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LVII. *On the probable Cause of the Displacement of Shore-lines, an Attempt at a Geological Chronology.* By A. BLYTT.

[Plate X.]

[Concluded from p. 429.]

THE Trias period has received its name because it shows a distinct triple division. It commences with freshwater and littoral formations, upon which follow formations of deeper water, and then closes with freshwater and shore-formations. At its commencement the land was high relatively to the sea; as it went on the sea rose higher and higher; then the land again began to rise, and at the end of the period it was again high in relation to the sea. And these great changes in the situation of the coast-line were no doubt effected by means of many smaller oscillations.

But just as it is with the Trias, so is it also with other geological formations. They commence with littoral formations (there is often a conglomerate at the bottom); these are followed by deeper marine formations, and at the close we have again shore-formations. The name of Trias would therefore really apply to all of them. The first person to call attention to this remarkable triple division of formations would seem to have been Eaton. It was subsequently discussed by J. S. Newberry in his memoir entitled "Circles of Deposition in American Sedimentary Rocks" (Proc. Amer. Assoc. 1873, vol. xxii. p. 185), and Hull (Trans. Geol. Soc. Glasgow, 1868, iii. pt. 1, p. 39); see also A. Geikie, 'Text-book of Geology,' p. 498, where further references to literature will be found. Principal Dawson called these tripartite periods "cycles," and in his 'Story of the Earth and Man' he established the following cycles of this kind:—1. Cambrian; 2. Lower Silurian; 3. Upper Silurian; 4. Devonian; 5. Carboniferous; 6. Permian; 7. Trias; 8. Lower Jurassic; 9. Middle Jurassic; 10. Upper Jurassic; 11. Cretaceous; and 12. Tertiary*. It appears therefore that these cycles are periods of long duration; each of them has certainly lasted several hundred thousand years. And in the middle of each cycle the great overflows of the sea have attained their highest point. The cycles alternate with continental periods. During the elevation of the land the horizontal position of the strata was often disturbed, so that the deposits of the new cycle lie unconformably upon the older ones.

In this way the development has gone on, at any rate in the northern hemisphere. Mojsisowics, Suess, and others

* We shall see hereafter that this formation includes two cycles.

have pointed out that it has taken place simultaneously in the same direction in Europe, Asia, and North America. These great changes have taken place over the whole of the northern hemisphere, and on both sides of the oceans they have constantly had the same direction. And the same geologists have justly insisted that this law is one of the most remarkable results of geological investigations.

The development of organic life, as we now know, has gone on uninterruptedly from the earliest times. There has certainly never been any general destruction, never any completely new creation. The new has developed from the old through transitional forms and in the course of millions of years. If we knew all the deposits which have been formed it would be impossible to draw any boundaries between geological formations. One would imperceptibly pass over into the other. The boundaries between formations correspond with great gaps in the series of beds. In the time which intervened between the youngest bed in an older and the oldest in a younger cycle, the land in the northern hemisphere lay so high that no marine deposits were formed in the parts of the earth's crust which are accessible to our investigations. Nevertheless the development of living forms went on its even course. But when, after a long time, the land was again submerged, the life in the sea had changed, and beds with new fossils were deposited upon the old ones. And it is from the animal remains of marine deposits that the formations are determined. Hence the sudden change of fossils where a new formation commences is not due to any catastrophe, but simply to a shorter or longer interruption in the formation of deposits in the parts of the earth which we are able to examine. There is no doubt that there are transition-beds between formations, but they lie concealed from us at the bottom of the sea. It is only in certain strongly plicated chains that these beds are upheaved and can be examined. Thus in the Alps there are transitional beds between the Cretaceous and Tertiary, between the Permian and Trias, &c.*

* "As long ago as 1846, Darwin, in his observations in South America, showed that certain assemblages of fossils presented a blending of characters which are of Jurassic and Cretaceous age respectively. Since that date, the study of the fossil faunas of South Africa, India, Australia, New Zealand, and the Western Territories of North America has furnished an abundance of facts of the same kind, showing that no classification of geological periods can possibly be of world-wide application" (J. W. Judd, Presidential Address to the Geological Society, 1888, and 'Nature,' March 1, 1888, p. 426). See also Mojsisowics, *Die Dolomitriffe Südtirols und Venetiens*, Vienna, 1879, p. 36; and von Hauer, *Die Geologie*, Vienna, 1875, p. 515.

If we should attempt to establish geological formations by the aid of the known remains of terrestrial animals and plants, the boundaries of these would not coincide with those which are defined by marine animals*. Thus, to mention an example, the appearance of Dicotyledons does not coincide with the boundary of any formation; but they first appear with a number of forms in the Upper Cretaceous period (Cenomanian).

From Tertiary times, with the exception of the deposits in the great mountain-chains, we know only formations of shallow seas. The Tertiary deposits which correspond to the deep-sea strata of older formations, and which were deposited further from the land during that period without their formation being interfered with by the numerous minor oscillations of the coast-lines, still remain for the most part concealed from us in the sea.

Land-formations, freshwater and littoral formations such as we have in abundance in our Tertiary basins, are greatly exposed to destruction, for they are more frequently elevated above the protecting sea. In the older cycles such formations are more rare, probably to a great extent because they have been destroyed by denudation. We may therefore conclude that the Tertiary formations would much more resemble those of the older cycles if our knowledge of them all were equal. Of the older cycles we often know especially the deep-water formations, of the youngest chiefly those of more shallow waters. At some far distant period the exposed Tertiary formations will come to equal those which are now visible from older cycles.

Dawson (*l. c.* pp. 176-179) expresses the notion that the remarkable regularity with which such cycles recur may perhaps have a cosmical cause and be conditioned by one or another astronomical period. But he seems afterwards to reject this idea, because the Palæozoic cycles have deposits which are four or five times as thick as the Mesozoic (*l. c.* p. 195), and we might therefore believe that more time must have been occupied in their formation. But, on the other hand, he notes that in Palæozoic times changes in the organic world went on much more slowly in relation to the formation of deposits than subsequently, so that the fossils extend through greater thicknesses of strata than in the thinner, newer cycles. If I were to judge from these facts adduced by Dawson, I should

* "The growth of our knowledge concerning the terrestrial faunas and floras of ancient geological periods has constantly forced upon the minds of many geologists the necessity of a duplicate classification of geological periods, based on the study of marine and terrestrial organisms respectively." (J. W. Judd, *loc. cit.* p. 427.)

come to a different conclusion; I should regard it as a probable supposition that the formation of deposits went on more rapidly in Palæozoic times than later on. If the moon at that time were nearer to us and the sidereal day shorter, as Darwin thinks, the tidal wave must both have been stronger and have acted more frequently than at present. The coasts would be destroyed much more rapidly, and the sea would have much more material to deposit. A cycle of this period would be thicker than the younger cycles, and the fossils would extend through a greater thickness of strata than in the latter. For I see at present no probable ground for the supposition that the development of new species would be accelerated in the same degree as the formation of deposits.

There is therefore reason to assume that it is owing to these great changes in the form of the earth, occurring at long intervals, that we can distinguish between geological formations. But such great changes in the distribution of land and sea must necessarily also bring with them considerable changes of climate, and at the same time also changes of living forms. I have already, in one of my memoirs, put forward the opinion that the glacial period had its origin in a change of the distribution of land and sea. If the land gained a great extension in the middle and higher latitudes, especially if there should be a formation of bridges across the sea such as the supposed bridge through the Faröes and Iceland from Scotland to Greenland, the warm sea-currents would be excluded from the higher latitudes. The northern seas would then become icy seas, and where the snowfall is sufficient inland ice would be formed. In a memoir entitled "Natürliche Warmwasserheizung als Princip der klimatischen Zustände der geologischen Formationen" (in *Abhandl. Senckenb. Gesellsch.* vol. xiii. p. 277 *et seqq.*), J. Probst (like Sartorius von Waltershausen, in his *Untersuchungen über die Klimate der Gegenwart und Vergangenheit*, 1865) has with justice pointed out the great importance which warm sea-currents have, and have had, in rendering milder the climate of high latitudes.

It has been generally accepted among geologists that during the older formations animal- and plant-life was more uniform over the whole earth than at present. But this opinion must be changed according to recent investigations. Thus J. W. Judd says ('Nature,' March 1, 1888, pp. 424 *et seqq.*), with regard to the oldest fossiliferous deposits (the Cambrian):—"Even at that early period there were life-provinces with a distribution of organisms in space quite analogous to that which exists at the present day." Examples of geographical provinces are indicated by him in the Silurian, Trias, Jura,

and Cretaceous; and he says further:—"I believe that the study of fossils from remote parts of the earth's surface has abundantly substantiated Prof. Huxley's suggestion that geographical provinces and zones may have been as distinctly marked in the Palæozoic epoch as at present."

Most deposits of ancient times belong to periods in which the land lay low in relation to the sea, and the difference between the geographical provinces is far less in the great depths of the sea than near the shores and on the solid ground. It has also hitherto been a general theory that the climate in old times was warmer and more uniform over the whole earth than now. The further we go back, it is said, the warmer it was, and this has been regarded as connected with the interior heat of the earth. The Glacial period was an interruption of the continuity of its gradual cooling. In periods of overflow, when the land lay low and the sea had great extension under high latitudes, warm marine currents had much easier access to the Poles than during continental periods. As we now know most about the deposits formed during periods of overflow, and as most of the deposits of continental periods are either removed by denudation or concealed under the sea, it is still probable that the deposits of older cycles might show less strongly marked geographical provinces, and, as a rule, bear witness to warmer climates even under high latitudes. But the great changes in the distribution of land and sea compel us to assume that, hand in hand with them, occurred a periodical alteration of climate, which has been far greater and more radical than the change produced by the precessional periods.

Ramsay, Croll, J. Geikie, and others have thought that they found more or less certain traces of Glacial periods in the older formations (see, *e. g.*, J. Geikie, 'The Great Ice Age,' ed. 2, 1887, pp. 566 *et seqq.*). Some of these traces seem to prove that, at any rate, there have been more Glacial periods than the Post-tertiary one. Nevertheless von Richthofen remarks (*Führer für Forschungsreisende*, p. 362) that these supposed traces of Glacial periods are perhaps only a phenomenon of abrasion, and that the action of the waves upon the shore could produce conglomerates with striated stones. As regards these supposed old Glacial periods, the most certain traces (see J. Geikie, *l. c.*) appear to be furnished by the Devonian Sandstone, "Old Red," in England and Scotland, by the commencement of the Carboniferous period (Scotland), by the Permian conglomerate (England), and by the Eocene (Switzerland). The most striking evidence (with striated stones) is from the periods when the land had great extension.

As regards these great overflows, it must be remembered that it is only in folded chains and in strongly elevated regions (*e. g.* in the Alps, Himalaya, Colorado, &c.) that sea-formed deposits of the later and latest geological periods occur at very considerable elevations above the sea. These great elevations, if we consider them in relation to the whole, can only be regarded as quite local phenomena. At the time when the deposits were formed they lay much lower, and when we now find an alternation of marine and freshwater deposits in such formations we must not suppose that the sea rose and sank in relation to the land by thousands of feet at each oscillation. During the period of formation the shoreline need only have moved up and down a few metres. Afterwards the whole system of strata was lifted high above its original level by locally acting "geotectonic" forces.

Therefore I assume that even the great overflows do not depend upon any very considerable displacement of coast-lines in a vertical direction. When there are large flat countries with basin-shaped depressions, a small elevation may suffice to produce great geographical changes.

Possibly also these overflows may be due to changes in the eccentricity of the orbit.

We will now test our hypothesis by a comparison between the astronomical periods and the geological series of deposits.

The curve of the eccentricity of the earth's orbit has been calculated from Leverrier's formulæ by J. Croll ('Climate and Time,' 1875, p. 312) for a period of four millions of years; three millions of years backward, and 1 million forward from the present time. The curve is also calculated according to the same formulæ by McFarland (*Amer. Journ. Sci.* [3] vol. xx. 1880, p. 105). His calculation extends from 3,250,000 years backward to 1,250,000 years forward in time. He has calculated with shorter intervals of time than Croll (Croll 50,000, McFarland 10,000 years), which, however, has had no particular influence in altering the form of the curves. McFarland has in the same place calculated the curve for the same period of time from new formulæ of Stockwell's. The two curves, taken in the gross, show a uniform course throughout their length, but as regards the first half Leverrier's curve is thrown somewhat backward. Stockwell's formulæ are considered to be more accurate than Leverrier's.

Both curves are given by McFarland. If we compare them together it appears :—

1. The curves coincide with only a small essential difference from the present day until 1 million years back.

2. If we omit the portion between 7' and 8' of Leverrier's curve, Leverrier's and Stockwell's curves are in all essential points identical also as regards the older part, although the agreement is not so complete as for the last million of years. The reason of this is that the calculations are less certain with regard to the older periods ; when the number of years enters as a factor in the formula, small errors in the values adopted for the planets' masses will be enlarged in proportion to the time, and the result becomes less certain.

3. A very remarkable consequence proceeds from these calculations. *The curve repeats itself after the lapse of 1,450,000 years*, when it is calculated according to Stockwell's formulæ. In the period of $4\frac{1}{2}$ million years for which McFarland has calculated it, it repeats itself in this way with remarkable regularity a little more than three times. In each of these cycles there are 16 arcs of the curve. Thus the arcs which in the accompanying plate (Pl. X.) are indicated by 1-16 correspond with 1'-16' and 1''-16''. From calculations which he made at my request, Mr. Geelmuyden has declared that the course of the curve will probably be sufficiently correct to be adopted with safety as the foundation for geological considerations, and that uncertainties in the curve caused by errors in the masses employed by Stockwell will probably not be of any importance.

4. The mean value of the eccentricity is least at the limits of two cycles ; it rises in the first and sinks in the last half of each cycle, and therefore attains its greatest value about the middle of each cycle. Thus for the first and second of the calculated cycles and their subdivisions it is as follows :—

Cycle I.	÷ 3,250,000—2,720,000 years, 0·0304.
	÷ 2,720,000—2,150,000 years, 0·0332.
	÷ 2,150,000—1,810,000 years, 0·0203.
Cycle II.	÷ 1,810,000—1,250,000 years, 0·0247.
	÷ 1,250,000— 700,000 years, 0·0340.
	÷ 700,000— 350,000 years, 0·0280.
Cycle III.	÷ 350,000 to the present time, 0·0291.

Now as, according to our hypothesis, the sea-level under high latitudes will rise and fall with the eccentricity, then it must not only rise and fall once for each arc of the curve, but the “mean sea-level” for longer periods must also rise and fall with the mean value of the eccentricity, and such cycles as cycles I. and II. must then correspond to two cycles in the geological sequence of deposits. The limits between the cycles of the curve must correspond to the periods of denudation which divide the geological cycles, and the middle must correspond to the periods of overflow.

CURVES OF THE ECCENTRICITY OF THE EARTH'S ORBIT
 from 3.250.000 years before to 1.100.000 years after A.D. 1850 copied from R.W.M^c Farland,
 (Amer. Journ. of Science 3 Ser. Vol. 20.)

Cycle I.

Cycle II.

Cycle III.

The correctness of the two hypotheses put forward in my memoir on the Alternation of Strata may, as already indicated, be tested in one way by the comparison of geological profiles with the curves of the eccentricity of the earth's orbit. A first attempt was made at the time with the Upper Eocene and Oligocene beds of the Paris-basin.

Many difficulties, however, stood in the way of this work. First and foremost the calculation of the curve is less certain for distant periods. This difficulty is to a certain extent got rid of by the circumstance that, as the curves repeat themselves, it may be less essential.

Another difficulty is in the finding of long and accurately described profiles without gaps in the series of deposits. Survey-profiles are not sufficient. Geologists often only state that there are few, some, or many alternations of strata, without giving definite numbers.

A third difficulty is the distinguishing between the alternations of deposits which are due to precessions and those which have their cause in other more transitory and local conditions. In the case of shore-formations this difficulty is especially perceptible; but it has proved to be less than I supposed at first.

A fourth difficulty consists in the determination of the number of oscillations of coast-lines. The higher a place was situated, the more rarely was it overflowed; the lower it lay, the more rarely was it uplifted above the sea. And movements of the solid body of the earth, as might be supposed, have not been so uniform everywhere as those of the sea.

A fifth difficulty lies in the finding of perfectly typical profiles of the stages produced by the oscillations. When the sea rose and sank slowly the number of marine alternations of strata will be less, and of land and freshwater formations greater, the higher the place lay and the shorter the time which it remained submerged in the sea during each oscillation. But this difficulty is of importance only when the continuous profiles are so short that they do not embrace several oscillations.

In the absence of longer, connected and accurately traced profiles I have first endeavoured to determine the number of oscillations of coast-lines as regards the Tertiary and Quaternary periods. Each of these oscillations, of which there have been about 36 from the commencement of the Tertiary period until now, has, in temporarily submerged localities, produced an alternation of marine beds with freshwater or terrestrial formations. To each more considerable oscillation corresponds a geological "stage." In these "stages" there

is a certain number of alternations. By studying the literature of the Tertiary basins of Europe I have in this way formed a combined profile, which, as regards the alternations of strata, is not yet completed throughout, but which goes from the commencement of the Tertiary to the present time, and which I shall now proceed to describe.

The mode in which profiles can be compared with the curve to test the correctness of the hypotheses is as follows:— Each arc in the curve will correspond to an oscillation of the sea. It is supposed that under high latitudes the coast-lines move up and down with the curve. Such an oscillation I call a “geological stage.” Each arc will therefore have its corresponding oscillation or “stage,” and in each “stage” there will be as many alternations of strata as there are precessional periods in the corresponding arc. When the eccentricity only sinks inconsiderably between two or more arcs, the arcs run into one another and form, as it were, ranges with two or three small summits. We have then “stages” with more oscillations and more alternations of strata than the ordinary ones. We shall see examples of this in what follows. We can draw a line which indicates the boundary between marine and freshwater formations. This line may be nearly or quite horizontal. Whether it is to be drawn high or low depends upon how much above the sea the place was situated where the deposits were formed at the time when the deposition took place. The higher it lay, the higher must the line be drawn. The place may have been so elevated that it never was submerged. Then the lines are situated higher than the curve, and all the deposits are freshwater or terrestrial formations. But it may have lain so low that it never rose above the sea, and all the deposits are marine formations. But the line may cut the curve. Then marine formations alternate with land- and freshwater-formations. The former correspond to those arcs of the curve which project above the line; the latter to those which lie below it. And when there are no gaps in the series of deposits, there will be as many alternations of deposits in the marine, freshwater, and terrestrial formations as there are precessional periods in the corresponding arcs of the curve.

As a starting-point I will take the profile of the Paris-basin*, which I will endeavour to join on to recent times. Afterwards I will refer to the lower and middle parts of the Eocene period.

The section of the Paris-basin about Méry-sur-Oise (*Bull.*

* This section is given in my memoir on Alternations of Strata.

Soc. Géol. Fr. 1878, pp. 243 *et seqq.*) shows the following oscillations and alternations of strata, and may, as regards the continuous portion, fit into Stockwell's curve, as appears from the arc-numbers cited for each oscillation :—

Sables de Cuise, marine.

Calcaire grossier inférieur et moyen, marine, with 7 alternations.

Calcaire grossier ; Caillasses à Cerithium, 2 marine alternations, and between them a deposit with freshwater shells.

Calcaire grossier ; Caillasses à Lucina, marine, with 5 alternations.

Calcaire grossier : Caillasses à Cardium, marine, with 11 alternations. Gap in the series.

Sables de Beauchamp, freshwater and marine, about 4 alternations. Arcs 14–15.

Calcaire de St. Ouen, freshwater, 4, above which a marine deposit (summit of arc 16), then 6 freshwater alternations. Arcs 15–2'.

Gypsum, marine, about 11 alternations. Arcs 2'–4'.

Gypse palustre, freshwater, about 6 alternations. Arc 5'.

Marne verte, brackish, 2 alternations. Arc 6'.

Calcaire de Brie, freshwater, 1 alt. Between arcs 6' and 7'.

Marne et Mollasse, sables de Fontenaye, marine, 3 alternations. Arc 7'.

Meulière de Montmorency, Calcaire de Beauce (p. p.), freshwater. Between arcs 7' and 8'.

There is only one discrepancy :—Arc 16, the summit of which should correspond to the marine deposit in the middle of the Calcaire de St. Ouen, does not go so high that we should expect an inundation of the sea. But the oscillation is at any rate also indicated in Stockwell's curve, and the marine formation consists of a single bed, and is so faintly marked that it has only recently been recognized.

Another profile from another place in the Paris-basin (la Frette, *Bull. Soc. Géol. Fr.* 1876, pp. 471 *et seqq.*) has the same number of alternations as the above and extends from 13 to 2'. The marine bed at 16 is wanting in this profile, otherwise the same oscillations are indicated.

The profile at Méry-sur-Oise has in all 71 alternations of strata, of which 25 are in the Calcaire grossier. A great part of the calculated curve is therefore filled up by the occurrence of 37 alternations without a gap in the series of deposits. With arc 7' the marine formations of the basin

terminate. In Miocene times came the volcanic outbursts in the Auvergne.

These oscillations of the coast-lines were not confined to the Paris-basin. The sequence of deposits in the basin of the Gironde, which seems to have been connected with the Paris-basin only through the Atlantic Ocean, is as follows (according to Vasseur, *Ann. Sci. Géol.* vol. xiii. pp. 398 *et seqq.*):—

The Tertiary formations commence with the Middle Eocene: Nummulitic sand and coarse limestone, marine. After this, elevation and erosion. Then again followed a depression: clay with *Ostrea cucullaris* (arcs 14–15), and another elevation: lacustrine limestone of Plassac, and simultaneously with this brackish-water limestone of Bégadan (16–1'). Then a new depression:—marine limestone of St. Estèphe and limestones and marls with *Anomia girondica* (2'–4'). Elevation and erosion:—Mollasse (freshwater) of Fronsadais (6'?). Depression:—Calcaire à Astéries de Bourg (marine, 7'). Elevation:—lacustrine limestone of l'Agenais, level 1 (between 7' and 8'). This is contemporaneous with the Calcaire de Beauce of the Paris-basin. In the basin of the Gironde fresh oscillations took place, namely the following, which are Miocene:—Faluns de Bazas, marine, 8'; elevation: lacustrine limestone of l'Agenais, level 2 (between 8' and 9'); depression: Faluns de Léognan et Merignac, marine (9'). The so-called Mollasse of Anjou, which is wanting in the basin of the Gironde, is, according to Tournouer (*Ann. Sci. Géol. l. c.* p. 62) younger than 9', but older than the Faluns de Salles of the Gironde; both are marine, and probably indicate two oscillations, 10', 11'. Then followed another Miocene oscillation, which has left its traces in the basin of the Loire, in the marine Faluns of la Dixmerie (arc 12').

Thus the Miocene period in France had five oscillations. I have not, however, been able to obtain detailed profiles of all these series of deposits.

We now pass to England. In the Memoirs of the Geological Survey of Great Britain, 1856, we have accurate profiles of the Tertiary formations of the Isle of Wight (by Forbes and Bristow). The series of beds, from below upwards, has the following oscillations and alternations*:—

Plastic Clay (brackish?), 4 alternations.

London Clay, marine, at least 11 alternations.

Lower Bagshot, (in part?) freshwater, 7 alternations.

Middle Bagshot (Bracklesham and Barton), the first freshwater, the second marine, and with 5 alternations.

Upper Bagshot, without alternations.

* See Postscript, p. 513.

This part of the series is in part older than the Calcaire grossier, and there are at least one, probably two gaps in it. The following series, on the contrary, is continuous :—

Lower Headon, freshwater and brackish, 7 to 8 alternations (arc 13 and the first part of 14).

Middle Headon, marine, 1 alternation, at 14.

Upper Headon, freshwater and brackish, 5 alternations, between arcs 14 and 15.

Osborne, freshwater, 3 alternations, between arcs 15 and 1'.

Bembridge limestone, freshwater, 3 alternations, between arcs 1' and 2'.

Bembridge oyster-bed, marine, at least 1 alternation, at 2'.

Bembridge marl, freshwater, 6 alternations, arcs 2' and 3'.

Hempstead marl, freshwater and brackish, 2 alternations, 4' or 5'?

Hempstead Corbula-beds, marine, imperfect above by denudation, 1 alternation.

The profiles of the different stages are taken at different parts of the island which have lain at different levels. Bearing this in mind, the series may be fitted into the curve, and at any rate correspond with them pretty closely.

The number of alternations in this last continuous part of this series of deposits is about the same as in the contemporaneous deposits of the Paris-basin, although the beds are more than three times as thick (48 metres in the Paris-basin, 156 metres in the Isle of Wight).

With the marine deposits of Hempstead the marine formations of England are interrupted, and it is only in the Pliocene that we have indications of a new marine submergence. The basalts and volcanic eruptions of Ireland and the Hebrides are probably, at any rate in part, Miocene. Basaltic dykes extend in places across the whole of England; but the chief outbreaks were on the western side, and hence they can be traced through the Faröes to Iceland.

We will now see whether we can fill up the curve from 7', where the continuous profile from the Paris-basin closes, up to recent times. The uppermost bed of the Paris-basin lies upon the boundary between Oligocene and Miocene. As we have already seen, the Miocene period in France had five oscillations. In Transylvania (according to Koch, in the *Földtani Közlöny*) there are five Miocene stages, namely :—Koroder beds, Kettösmező beds, Hidasalmas beds, Mezőseger beds, and Feleker beds. All these stages are marine. Even

if they are not throughout separated by freshwater formations, as in the case of several, at any rate, of the French Faluns, they may nevertheless be regarded as corresponding to five oscillations. In the deeper seas the bottom will not always be upheaved above the sea under low eccentricities; but the oscillations will nevertheless operate in changing the fauna, and also frequently the constitution of the deposits.

The Miocene deposits of the Vienna-basin are divided into three principal stages,—the first and second Mediterranean, and the Sarmatian. But if we study the detailed profiles more closely, there appear to have been here also five Miocene oscillations. Thus (according to Suess, *Sitzungsb. Wiener Akad.* 1866) the first Mediterranean stage shows the following sequence of strata from below upwards:—

Beds at Molt, with oyster-shells (broken), at the top with lignite, 4 alternations, arc 8'.—Supposed by Suess to be on the same horizon with the Faluns of Bazas.

Beds near Loibersdorf, Gauderndorf, and Eggenburg, marine, probably with 8 alternations, at any rate in part younger than the beds at Molt (arcs 8' ? and 9').

“Schlier” with gypsum, at the top with land-plants.—Suess calls it “ein ersterbendes Meer,” and seems inclined to regard it as a peculiar stage. Alternations, but scarcely more than two. The last part of arc 9'.

Beds at Grund, marine, with few (3–4) alternations, to judge from Suess' profiles.—The fauna forms a transition from the first to the second Mediterranean stage, and this deposit at Grund is with reason regarded by several Viennese geologists as representing a distinct stage. Arc 10'.

This was followed by the greatest submergence, the second Mediterranean stage (arc 11'), contemporaneous with the French Faluns de Salles. The sea rose quite up into the inner Alpine Vienna-basin. I have been unable to make out the number of alternations in this stage. I have only seen sections of the littoral formations described.

Finally, the last Miocene oscillation, the Sarmatian stage, arc 12'. In some localities (*e. g.* near Constantinople) this stage commences with freshwater covered by marine formations (see Suess, *Antlitz der Erde*, i. p. 419). According to a profile from Hungary (by Peters in *Sitzungsb. Wiener Akad.* 1861) the stage has 4 alternations.

This stage is followed by the Pliocene Congeria-beds, which in the Vienna basin are represented only by brackish-water formations, according to Fuchs (*Jahrb. k. k. Geol. Reichs.*

1875) with 4 alternations ; arc 13'. And with these the marine formations of the Vienna-basin, Hungary, and Transylvania come to a close. Volcanic outbursts commenced in these countries even in the Oligocene period ; they became very frequent in the Miocene, and during this period the Alps rose to great altitudes.

In the basin of Mayence the marine Oligocene formations (Weinheimer marine sand and Septaria-clay) are followed first by a freshwater formation ; then the Miocene period commenced with a depression. But during volcanic eruptions the basin was upheaved and became more and more freshwater. A continuous formation of beds took place. Over the Cerithium-limestone, the Corbicula-limestone and Littorinella-clay were deposited, in all with 20 or more alternations (according to Lepsius, *Das Mainzerbecken*). All these deposits are Miocene.

We now pass further forward in time. The Pliocene has four oscillations, 13', 14', 15', and 16'. We have already mentioned the Congeria-beds of the Vienna-basin. In England there are three oscillations :—Coralline Crag (14'), Red Crag (15'), and Cromer Clay or Westleton Shingle (16'). Profiles of these are to be found in Quart. Journ. Geol. Soc. Lond. 1871 (by Prestwich). The climate of Europe began to become colder in the Pliocene. Even the oldest deposit in the Pliocene of England contains stones which may have been grooved by ice, and at the close of the Pliocene there were already great glaciers ; the Pliocene was followed by the Glacial epoch. We have seen how, during strong and extensive volcanic action, previously marine basins were during Oligocene, and especially Miocene, times uplifted above the sea not to be depressed afterwards (Paris, Vienna, Hungary, the Mayence-basin, and we may add Switzerland), and we have seen that the Alps were upheaved in Miocene times. The Faröes and Iceland were built up, at any rate in great part, at the same time by basalts and lavas ; perhaps, moreover, the submarine bank which connects Europe with Greenland was uplifted during the last portion of the Miocene period. In the Mediterranean, according to Neumayr (see Suess, *Antlitz der Erde*, i. p. 425) the coast-lines at the close of the Pliocene lay even lower than at the present day. No doubt all these elevations have had much influence upon climate. Changes in the length of the day are dependent upon variations of the eccentricity. Geographical changes follow upon the increase of the day, and climate changes with the distribution of land and sea.

The Coralline Crag in England (according to Prestwich)

has a thickness of only 25 metres, and cannot have many alternations. After this stage was formed the land rose, but was again partially depressed under the sea. During this depression was formed the Red Crag, with the Chillesford Clay. In the Coralline Crag two shore-lines were hollowed out one over the other and the new stage lies now on the old shore-platforms. The Red Crag is thinner than the Coralline Crag and cannot include many alternations.

In Belgium, also, we have two Pliocene stages, which correspond to the two English Crag-stages:—the Scaldisien, étages supérieur et inférieur. To these two oscillations of the North Sea correspond two contemporaneous ones of the Mediterranean. Suess calls them the third and fourth Mediterranean stages. And even in the earliest part of the Pliocene the Mediterranean fauna indicates a somewhat colder climate (Suess, *l. c. i. p. 431*).

Italy possesses thick Pliocene formations. Seguenza describes deposits 500–600 metres in thickness from this period. I have been unable to obtain profiles of these deposits. They are in part conglomerates and shore-formations, like the great Miocene Mollasse of Switzerland, and near the shore thick deposits can be formed in a short time.

The profiles of Roussillon (by Depéret, in *Ann. Sci. Géol.* vol. xvii. 1885) show four alternations in the stage contemporaneous with the Coralline Crag (arc 14'). The overlying stage in Roussillon is a freshwater formation. The land had risen. The freshwater stage has several alternations, probably 6–8, so far as I can see from the profiles given, which, however, are not quite accurately described (arcs 15'–16').

We now turn again to England. The fossils of the Red Crag show a colder climate than that of the Coralline Crag, and the Chillesford beds, which belong to the last portion of the Red Crag, have distinctly arctic shells. The Glacial epoch was advancing. After the Red Crag was formed England again rose and became united by land with the continent. Extinct mammals wandered in its forests, which consisted of existing trees (spruce, pines, &c.) and show a temperate climate, milder than that of the Chillesford beds, and about as at present. “The forest-bed of Cromer” was overlain by marine deposits—Westleton Shingle and Cromer Clay (arc 16'). In the latest terrestrial formation at Cromer Nathorst has found Arctic plants (*Salix polaris*, &c.), and the Cromer Clay indicates the vicinity of inland ice. With this the Pliocene closes.

As regards the Quaternary oscillations, we will take the

English deposits as described by J. Geikie ('Great Ice Age,' ed. 2, pp. 387 *et seqq.*) as our guide.

The Quaternary period commences with the retrogression of the ice and with a considerable denudation. Then the sea again rose and covered a great part of the east of England. The inland ice again extended itself and formed a bottom-moraine, "the great chalky boulder-clay" (arc 1"). After this glacial period an elevation of the land seems to have followed, and the ice retreated. But a new depression followed (Bridlington Crag) and a new glacial period (purple boulder-clay, arc 2"). A fresh elevation seems to have followed, with a new interglacial period. Then came a new depression, which was very considerable, and which at Moel Tryfaen in Wales, at Macclesfield, and in Ireland has left marine shells at heights of 1000 to 1300 feet above the sea (nearly approaching that at which the old "seter" or beach-lines in Østerdalen, Læsje, &c. occur). Like the preceding depression, this was also followed by a glacial period, the last (Hessle boulder-clay, arc 3"). Finally the land rose and the ice melted. The Postglacial period came with its four peat-beds (the last portion of 3" and 4"). To arc 4" corresponds a small oscillation of the sea immediately before the recent period. In Scania, Gäravallen, a raised beach-formation, rests upon peat; in Gotland, in the British Islands (Carse Clay, &c.), and even in North America, we may trace the same oscillation of the sea; it was no doubt too great to be capable of explanation by local conditions, compression of peat-beds by shifting sand-dunes, &c.

We have already seen that the land (according to Howorth and Suess) in many places under high latitudes rose considerably in the Postglacial period, and that a corresponding depression took place in the warm coral-seas. The last oscillations therefore affected a great part of the earth. From this we may conclude that this was the case also with the oscillations of former times, and that they have their cause in general cosmical conditions. The small oscillation (arc 4") forms an interruption in this great upheaval under high latitudes. A similar interruption of the depression, if our theory be correct, must be exhibited under the tropics; and in reality in the equatorial parts both of America and the Old World, there are numerous evidences of such a small postglacial oscillation in coral-reefs, which have been upraised several metres and are now lying dry (see Suess, *Anthitz der Erde*, ii. pp. 630 *et seqq.*). These coral-reefs may date from the same time when the northern peat-beds were submerged. The sunken peat-beds with the marine deposits formed during the

depression have been again uplifted, and the raised coral-banks have probably again begun to sink (at Bombay there is a sunken forest), but the depression has not yet brought them down beneath the sea.

We may make one or two further observations upon the Glacial period and its formations. Contemporaneous with "the forest-bed of Cromer" (according to Heer) are the lignites of Dürnten in Switzerland. The fossils show this. They have nearly the same plant-remains, and the same extinct animals. The lignites rest upon and are covered by bottom-moraines, and are therefore "interglacial." They have 7 alternations of peat and forest-beds, and may be fitted into the curve between the arcs 15' and 1". From this the Alps must have had large glaciers even during the time of the Red Crag. And there is no improbability in this if we remember that *Leda arctica* and other Arctic animals were already living on the English coast at this period, and that the Chillesford beds indicate a much colder climate than the subsequent forest-bed of Cromer.

It is instructive to see how each rising of the sea in England during the Quaternary period had as its consequence the increase of the inland ice. This seems to agree with Croll's theory, that glacial periods are a consequence of great eccentricities. But the scanty traces of glacial periods in the older formations, and above all the distribution of glaciers at the present day, show that geographical conditions have the greatest influence. It is only when these are favourable that a high eccentricity can cause the glaciers to increase; if they are very favourable, there may be a glacial period even during a small eccentricity, as in Greenland at the present day. When the eccentricity increases, the precipitation during rainy periods also increases. If the sea is cold, the precipitation will fall as snow, and in this way the glaciers will grow as the eccentricity increases.

North Germany (according to Jentzsch) has also had three glacial periods with corresponding bottom-moraines (and oscillations?); and in the Alps there have been (according to Penck, *Vergletsch. d. deutsch. Alpen*) at least three glacial periods.

We have thus filled up the curve to the present time, and connected the profile of the Paris-basin therewith. We will now trace the oscillations back to the close of the Cretaceous period in order, if possible, to see how many oscillations are included in the Geological period known as the Tertiary.

The Cretaceous period is separated from the Tertiary by a period of denudation, during which the land was high rela-

tively to the sea. The oldest marine formation of the Tertiary period in Europe is considered to be the limestone of Mons, in Belgium. This indicates the first oscillation; but this submergence appears not to have left traces in the other Tertiary basins. The first marine inundation of the Paris-basin during Tertiary times formed the conglomerate of Rilly and Nemours. It was followed by an elevation of the land, and the marine conglomerate was covered by the freshwater limestone of Rilly. This oscillation in the Paris-basin is perhaps represented in Belgium by the so-called "système Heersien," which is at the bottom a purely marine formation, but has remains of land-plants at the top. Then came a new oscillation, and now England also was partially submerged. Here was deposited the marine Thanet Sand, and upon this the Woolwich and Reading Series (=Plastic Clay), the latter partly a brackish and freshwater formation, and which shows that the shore-line had again retreated. In Belgium the "système Landenien" was formed during this oscillation—below purely marine, above brackish. In the Paris-basin there was formed the marine sand of Bracheux, which was followed by a freshwater formation with lignite (the Lignites de Soissonnais). Then followed a new depression, and again an upheaval. This has left no traces in the Paris-basin; but in England the London Clay was formed, and in Belgium the "système Yprésien." The London Clay commences with a shore-formation of shingle or gravel (Oldhaven Beds), and the upper part of the stage shows that the sea again became shallower, in consequence of a new elevation of the land*. The "système Yprésien" in Belgium is divided into two substages:—the older, a clay with Foraminifera; the younger sandy, with numerous fossils, and therefore probably indicating a shallower sea. A new submergence formed, in Belgium, the marine "système Panisélien" (sand), and in the Paris-basin the marine sand of Cuise. With this the Lower Eocene closes. It has therefore, in all probability, 6 oscillations.

The Middle Eocene is represented in France chiefly by the "Calcaire grossier." In this stage there are 5-6 substages, and in several places breaks in the series of deposits. The Middle Eocene is on the whole marine, but with intercalated freshwater beds, and it probably also represents 6 oscillations. In Transylvania it commences (according to Koch in *Földtani Közöny*, 1883, pp. 118 *et seqq.*) with alternations of clay and marl, upon which follow alternations of gypsum and marl ("lower gypsum horizon," 1st oscillation). Above it, marine

* This stage, as was shown above, contains at least 11 alternations, and therefore probably corresponds with at least two arcs of the curve.

deposits, the *Perforata-beds*:—from below upwards—(α) an oyster-bed, (β) argillaceous marl, (γ) calcareous marl (“lower striata-horizon”), (δ) a shell-bed (“lower perforata-horizon”), (ϵ) clay (“upper striata horizon,” second oscillation?), (ζ) clay with a few hard marly beds and the same fossils as in β , (η) another oyster-bed, (θ) clay with oysters, (ι) calcareous marl (“upper perforata horizon,” third oscillation?); above this the *Ostrea-clay*, a thick clay with oysters and marly beds, and with a sandy calcareous bed in the middle (fourth oscillation). Over this again the *Lower Coarse limestone*, generally in two thick beds (fifth oscillation), covered by a thick bed of clay varied with layers of sand, probably a freshwater formation, and covered by freshwater limestone. Finally, the last (6th) oscillation, the *Upper Gypsum horizon*, gypsum alternating with clay; and above it coarse limestone alternating with gypsum; in other places clay with Foraminifera, marine:—the *Upper Coarse limestone*. I have cited all these details in order to show that these beds, which are all contemporaneous with the “Calcaire grossier” of Paris, seem to indicate six oscillations.

Above the “Calcaire grossier” the Upper Eocene commences with the continuous series of the Paris basin, which has already been described.

The Lower and Middle Eocene therefore appear to include 12 oscillations, six of which pertain to each of the two divisions of the formation. By this the first cycle of the curve is filled up; so that the beginning of the cycle will about fall upon the boundary between Cretaceous and Eocene. In the Paris-basin the Middle Eocene has 25 alternations of strata, and perhaps one or two breaks. Six oscillations about correspond to 25–30 precessional periods.

At the commencement of the cycles the mean value of the eccentricity is low; it rises in the middle of the cycle, and sinks again towards the conclusion. The position of the shore-lines must also depend upon the mean value of the eccentricity. But as it increases very slowly through very long periods, it will be very long before its action is to be seen on the solid earth. The middle of the cycles ought thus to correspond to the overflows of the sea, the beginning and close to the periods of denudation which separate the formations. Breaks in the series of beds may therefore be expected under high latitudes, especially at the limits between the cycles.

The boundary between Cretaceous and Eocene is indicated by what Suess (*Antlitz der Erde*, ii. 7ter Abschn. p. 376) calls a negative phase: the sea had retreated in higher latitudes.

During the Eocene it rose again, and the Eocene sea had a great extension ; we find its formations even in the heart of Upper Asia. The limit between the Eocene and Oligocene is again distinguished by a negative phase. In the latter part of the Oligocene period, and still more during the Miocene, the sea again rose ; between the Miocene and Pliocene it retreated far, and at the beginning of the Quaternary epoch it rose again. Similar great oscillations are also to be traced in North America and in Patagonia. But marine Miocene deposits are wanting in the last-mentioned locality, where the Miocene freshwater beds are associated with great quantities of volcanic products.

At the commencement of the Tertiary period, when the sea had retreated far under high latitudes, the climate of Europe was temperate rather than tropical (see Saporta, *Le Monde des Plantes avant l'apparition de l'homme*, 1879). According as the sea rose, and the Eocene overflow advanced, the climate became warmer ; and at the close of the Eocene period the climate of Southern Europe was hot and dry. The abundant Tertiary flora of the Arctic lands is (according to Saporta and Gardner) rather Eocene than Miocene (as Heer supposed). At the boundary between Eocene and Oligocene the sea retreated, and the Arctic Tertiary flora began to migrate into Europe, supplanting the more southern plants. Then came the Miocene overflow, and with it a rich tropical or sub-tropical flora. But in proportion as the Miocene sea retreated, the European flora also, little by little, lost in richness and beauty, and the tropical elements became more and more rare. During the Pliocene epoch the sea retreated still further, and the climate became colder and colder until the Glacial period came in. But the last Quaternary overflow has again, after several oscillations, caused the ice to retreat, and our climate has again become temperate. There is thus clearly a relation of dependency between the climate and geographical conditions. Great seas under high latitudes produce warm climates and *vice versâ*.

Now, we have seen that these great geographical changes were in all probability a consequence of the rising and sinking of the mean value of the eccentricity ; and we must therefore believe that these great changes of the climate had a cosmical origin, and occurred at the same time over the whole earth. We still know too little of the geology of tropical countries ; but there is ground for the belief that here also great changes have taken place in the distribution of land and sea, and that these changes must also have had an influence upon the climate of the warm countries.

It is, further, probable that the force of vulcanicity stands in relation to the changes in the eccentricity. Each of the great geological formations, from the Pre-Cambrian itself, has had its volcanoes (see A. Geikie, 'Textbook,' pp. 259-260); and we have already seen that the same author states that there have been periods in the earth's history when vulcanicity was much more powerful and widely distributed than at other times. We have seen how the upheaval of the land was accompanied by volcanic outbursts; and as regards the Tertiary period, at any rate, it appears that the great overflows of the sea were followed by periods during which the solid ground began to rise during violent and wide-spread volcanic eruptions.

For easy reference we will finally enumerate all the arcs in the curve, and name the geological stages supposed to correspond to them. To some extent we adopt the names given by Charles Mayer Eymar*.

LOWER TERTIARY; EOCENE.

Cycle I. in the curve.

LOWER EOCENE. Arcs 1-6.

From 3,250,000 years to 2,720,000 years before the present time.

Arc 1.	Etage Montien?	
2.	" Heersien.	
3.	" Suesonien.	
4.	" Yprésien inférieur?	} Londinien.
5.	" Yprésien supérieur?	
6.	" Panisélien.	

MIDDLE EOCENE.

From 2,720,000 to 2,150,000 years before the present time.

Arcs 7-12. Etage Parisien, with 6 oscillations.

UPPER EOCENE.

From 2,150,000 to 1,810,000 years before the present time.

Arcs 13-16. Etage Bartonien, with 4 oscillations.

* See his valuable *Classification des Terrains Tertiaires* (Zurich, 1884). He divides his stages into two substages—one with "mers amples," and one with "mers basses." Some of his stages, however, represent several oscillations. He thinks that the precession of the equinoxes is the cause of the changes in the level of the sea. The whole of the Tertiary and Quaternary periods must, according to him, have had a duration of only a little over 300,000 years. He founds his views upon Schmick's untenable hypothesis of the dependence of the sea-level upon the precessions.

UPPER TERTIARY. Cycle II.

OLIGOCENE.

From 1,810,000 to 1,160,000 years before the present time.

Arcs 1'-4'. Etage Ligurien, with 4 oscillations.
 5'-7'. „ Tongrien, with 5 oscillations.

MIOCENE.

From 1,160,000 to 700,000 years before the present time.

Arc 8'. Etage Aquitanien ?
 9'. „ Langhien.
 10'. „ Helvétien.
 11'. „ Tortonien.
 12'. „ Messinien.

PLIOCENE.

From 700,000 to 350,000 years before the present time.

Arc 13'. Etage Matérin.
 14'. „ Plaisancien.
 15'. „ Astien.
 16'. „ Arnusien.

QUATERNARY. Cycle III.

From 350,000 years ago, to the present time.

Arcs 1''-3''. Etage Saharien, with 3 oscillations.

The limits between the cycles of the curve are not drawn arbitrarily. The beginning and the close of the first two cycles are distinguished by their unusually low eccentricity. The last arc in one cycle and the first in the following one have, together, a duration of about 150,000 years; and in all this time the eccentricity was very low. In these two cycles, likewise, the highest mean eccentricity occurs in the middle of the cycle.

The Eocene period appears to have had 16 oscillations, and should correspond to the first cycle; the Oligocene, Miocene, and Pliocene have likewise together 16 oscillations, and correspond to the second cycle. The Lower Eocene corresponds to arcs 1-6, the Middle Eocene to 7-12, and the Upper Eocene to 13-16. In the same way the Oligocene corresponds to arcs 1'-7', the Miocene to 8'-12', and the Pliocene to 13'-16'. There is thus a certain analogy between the older and the younger Tertiary periods. We have here 6 divisions,

which nearly correspond to each other in the following manner :—

Lower Eocene to the Oligocene : the former with 6, the latter with 7 oscillations.

Middle Eocene to the Miocene : the former with 6, the latter with 5 oscillations.

Upper Eocene to the Pliocene : both with 4 oscillations.

The great overflows of the sea occur in the middle of the cycles, in the Middle Eocene, the Upper Oligocene, and the Miocene. In the middle of the cycles the mean value of the eccentricity was greatest. At the commencement and the last part of the cycles, when the mean value of the eccentricity was small, the sea retreated far, as between the Cretaceous and the Eocene, and in the Upper Eocene and Pliocene. The notion therefore presents itself with great probability that there is a connexion between the cycles in the curve representing the eccentricity of the earth's orbit and what is called a geological epoch, or what has also been called a "cycle" or "circle of deposition." The two Tertiary cycles are as it were great stages, each composed of 16 smaller ones. Just as each of these 16 represents a small oscillation of the sea, so does each cycle represent a great oscillation ; but this great oscillation has been accomplished by means of the 16 small ones. In the same way the mean value of the eccentricity rises and falls in each cycle with 16 oscillations ; it is low at the commencement of the cycle, attains its greatest value in the middle of the cycle, and falls again towards the close. These agreements between the cycles of the curve and the formations, between the arcs of the curve and the stages, and between the number of the arcs' precessions and the alternations of the strata in the stages wherever these could be checked, appear to me to be so striking as to exclude the notion of an accidental coincidence, and distinctly point to a causal relation.

If we would test the correctness of our hypotheses by means of the older formations, the following points must be borne in mind :—After investigating the laws of the variations of eccentricity, Geelmuyden told me that it is probable that a cycle of about 1,500,000 years must appear in the curve, but that without more extended investigation we cannot conclude that this will continue unchanged for unlimited periods. Even in the calculated curve the Cycle III. is distinguished from the other two by a much lower eccentricity in the arcs 4''–9''.

If the polar compression in old times was greater, then the

precessional period was also shorter. According to Geelmuyden it would be very nearly proportional to the square of the time of rotation. For example, to a rotation-time of 16 hours corresponds a (synodic) precessional period of 10,000 years, consequently only half the present period. The shorter the period the less marked (other things being equal) must the climatic period be, and the more indistinct the alternation of the strata.

Further, it must be remembered, that in Palæozoic and Mesozoic times the moon was probably much nearer. In that case the lunar tide was much stronger, and stronger in proportion to the solar tide than at present. The day was shorter, and the stronger tidal wave acted more frequently. The shores were more rapidly destroyed. Deposition, no doubt, took place more rapidly. The sidereal day increased more quickly in length than at present. All these circumstances must have had an influence upon the form of the earth, upon the distribution of land and sea, upon the displacement of shore-lines, upon the changes of climate, upon the ocean-currents, upon the distribution of chemical and mechanical sediments and the alternations of strata, so that, without taking these and perhaps other circumstances into consideration, we cannot prove the applicability of the hypotheses to the Palæozoic and Mesozoic series.

In conclusion, I will briefly notice the chief points in my hypothesis.

The precession of the equinoxes and the periodical change in the eccentricity of the earth's orbit, are reflected in the series of strata and furnish the key to the calculation of the duration of geological epochs.

Precession causes winter and summer to be alternately longer and shorter. In the semi-period when the winter is longer than the summer, the difference between the inland and coast climate becomes more marked. The atmospheric currents become stronger. As a consequence of this the currents of the ocean increase in strength, and this again reacts on the climate. The periodical change of the climate caused by precession is not very considerable, but still great enough to leave its mark in the alternations of strata, and in the formation of shore-lines, terraces, series of moraines, &c. One alternation of strata corresponds to each precessional period.

The eccentricity of the earth's orbit is periodically variable. Its mean value rises and falls in periods of about $1\frac{1}{2}$ million years, with 16 oscillations. Such a rise and fall I call a

cycle, and each cycle, in the calculated curve, is composed of 16 arcs.

The tidal wave, which is the most important agent in altering the sidereal day, and which makes it longer, rises and falls to a certain extent with the eccentricity. It so predominates over the other forces which alter the length of the sidereal day, that the day steadily lengthens on the average more rapidly in the middle of the cycles when the mean value of the eccentricity is greatest, and more slowly at the boundaries between them, when it is least, and, as regards the individual arcs, with increasing rapidity during rising, and decreasing rapidity during falling eccentricity.

The interior of the earth is plastic in consequence of the great pressure. The surface or "crust," opposes the greatest resistance to change of form. But as the sidereal day lengthens and the equatorial parts of the earth increase in weight, a constantly increasing strain acts outwards towards higher latitudes, and this strain increases until the resistance is overcome. It must also be remembered that forces which are too small to effect any sudden alteration in a solid body, may, nevertheless, produce a change of form when they act for a long time.

Hence the lengthening of the sidereal day does not act only upon the sea, but also upon the form of the solid earth. The earth constantly approaches more and more to the spherical form; but the solid earth, in its movements, lags behind the sea, which accommodates itself at once to the altered time of rotation.

As the motive power of these movements of the sea and the solid earth is periodically variable in accordance with the eccentricity of the orbit, these movements also take place periodically more rapidly and more slowly. And as the sea always adjusts itself to the forces before the solid earth, it is probable that the shore-lines oscillate up and down once for each rising and sinking of the eccentricity of the orbit. This applies both to the individual arcs of the curve and to the cycles. In such a cycle "the mean level of the sea" rises and falls once during 16 oscillations.

According to Darwin the sidereal day has become several hours longer. It is therefore probable that so great a strain must have accumulated in the mass of the earth, that a slight increase of the strain would suffice to effect changes of form at the weakest points. It is also probable that these partial changes in the solid body of the earth must occur especially during great eccentricities, or some time after them, when the motive power increases most rapidly.

The change in the tidal wave with the eccentricity is supposed to be sufficiently great to explain the displacement of shore-lines. A vertical displacement of the shore-line by a few metres is sufficient to produce, in the deeper basins, an alternation of many metres of thick marine and freshwater deposits. And as regards the changes of the solid mass of the earth, we must remember that the series of strata is not complete at any single place. In other words, the oscillations were not general to such an extent as to render them contemporaneous everywhere. It is only by partial changes of form, sometimes here, sometimes there, at those points which were weakest at each period, that the solid earth has approached the spherical form. To each arc of the curve, therefore, there corresponds only a partial, not a general, alteration of the form of the solid earth. And the oscillation of the shore-lines corresponding to the arcs, therefore, cannot be demonstrated everywhere, but only in the basins where the forces at the time exerted their action. Hence we can only obtain a complete profile by combining the beds of all the Tertiary basins. Nor were the changes of the solid earth everywhere equally great, but they were greatest at the most yielding parts of the surface, so that very considerable local upheavals may be consequent upon small changes in the length of the sidereal day. This applies to the individual oscillations; but even the great overflows of the sea of which one falls in each cycle need not be due to any very great rise in the level of the sea, for great plains may be flooded and drained by a comparatively small vertical displacement of the shore-line. But these great changes in the distribution of land and sea were undoubtedly great enough to cause considerable alterations of climate. Great seas in high latitudes render their climate mild, and *vice versâ*.

If now, keeping these principles in view, we compare the curve of the eccentricity with the geological series of strata, we find an agreement which indicates that the hypotheses are correct. The two cycles of the calculated curve correspond to two geological cycles. Each of these cycles has 16 arcs, which correspond to 16 smaller oscillations of the shore-lines, or 16 geological stages. In each of these stages there are as many alternations of strata as there are precessions in the corresponding arc. And the "mean sea-level" rises with the mean eccentricity in the middle of the cycles, and falls at the boundary between them, and hand in hand with the mean sea-level the temperature in the higher latitudes also rises and falls.

The theory here discussed agrees with Lyell's great

principle. Slow changes in the length of winter and summer and in the force of the tidal wave produce periodical changes of climate and displacements of shore-lines. The changes take place so slowly that the effects begin to appear distinctly only after the lapse of many thousands of years. There are two astronomical periods which are the cause of the great and fundamental changes of which geology bears testimony to us from long past days, and which will still continue, for millions of years, to effect similar changes in the geography of our globe, in its climate, and its animal and vegetable life.

POSTSCRIPT.

With reference to the profile of the Isle of Wight above cited (p. 497), I must make a few remarks. Although with some doubt, I have referred the Headon beds to the Upper Eocene. But the difference between the faunas of the Grès de Beauchamp and the Middle Headon is far too great for these beds to be synchronous.

The cause of the error is that I reckoned too many alternations of climate in the Isle of Wight beds. In these fluvio-marine deposits there is by no means the same regularity as in beds which are formed in basins with less sedimentation. The river eroded its borders and shifted its bed, banks were formed and carried away, according as the direction of the stream varied and the channel changed. Hence lenticular intercalations were often formed in the beds, and as precipitous cliffs of the Isle of Wight break down, the minor details of the profiles change in appearance. But with all this irregularity there are certain beds which appear far more constantly, and which we can recognize in the different profiles even although their condition is somewhat altered. By the aid of these constant beds we find order in the variations, and it appears that the great features of the profiles are maintained unaltered; and it is these great features that we must follow when we wish to determine the number of climatic alternations. In the Paris-basin, where sedimentation was much less, chemically deposited beds play a much more prominent part. In the Isle of Wight the stages are of much greater thickness. The Oligocene deposits of the Isle of Wight are 156 metres in thickness, and more than three times as thick as the contemporaneous beds in the Paris-basin, which have a thickness of only 48 metres.

In the dry periods the deposition of clay and mud was much less, the water of the river was purer, and chemically formed

beds had time to be deposited. Instead of clay and marl, limestone, *Septaria*-beds, ironstone, &c., were formed. These beds were undoubtedly formed much more slowly than the sand-, clay-, and marl-deposits which alternate with them. They are analogous to the forest-beds in peat-mosses. Forest-beds often separate peat-deposits with different species of plants. This shows that the forest-beds indicate long dry periods, during which the formation of peat ceased, and the flora became changed * ; when the quantity of rain again increased and the formation of peat commenced anew, the forest-trees which grew around the mosses were changed, and the forest-beds thus make divisions between different substages or zones in the peat.

Among the beds deposited in water (whether fresh- or salt-water formations) it is chiefly the above-mentioned chemically-formed beds that are formed in dry periods. And just as in the peat-mosses forest-beds often separate peat-deposits with a different flora, so limestone- and *Septaria*-beds also frequently intervene between clay-, marl-, and sand-deposits with a more or less different fauna, so that these chemically-produced deposits often form boundaries between geological stages and substages. This is the case, for example, in the Fluvio-marine series of the Isle of Wight, the main features of which we shall now pass on to describe with the aid of Forbes's detailed and classical statements. We shall then see that we have fewer climatic changes than I previously supposed, and that the series of beds in the Isle of Wight coincides as admirably with the curve of eccentricities as the Parisian deposits, although somewhat later on in time than was hitherto supposed ; thus the agreement with the palæontological results becomes complete.

We begin from below, with the Upper Eocene *Barton Clay*. Judging from the fossils this is synchronous with the Grès de Beauchamp in the Paris-basin. It has 5 *Septaria*-beds, and corresponds to arc 14 of the curve, which has the same number of precessional periods. The Barton Clay is covered by the *Headon Sands* (previously referred to the Upper Bagshot), which have no alternations, and which were probably formed in a comparatively short time.

A great gap now follows in the series in the Isle of Wight. In the Paris-basin the freshwater Calcaire de St. Ouen was formed at this time. This is only 6-7 metres thick, but it has 10 alternations, which should represent 200,000 years according

* See "Theori om Indvandringen af Norges Flora under vekslende regnfulde og tørre Tider," in *Nyt Mag. for Naturv.* xxi. 1876 (pp. 52, 53 of separate copies).

to my calculation. It might seem that this was a long time for the formation of a stage of so little thickness ; but while this stage was deposited the marine fauna was changed to such an extent that a great geological boundary has been drawn through this point, the boundary between the Eocene and Oligocene. The first marine Oligocene bed in the Isle of Wight (the Marine Headon) has a fauna of which only 30-50 per cent. of the species occur in the Barton Beds. The 6-7 metres of the freshwater limestone in the Paris-basin probably represents more than half the time which elapsed between the formation of the Marine Barton and Headon.

Then the sea rose again, and the Oligocene period commenced. The oldest Oligocene stage in the Isle of Wight is the Lower Headon ; it is a fresh- and brackish-water formation showing one oscillation of the shore-line. I have given it 7-8 alternations. The stage contains five limestones, separated by deposits of sand and clay, and besides these, two horizons with ferruginous concretions. Reckoning these, it has 7 periods. Marine fossils (*Cytherea*, *Mytilus*) sometimes occur in the middle of the stage ; freshwater and brackish forms above and below. The Lower Headon thus represents one oscillation of the shore-line (or a little more) with 7 climatic changes.

The next stage or oscillation is the *Middle* and *Upper Headon*. These have together 6 alternations of strata, 4 limestones, and 2 beds with iron concretions separated by clays and sands. The Middle Headon is brackish at the base, but soon becomes a purely marine formation, with an abundant fossil fauna. The Upper Headon contains fresh- and brackish-water animals.

Above the Headon come the *Osborne Beds*, a nearly pure freshwater formation. It has 8-10 alternations:—2 *Septaria*-beds, 2 ironstone bands, and 6 horizons with concretions of argillaceous limestone, separated by clay, and marl. 10 alternations represent 2 oscillations and 2 arcs of the curve.

Over the Osborne comes the *Bembridge Stage*. The Bembridge beds consist of : first, a freshwater limestone, which has 3 well-marked alternations of compact limestone with clay and marl ; these 3 alternations recur in profiles from the most different localities ; over this the marine Bembridge Oyster-bed, and immediately above this a *Septaria*-bed, of which Forbes says that it is "very remarkable and constant." Above this come the Lower Bembridge Marls with brackish and freshwater animals, but without alternations ; upon this a *Septaria*-bed, "sometimes siliceous, sometimes

calcareous," which forms the boundary between the two sub-stages, the Lower and Upper Bembridge Marls. In these Upper Marls, which likewise contain brackish and freshwater shells and even lignites, I have assumed 4 climatic alternations:—there are two pyritous bands and a marly bed, and at the top, at the limit of the overlying Hamstead* stage, a bed with ferruginous concretions capped with marl. But the two pyritous bands and the first of the above-mentioned marls constitute no palæontological boundary, and are far from being so prominent as the Septaria-bed. I therefore regard it as the most probable assumption that the whole of the Bembridge Marls indicate only 3 alternations of climate, and thus for the whole stage we have 6 climatic periods.

Finally, we come to the *Hamstead* Beds*. These at the lowest part consist of brackish and freshwater marls, in which, besides a pyritiferous horizon of little importance, and which forms no palæontological horizon, we find indications of two dry periods. One of these, the so-called "White Band," a more or less hardened ferruginous bed rich in fossils, forms the boundary between the two sub-stages, the Lower and Middle Hamstead Marls; and higher up there is a bed of ironstone concretions, which nearly coincides with the limit between the sub-stages of the Middle and Upper Hamstead Marls. The uppermost part of the Hamstead Stage is formed by the marine *Corbula*-bed, in which there is a bed with *Septaria*. The stage therefore represents one oscillation with 3 climatic alternations; but it is not completely preserved, the top having been removed by denudation.

If we now sum up the above statements, we obtain the following numbers of oscillations of shore-lines and climatic alternations:—

Barton, 1 oscillation, with 5 climatic alternations.

Headon Hill Sand, without alternations.

Break in the series.

Lower Headon, 1 oscillation (or a little more), 7 alternations.

Middle and Upper Headon, 1 oscillation, with 6 alternations.

Osborne, with 8–10 alternations, corresponding to 2 oscillations.

Bembridge, 1 oscillation, with 6 alternations.

Hamstead, 1 (incomplete) oscillation, with 3 alternations.

Besides the Eocene Barton there are 3 well-marked marine

* The name is also often written "Hempstead," but this is incorrect.

Oligocene horizons in this series :—the Middle Headon, Bembridge Oyster-bed, and Hamstead Corbula-beds. The Middle Headon is regarded by palæontologists as synchronous with the marine gypsum in the Paris-basin. I have fitted the Paris beds, so that the marine gypsum coincides with the arc 3', and the Fontainebleau Sands with the arc 7'. If we now arrange the equivalent beds in the Isle of Wight in the same arcs, we see that the Isle of Wight profile fits perfectly into the curve of eccentricity, as follows :—

Lower Headon to the arc 2' and perhaps the last part of 1', with 7 alternations and 7 precessions.

Middle and Upper Headon, with 5 alternations, to the arc 3', with 5 precessions.

Osborne, with 10 alternations, to the arcs 4' and 5', with 10 precessions.

Bembridge, with 6 oscillations, to the arc 6', with 5 or 6 precessions.

Hamstead, with 3 alternations, to the first part of arc 7', with 3 precessions.

It thus appears that the 3 marine horizons coincide with the 3 highest eccentricities, the summits of the arcs 3', 6', and 7', while the lower arcs and parts of arcs correspond to brackish and freshwater beds. The most unmixed freshwater formation, the Osborne, coincides with the two lowest arcs, 4' and 5'.

For the sake of comparison, we will again carefully go through the profile of the Paris basin, and compare this with Stockwell's curve, commencing from the bottom. The beds are numbered in the same way as in the original description of Dollfus and Vasseur (*Bull. Soc. Géol. Fr. sér. 3, tom. vi. 1878, pp. 243, et seq.*).

Sables de Beauchamp et Mortefontaine &c., beds 89–111.—Arc 14 and first half of 15. In this series we have, first 5 marine sandstones alternating with sand ; then a limestone and a calcareous marl, with intercalated sand and marl. Thus in all 6 or 7 alternations.

Calcaire de St. Ouen, beds 112–142.—A freshwater formation which is divided by a marine deposit (128) into two subdivisions. In the lower part (from the summit of arc 15 to the summit of arc 16) there are 4 horizons of hard limestone and siliceous limestone with intercalated marls. Then comes the marine bed (at the summit of 16). It must be remarked that the corresponding arc in Leverrier's curve reaches higher up. In the upper division of freshwater limestones we have 6 alternations of hard limestone and

siliceous limestone with marl and clay. This division therefore finishes a little to the left of the summit of arc 2'.

Sables de Monceaux, beds 143-145. Marine sand with 3 *Septaria* layers.—The rest of arc 2'.

Marnes à Pholadomya, beds 146-154. Marine, with 2 alternations of siliceous limestone and marl.—The first part of arc 3'.

Gypsum No. 3, beds 155-158. Marine marl and gypsum, 1 alternation, and

Marne à Lucina, bed 159.—The rest of arc 3'.

(The beds 146-159 thus have together 3 alternations and correspond to the arc 3'.)

Gypsum No. 2, beds 160-196, arc 4'.—Marine, at any rate for a great part. But it must be remarked that no fossils have been cited from the last part of this series. Gypsum alternating with marls about 5 times. The most important gypsiferous horizons are the beds 161, 171-176, 178-188, 191 and 194.

Gypsum No. 1, bed 197, 8 metres thick, with freshwater animals. 1 alternation.—Between arcs 4' and 5'.

Marne bleue, beds 198-204, and *Marne blanche*, beds 205-209, freshwater marls alternating with marly limestones and ferruginous marls about 4 or 5 times.—Arc 5' and the first third of arc 6'.

Marne verte, beds 210-217, a brackish-water formation with 2 alternations of clay with marl and siliceous limestone.—The upper part of arc 6'.

Calcaire de Brie, beds 218-220, a freshwater limestone. Perhaps we have here indications of several climatic alternations, for limestones occur alternating with marl 3 or 4 times, though certainly in very thin beds.—Its place is in the hollow between arcs 6' and 7'.

Marne et Mollasse Marine, beds 221-231. Clay alternating with marly limestone and sandstone 3 or 4 times.—The upper part of arc 7'.

Sables de Fontenaye, bed 232. Marine sand with a few layers of clay, but without marked alternations.—The latter part of arc 7'.

Calcaire de Beauce (p. p.).—Freshwater, between arcs 7' and 8'.

From this we get a complete agreement with the palæontological results, as shown by the following comparison of the equivalent formations in both basins :—

PARIS.	ISLE OF WIGHT.
Grès de Beauchamp, &c.	Barton Clay. Headon Hill Sand.
Calcaire de St. Ouen.	Wanting.
Sables de Monceaux.	Lower Headon.
Marne à Pholadomya, Gypse	Middle and Upper Headon.
No. 3, Marne à Lucina.	
Gypse No. 2-1. Marne bleue.	Osborne.
Marne blanche.	Bembridge Limestone.
Marne verte.	Bembridge Oyster-bed.
Calcaire de Brie.	{ Bembridge and
	Hamstead Marls.
Marne et Mollasse marine.	Hamstead Corbula-beds.

It will be seen that the number of alternations of strata is about the same in the synchronous formations in the Paris and Hampshire basins. This shows that this alternation of strata was due to a general cause, and that this cause is the precession of the equinoxes seems highly probable.

As, moreover, the curve of the eccentricity of the earth's orbit appears at the same time to be a curve of the variations of the sea-level, we may also conclude with probability that for one reason or another the sea rose and fell with the eccentricity.

LVIII. On the Achromatism of Interferences.

By M. MASCART*.

1. **I**N a communication to the Académie des Sciences, M. Cornu† investigated the phenomenon of the displacement of interference-fringes in white light by the interposition in the path of one of the rays of a refracting plate, and showed that the new position in which the central fringe appears depends not only on the optical retardation, but also on the dispersion of the interposed medium. He applied the name "*achromatic fringe*" to that corresponding to the same phase for the most important colours of the spectrum.

Prof. Stokes‡ had already pointed out this property, and had proved by experiment that observing the fringes through a prism of small angle produces an apparent displacement of the fringe from symmetry.

It should also be added that, since the first application of the method of fringe-displacement to the measurement of indices of refraction, Fresnel§ recognized that it was in-

* Translated from the *Comptes Rendus*, March 25, 1889, p. 591.

† *Comptes Rendus*, xciii. p. 809 (1881).

‡ Brit. Assoc. Rep. pt. 2, p. 20 (1850).

§ *Œuvres de Fresnel*, ii. p. 268.