspected.†

What becomes of all these mineral matters ceaselessly flowing into the sea? It has been shown by Mr. Buchanan‡ that the proportions of mineral matters to each other in sea water is nearly constant everywhere, although there is a variation in different seas in the proportion of total mineral matter in solution to the water it is dissolved in. Nature has achieved a balance of supply and demand. It is also well known that the coarser matters in suspension, unless brought under the influence of a strong current, settle near the mouths of the rivers and then spread themselves by help of tides and winds along the coast and there mingle with the detritus the sea wears away from the coast. The finer particles distribute themselves over a larger area and probably the very finest over the whole sea bottom. In every ocean dredging there is a greater or less amount of argillaceous matter, whether it be in the ooze or the red clay, which I suggest is more likely to be the "dust of continents," than to arise from the disintegration of volcanic matter, such as pumice, but it is no doubt largely mingled with such volcanic matters as Mr. Murray clearly shows. It seems to me rather a far-fetched notion that the winds should contribute dust to the deepest ocean, but that the waters should make no mechanical contribution to the deposit. The bulk of

* Chemical Denudation.

† It is singular that Hutton in his theory of the earth estimates at a gross computation "that the fourth of the solid land is composed of matter which had formed the calcareous tests of animals"

‡ Challenger Reports.

the ocean water is so great as compared to the probable amount of matter in a state of the finest comminution that can get into it, that it might not even be possible to detect its presence in a sample of ocean water. At the same time it might contain quite sufficient to account for much of the argillaceous matter found in the deep ocean soundings. I have shown that the matters in solution in rain waters are, roughly speaking, one quarter of the whole matter in the water in solution and suspension. The finest particles, sufficiently fine to be carried away by oceanic surface currents, such as the Gulf Stream, are probably not in bulk half as great as the matter in solution. If we take as an example the estimate I have given of the chemical denudation of England and Wales it amounts, as I have already shown, to $\frac{1}{36}$ of an inch in 30 years. This would give, supposing the impalpable mud to be worn off at half that rate, 60 years for the denudation of $\frac{1}{36}$ of an inch. The area of the sea to land is roughly as 3 to 1, therefore at this rate it would take 180 years for $\frac{1}{36}$ of an inch of mud converted into rock to accumulate if distributed evenly over the ocean floor. When we consider the average depth of the ocean is over two miles, $\frac{1}{36}$ of an inch distributed through it would amount to no more than about one five-millionth part, and this, be it remembered, has 180 years to accumulate and settle, so that if we give each particle of these fine matters in suspension 10 years to settle to the bottom there would never be in the ocean water at one time more than one ninety-millionth part of matters in suspension, an amount so small as to be practically imperceptible. The probability that such an infinitesimal amount of matter in suspension may be present is still more evident when we find that fine sand floats on the surface of the sea for considerable distances, for Prof. Verrill says that in the course of the Gulf Stream they always take with their towing nets more or less fine siliceous sand* (this Journ., 1882, xxiv, p. 449).

I think it is fairly evident from the foregoing calculations

* Prof. A. E. Verrill also says that, in the Gulf Stream slope examined by us, the bottom in 70 to 300 fathoms, 60 to 120 miles from the shore, is composed mainly of very fine sand, largely quartz, with grains of feldspar, mica, magnetite, &c.; with it there is always a considerable percentage of shells of foraminifera and other calcareous organisms, and also spherical, rod-like and stellate sand-covered rhizopods often in large quantities. In the deeper localities there is usually more or less genuine mud or clay, but this is often almost entirely absent even in 300 to 500 fathoms. The sand however is often so fine as to resemble mud and is frequently so reported when the preliminary soundings are made and recorded." "The prevalence of fine sand along the Gulf Stream slopes in this region and the remarkable absence of actual mud or clay deposits indicate that there is here at the bottom sufficient current to prevent for the most part the deposition of fine argillaceous sediments over the upper portion of the slope in 65 to 150 fathoms. Such materials are probably carried along till they eventually sink into the greater depths nearer the base of the slope, or beyond in the ocean basin itself, where the currents are less active." (This Journal, vol. xxiv, pp. 448-9. 1882.)

that there may be accumulations going on in the great oceans which we can no more see than we can the matters in solution.* It is only because the mineral matters get concentrated in the sea water that they are forced upon our notice. They slowly concentrate until a balance is attained and they are removed from the sea water at the same rate that they are poured into it.