FIG. 5.—Portion of the anterior groove as seen on the inside of the test, drawn from a wax squeeze of the internal cast; $\times 5$ diam. *ta.* interambulacra. *p.* pores for the passage of the podia or of the ampullæ from the podia. *f.p.* flooring-plates. The proximal end is uppermost in the drawing.

FIG. 6.—The internal cast of part of a subjective groove; the complement of Fig. 5. $\times 5$ diam. *p.* projecting scars of matrix that filled the podial pores.

FIG. 7.—The distal end of the left posterior groove, from a wax squeeze of the external impression; $\times 4$ diam. Lettering as in Fig. 5.

FIG. 8.—The central part of the abactinal surface, from a wax squeeze of the external cast (Pl. IX), slightly diagrammatised, since details are often obscure in the specimen; $\times 3$ diam. *per.* peripheral area. *fr.* frame. *cent.* central area, with its flexible plated membrane, raised in five interradially situate lobes. * position of posterior (anal) interradius. *P.I.A.* the meridian in which plates of the posterior interradius (i.e. posterior interambulacra) pass from the actinal to the abactinal surface and merge with the peripheral plates of the latter.

II.—BALA LAKE AND THE RIVER SYSTEM OF NORTH WALES.

By PHILIP LAKE, M.A., F.G.S.

Introduction.

THE evolution of rivers and the origin of lakes have recently attracted a considerable share of attention; and the principles which should guide us in tracing the development of a drainage system have been expounded by several authors, both in England and in America.

Little, however, has been written on the lakes and rivers of North Wales. In 1876 Ramsay,¹ who was one of the pioneers in questions of this kind, endeavoured to decipher the history of the Dee and of Bala Lake; and subsequently he performed a similar office for the Clwyd.² More recently Mr. Strahan and Mr. Morton³ have dealt with the latter river.

A few papers,⁴ also, have been written on the tarns or 'Llyniau' of Caernarvonshire; but with these we are not directly concerned.

In the following pages an attempt is made to explain the origin of Bala Lake, and to show how the river system of North Wales was established and was subsequently modified; but the formation of the Vale of Clwyd is barely touched in this investigation.

It is scarcely necessary to point out how deeply I am indebted to the writings of Mr. Marr, to which, in fact, whatever there may be of value in my labours is primarily due. For although the present drainage system of North Wales differs greatly from that of Cumberland and Westmoreland, yet in some respects the resemblance is so close that it is Mr. Marr's work in the Lake District which has enabled me to attempt an interpretation of the river

¹ Quart. Journ. Geol. Soc., vol. xxxii (1876), pp. 219–229. See also Mem. Geol. Surv., vol. iii (1881), 2nd ed., pp. 314–323.

² Mem. Geol. Surv., vol. iii (1881), 2nd ed., pp. 306–313.

³ G. H. Morton: Proc. Liverpool Geol. Soc., vol. viii (1897–98), pp. 32–65, 181–204. A. Strahan: GEOL. MAG., 1899, pp. 111–117.

⁴ W. W. Watts: Brit. Assoc. Reports, 1895, pp. 683, 684. W. A. Brend: GEOL. MAG., 1897, pp. 404–407. J. E. Marr & R. H. Adie: GEOL. MAG., 1898, pp. 51–61.

system of North Wales. Mr. Marr, however, finds no evidence of the differential movements which seem in Wales to have played so important a part in modifying the original drainage system.

My thanks are also due to Mr. A. L. Hall, of Caius College, Cambridge, and to Mr. J. B. Scrivenor, of Hertford College, Oxford, for invaluable assistance in sounding Bala Lake; and I am, besides, under obligation to Mr. Hall for help in other portions of the work.

FIG. 1.

Contours below 1,000 feet indicated by dotted lines.
Contours 1,000 feet and over indicated by continuous lines.

Topography of Bala Lake and of the valley in which it lies.

Bala Lake (see Fig. 1), the largest natural sheet of water in Wales, is nearly four miles long and about half a mile wide. It is oblong in shape and unusually regular, the two sides being remarkably straight and parallel, so that the width is nearly uniform throughout. The straightness of the sides is interrupted only by the peninsulas of Llafar, Llangower, and one or two smaller points; and all of these are mere tongues of alluvium. At each end there is a wide alluvial plain, and the lake owes its symmetry partly, but not entirely, to these alluvial deposits.

On February 19, 1885, the surface of the water was determined by the Ordnance Survey to be 529·9 feet above Ordnance Datum;¹

¹ Merionethshire (6 inches to 1 mile): Quarter-sheets xxii S.W., xxii N.W., and xxii N.E.

and on August 3, 1899, in a dry season, Mr. Hall and I found it to be 15.3 feet below B.M. 543.7 (about a mile south-west of Llangower), or 528.4 feet above O.D. The level of the water, therefore, seems to vary but little, and it may be taken as about 530 feet above the sea.

The depth of the lake is stated by Ramsay to be about 130 feet.¹ On August 1, 1899, Mr. Hall, Mr. Scrivenor, and myself took a series of soundings, and the greatest depth which we measured was 126 feet. This was at a point a little distance north of the Llangower peninsula.

Our soundings were taken along the three lines shown upon the map (Fig. 1). As they were made with 'water-cord,' which is liable to stretch, they are not exact, but (corrected by subsequent experiment) they are probably not more than a few feet out in any case. All the sections² (Fig. 2) showed that the sides of the lake

FIG. 2.—Sections of Bala Lake along the lines A-B and E-F in Fig. 1. Scale (horizontal and vertical), 3 inches = 1 mile.

slope inwards at an angle, which, indeed, is not very steep; but the bottom of the slope is well defined, and the central portion of each section is nearly flat. The maximum depth in the line A-B was 66 feet, in the line C-D 77 feet, and in the line E-F 126 feet. The floor of the lake, therefore, appears to slope from north-east to south-west, that is to say, in a direction opposite to the present flow of the water. It would, however, require a more extended series of observations to prove that this slope is continuous.

In the paper already mentioned,³ Ramsay assumes that there never could have been any other outlet for the water of the lake than the channel of the Dee; and because the Dee flows over rock *in situ* at a higher level than the bottom of the lake, he concludes that the lake must lie in a rock basin. In the light of Mr. Marr's recent researches on the tarns and lakes of Cumberland and

¹ Quart. Journ. Geol. Soc., vol. xxxii (1876), p. 219.

² Our positions were determined by compass bearings from the shore, and have no pretensions to precise accuracy. The section A-B and the south-eastern half of the section E-F are probably correct; but in the north-western half of the section E-F the angles of intersection were somewhat acute, and the positions of the soundings are therefore not so accurately fixed.

³ "On the Physical History of the Dee, Wales": Quart. Journ. Geol. Soc., vol. xxxii (1876), pp. 219-229. See also Mem. Geol. Surv., vol. iii (1881), 2nd ed., pp. 314-323.

Westmoreland,¹ it is impossible now to maintain this view without a closer examination of other possible outlets.

Now, although Bala Lake empties itself through the Dee, which flows in an easterly direction from its north-eastern end, this is not what the general topography of the district would lead us to expect. The lake does not lie in the continuation of the Vale of Edeyrnion (as the valley of the Dee between Llandderfel and Corwen is called); but it lies in a very distinct and well-defined valley which runs from the sea at Barmouth in a north-easterly direction to the town of Bala; and this valley is entirely shut off from the Vale of Edeyrnion by a ridge of hills, except for the narrow gorge through which the Dee now flows. This great valley is in the line of the Bala fault, and from Dolgelly to Bala its direction is S.W.—N.E., which is precisely that of the lake; while the general direction of the Dee for several miles after leaving the lake is nearly west to east.

It is true that the actual watershed crosses the valley at Pant-gwyn, and that on the one side the waters flow into Bala Lake and thence to the Dee, while on the other side they flow into Afon Wnion and finally into the estuary of the Mawddach. But the watershed forms no feature in the valley, and the slope which determines the direction of flow is so slight that it requires a very careful examination of the streams to discover the position of the water-parting. The floor of the valley in no place rises to a greater height than 774 feet above the sea, i.e. about 374 feet above the bottom of the lake. The depth of the valley near this point is entirely out of proportion to the size of the little rivulets which now flow in it.

Continuing the line of the valley in which Bala Lake lies, it leads us in a north-easterly direction, not along the course of the Dee, but into the valley which is now occupied by Nant Meloch and its tributary from Cors-y-Sarnau. This is a stream which flows from north-east to south-west, and which would enter the lake near Bala, were it not that before it reaches that point it is suddenly deflected almost at right angles, so as to join the Dee at Melin Meloch.

If the gorge near Llandderfel were blocked, this stream would flow into Bala Lake, and Bala Lake would empty itself into the Wnion; and we should have a continuous flow of water down what is now undoubtedly a continuous valley running from north-east to south-west.

From these topographical considerations alone, it appears probable that the drainage of the district originally flowed in this direction, and that the present outlet of the lake is of subsequent formation. In favour of this view it may be noted that at the foot of the lake there is an alluvial plain, which is even more extensive than that which is now being formed at its head; and also that the floor of the lake appears to slope from north-east to south-west.

¹ See, especially, "The Tarns of Lakeland": *Quart. Journ. Geol. Soc.*, vol. li (1895), pp. 35–48. "Additional Notes on the Tarns of Lakeland": *ibid.*, vol. lii (1896), pp. 12–16. "On the Lake Basins of Lakeland": *Proc. Geol. Assoc.*, vol. xiv (1896), pp. 273–286.

Is Bala Lake a rock-basin?

There are only three directions in which we can leave Bala Lake and travel towards the sea without crossing the contour-line of 1,000 feet.

The first of these is north-east, up the valley of Nant Meloch, and along the road to Corwen, where the greatest height to which we are compelled to rise is 891 feet, about $1\frac{1}{4}$ mile from Bethel Inn.

The second is east, along the course of the Dee; and this is necessarily a continuous descent.

The third is south-west, along the valley of the Bala fault, where we can reach the sea without ever rising higher than 774 feet.

Elsewhere the lake is completely shut in by the 1,000 foot contour-line, and there is no reason to suspect the existence of any former outlet.

I have not examined very closely the valley of Nant Meloch; but I believe that in this direction the rocky floor rises considerably above the level of the bottom of the lake. Even now, where the bottom of the valley is 600 or 700 feet above the sea, the valley is narrow and steep-sided, and it seems improbable that the solid floor lies two or three hundred feet below the present level. The valley, however, deserves a more careful examination than I have been able to give it.

If we follow the present course of the Dee from Bala Lake, we pass first over a wide alluvial plain until we near the ridge which crosses the line of the river at Bodweni, about $2\frac{1}{2}$ miles east of Bala. Here the Dee enters a narrow and rather steep-sided gorge, and is closely hemmed in by hills of solid rock; and a little farther on, the bed itself is formed of rock at a height of about 495 feet above the sea, or 95 feet above the bottom of the lake. So narrow is the valley at this point, and so close lie the exposures of solid rock, that there seems to be no room for any drift-filled gorge; and there can be but little doubt that in this direction at least, as Ramsay pointed out, the lake is rock-bound.

South-westerly, however, along the line of the Bala fault, it is impossible to prove that the solid floor of the valley is at any point higher than the bottom of the lake. Following upwards the course of the Dyfrdwy, we find that at Tal-y-bont the stream flows over rock *in situ* at a height of more than 600 feet. But the valley here is very wide, and for many hundred yards south-east of the stream there is nothing to be seen but drift. It is quite possible, therefore, that another channel may exist which is now concealed.

No more rock is exposed *in situ* in the bottom of the valley until we have passed the watershed and proceeded down the other slope to Drws-y-nant-isaf. A few hundred yards below the railway station the river runs in a little rocky gorge, the floor of which is also made of rock; and the height of this floor is about 460 feet above the sea, that is to say, about 60 feet above the bottom of the lake. But at this point, exactly, in fact, where it enters the gorge, the river has left the line of the Bala fault and has been deflected

to the right; while in the direct line there is a slight depression, which is certainly filled with drift, however deep or shallow that drift may be.

Here, again, it is impossible to assert that the solid floor of the valley is higher than the bottom of the lake. And as no more rock is seen *in situ* until we pass below the level of the lowest point of the lake, we are compelled to admit that in this direction there is no certain evidence that the lake is rock-bound.

So far, then, as this evidence goes, Bala Lake may have been formed in the same way as the lakes of Cumberland and Westmoreland. The sections show that, like them, it is a submerged river valley. Its general direction and the slope of its bed indicate that the valley of which it is a portion is the valley of the Bala fault. Originally, no doubt, the waters drained south-westward into the sea at Barmouth (or, perhaps, at Towyn). But the channel was subsequently blocked, and the drainage of the upper portion was forced to seek a fresh outlet.

I shall, however, give reasons for supposing that, although the old channel may have been choked by drift, the reversal of the drainage was due, at least in part, to earth-movements; and that it was these earth-movements which determined the position of the watershed.

Relation of the Faults to the Valley and to the Watershed.

That the valley to which, as we have seen, Bala Lake belongs, is in the line of a great fault, has long been known; and the fault is represented on the Survey maps as passing down the middle of the lake. It lies, I believe, more nearly along the south-eastern shore, and the opposite shore coincides with the line of a second fault, which, like the former, has its downthrow towards the lake. Thus the lake lies in the continuation of a trough, and its two sides coincide or nearly coincide with the two faults enclosing the trough.

South of Pant-gwyn the valley is very narrow. Its north-western side is formed of volcanic rocks, which are usually supposed to be of Arenig age, while the south-eastern side is formed of Middle Lingula beds containing *Lingulella Davisi*. But the floor of the valley is concealed by drift and alluvium, and there is nothing to indicate the exact position of the fault which undoubtedly exists, nor is there any evidence to show whether this fault is simple or compound.

At Pant-gwyn, however, the valley opens out; the faults are much more clearly seen, and here they form a complex system which we shall now proceed to examine. (Fig. 3.)

It is, perhaps, unnecessary to give in detail the evidence on which these faults are drawn. It will almost be sufficient to say that, in general, wherever the volcanic series exists, it is conspicuously visible, and it is an easy matter to trace its boundary.

The slates below the volcanic series are also well enough exposed, but it is different with the post-volcanic slates in the valley; and as many of the exposures of these beds are difficult to find, it may be well to enumerate them.

On the south-east side of the valley, these slates are visible close to the Bala fault at Cilgellan, and again between Cefn-gwyn and Cwm-onen. They, as well as all the other rocks, are well exposed in and near Afon Dwrnudo.¹ They occur also in the banks of a small stream about 300 yards below Bryn Amlwg; and again, close to the Bryn Amlwg patch of volcanics, in the streamlets near the transverse fault.

On the other side of the valley, the slates are found in the farm-yard of Pant-gwyn. They are well exposed in the triangular patch four or five hundred yards north-west of that farm; and in the Dyfrdwy they are seen to overlie the volcanic series, dipping 5° S. of E. (true) at an angle of 38°. They occur also in the quarry near Ty-mawr and in the bed of the river close to Tal-y-bont.

In the neighbourhood of Llwyn-gwern these slates are visible in several places, and the volcanic series dips beneath them. South-east of Llanuwchllyn also, in the valley of Afon Twrch, the slates and ashes are clearly shown, and the ashes dip beneath the slates; but the boundary is here more complex than is represented upon the map, being faulted by a series of little faults of which only one or two are indicated.

The north-to-south fault which lies east of Drws-y-nant-uchaf is plainly visible in the stream 300 yards above the farm, where it brings black slates (presumably Upper Lingula) on its eastern side into contact with Middle Lingula Flags (containing *Lingulella Davisi*) on its western side. The eastern is therefore the downthrow side, and as the hade is towards the west the fault is reversed. The crushing due to this fault is also seen in the little rivulet some 200 yards north-east of the farm.

The fault which is drawn between Moel Caws and Creigiau Llwyn-gwern nowhere, so far as is visible, brings beds of different character into contact with each other, and is inserted upon less evidence than the rest. But I venture to think that few who examine the remarkable little valley in which it lies will be disposed to deny the existence of this fault.

The evidence for the other faults is manifest upon the map, and need not here be recapitulated. In most cases the position and direction can be fixed with considerable accuracy, but seldom so precisely as to determine which of two intersecting faults displaces the other. It may be noted that the fault which crosses the Dwrnudo 600 yards above Llechwedd-fwyalchen is probably continued for a considerable distance in both directions.

One or two patches of intrusive rock exist besides that which is shown upon the map. Granophyre occurs on both sides of the Bala fault at several points north-east of Drws-y-nant-uchaf, but is too imperfectly exposed to be satisfactorily mapped. There are also some masses of intrusive rock on the left bank of the Dyfrdwy, near Rhyd-y-drain; but these have not yet been examined in detail.

¹ Afon Dwrnudo is the stream which flows past Llechwedd-fwyalchen.

FIG. 4.—Diagram of the Bala Faults.

In the accompanying diagram of the faults (Fig. 4), the downthrow side of each (when it is known) is shaded, and the bottom of the

valley is indicated by a heavy line. Some of the faults are continued, in their probable directions, into the area which is now concealed by drift and alluvium; and an additional fault (N) is inserted which is not shown upon the geological map. The existence of this is somewhat doubtful, but the foot of the hills is here so extraordinarily straight that I cannot help suspecting that it coincides with a line of fault.

A comparison of this diagram with the topographical map (Fig. 5) will show that the actual contour of the ground agrees very closely with the contour which would be produced by the faults, if it were determined by them alone. It is true that a few of the faults, such as that near Drws-y-nant-uchaf, have no effect upon the surface.

FIG. 5.—Sketch-map of the topography of the valley of the Bala Fault near the watershed.

But generally each fault is marked by a more or less sudden change of slope, and the ground on the downthrow side of the fault lies lower than that on the upthrow side. This is sometimes well shown even where the rock is similar in character on both sides of the fault. Attention may be drawn, for example, to the fault west of Pant-gwyn.

It will be observed that several of the most important faults run parallel to the general direction of the valley, some on one side and some on the other, and that in most cases the downthrow of these faults is towards the valley; the only exceptions are the faults D and E, which indeed are not parallel to the valley, but are nearly so, and are placed symmetrically with regard to it. In these two cases the downthrow is away from the valley.

There is also a series of transverse or oblique faults, and these throw down either towards Bala Lake or towards the bottom of the valley.

Except for a wide curve, convex towards the north-west, the whole of the valley north of Pant-gwyn is enclosed between the outermost of the longitudinal faults—the Bala fault (A) on the one hand and the fault B on the other; and both of these throw down towards the centre of the valley. Moreover, the fault B, if produced, coincides precisely (as is very clearly seen in the field from a position near its southern end) with the north-west shore of Bala Lake. The Bala fault is dislocated at several points, but if the northernmost portion be continued in a straight line it will be found to lie nearly parallel to the south-east shore of the lake, but some distance within the water's edge.

Without any aid from denudation these faults would, of themselves alone, form a valley very similar to that which now exists; and if we take into account the oblique faults F, M,¹ and L and the doubtful fault N, even the convex bend of the valley out of its regular course may be explained as directly due to the faulting.

The general shape of the valley is, in fact, not unlike that which the faults themselves might be expected to produce. But it must be allowed that the form produced by the faults has been considerably modified by subsequent denudation; and it is difficult, if not impossible, to determine how far the present configuration is to be attributed to the direct effect of the faults and how far to their influence in guiding denudation. The relation of the faults to the configuration of the ground is, however, so close that they must, either directly or indirectly, be the cause of that configuration.

Even if we assume that the valley has been actually formed by the faults themselves, it is by no means necessary to suppose that it is so old as, for example, the Bala fault. A comparatively small movement along this fault, perhaps long after its original formation, would be sufficient to account for all the phenomena so far as it is concerned.

The transverse fault at Pant-gwyn is particularly interesting. Its downthrow is towards the north-east, that is, towards Bala Lake; and it appears to form the southern end of the trough produced by the longitudinal faults. On the north-west bank of the valley the ground is much higher on the upthrow side of the fault than on the downthrow side. But this is not the case on the south-east bank. Yet here, near the bottom of the valley, drift on the downthrow

¹ It should be noted that there is no evidence to show which is the downthrow side of either M or N.

side is in contact with solid rock on the upthrow side, and it is possible that the fault produces its full effect upon the solid floor. However this may be, the fault coincides very closely with the watershed in the valley. No water crosses it except a single streamlet, and this rises only a yard or two away.

Whatever the reason may be, therefore, we may safely say that the valley north of Pant-gwyn lies in the trough between two faults, and that this trough is closed at its southern end by a transverse fault, which coincides with the watershed crossing the valley; and further, that many of the other faults apparently produce on the surface of the ground an effect which is similar in kind, if not in degree, to that which they produce on the strata themselves.

That these coincidences are accidental is, to say the least, improbable; and a simple explanation appears to be that the valley was blocked out, so to speak, by the faults themselves, and that the form so produced has been somewhat modified by subsequent denudation.

In advancing this view I am aware that it attributes to the faults a more direct influence upon the topography than many geologists will be disposed to allow. But although most valleys may have been carved out by rivers, it is impossible to deny that some have been formed by faults.

It may be urged that since the formation of the faults there must have been a vast amount of denudation which would obliterate their effect upon the surface. But where erosion exceeds deposition, the tendency of subaerial denudation is to accentuate rather than to obliterate inequalities. Moreover, the evidence of the age of the faults is extremely slight, and there is nothing to show that no movement has taken place along them in comparatively recent times.¹ I shall show subsequently that, however the valley may have been formed, it was probably not in existence when the drainage system of the district was first established.

(To be concluded in our next Number.)

III.—PLANT-STEMS IN THE GUTTANNEN GNEISS.

By Professor T. G. BONNEY, D.Sc., LL.D., F.R.S.

AN important paper² on the reputed occurrence of fossil plant-stems in gneiss of Carboniferous age at Guttannen, Switzerland, by Messrs. E. v. Fellenberg & C. Schmidt, for a copy of which I am indebted to the courtesy of the authors, closes, if their view be adopted, a comedy of errors. On this account a brief outline of the story may be of service; for it reduces this supposed relic of Palæozoic forests to a *lusus naturæ*, and, in any case, once more illustrates the truth of the saying, "we are all fallible mortals."

¹ It may be noted that Mr. C. Davison's researches on earthquakes in Great Britain seem to indicate that even at the present time slips occasionally take place along faults which are, in their origin, of very ancient date.

² E. v. Fellenberg & C. Schmidt, "Neuere Untersuchungen über den sogen. Stamm im Gneisse von Guttannen": Separat-Abdruck aus den Mitt. der Naturforsch. Gesell. in Bern, Jahrgang 1898.