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ORIGINAL ARTICLES.

I.—On a Method of Determining the Mean Thickness of the Sedimentary Rocks of the Globe.

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VARIOUS attempts have been made to measure the positive length of geological periods. Some geologists have sought to determine, roughly, the age of the stratified rocks by calculations based upon their probable thickness and the rate at which they may have been deposited. This method, however, is worthless, because the rates which have been adopted are purely arbitrary. One geologist will take the rate of deposit at a foot in a hundred years, while another will assume it to be a foot in a thousand or perhaps ten thousand years; and, for any reasons that have been assigned, the one rate is just as likely to be correct as the other: for if we examine what is taking place in the ocean bed at the present day, we shall find in some places a foot of sediment laid down in a year, while in other places a foot may not be deposited in a thousand years. The stratified rocks were evidently formed at all possible rates. When we speak of the rate of their formation, we must of course refer to the *mean rate;* and it is perfectly true that if we knew the thickness of these rocks and the mean rate at which they were deposited, we should have a ready means of determining their positive age. But there appears to be nearly as great uncertainty regarding the thickness of the sedimentary rocks as regarding the rate at which they were formed. No doubt we can roughly estimate their probable maximum thickness; for instance, Professor Ramsay has found, from actual measurement, that the sedimentary formations of Great Britain have a maximum thickness of upwards of 72,000 feet; but all such measurements give us no idea of their mean thickness. What is the mean thickness of the sedimentary rocks of the globe? On this point geology does not afford a definite answer. Whatever the present mean thickness of the sedimentary rocks of our globe may be, it must be small in comparison to the mean thickness of all the sedimentary rocks which have been formed. This is obvious from the fact that the sedimentary rocks of one age are partly formed from the destruction of the sedimentary rocks of former ages. From the Laurentian age down to the present day, the stratified rocks have been undergoing constant denudation.

Unless we take into consideration the quantity of rock removed during past ages by denudation, we cannot—even though we knew the actual mean thickness of the existing sedimentary rocks of the globe and the rate at which they were formed—arrive at an estimate regarding the length of time represented by these rocks. For if we are to determine the age of the stratified rocks from the rate at which they were formed, we must have, not the present quantity of sedimentary rocks, but the present plus the quantity which has been denuded during past ages. In other words, we must have the absolute quantity formed. In many places the missing beds must have been of enormous thickness. The time represented by beds which have disappeared is doubtless, as already remarked, much greater than that represented by the beds which now remain. The greater mass of the sedimentary rocks has been formed out of previously existing sedimentary rocks, and these again out of sedimentary rocks still older. As the materials composing our stratified beds may have passed through many cycles of destruction and re-formation, the time required to have deposited at a given rate the present existing mass of sedimentary rocks may be but a fraction of the time required to have deposited at the same rate the total mass that has actually been formed. To measure the age of the sedimentary rocks by the present existing rocks, assumed to be formed at some given rate, even supposing the rate to be correct, is a method wholly fallacious.

"The aggregate of sedimentary strata in the earth's crust," says Sir Charles Lyell, "can never exceed in volume the amount of solid matter which has been ground down and washed away by rivers, waves, and currents. How vast then must be the spaces which this abstraction of matter has left vacant! How far exceeding in dimensions all the valleys, however numerous, and the hollows, however vast, which we can prove to have been cleared out by aqueous erosion!"[1]

I presume there are few geologists but would admit that if all the rocks which have in past ages been removed by denudation were restored, the mean thickness of the sedimentary rocks of the globe would be at least equal to their present maximum thickness, which we may take at 72,000 feet.

There are three elements in the question; if two of them are known, the third is known in terms of the other two. If we have the mean thickness of all the sedimentary rocks which have been formed and the mean rate of formation, then we have the time which elapsed during the formation; or, having the thickness and the time, we have the rate; or, having the rate and the time, we have the thickness.

One of these three, namely, the rate, can, however, be determined with tolerable accuracy if we are simply allowed to assume—what is very probable, as will be shown—that the present rate at which the sedimentary deposits are being formed may be taken as the mean rate for past ages. If we know the rate at which the land is being

[1] "Principles," vol. i. p. 107 (tenth edition).

denuded, then we know with perfect accuracy the rate at which the sedimentary deposits are being formed in the ocean. This is obvious, because all the materials denuded from the land are deposited in the sea; and what is deposited in the sea is just what comes off the land, with the exception of the small proportion of calcareous matter which may not have been derived from the land, and which in our rough estimate may be left out of account.

But how are we to determine the rate of sub-aërial denudation? This rate can be determined by a method advanced a few years ago.[1] It is this: the rate at which the land is being lowered by denudation is measured by the amount of sediment carried down to the sea by the river systems. The rate, for example, at which the basin of a river is being denuded is determined with perfect accuracy by the quantity of sediment carried into the sea by the river.

Unfortunately—except in the case of the Mississippi—no very accurate determination has as yet been made of the quantity of sediment carried down to the ocean by rivers. The annual amount conveyed into the ocean by the Mississippi has been accurately measured by Messrs. Humphreys and Abbot. Taking their estimate of the amount of sediment and area of drainage of the Mississippi, it is found, by the method above referred to, that its basin is being lowered at the rate of one foot in 6,000 years.

Sir Charles Lyell has shown clearly that in regard to the amount of sediment carried down into the sea, there is perhaps no river which may more safely be taken as a fair representative of rivers in general; and in the mean time we may be warranted in taking one foot in 6,000 years as representing the mean rate at which the land is being abraded.

Taking the proportion of land to that of water at 576 to 1,390, then one foot taken off the land and spread over the sea-bottom would form a layer five inches thick. Consequently, if one foot in 6,000 years represents the mean rate at which the land is being denuded, one foot in 14,400 years represents the mean rate at which the sedimentary rocks are being formed.

Assuming, as before, that 72,000 feet would represent the mean thickness of all the sedimentary rocks which have ever been formed, this, at the rate of one foot in 14,400 years, gives 1,036,800,000 as the age of the stratified rocks.

Professor Huxley, in his endeavour to show that 100,000,000 years is a period sufficiently long for all the demands of geologists, takes the thickness of the stratified rocks at 100,000 feet, and the rate of deposit at a foot in 1,000 years. One foot of rock per 1,000 years gives, it is true, 100,000 feet in 100,000,000 years. But what about the rocks which have disappeared? If it takes a hundred millions of years to produce a mass of rock equal to that which now exists, how many hundreds of millions of years will it require to produce a mass equal to what has actually been produced?

[1] Philosophical Magazine for February, 1867, p. 130, and May, 1868, p. 379; see also Mr. Geikie's Memoir "On Modern Denudation," Trans. of Glasgow Geol. Soc. for 1868.

Professor Huxley adds, "I do not know that any one is prepared to maintain that the stratified rocks may not have been formed on the average at the rate of $\frac{1}{83}$ of an inch per annum." When the rate, however, is accurately determined, it is found to be, not $\frac{1}{83}$ of an inch per annum, but only $\frac{1}{1200}$ of an inch, so that the 100,000 feet of rock must have taken 1,440,000,000 years in its formation—a conclusion which, according to the results of modern physics, is wholly inadmissible.

Either the thickness of the sedimentary rocks has been over-estimated, or the rate of their formation has been under-estimated, or both. If it be maintained that a foot in 14,400 years is too slow a rate of deposit, then it must be maintained that the land must have been denuded at a greater rate than one foot in 6,000 years. But most geologists, I presume, felt surprised when the announcement was first made, that at this rate of denudation the whole existing land of the globe would be brought under the ocean in 6,000,000 of years.

The error no doubt consists in over-estimating the thickness of the sedimentary rocks. Assuming, for physical reasons stated on a former occasion,[1] that 100,000,000 years limits the age of the stratified rocks, and that the proportion of land to that of water and the rate of denudation to have been on the average the same as at present, the mean thickness of sedimentary rocks formed in the 100,000,000 years amounts to only 7,000 feet.

But be it observed that this is the mean thickness on an area equal to that of the ocean. Over the area of the globe it amounts to only 5,000 feet; and this, let it be observed also, is the total mean thickness formed, without taking into account what has been removed by denudation. If we want to ascertain what is actually the present mean thickness, we must deduct from this 5,000 feet an amount of rock equal to all the sedimentary rocks which have been denuded during the 100,000,000 years; for the 5,000 feet is not the present mean thickness, but the total mean thickness formed during the whole of the 100,000,000 years. If we assume, what no doubt most geologists would be willing to grant, that the quantity of sedimentary rocks now remaining is not over one-half of what has been actually deposited during the history of the globe, then the actual mean thickness of the stratified rocks of the globe is not over 2,500 feet. This startling result would almost necessitate us to suspect that the rate of sub-aërial denudation is probably greater than one foot in 6,000 years. But be this as it may, we are apt, in estimating the mean thickness of the stratified rocks of the globe, from their ascertained maximum thickness, to arrive at erroneous conclusions. There are considerations which show that the mean thickness of these rocks must be small in proportion to their maximum thickness. The stratified rocks are formed from the sediment carried down by rivers and streamlets and deposited in the sea. It is obvious that the greater quantity of this sediment is deposited

[1] Phil. Mag. for May, 1868, p. 371.

near the mouths of rivers and along a narrow margin extending to no great distance from the land. Did the land consist of numerous small islands equally distributed over the globe, the sediment carried off from these islands would be spread pretty equally over the sea-bottom. But the greater part of the land-surface consists of two immense continents. Consequently the materials removed by denudation are not spread over the ocean-bottom, but on a narrow fringe surrounding those two continents. Were the materials spread over the entire ocean-bed, a foot removed off the general surface of the land would form a layer of rock only five inches thick. But in the way in which the materials are at present deposited, the foot removed from the land would form a layer of rock many feet in thickness. The greater part of the sediment is deposited within a few miles of the shore.

The entire coast-line of the globe is about 116,500 miles. I should think that the quantity of sediment deposited beyond, say, a hundred miles from this coast-line is not very great. No doubt several of the large rivers carry sediment to a much greater distance from their mouths than a hundred miles, and ocean currents may in some cases carry mud and other materials also to great distances. But it must be borne in mind that at many places within the hundred miles of this immense coast-line little or no sediment is deposited, so that the actual area over which the sediment carried off the land is deposited is probably not greater than the area of this belt —116,500 miles long and 100 miles broad. This area on which the sediment is deposited, on the above supposition, is therefore equal to about 11,650,000 square miles. The amount of land on the globe is about 57,600,000 square miles. Consequently one foot of rock, denuded from the surface of the land and deposited on this belt, would make a stratum of rock five feet in thickness; but were the sediment spread over the entire bed of the ocean, it would form, as has already been stated, a stratum of rock of only five inches in thickness.

Suppose that no subsidence of the land should take place for a period of, say, three millions of years. During that period 500 feet would be removed by denudation, on an average, off the land. This would make a formation 2,500 feet thick, which some future geologist might call the Post-Tertiary formation. But this, be it observed, would be only the mean thickness of the formation; its maximum thickness would evidently be much greater, perhaps twice, thrice, or even four times that thickness. A geologist in the future measuring the actual thickness of the formation might find it in some places 10,000 feet in thickness or perhaps far more. But had the materials been spread over the entire ocean bed, the formation would have a mean thickness of little more than 200 feet; and spread over the entire surface of the globe, would form a stratum of scarcely 150 feet in thickness. Therefore, in estimating the mean thickness of the stratified rocks of the globe, a formation with a maximum thickness of 10,000 feet may not represent more than 150 feet. A formation with a *mean* thickness of 10,000 feet represents only 600 feet.

It may be objected that in taking the present rate at which the sedimentary deposits are being formed as the mean rate for all ages, we probably under-estimate the total amount of rock formed, because during the many Glacial periods which must have occurred in past ages the amount of materials ground off the rocky surface of the land in a given period would be far greater than at present. But in reply it must be remembered that although the destruction in ice-covered regions would be greater during these periods than at present, yet the quantity of materials carried down by rivers into the sea would be less than at present. At the present day the greater part of the materials carried down by our rivers is not what is being removed off the rocky face of the country, but the Boulder-clay, sand, and other materials which were ground off during the Glacial epoch. It is therefore possible, on this account, that the rate of deposit may have been less during the Glacial epoch than at present.

When any particular formation is wanting in a given area, the inference generally drawn is, that either the formation has been denuded off the area, or the area was a land-surface during the period when that formation was being deposited. From the foregoing it will be seen that this inference is not legitimate; for, supposing that the area had been under water, the chances that materials should have been deposited on that area are far less than are the chances that there should not. There are sixteen chances against one that no formation ever existed in the area.

II.—On *Euphoberia Brownii*, H. Woodw., a New Species of Myriapod from the Coal-measures of the West of Scotland.

By Henry Woodward, F.G.S., F.Z.S.,
of the British Museum.

(PLATE III., Fig. 6.)

I HAD the honour in 1866[1] to describe the first specimen of a fossil Myriapod from the Coal-measures met with in this country. It was discovered by the late Mr. Thomas Brown, of Glasgow, an indefatigable geologist and an ardent collector of fossils, who obtained it in a nodule of Clay-ironstone from Kilmaurs.

I determined it to be identical with the *Xylobius sigillariæ*, described by Dr. Dawson from the South Joggins Coal-formation of Nova Scotia.[2]

Other remains of *Xylobius* have also been obtained in Clay-ironstone-nodules, from the Coal-measures near Huddersfield, by Mr. Joseph Tindall of that town, which were referred by me to the same species, and figured in the plate with the Kilmaurs example.

Having been in 1869 entrusted by my friend Mr. James Armstrong, at that time the Honorary Secretary of the Glasgow Geological Society, with another and much larger form of Myriapod from

[1] Trans. Glasgow Geol. Soc., 1866, vol. ii. p. 234, pl. iii.
[2] Quart. Journ. Geol. Soc., Lond., 1859, vol. xvi., p. 268.