II.—ON THE FORMATION OF DELTAS: AND ON THE EVIDENCE AND CAUSE OF GREAT CHANGES IN THE SEA-LEVEL DURING THE GLACIAL PERIOD.

By ALFRED TYLOR, F.G.S.

(PLATE XI.)

Part II.—Continued from page 399.

IT would be the safer plan, in considering the remarkable Gravel and Crag deposits which characterize so distinctly the Quaternary Period, to infer the size of rivers, amount of rainfall, and elevation of tides from the deposits themselves. Further acquaintance with meteorological phenomena may find a fitting explanation of the difficulties we meet with in explaining the position of the gravel at such heights above our present streams, and fresh-water, alternating with marine clay, and sands at such depths below the sea-level.

DELTA OF THE Po.—The diagram, Pl. XI., Fig. 1, represents the different strata passed through in making 20 borings for water in the Delta of the River Po, near Venice. These extend from St. Servolo to Ghetto Nuovo, a distance of about 6 miles. The well at Casa de Dio reaches a depth of 572 feet. That of St. Maria Formosa 452 feet. M. Laurent, of Paris, the experienced well-borer, who is well acquainted also with geology, kindly made the drawing for me many years since, a copy of which I now use as a diagram. Of course the only points accurately determined are those in the 18 borings. The two great water-bearing beds have been traced throughout the 18 borings, and are represented as continuous in the diagram marked A. and B. They can only supply water equal to the quantity of rain on their outcrop.

The clays, lignitiferous sandy pebble and shell beds, are represented by different colours; also the wells from which gases escape are distinguished on the drawing Fig. 1. At St. Leonardo, No. 17, the lignitiferous beds occupy nearly one-third of the first 190 feet of strata passed through. The great water-bearing sands are 40 feet thick at the A. point.

The lignites sometimes succeed clays, sometimes sand, and are not continuous, they are therefore entirely distinct in stratification from the true coals of the Carboniferous formation, which are stratified continuously and usually repose upon clay. It is however interesting to observe the horizontal development of the water-bearing sands of a Delta, which may compare with similar horizontal bands in the Coal-measures. The evidence offered by these two remarkable beds of sand is that there was a marked change in the amount of denudation in the area drained by the Po, or in the material thrown back on to that part of the Delta by the sea, arising from a change in the position of the margin of the Delta (when these sands were deposited), as well as the coarse material indicating a greater rainfall.

The surface of the soil at Venice is 5 feet, on an average, above high-water mark in the Adriatic.

The mineral character of the first and last stratum perforated at Casa de Dio are remarkably alike, although separated by 500 feet of strata. The upper bed contains fragments of human industry and marine shells exclusively. In descending from the surface the marine shells become mixed with freshwater species. Sands are

most frequent in the lower beds, and contain lignite, consisting of broken pieces of vegetable origin, distributed through the mass of sand like some beds in the Hastings Wealden, where subsequent denudation enables the relations of clay beds to sands to be well seen (see A. Tylor, on the Wealden, Q. J. Geol. Soc., 1862, vol. xviii., p. 250).

In the middle and upper series the lignite occurs in veins or threads, and in beds alternating with sands and clays. The lower beds are very micaceous, but there are only traces of mica in the upper series.

The beds in this Delta may be said to be horizontal, as in a distance of six miles there is no sensible difference of level. In the Wealden there are numerous flexures.¹

At St. Maria Formosa, No. 8, there are 5 water-bearing beds, one within 8 feet of the surface. At St. Leonardo the spring of water is 80 feet from the surface. There are great variations in the water-level of springs and wells in most deltas.

The course of the river Po from its source at Monte Viso, 801 feet above the mean level of the sea, to the mouth at Maestro, has been drawn by Mr. Beardmore (Man. Hydro., plate xiii.), who also gives sections of the tributaries.

For a distance of 150 miles between Chivasso and Cremona the line represented by the level of the bank of the Po closely coincides with the parabolic curve; at no part is there a greater error than 5 feet in a course of 150 miles.

I mention these circumstances, as Deltas and alluvial formations are described as planes, while their surface really is a close approximation, I believe, to a true parabolic curve. It is sufficient here to record the fact that the approximate level of the bank of the Po at any point can be ascertained, if three points are given in the manner above stated.

M. Ch. Laurent writes to me, Oct. 31, 1868:—"The wells of Venice, are, as you know, in the enormous Delta formed by the Po, the Adige, the Tagliamento, and the Brenta, filling up a gulf. The alternations of sand met with often present debris of marine shells, *Cardium*, etc. The lignites and lignitiferous clays, as far as I could observe, in the well sunk in the Island of San Servolo and at the Madonna del Orto, contained fresh-water debris and terrestrial remains. In this debris I have seen *Succinea*, *Pupa*, *Helix*, and even in the lignites in the well sunk in the Place St. Marc, an elytra, perfectly preserved, of an insect (*Buprestis*). This insect was unfortunately destroyed by contact with the air. There is in these deposits an oscillation or alternation (*balancement*) between the marine products and the fresh-water products. It is altogether what takes place now at the surface in modern deposits."

Flexures² arising from the original or (latest) uneven upheaval of

¹ Not fractures exclusively (see Quart. Journ., p. 251, 1862, by the author). The author thinks these flexures are in consequence of uneven upheaval, often in binomial curves, along and at right angles to a curved axis, elevated most in the Pluvial Period at Crowboro', and before denudation commenced; flexures, longitudinal and transverse, aided by side streams, principally guide the Wealden watercourses and rivers in their remarkable course; this I shall prove by measured sections hereafter. (See Figs. 5 and 6.)—A. T., Nov. 1868.

² Flexures in binomial curves may be seen in all Geological books, although they are not described as such by those who have drawn them.

the tract situated within the water-shed, consisting of unequally inclined, unequally hard, and of unequally pervious strata, start and determine the subsequent direction of every watercourse, and all main, tributary, and pluvial denudation¹ in the valleys of the Po, Weald, Thames, and all other rivers. Thus tributaries and side streams, flowing off the soft Oolites near Schaffhausen, from their inclination against the stream flowing from very high ground, oppose and repel the Rhine, while others further on, inclining towards the stream, attract and assist it to pierce the much harder rocks² between Bingen and Bonn.³ Thus the hard rocks sometimes are denuded, while soft ones out of the track escape.

M. Lombardini, in his work "*Changes in the Hydraulic Conditions of the Po*"⁴ (1852, Milan), removes some misconception about the position of the bed of the river Po, which have not only passed current for many years, but have been quoted as typical conditions of rivers. M. Lombardini shows that the flood high-water mark of 1839 was only 5 feet above the ancient natural bank, and was 3 feet actually below the surface of the ancient embankment of the Po. The prolongation of the Po, as erroneously calculated by M. de Prony, was from A.D. 1200 to A.D. 1600, at the rate of 815 feet per annum. from A.D. 1600 to the present century, at the rate of 227 feet per annum. M. Lombardini shows that the rate of progress of the Delta from A.D. 1600 to the present day is only one-fifth greater than formerly, and that increase is owing to the levées, which have raised the level of the river 3 feet 3 inches.

There appears to be no foundation whatever, according to Lombardini, for the statements made about the condition of the river Po, for Lombardini proves by reference to flood-gates that the extreme low-water surface of the river has not changed sensibly in two centuries; also that at Stellata, 16 miles above Ferrara, the surface of the river at that point could not have been elevated since that day by the prolongation of the Po. There are no lumps of clay in the Po, raised by subsidence elsewhere, as in the Mississippi. The drainage of a lake, or melting of snow, or denudation, or deposition, disturb the existing equilibrium of the crust of the earth, but gravity must have always assisted the force producing subsidence, and opposed that producing elevation. If the mass of freshwater strata from the earliest period has always borne the same proportion to marine strata above the sea-level that it does now, and that the mass of earth above the sea-level has always borne to the mass of the sea, then extra heat must have been obtained from above and below, or from chemical action,⁵ to produce elevatory and depressing force exactly sufficient to do the required work, less the effective force of gravity

¹ Denudation is work done to produce stability in strata to bear their load under the new physical conditions established.

² The author has a very interesting case of a river piercing a rock near Istrad Vellte, South Wales, which he will shortly describe, showing an actual case of denudation.

³ See, "*Remarks on Denudation*," by the Author, read May, 1868, p. 71, vol. xxv., Quart. Journ. All tributaries adjust their bottom levels in relation to the main stream. They cannot cut down their beds when the main stream blocks their water.

⁴ Humphreys and Abbot, page 414.

⁵ See Sir H. Davy.

employed in favour of subsidence, and producing elevation in balance; for instance, the conversion of a dry valley into a lake must tend to lower the earth's crust by its extra weight, tending to produce subsidence at one point and elevation at another. Any delta deposit would tend to produce subsidence. The depression of the Channel must have lowered a much larger mass, apart from volcanic energy, than the Wealden elevation raised. In the opinion of the author, all elevations are uneven and sudden. The elevation of the Alps in the Miocene period must have accompanied or been the consequence of a much larger movement of depression; probably at the time a Miocene island or continent (near Plato's Atlantis) in the Atlantic was suddenly depressed. E. Forbes thought the position of the great floating masses of sea-weed marked the site of this ancient land. A subsidence of solid matter in one part may displace fluid or gas, on Sir H. Davy's theory, and produce an elevation of solid matter to an equivalent height elsewhere; but it cannot produce a corresponding elevation elsewhere (as part of the force is expended without producing motion), except where there is a fluid, or the equivalent of a fluid (as in the Delta of the Mississippi), to communicate movement without loss of energy, or below the surface of the solid crust where matter may be fluid.

In concluding my remarks upon the Delta of the River Po, it is only necessary to repeat that it is shown in the diagram Fig. 1, by the strata, A. and B., that there are two principal beds which are always water-bearing, one between the limits of 145 and 181 feet, and the other at about 200 feet. The upper sand bed, B., is so full of carburetted hydrogen gas, that in applying a light to the mouth of some of the wells the gas first detonates and then continues burning with a constant flame. The lower sand bed contains less gas, but is always full of water, which flows with great regularity.

The writer exhibited at the Geological Society a drawing by Mr. Jenkins of some of the Eocene *Cyrena* beds, with plants, etc., which prove that at Dulwich a deposit like that of the Delta beds of the Po existed in Eocene times.

DELTA OF THE MISSISSIPPI.—A somewhat similar bed of sand exists in the Delta of the Mississippi, near New Orleans, at a depth of 60 feet from the surface. This has been tapped in many parts of New Orleans for the carburetted hydrogen gas it contains. Iron tubes, three or four inches in diameter, are forced down 60 feet, and the gas is sufficiently good for burning. I will now give an abstract of the description which has been published, of the section of a well, by Dr. Bendict.

The well, commenced in New Orleans in 1854, was only continued to a depth of about 630 feet. There are 36 well-marked alternations of clay and sands; 4 lignitiferous beds, some with rootlets, and the lowest at 150 feet from the surface containing a sound cedar log striated with thin plates of siliceous matter. There are 6 shell-beds in different parts of the series of marine and fresh water-beds? making a total of 14 feet. The lowest, No. 54, was 543 feet from the surface. The 18 beds of clay make a total thickness of 266 feet. The lowest of these is 36 feet thick, and is No. 55 in the series. No. 53,

clay, was found to be 63 feet thick. No. 48, 29 feet thick, very pure clay. No. 42, 32 feet thick, leaden blue clay effervesced with acid. No. 22 clay is described as identical with No. 19, and effervesced with acid. No. 19, blue clay, with amber-coloured masses, each containing a yellow pebble. The remaining 12 clay-beds only amount to 205 feet in thickness, or an average of 17 feet each.

As in the Delta of the Po, so in the Mississippi Delta, the lower beds are the most sandy. Messrs. Humphreys and Abbot¹ give the dimensions of the Delta as follows:—

	SQUARE MILES.
The St. Francis bottom	6,900
The Yazoo bottom	7,110
The Tensas bottom	4,440
Small Swamps in the east bank, from Cairo to Baton Rouge	1,000
	<u>19,450</u>

The area now drained by the Mississippi and its tributaries is estimated at 2,455,350 square miles.²

From Humphreys and Abbot's report we learn that the Mississippi water is never charged with matter in suspension up to the quantity the water could hold. At high-water, both in 1857 and 1858, the river held little more sediment per cubic foot than at dead low-water, when the soundings of the Survey proved that the river made no deposit in its channel. The caving in of the banks when the river is falling temporarily affects the amount of sediment in the river.

SLOPE OF THE MISSISSIPPI RIVER.³

	Miles from head of passes.	High water above gulf.	Resulting fall per mile in water surface.			
			ft. inch.		Highwater.	
					Miles.	feet.
				Gulf by		
					S. W. pass 17	0·165
					N. E. pass 16	0·175
					Passe l'Outre 15	0·187
					S. pass 14	0·200
Head of Passes of Mississippi in Gulf of Mexico ...	0	2 8	...	...	20	0·115
Fort St. Philip ...	20	5 1	...	...	84	0·121
Carrolton ...	104	15 3	...	...	72	0·146
Donaldsonville ...	176	25 8	...	...	52	0·156
Baton Rouge ...	228	33 9	...	...	71	0·220
Red River Landing	299	49 5	...	...	62	0·226
Natchez ...	361	66 0	...	...	269	0·309
Vicksburg ...	470	...	...	...	225	0·320
Games Landing ...	630	149 0	...	...	...	...
Napoleon ...	672	...	...	...	...	...
Memphis ...	855	221 0	...	...	204	0·436
Columbus ...	1059	310 0	...	...	21	0·571
Cairo ...	1080	322 0	...	...	173	0·497
St. Louis ...	1253	408 0	...	...	...	...

¹ Report on the Mississippi. U. S. War Department, 1864, p. 434.

² Op. cit., p. 93.

³ Page 113, Humphreys and Abbot, 1864.

The heights are not determined from a trigonometrical survey at points above Natchez, and are therefore only approximate. They are derived from the information given by different railway engineers, whose lines have crossed the Mississippi.

By drawing a parabola, the curve will pass near all the chief intermediate points. There is a deviation of twenty-two feet at Red River Landing, and of three feet at St. Louis. The fall of the Mississippi is six inches per mile at Cairo. This is the case of greatest error south of Cairo. At many points the parabolic curve corresponds exactly with the surface of the alluvium, so that by knowing the distance from any point, you could find the height; or, by knowing the height, you could tell the distance precisely from Cairo or New Orleans. It will be seen that a similar law holds good for the navigable part of other rivers.

The heights at some points are probably not correct within several feet, as they are not based upon a trigonometrical survey.

In a paper published in 1853, the author considered the probability of the rainfall all over the globe being many times the present average throughout the world, on the evidence of the fineness of the present river sediment compared with the coarseness of the old alluvial and gravel deposits.

The average maximum depth of the Mississippi between the Ohio and the head of passes in the Gulf of Mexico, determined from the average of forty-five cross sections, is 104 feet.

The highest maximum recorded is 180 feet, and the lowest maximum is 71 feet. The greatest width of river is 7,800 feet, and smallest recorded 1900 feet. The average area of the cross section is 197,250 square feet. The average width is 3,505 feet; so that according to these figures the average depth must be $56\frac{1}{2}$ feet from the Ohio to the sea, although it is not printed in the report.

YEARLY AMOUNT OF RAIN IN THE VALLEY OF THE MISSISSIPPI.

	Square Miles.	Downfall of rain in inches.	Cubic feet of rain.
Delta	12,300	60·9	1,700,000,000
Red River	97,000	39·0	8,800,000,000
Arkansas and White Rivers	189,000	29·0	13,000,000,000
St. Francis	1,000	41·1	1,100,000,000
Missouri	518,000	20·9	25,200,000,000
Up Mississippi	169,000	35·2	13,800,000,000
Ohio	214,000	41·5	20,700,000,000
Yazoo	13,850	46·3	1,500,000,000
Small	32,400	47·8	3,600,000,000
			89,400,000,000

In extreme low-water years, as 1839 and 1835, the discharge of water is only about 11,000,000,000 of cubic feet. In ordinary years it is 19,500,000,000 cubic feet.

In great flood years, as 1823, 1828, 1844, 1849, 1858, it is supposed to average about 27,000,000,000 cubic feet. The discharge is now

19½, and compared with the rainfall at 89½, is about as 1 to 4½. This difference arises from the re-evaporation of the rainfall several times before it reaches the Gulf.

In 1851 the mean proportion of sediment to water for the whole year was $\frac{1}{803}$, the maximum was $\frac{1}{817}$.

Professor Riddell's last experiment was $\frac{1}{1138}$ by weight.

By Mr. Meade's experiments, page 149, it appears that, at Carrollton, sand is always moving along the bottom of the Mississippi. An engineer who has resided in a plantation near Fort St. Philip, below New Orleans, describes the newly-deposited material to be sand, and not mud, and that it is observed to move along the bottom of the river at a point within thirty miles of the Gulf of Mexico. At Carrollton the mean temperature of the air in 1851 was 67°·6, the river water being 63°·9. The mean temperature of the Mississippi increases 3° between Memphis and Carrollton.

Taking the present rainfall at 41·5 in., and that in the Pluvial Period at 300 in. (p. 9, Quart. Journ., vol. xxv.), the ratio is 7·23 to 1, or sevenfold. If the solid matter in suspension was seven times coarser than at present, on the average, we have a new measure of the power of denudation and of the extent of rainfall in the Pluvial Period, for the velocity and quantity of water flowing at the same slope must be in a definite proportion to the coarseness of the materials carried by the water, and *vice versa*. If 300 inches of rain fell in large storms, there might have been floods carrying 125 times the present quantity of water, an amount deduced by the author from observing the form and dimensions of the Quaternary deposits in the Valley of the Aire, Yorkshire.¹ The width, depth, and coarseness of the fluvial deposits of the Mississippi are, in proportion to an average of sevenfold the rainfall and nearly twofold the velocity.

On the 4th of October, 1858, the current was 1·72 feet per second, and the water held in suspension 138 grains of solid matter per cubic foot of water, or 22·13 grains per gallon. In the Pluvial Period the author supposes the water held in suspension 160 grains per gallon in $\frac{1}{37}$ of the weight of water.

Messrs. Humphreys and Abbot state (p. 399, *op. cit.*) that at New Orleans, thirty-nine feet below the surface, the marine² strata begin, or those belonging to an earlier geological age than the present, or, at least, before the material brought down by the Mississippi river as now existing began to accumulate in this locality.

I have written to Dr. Bendict, at New Orleans, for the names of the shells, but have as yet received no answer. Sir C. Lyell records the occurrence of an estuarine shell³ near Lake Pontchartrain at a great depth, and very near New Orleans, where, on the contrary, Humphreys and Abbot describe marine shells. This requires explanation, as well as many of their other opinions as to the age of the clay imme-

¹ See p. 63, Quart. Journ., 1869.

² The probability of the Mississippi Delta being partly marine was suggested by A. T., p. 272, Phil. Mag., 1853:—"If the further examination of the Delta of the Mississippi shows marine or fluvio-marine strata," etc.

³ *Gnathodon cuneatus*, a common brackish-water bivalve.

diately below the modern alluvium. Sir C. Lyell's account of the stratification of the Delta appears much more precise than that of Messrs. Humphreys and Abbot, who seem to wish to bring the formation of the whole of the alluvium of the Mississippi within a period of 4,400 years. As far as I can ascertain, this view of the Delta, 280 miles long, 70 miles wide, having been formed in 4,400 years, is entirely contrary to their own evidence.

Mr. Sidell (p. 10, Appendix A, *op. cit.*) writes respecting the lumps which rise on the river and sea-bottom near the passes of the Mississippi into the Gulf of Mexico. These lumps have a peculiar appearance. In entering the mouth of the river they may be taken for rocks, from the steepness of their sides, their compactness, and the appearance of stratification produced by cracks. In some cases they rise eight or ten feet, nearly perpendicularly, and at one place there is a mound in the shape of a truncated cone, ascertained to be at least eighteen feet high. It is nearly inaccessible through the marsh or flat that surrounds it.

The material of the lumps is a very fine clay; it decrepitates with heat. On many of these lumps are found springs of salt water. The spring issues through a well-defined crater as firm on the sides as a chimney, generally of about six inches diameter. There is an ebullition of the water of the spring at considerable intervals, and inflammable gas constantly escapes from some of them. This is probably light carburetted hydrogen gas. The salt water stands in these springs two or three feet higher than the level of fresh water of the surrounding river. Some of these lumps form islands several acres in extent, they are only found in the immediate vicinity of the Gulf, and they form the nucleus for shoals. They are reduced by violent rain, and are supposed to be raised by pressure of gas formed below the surface by the decomposition of vegetable matter, the hollow being filled up with mud. The surface of many lumps is covered with white pure salt, evaporated from the deposit of the springs (see p. 16, Appendix A).

The origin of these lumps is thought to be chemical rather than mechanical, and they evidently differ from mounds formed in marsh ground which have been raised by tipping ballast near it.

It is recorded that during the Survey of the Mississippi bar a lump two feet high was discovered in the Channel which had arisen within two or three hours.

On the more probable hypothesis that 3 parts in 100 of the whole material denuded are deposited on the Delta, and not removed again, and that the remaining 97 parts are carried out to sea before being deposited, then the extension of the whole Delta, 55 miles (by means of fluvial deposit alone), into the Gulf of Mexico would require sufficient time to effect the denudation of over 2,455,250 square miles of surface, averaging 100 feet.

I calculated the present rate of denudation of this area in 1853, and my figures have been recently adopted by Mr. Croll. I found that the denudation was going on at the rate of 1 foot in 10,000 years in the above area, and at this rate we should require $10,000 \times 100$,

or above 1,000,000 years for a denudation of 100 feet under present conditions, or 138,393 years on the hypothesis of a Pluvial Period.

If the whole area of the Mississippi basin was 600 feet higher on the average above the sea than it is now, and glacial and pluvial conditions exerted in greater force (indicated by the coarseness 7·3 times of the deposits), the rate of annual denudation would also be much increased and the time shortened in proportion.

It certainly appears by the diagram, made from soundings in the Gulf of Mexico and River Mississippi, that modern marine strata, 600 feet or more in thickness, have been deposited on the bottom of the Gulf of Mexico, extending over some thousand square miles. I say modern, for it must be identical in age with the Mississippi Delta deposit.

According to Humphreys and Abbot, about one-eighth of a cubic mile of detritus is annually transported to the Gulf of Mexico by the Mississippi. They have calculated the rate of progress seaward of the river, and extension of the Delta, as if the Delta had been recently prolonged all along its outer edge, instead of at a mere point. Sir C. Lyell has also drawn attention to the narrowness of the present deposit near the passes. It is clear that only a very narrow tongue of land has been pushed out into the gulf by the river. The river would have to change its course from time to time in order to push out similar tongues of land round the Delta, which is a sector of a circle; and it would take evidently above 30 times as long to add 50 miles all round the Delta as it has taken to make the single strip of land, which contains the present river channel.

There is also great probability that when the river changed its course, the previous accumulation might be removed by the sea and redeposited near the new channel.

Messrs. Humphreys and Abbot only consider the superficial deposit as belonging to the river, and speak of this exclusively as alluvium, and as totally distinct from the beds of clay and thick sands which occur below the alluvium, and which alluvium proper they describe in different parts of the basin as from 20 feet to 60 feet thick at the maximum. There seems as much distinction in mineral character between the alluvium of the present river and the ancient deposits below it, as there is between the peat and alluvium of England and the gravels below them.¹ This indicates, in the opinion of the author, as great a change in the rainfall and climate in America as in England, at a period not long antecedent to the true historical period, in all probability in the proportion of 20 inches to 300 inches, or even a still higher ratio.

Sir C. Lyell explains the occurrence of decayed wood and of freshwater and estuarine shells as far below the surface of Deltas as 380 feet, in the following manner (page 247, vol. ii. second visit, U.S.):—"These appearances may readily be accounted for, by assuming there was a gradual subsidence of the ground for ages, which was as constantly raised by the accession of fluvial sediment, so as to prevent any intrusion of the sea. Occasionally there were

¹ M. Belgrand has, since the date on which this paper was written, 1863, confirmed this view in his great work on the Seine.

pauses in the downward movement when trees grew on the soil, and vegetable matter of some thickness had time to accumulate.”¹

In the latter part of this paper I shall suggest that the appearances indicated in the Deltas of large rivers, of subsidence of the land, may possibly be caused by a great fall in the sea-level during the Glacial Period by contraction of the sea by cold and by abstraction of water for conversion into ice and snow, to be deposited on the colder regions of the earth. The subsequent elevation of the sea-level, and encroachment of the sea on the land, may account for the shallow soundings off the Delta of the Mississippi in the Gulf of Mexico. These indicate a large recent deposit there, and this may have been formed during the fall in the sea-level, and then have been submerged by the restoration of the sea-level to its original point near the close of the Glacial Period.

DELTA OF THE GANGES.—From the description of Lieut. R. Baird Smith, p. 4, Proceedings Geological Society, 1846, we learn that between the 382 feet and 423 feet level below Calcutta in the Delta was found gravel with bones of lizard and turtles associated with large rolled pebbles of quartz, felspar, limestone, and indurated clay.

At the 380 feet level there occurred two feet of blue calcareous clay, with many fragments of shells. At 382 feet this was succeeded by a layer of dark clay filled with decayed wood, ferruginous sands, and thin beds of clay from 208 feet to 380 feet. From 183 feet to 308 feet, indurated ferruginous clay. At 175 feet a coarse friable quartzose conglomerate occurs, composed of pebbles of different sizes cemented together by clay. From 130 feet to 150 feet argillaceous marl; from 75 feet to 120 feet, variegated clay. At 65 feet to 75 feet, green siliceous clay. At 55 feet to 65 feet, clay. At 30 feet to 50 feet, large portions of peat with decaying fragments of trees were found. These were identified with existing species still living on the spot. The clay was met with at ten feet from the surface. If we apply the hypothesis of a fall in the sea-level, we have a *vera causa* for producing a state of physical circumstances under which pebbles could be transported from the high land in the interior of India to an immense distance. During an average denudation of 100 feet over a large district, some points of land may have been reduced 1,000 feet in height. If some of the mountains were 1,000 feet higher, and the sea 600 feet lower, we should have an ancient Ganges river of immense carrying power and dimensions, such as might bring down large pebbles and boulders, where now the present Ganges can only bring down mud.²

Between Futhguhr, near Hurdwar (428 feet high), and the sea the distance is 1,219 miles. Testing this section by a parabolic curve, the deviation is five feet at Cawnpoor.

¹ The author suggested the Delta being marine in the Phil. Mag. p. 272, and also the probability of the rainfall and denudation being many times greater than at present. Phil. Mag. 1853.

² Mr. T. Login, Quart. Journ., vol. xxviii., has added some valuable information as to the Ganges deposits.

By knowing the direct distance from any point, you can determine the height of any other spot correctly, that is within six feet, or, by knowing the height, you can find the distance within a few miles between any points.

THE VOLGA.—For a great part of its course of 2,000 miles long, this parabolic curve truly represents the contour of the surface of the alluvial plain and Delta of the Volga. The Volga rises in a lake 630 feet above the level of the Caspian Sea.

Mr. Eyth, who has superintended irrigation works in Egypt, and is well acquainted practically with the Delta of the Nile, considers that the surface of the Delta is a mathematically exact curve, and thinks its straightness at the Delta portion, where he has particularly observed it, makes it more like an hyperbola than the parabola I suggested.

The engineers in the Mississippi Report treat that river as a plain, but their own table of the changes in level per mile in passing from Balize to St. Louis proves that it is a curve. See *antè* page 489.

The flatness of the Nile cannot be greater than that of the Mississippi, which, according to Mr. Meade (Appendix A. xix. Mississippi Report), is $1\frac{3}{4}$ feet in the last twelve miles of its course, or $1\frac{1}{4}$ inches to the mile on the average.

We have clear indications that these stratified gravels were deposited under very different meteorological and physical conditions from any we now meet with. We have found evidence of littoral conditions in Delta deposits and on the sea-bottom down to the 100 fathom line, wherever examinations have been made; these are only in scattered localities, and the evidence is only obtained by boring and dredging.

Such littoral deposits as we have been considering are small indeed compared with the littoral deposits to be seen in the Pacific Ocean formed by coral zoophytes over a tract of 5,000 miles in length. It is stated that many species of these zoophytes would be destroyed by immersion under water only a few fathoms deep. In ordinary cases reef-building polyyps do not flourish at greater depths than 20 to 30 fathoms. (Page 86, Darwin's Geological Observations.) Exposure to air for a few hours at the surface of the sea is also fatal to their existence. Mr. Darwin writes, "With respect to subsidence, I have shown in the last chapter that we cannot expect to obtain in countries inhabited by semi-civilized races demonstrative proofs of a movement which invariably tends to conceal its own evidence." (Page 127, Darwin's Geological Observations, 1851.) It was from this difficulty of absolutely proving subsidences of sea-bottoms that Mr. Darwin considered he had exhausted every demonstrable course before he adopted the theory of subsidence to explain the formation of the coral islands of the Pacific. At page 147 he speaks of subsidences as "the one alternative."

In the South Sea Islands every stranded root of a tree was examined for the hard stones attached to it.¹ It is therefore

¹ According to the accounts of early travellers.

possible that pieces of rock, with living coral attached to sea-weed or wood, might be thus floated from one island to another, etc. Also the fundamental rocks, on which the coral reefs are attached, may have been of such a friable character as not to be able to stand above the level of the sea. Some such conditions may have prevailed in the Carboniferous epoch. We have no modern instance of such rocks, neither have we evidence in former periods of any coral deposit of the form and dimensions of the Pacific Islands. Modern peat is not a type of Coal. Geologists assume too much when they rely on the analogy of modern conditions being a complete key to the knowledge of former conditions on the earth. Nor is the reverse true.

There are fourteen cases of elevation recorded by Mr. Darwin varying from 20 to 30 feet above the sea-level to a maximum of 300 feet. Very few of these instances have been examined by any geologist. There is, therefore, no means of measuring the thickness of the upheaved coral deposits by sections beyond 300 feet, as there are no known cases of elevation beyond that limit of thickness.

Mr. Darwin writes, p. 146, *Geological Observations*, 1851. In the 4th chapter the growing powers of the reef-constructing polyps were discussed, and it was shown that they cannot flourish beyond a very limited depth. "In accordance with this limit there is no difficulty respecting the foundations on which fringing reefs are based; whereas with barrier reefs and atolls there is a great apparent difficulty on this head: in barrier reefs, from the improbability of the rock of the coast, or of banks of sediment, extending in every instance so far seaward within the required depth; and in atolls from the immensity of the spaces over which they were interspersed, and the apparent necessity for believing that they are all supported on mountain summits, which, although rising very near to the surface level of the sea, in no one instance emerge above it. To escape this most improbable admission, which implies the existence of submarine chains of mountains of almost the same height, extending over areas of many thousand square miles, there is but one alternative, namely, the prolonged subsidence of the foundations on which the atolls were primarily based together, with the upward growth of the reef-constructing corals. On this view every difficulty vanishes. Fringing reefs are thus converted into barrier reefs, and barrier reefs, when encircling islands, are thus converted into atolls the instant the last pinnacle of land sinks beneath the surface of the ocean."

The maximum depth of the coral lagoons is 60 fathoms, either in lagoons or between the shore and barrier reefs. In dredging outside coral reefs you have a sandy bottom, and not a coral bottom, at greater depths than 60 fathoms, and not often deeper than 20 or 30 fathoms. Then comes a very steep descent to very great depths, almost close to the coral islands.

Mr. Darwin and Sir H. T. De la Beche differ on the important point of there being no existing case of a sea-bottom of large extent sufficiently shallow to form a base for coralline zoophytes to work on. The following extract is most clear on this point:—

De la Beche writes, *Geological Observations*, p. 227, 1851—"As

regards inequalities of sea-bottom, if the Great Bank of Newfoundland were in coral regions, and were elevated from its present relative level, so that its broad platform with its common depth of 40 to 50 fathoms were raised about 20 fathoms, by which coral reefs making germs could fix and develop themselves under fitting conditions, we should have an area of between 35,000 to 40,000 square miles, around the irregular margin of which there would be conditions for an extended border of coral reefs: the sea round the margin would often be suddenly deep. Soundings up to 149 fathoms are found close to the south-eastern side of the bank."

Supposing that the sea-bottom in the Pacific was originally of similar heights to Sir H. T. De la Beche's case of the Newfoundland Banks, then applying our hypothesis of the fall of 600 feet in the sea-level during the Glacial Period, supposing that period to have continued 138,000 years, we should have a sufficient period and also a gradual change of conditions and level of sea so as to be most favourable to the growth of coral banks.

As far as the limit of 600 feet—which is a greater depth than we are certain coral ever reaches below the surface of the sea—the theory of a fall in the sea-level appears to explain the difficulties of the subject, as well as that of gradual subsidence and elevation. Having now hastily reviewed some of the more important littoral deposits that might have been formed in the last 138,000 (?) years, and having found that there are no greater difficulties presented by the hypothesis of a change in the sea-level than occurs with the theory of subsidence of the sea-bottom, I will add a few remarks on the growing importance of the Glacial Period geographically considered.

With regard to the importance of the Glacial Period, Prof. Agassiz long since wrote:—"The British Islands, Sweden, Norway and Russia, Germany and France, the mountainous regions of the Tyrol and Switzerland, down to the happy fields of Italy, together with the Continent of Northern Asia, formed undoubtedly but one ice-field, whose southern limits investigation has not yet determined. The polar ice, which at the present day covers the miserable regions of Spitzbergen, Greenland, and Siberia, extended far into the temperate zones of both hemispheres, leaving probably but a broader or narrower belt around the equator, upon which there were constantly developed aqueous vapours which again condensed at the poles."

Time has not modified Agassiz's views of the importance of ice action, for he writes, p. 424, *Journey in Brazil, 1868*, after applying the theory of ice action to the formation of immense beds of drift in the valley of the Amazon, near the Equator, and the level of the sea:—"I am aware that this suggestion will appear extravagant. But is it after all so improbable, that when Central Europe was covered with ice thousands of feet thick—when the glaciers of Great Britain ploughed into the sea, and when those of the Swiss mountains had ten times their present altitude, and Northern Italy was filled with ice, and these frozen masses extended into Northern Africa; when a sheet of ice reaching nearly to the summit of Mount Washington, in the White Mountains (that is having a thickness of nearly 6000

feet), moved over the Continent of North America—is it so improbable that in this epoch of universal cold, the valley of the Amazon also had its glacier, poured down into it from the accumulations of snow in the Cordillera, and swollen laterally by the tributary glaciers descending from the table lands of Brazil?"

After this, Oscar Fraas's account of the remains of true glacier moraines on Mount Sinai, at a height of 700 feet only above the sea-level, does not seem so astounding as it really is.

Prof. Forbes writes of the glacial sea (p. 382, vol. i., *Mem. Geol. Survey*, 1843):—"An arctic sea inhabited by a limited and uniform fauna" (I presume Prof. Forbes intended to restrict the uniformity of the fauna to the zones of equal depth and temperature), "extended from the then western coasts of Siberia into the heart of North America, and southwards in Europe to the parallel of the Severn, and in America to that of the Ohio."

Prof. W. W. Smyth quotes an estimate of the temperature of the summer months, of the space now occupied by London, in the Glacial Period at 126° F. The author calculates that a decrease of 30° Fahr. in the mean temperature of the ocean would reduce the level of the sea 150 ft., while a deposit of snow or ice 1500 feet thick in an area of land one-tenth of that of the sea would also reduce the level of the sea 150 feet.

APPENDIX.

Note on the theory of a "Pluvial Period," p. 486.—[Mr. Prestwich in all his writings has attributed the valley gravels to floods caused by sudden melting of ice and snow under the maximum rainfall now met with in similar localities. There is no trace in his works of the idea of a Pluvial Period until 1872. The average rainfall in some parts of Great Britain being five times that falling in other parts, Mr. Prestwich has taken the higher figure for his British Gravel Period, just as Sir C. Lyell refers to the greatest eruption in modern times as a gauge for all previous ones that have occurred. Both Mr. Prestwich and Sir C. Lyell consider present meteorological conditions as the test for those that previously existed. The writer, on the contrary, infers the amount of rain causing the Quaternary deposits from the coarseness and position of the gravel deposits themselves. Both plans may be useful in endeavouring to ascertain the truth about a very difficult question. Mr. Prestwich has, in his address of 1872, quoted M. Belgrand, 1870, for a 20 or 25-fold rainfall in the Quaternary Period, and given his qualified assent to the idea of a Wet or Pluvial Period; but he has not referred either to A. Tylor's paper in 1853, in which he first proposed the hypothesis of many times the present average rainfall and deposit, or to page 63, vol. xxv. *Quart. Journ.*, where A. Tylor calculated the volume of water in the Gravel Period as 125 times that at the present time. At page 9, same vol., A. Tylor writes of 300 inches of rain at the sea-level in the Quaternary Period. In the text of the paper, read November, 1868, and now published in the *GEOLOGICAL MAGAZINE*, this subject is treated at greater length. The term Pluvial Period was first used, page 105, vol. xxiv. *Quart. Journ.*, 1868, in a paper by the writer, and the term has been since used by Prof. T. R. Jones, Prof. Dawson, and other writers. Mr. Prestwich never contemplated any general excess of rainfall above what is known at the present time, and therefore differed from the author, who made an hypothesis of a general rainfall on the globe many times more than at present in 1852. Mr. Prestwich opposed every view brought forward by the author in 1852, and also in 1868 and 1869.]—Aug. 1872, A. T.

Note on "Elevations," pp. 397 and 399.—[The marine shells at Moel Tryfaen and at Coalbrook Dale at such different levels indicate a very unequal elevation of part of England and Wales. The hypothesis of a change of sea-level accounts for a very even change of position of land and water over large areas, totally differing from anything that could be produced by elevations or subsidences, which are always accompanied by flexures and uneven movement of strata.]—A. T. Aug. 1872.

Note on pp. 393 and 492.—[The author has sent full particulars of the slope of the Mississippi, Ganges, Rhine, and Indus, to the Institution of Civil Engineers, Feb., 1872.]

Note on page 397.—[The author cannot find any evidence whatever as to the real character of the rocks below the surface of the Pacific in the works of any geologist. It is quite an assumption, unsupported by any evidence, to state that they are formed of recent coral to considerable depths. It seems probable that reef-building coral zoophytes must have lived at much greater depths than has been supposed, or they could not have passed from one island to another, as they must have done to spread over such a mass of islands separated by seas of enormous depth. The low temperature of our atmosphere and of the Atlantic at great depths is probably a survival or a result of the Glacial period. In a warm period coral zoophytes might live at very great depths, as they are said to do in the Red Sea now. The supposition of immense continuous periods of subsidence, without a counterbalancing elevation, is against the principle of the conservation of force. There is no direct evidence of *EVEN* elevation or *EVEN* subsidence over any area of more than a few miles recorded in the writings of geologists. The strata are always curved where there is direct evidence of elevation or subsidence.]—A.T. Aug. 1872.

Note on page 495.—[It requires further examination. In the Nile valley there are now no constantly flowing tributaries, but there are immense side valleys, which must have been full of water in the Pluvial Period.]

Note on the Glacial Period.—[The geological teacher who takes his pupils on the field has a difficult task. Every valley almost that he can find is a case of pluvial and fluvial action, the evidence of ice action being rare in many districts. Yet the teacher has to teach the existence of the Glacial period by what is really the evidence of a Pluvial period.]

[The author has published this paper as read, with some slight alterations. He thinks it alludes to some points which should be more carefully considered by geologists than they have hitherto been. Fig. 2, Plate XI., has been corrected as to heights from the drawing exhibited in 1868. Fig. 3, Plate XI., is altogether new, and is inserted as necessary to explain Fig. 2 and the position of the Dour river referred to, in 1868, p. 396. Fig. 4, Plate XI., refers to the Binomial Curves spoken of in 1868, but not drawn, see note, p. 486.]—A.T., Aug. 1872.

* * The following note should have appeared on page 395, after line 12 from bottom :—The shape and height of any hill is dependent upon its power of resistance. Where the base is clay, exposed to the weather, or water action, either of the sea or brooks, the power of resistance is comparatively small. The presence of a thin band of clay in a position in which it could slip, might and has undermined and caused the denudation of strata thousands of feet thick in the Wealden area.

EXPLANATION OF PLATE XI.

NOTE BY MM. DEGOUSÉE AND LAURENT, IN EXPLANATION OF FIG. 1, PLATE XI.

The soil of Venice is only one metre above the high-water mark of the Adriatic. Most of the ground has been recovered from the deposit of alluvium which we have explored at twenty different points.

The first and the last beds of this deposit, of which the thickness is not less than 172 metres by the well-boring of the Ca di Dio, present a great similarity throughout. Nevertheless, the first beds contain shells generally all of marine species, together with fragments of human industry.

The lower beds contain fluviatile shells, intermixed more and more with marine shells.

The sands predominate towards the inferior part, and are frequently mixed with fragments of lignite disseminated through their mass. In the middle and upper parts these lignites occur in thin bands, and in beds alternating with clays or sands. Mica, very abundant in the lower part, is less so at the commencement of the deposit.

One may say that the beds of this deposit are almost horizontal throughout the area which we have explored. Thus, the two great lines which intervene between the soundings are—1st, of Guidicca to S. Francesco della Vigna, about two kilometres; 2nd, of Malghera to S. Servolo, about ten kilometres; it was to this last that we referred in our remark that it did not present any very great slope.

One would almost think the Venetians dreaded the scarcity of water, in the event of blockade, when one notices that everywhere there is abundance of spring water near the surface.

At Sta. Maria Formosa one finds five water-bearing beds, of which the first is at a depth of 2.50 metres. At St. Leonardo the water is found jetting up, at a depth of twenty-four metres. If at other points these different principal sources are not indicated, it is because they were of no importance, or were passed by unobserved; but it is probable that almost all these existed higher or lower.

Two principal beds illustrate the richness of these water-bearing alluvial deposits. The first, at forty-four to fifty-five metres, is so charged with gas, that at some points the expansion of the carburetted hydrogen gas projects the earthy matter (from the bore-hole) to a height of twelve metres. If a light is presented at the orifice of the boring from which the gas escapes, an explosion follows, and the gas continues to burn. The second water-bearing bed lies at an even depth of sixty metres; it is not so charged with gas as the first, and the water flows from it constantly and with great regularity; it is found everywhere, but occasionally the pressure of the water varies.

In 1850, these borings yielded 1,029 litres of water per minute.

DEGOUSSÉ ET LAURENT.

PLATE XI., FIG. 2.—Section along a line of eight miles from Folkestone to Dover, passing by the Holywell Spring B' B", thence to the watershed W' on the west of the Sugarloaf Hill (a marked feature of the escarpment of the South Downs), thence by Alkham to the village of River and to Dover. See V' V' V". Sugarloaf Hill projects a little beyond the line of the main escarpment of the Chalk, but not so much as Beechborough Hill near Cheriton, which has almost the appearance of a tumulus. There is a line of springs and brooks along the whole escarpment; but the level of the springs gradually falls as it approaches the sea, or one of the Wealden Rivers. The level of the escape water is reduced thus, from 180 feet at Cherry Gardens to 140 feet at Holywell, about half a mile, at Lydden Spout, three miles farther immediately on the coast the water escapes not far from high-water mark. The Springs above River, five miles from Holywell, are at a level of 112 feet above the sea (Fig. 2). The supposed underground water level is shown in Fig. 2 by a line A' A' A". This varies very much from year to year. In wet seasons the water level rises rapidly. When it changes as much as 20 feet, the springs overflow in a large bourne at Drillineourt (Fig. 2), making a temporary river.

PLATE XI., FIG. 3 represents the alternations of coombs and headlands along the valley and hill separating Folkestone and Dover, or along the escarpment of the Downs. This is only a diagram and it does not attempt to describe any local features. It is drawn to show the manner in which all headlands and coombs alternate in every valley or escarpment, and along all lines of coast section, more or less symmetrically. The Springs S' S" S" rise near the Watershed W' W" in several points, and then collect in one channel, flowing into the cross stream at the bottom of the Valley V' V' V", always joining it in a single stream at an acute angle. The upper terminations are often trifid. The different distances from the watersheds, the flexures in the impervious and pervious beds affect the quantity discharged from each side stream S' S", and introduce local changes in their relative positions and magnitudes affecting the sizes and distances of the headlands. In a map of Crete, by Capt. Spratt, the distances of the side streams from each other are surprisingly regular. Fig. 3 shows the form of denudation in binomial curves (page 6), which govern the general shape of all headlands and coombs, hills and valleys; the hard or soft beds or clays also affect the stability of all strata, and produce deviations from the true binomial curve of denudation which are not attempted to be represented. The line B' B' B" in Fig. 2 would represent the transverse section of the headlands and coombs in Fig. 3. The remains of watercourses of the Pluvial Period are less visible on chalk escarpments than on any others, but in chalk valleys they can be traced.

PLATE XI., FIG. 4 is a drawing of one of the infinite numbers of binomial curves of different powers and lengths that may be described. The base is divided into equal portions or abscissæ, and the ordinates are to scale, their lengths corresponding to the co-efficients of $(a+b)^{10}$. This form of curve was applied by Quetelet to represent the variations of lengths and numbers to illustrate certain statistical results; but the writer believes he was the first to indicate that actual accumulations as well as removals and elevations of materials forming the earth's surface, actually assumed a form which could be represented by binomial curves. He has measured beaches, flexures, as well as surfaces of valleys and hills, denuded by water, and found them coincide nearly with binomial curves. The binomial might be called the geological or physio-graphical curve, or the curve of denudation, or deposit, so marked is it in nature. It is essentially the heap curve. Everything heaped up, whether water in waves, or solids, like hay when heaped up, follow this curve. One of the principal characteristics of all binomial curves is that the upper part is convex, and the lower concave. The curve of a stream commencing at a watershed begins at 0, following a convex course, and gradually becomes steeper towards the middle portion, then

G. R. De Wilde del.

W. West & Co. imp.

Graptolites from the Moffat Group.

gradually flattens, following however a concave line; and when it enters a river, which has become navigable, passes into a parabola. In Fig. 3 the convex part is marked Hill H H; and the concave part, Valley, V V; and the convex or concave form of the surface enables us to divide a hill from a valley broadly. A new definition of a hill might be land situated above a valley having a convex form or surface, and that of a valley might be land situated below a hill, and concave in form.

The different powers of $(a + b)$ require a different number of divisions of the base line of the curve as well as different co-efficients, thus giving great variety to this form of the curve, while still preserving the feature of convexity and concavity pointed out. Hard rocks, or alternations of hard and soft, produce considerable deviations. No curve could be general in nature without great flexibility and variety, and the author thinks that Hogarth, who first tried to represent natural forms by particular curves, would have chosen the binomial as the line of grace, had he been aware of its properties.

The curves Hogarth has drawn have little variety, and therefore do not represent nature. Hard rocks do not always put on rugged features or outlines, they are sometimes denuded into smooth curves. In passing over the most varied formations, hills of identical contour but of different materials may be seen. The harder rocks have greater stability, and therefore are altogether larger, and stand up higher. May Hill and Shooters Hill, for instance, differ in size, but not in contour. No one can tell in all cases the formation from the surface alone. You may be certain that you are not looking at clay, but rock may put on various forms.

III.—ON SOME NEW SPECIES OF GRAPTOLITES FROM THE SOUTH OF SCOTLAND.

By JOHN HOPKINSON, F.G.S., F.R.M.S.

(PLATE XII.)

IN this communication I purpose describing a few new forms of Graptolites which I have obtained at various times from the Llandeilo rocks of the south of Scotland. Of one species, first collected at Moffat in 1866, a brief diagnosis has previously been given, and the names of two others, from the lead-mining district of Lanarkshire, have already been published. One of these also occurs near Moffat. The remaining species are all from one or other of these richly fossiliferous districts. Of their position in the geological series I need only say here that the black, more or less carbonaceous, shale in which they occur, appears, from the fossils it contains, to correspond to the higher portion of the Llandeilo flags of Wales; that it is almost immediately succeeded by a series of beds (the Gala group) containing fossils of Caradoc or Bala age; and that the unfossiliferous flagstone, or greywacké, in which it occurs, reposes on rocks which have yielded to the persevering search of Prof. Elliot and Messrs. Lapworth and Wilson a few fossils of Cambrian age.

The Lanarkshire graptolitic shale is considered by Prof. Geikie to form "an upper part of the Moffat group,"¹ but while decisive stratigraphical evidence is wanting, from the evidence afforded by the fossils it seems more probable that but one band of graptolitic shale runs through the Llandeilo rocks of the south of Scotland, there being in this band several distinct zones, each marked by a different assemblage of fossils, but with many species in common.

Several of these new species were collected in the course of a few days' walking tour in these districts, during part of which I had the advantage of the company of Mr. Chas. Lapworth, of Galashiels,

¹ Brit. Assoc. Report for 1871, Sections, p. 96.