found in both. The opening into the larger cave was originally a mere crevice four to six inches wide, requiring many tons of cliff to be removed ere we could effect an entrance. Even then, for some 20 feet, it was but a natural "tunnel," too small, in most parts, either to creep or turn in. No large animals could possibly have entered *there;* so that the presence of their bones beyond, more or less imbedded in stalagmite, proved that some other entrance, not yet detected, must once have existed.

From one of the ramifications, we extracted almost the entire skeleton of a Wolf. Its bones were intermingled with those of a Roebuck, on which it had probably been feeding. The Wolf's skull was a little over three-fourths the size of a full-grown male Arctic specimen. A single canine tooth, belonging to a much larger Wolf, was found at no great distance, and near to the place where the Lynx bones were imbedded.

I see no reason to doubt that the Lynx may have roamed throughout our forests and mountain glens, along with the Wolf and the Bear, till a comparatively recent period, just as it still does in Norway; albeit its origin in Great Britain probably dated from the time when these islands were united to the Continent. JAMES BACKHOUSE.]

EXPLANATION OF PLATES XI. AND XII.

Plate XI. Figs. 1*a*, 1*b*, and 1*c*. Three views of the humerus of the Lynx (*Felis borealis*) from Teesdale.

1*a*. Front view.

1*b*. Outer side-view.

1*c*. Back view.

Plate XII. View of the interior of the cave where the bones of the Lynx and the skeleton of the Wolf were found. From a sketch made on the spot by Mr. Backhouse.

IV.—INFLUENCE OF EARTH MOVEMENTS ON THE GEOLOGICAL STRUCTURE OF THE BRITISH ISLES.[1]

By J. J. HARRIS TEALL, M.A., F.G.S.,
Late Fellow of St. John's College, Cambridge.

IN the formation of a country three more or less distinct geological operations are concerned:—*a*. Rock formation; *b*. Earth movements; *c*. Denudation. In the case of our own country, to which the present paper more especially refers, these three operations have succeeded each other again and again; so that a very complicated structure is the result. The earth movements and denudations of one period have been interfered with by those of subsequent periods, and any attempt to trace the exact steps by which the evolution of the British Isles has been effected is therefore attended with very great difficulty. Earth movements may be divided into three groups, as follows:—

a. Slow movements of elevation and depression analogous to those now going on in the Scandinavian peninsula.

b. Movements which result in the displacement of rocks along planes usually inclined at a high angle to the horizontal surface; these are more familiarly known as faults.

[1] This article contains the substance of a paper read before the Literary and Philosophical Society, Nottingham.

c. Movements due to lateral pressure which produce a folding or contortion of the stratified rocks along certain definite lines.

It must be understood that this classification is proposed merely for the purpose of aiding description, and not because I believe that these three classes of movements are radically distinct. I have little doubt that they are very closely connected and that the nature of this connexion will at some future time be fully established. In the present communication I propose to refer to those movements of the third class which have affected the stratified rocks of Great Britain and Ireland, to discuss their geological age, and to describe the effects they have produced on the actual structure of our country. I have nothing new in the shape of facts to offer; my object is merely to collect together the knowledge which various workers in the field of geology have accumulated with reference to this interesting topic, and in conclusion to suggest an extension of what may be fairly called the American theory of the origin of mountains to the subject in question.

The earliest earth movement of which we have direct evidence is one which affected the Pre-Cambrian rocks of the N.W. of Scotland and S.W. of Wales. In the former locality these rocks consist of highly crystalline gneiss, with occasional beds of limestone and ironstone, evidently the metamorphosed representatives of marine formations. They are now arranged in strata dipping towards the N.E. and S.W., in such a way as to show that subsequent to their formation, and probably during the time when the metamorphism was produced, they were subjected to forces which contorted the rocks along axes running N.W. and S.E. In the S.W. of Wales, in Pembrokeshire, rocks similarly related to the Cambrian occur. These have been divided by Dr. Hicks into two groups,[1] to the earlier of which he gives the name Dimetian, and to the later Pebidean.

The lower, or Dimetian series consists of compact quartziferous beds and altered shales and limestones, which strike in a N.W. and S.E. direction, thus showing, in all probability, that they were affected by the same earth movements as the homotaxial beds of the N.W. of Scotland and the Hebrides. The upper or Pebidean series consists of altered conglomerates and shales, the pebbles of the conglomerate having been derived from the earlier formation. These beds are entirely unconformable to the Dimetian series, and strike in a direction W.S.W. and E.N.E. The same old Pre-Cambrian rocks as those to which Dr. Hicks has given the term Dimetian in all probability again come to the surface in the Malvern Hills, where they consist of regularly stratified gneiss, having the usual strike.

If the newer formations which cover the country at all those points intermediate between the localities above mentioned could be removed, we should find in all probability that these early Pre-Cambrian rocks are very widely distributed, even at present. During the Cambrian period they formed the superficial crust of the earth,

[1] Dr. Hicks now divides the Pre-Cambrian rocks into three groups, Dimetian, Arvonian, and Pebidean.

and on them, as on a floor, the Cambrian rocks were formed. Dr. Hicks believes that a large continent, formed principally of these rocks, existed very much in the position now occupied by Europe, and that the Cambrian deposits were formed on the borders of this continent as it gradually became submerged. The submergence, he supposes, commenced in the West, where the Cambrian rocks are thickest, and gradually extended eastwards. If, however, we hold with Dr. Hicks that these Pre-Cambrian rocks were originally distributed over the whole of the British Isles, and formed the floor on which the later deposits were formed, we must not suppose that at present they would be found at all points, if the later deposits were removed. Owing to the depression which accompanied the deposition of many of the later deposits, such as the Cambrian, the early Pre-Cambrian floor must have been buried sufficiently deep in the earth's crust to have been completely fused.

We conclude, then, from the arrangement of these early rocks, that the first earth movements of which we have direct evidence took place along axes running N.W. and S.E., and that they were probably due to lateral pressure acting from N.E. and S.W.

Passing over, for the present, the evidence of additional Pre-Cambrian earth movements furnished by the Pebidean rocks of Hicks, we come to the Cambrian rocks proper. And here it must be understood that I use the term Cambrian to include the entire series of deposits intervening between the Longmynd, Harlech and Llanberis group, and the Llandovery beds. Whatever may be our views as to the propriety of abolishing the term Lower Silurian from geological nomenclature, there cannot be a shadow of a doubt that for our present purpose the rocks indicated above must be treated as forming one great natural group. They have all been affected by the same earth movements.

The total maximum thickness of the Cambrian series, according to Woodward, is about 30,000 ft. in Wales, and 20,000 ft. in the Lake District. In the Highlands of Scotland[1] it is quite impossible to form an estimate of the total thickness, on account of the difficulty of determining particular horizons. Now since the basement beds of the Cambrian consist of deposits that were certainly formed in shallow water, if not in inland seas or lakes, we must suppose that during the Cambrian period there was depression at least to the extent of the thickness of the deposit, that is, to the extent of 30,000 ft. To this depth in the crust of the earth must the original surface, composed as we have seen of Dimetian and Pebidean formations, have been carried.

The Cambrian rocks are now found to be arranged in anticlinal and synclinal folds, running N.E. and S.W., showing that at the close of the Cambrian period, and, as we shall see in a moment or two, before the Silurian period, they must have been puckered up by lateral pressure acting from the N.W. and S.E. over the whole of our area.

This anticlinal and synclinal arrangement of rocks is well seen on

[1] Are these rocks Cambrian or Pre-Cambrian?

a large scale in North Wales, where, if we leave out of account certain smaller undulations, and neglect the effect of faults, we may describe the rocks as arranged in two great synclinal folds, separated by an anticlinal fold. Thus, beginning in the N.W., we have first of all the great synclinal roll, along the axis of which lie the mountains Moel Hebog, Snowdon, and Glyder Fawr; then, following this, the Merionethshire anticlinal (see Memoirs of the Geological Survey, vol. iii.); and following this again the Berwyn synclinal. It is worthy of note that the anticlinal axis of Merionethshire is not horizontal, but slightly inclined to the N.E., so that the mountains of Cader Idris, the Arans, and the Arenigs, which are all formed by the outcrop of the harder igneous rocks of Llandeilo age, do not trend in a N.E. and S.W. direction, but bend round towards the N., following of course the strike of the beds. The same igneous beds about Ffestiniog run in a N.E. and S.W. direction. The effect of the earth movements here referred to may be traced over the whole of the area now occupied by Cambrian formations, the strike of the beds in all districts varying little from a N.E. and S.W. direction. Where igneous rocks are intercalated with the sedimentary deposits, the prevalent strike may be observed at once by a glance at the geological map, as in N. Wales, S.W. Wales, and the S.E. of Ireland. In other districts, though not indicated by any feature on the maps, it may readily be detected in the field. There can be little doubt that the Cambrian strata were formed over all the area now occupied by the British Isles, and that the earth movements which have affected the Cambrian rocks extended also over the whole of the district. To these earth movements then we are indebted for the present physical structure, and, to a certain extent, though only indirectly, for the scenery also of our mountainous regions. With regard to the age of these disturbances, I have already stated that they took place before the Silurian period. This is borne out by the fact that in Wales the Silurian rocks rest unconformably on the Cambrian, and do not seem to have been affected by the movements which produced the anticlinal and synclinal folds so marked in the Cambrian regions. Cleavage, moreover, is for the most part absent in Silurian formations. There is, however, some little difficulty here, for the Denbighshire grits appear to have been affected by movements which have also affected the Cambrian, and in the Lake District a similar condition of things has been observed. In all probability these facts are to be explained by a second series of earth movements, of Post-Silurian date, which affected the already disturbed Cambrian rocks, and also the comparatively undisturbed Silurian rocks. One bit of evidence of great importance in determining the date of the earth movements we are considering, and the metamorphism which seems to have accompanied them in the region now occupied by the Highlands of Scotland and the North Western Highlands of Ireland, is to be found on the shores of Killery Harbour, and in the Eriff Valley on the borders of Counties Galway and Mayo (see Geology and Physical Geography of Ireland, by Prof. Hull). Here Silurian rocks of the Llandovery age rest

unconformably on the denuded edges of the old metamorphic rocks, and consist at the base of a conglomerate containing pebbles of the older Cambrian formation. If then, as is extremely probable, the N.W. and S.E. strike of the Cambrian rocks of all localities was produced by one series of earth movements, due probably to lateral pressure acting from the N.W. and S.E., then this observation at Killery Harbour serves to fix the date of these earth movements in every locality.

During the time which elapsed between the commencement of the Silurian and the close of the Carboniferous, the British Islands do not seem to have been subjected to any forces giving rise to anticlinal and synclinal folds on a large scale. Various earth movements must have taken place, but these seem to have been gradual movements of elevation and depression, rather than movements due to lateral pressure. During the deposition of the Silurian, Old Red Sandstone, Devonian and Carboniferous rocks, depression must have taken place. The depression, however, was not a continuous one, for in Scotland there are at least two distinct unconformabilities, one between the Middle and Lower Old Red Sandstone, the other between the Upper and Middle. In Herefordshire and Shropshire, and the adjoining counties, no unconformability has been detected in the Old Red Sandstone, though one is strongly suspected. In Ireland there is a marked unconformability between the Old Red Sandstone and Dingle beds, and in all probability another of less importance between these latter and the Silurian. In addition to the movements of elevation indicated by the unconformability, there must have been others, the only evidence for which is to be found in the change of character in successive deposits. Thus the Old Red Sandstone rocks, which succeed the Silurian conformably, were formed, in all probability, in a land-locked area, while the latter were certainly laid down in the open ocean. In order that a given spot may at one time be situated in the open ocean, and at another in a land-locked basin, it is necessary that elevation of some sort should take place in the adjoining area.

The movements of this period were not, however, of such a character as to influence in any marked way the physical structure of the country, and therefore, although they have an importance of their own, which it is impossible to overestimate, we may leave them without further notice.

The next great series of earth movements of the character we are more especially considering took place at the close of the Carboniferous period; like the previous earth movements of a similar character, they seem to have exerted an influence over the whole of the area occupied by Carboniferous formations. They may, however, be best studied in the district of Lancashire, Derbyshire, and Yorkshire, where facts may be observed which enable us to determine their geological ages. In the Q.J.G.S. vol. xxiv. p. 323, there is an able paper by Prof. Hull on the relative ages of the leading physical features and lines of elevation of the Carboniferous district of Lancashire and Yorkshire. In this paper

the author discusses the ages of two great series of earth movements which have affected the Carboniferous rocks. With regard to the first of these he points out that the Permian rocks, consisting of red sandstones and magnesian limestones, rest on the denuded edges of the Millstone-grit near the south-western termination of the Pendle Range; thus proving beyond a doubt that the disturbances to which the anticlinal and synclinal axes of the Pendle District are due took place before the Permian period. He further points out that even in the absence of such direct evidence as that which is furnished by the superposition of Permian rocks on Lower Carboniferous deposits, we could still infer with certainty the Pre-Permian date of the movements in question; for the uprising of Millstone-grit and Yoredale rocks on the northern side of the Yorkshire Coal-basin is undoubtedly due to an extension of the movements which produced the anticlinal and synclinal of the Lancashire District towards the east. The Permian rocks, however, consisting of red sandstones, marls, and magnesian limestones, have not been affected by these movements, for, as may be seen by a glance at the geological map, they rest unconformably on the edges of the Carboniferous rocks striking N. and S., whereas these latter strike nearly E. and W. There cannot then be a shadow of a doubt that the E. and W. axes of Lancashire belong to the period intervening between the Carboniferous and Permian. The geological map shows also that many other districts have been affected by movements along E. and W. axes; and, since parallelism is to a certain extent evidence of contemporaneity, many of these probably belong to the same period of disturbances. Thus in S. Wales we notice the E. and W. strike of the Carboniferous rocks. In the Mendips the axis runs E. and W., and, again, over the whole of Devon and Cornwall, we notice a prevailing E. and W. strike. Tracing the Devonian and Carboniferous rocks towards the east, we find that they disappear under the Mesozoic formations which rest upon them unconformably; still we have reason to believe that the E. and W. strike is continued; for, at a depth of a thousand feet under London, Devonian rocks have recently been obtained, and in France, in the Ardennes, they again emerge from beneath the Secondary formations. Passing west instead of east, from the district of Devon and Cornwall, we find in the South of Ireland rocks which represent the Carboniferous, Old Red Sandstone, and possibly the Devonian formations striking E. and W., or rather slightly S. of E. and N. of W. In the district of Killarney the arrangement of the rocks in question has been carefully observed, and is well represented in the Survey Section drawn N. and S. From these facts then we conclude that the district over which Carboniferous rocks had accumulated to such a great extent was at the close of that period subjected to lateral pressure from the N. and S., or from N.N.W. and S.S.E., and that as a consequence of this pressure the surface of our country became puckered up along lines running E.N.E. and W.S.W. It was during this period that the Pendle Hills of Lancashire, the Mendip Hills of Somersetshire, the Mountains of Kerry, and in all probability the Carmarthenshire Vans became stretched out.

We have now to consider another series of earth movements, about the age of which there is some difference of opinion. I refer to the N. and S. movements that have affected Carboniferous rocks, and of which the Pennine Anticlinal may be taken as a type. In the paper above quoted Prof. Hull discusses their age, and arrives at the conclusion that it was Post-Permian and Pre-Triassic. Now for a long time, ever since I became acquainted with Nottingham in fact, I have been of opinion that Prof. Hull is wrong on this point. I propose briefly to discuss the evidence which Prof. Hull offers in support of his view, and then to call attention to facts which convince me that he is wrong. To Mr. Wilson belongs the credit of first pointing out the error in the date of these N. and S. movements (see Q.J.G.S. vol. 1876, page 76). The axis of the Pennine Chain is marked by a fault, which Prof. Hull calls the "Anticlinal Fault," on account of the strata dipping away from it on either side; this fault may be traced for a distance of fifty miles or more in a N. and S. direction, from Colne to Leek. Near this latter place it passes beneath Triassic rocks without fracturing them, thus proving that it was Pre-Triassic. Running parallel with this fault are several others in all probability of the same age; one of these, the so-called Red Rock Fault, forms the boundary between the Coal-measures and the later formations from Bredbury and Poynton southward for several miles. At one point this fault affects the Permian sandstones, and thus is proved to be Post-Permian. From this Prof. Hull concludes that the Pennine Anticlinal was first stretched out in Post-Permian and Pre-Triassic times. Prof. Hull next proceeds to consider an objection to the Pre-Triassic age of the Red Rock Fault. Near Macclesfield and Congleton this fault affects Triassic rocks, thus apparently showing that the fault is of later date than the Triassic formation. This objection is answered by the supposition that there were two series of earth movements along the same lines, one before the Triassic rocks were formed, and another after, and certainly nothing can be more probable than this, especially when we remember that at a point near Leek the anticlinal fault passes under but does not dislocate Triassic rocks. That is the evidence on which the Post-Permian and Pre-Triassic date of the Pennine axis is based. Now there is one consideration which to my mind completely destroys the value of the evidence; in order to explain the facts observed with reference to the Red Rock and Anticlinal Faults, two series of movements along the same lines have to be assumed; but if two movements took place, why not three? And why may not the first of these have been Pre-Permian? *The evidence is not conclusive until it can be shown that N. and S. movements did not take place until after the Permian period, and no attempt is made to prove this.*

From a discussion of the evidence as advanced in the above-mentioned paper, let us pass to the consideration of some additional facts which prove, beyond the shadow of a doubt, that north and south movements did affect the Carboniferous rocks before Permian times. The eastern side of the exposed portion of the Nottinghamshire and Yorkshire Coal-basin is bounded by the Magnesian Lime-

stone (Permian) formation which rests *unconformably* upon the Carboniferous rocks along the whole line. Moreover, the strike of the Carboniferous rocks beneath the Permian formations is the same as that in the exposed portion of the Coal-field, that is, approximately N. and S. These relations are admirably exhibited in the neighbourhood of Nottingham, and they are well known to be true of regions north of Nottingham by all mining engineers and others who have specially studied the structure of the district. Now the N. and S. strike of the Carboniferous rocks both on the east and west side of the Pennine axis must have been determined by N. and S. movements; and since this strike is continued beneath the Permian formations, it is clear that the cause which determined it must have acted before that period. I have no hesitation, then, in asserting that Mr. Wilson is right when he says, that "the lapse of time which is represented by the unconformability between the Carboniferous and Permian was accompanied by the elevation and folding of the strata, not only along east and west (*e.g.* Pendle and Cheshire anticlinals), but also north and south (*e.g.* Pennine) axes, and by the sketching out of the great Coal-basins by denudation." To sum up, we find that at the close of the Carboniferous and before the Permian period two great series of earth movements affected Carboniferous strata, the one series acting nearly in an E. and W. direction, the other nearly N. and S.; which was the earlier series I do not know. The intersection of the axes due to these two series of movements has evidently given rise to the basin-shaped form of our Coal-fields, in the manner so admirably pointed out by Professor Hull. From the Permian to the close of the Eocene we have an immense period of time, during which no movements of the kind I am now speaking about appear to have taken place in our area. Numerous elevations and depressions undoubtedly occurred, but nothing like the puckering and crumpling of a great thickness of stratified deposit. Some time after the close of the Eocene period, however, we find that the South of England was subjected to forces which rolled the Cretaceous and Eocene rocks along axes running E. and W. and gave rise to the anticlinal arrangement of the rocks in the Wealden district as well as the nearly vertical position of homotaxial deposits in the Isles of Wight and Purbeck. These movements have an interest for us even greater than their magnitude would indicate, for they appear to have been contemporaneous with the breaking up of the vast geosynclinal in Central Europe which resulted in the formation of the Alpine system of mountains; they are the ripples, so to speak, which have extended from this great centre of disturbance.

We have now considered the various movements which have resulted in the crumpling, contortion and metamorphosis of our British stratified deposits. They may be classified as follows:

(1) Pre-Cambrian	N.W. and S.E.
(2) Pre-Silurian	N.E. and S.W.
(3) Pre-Permian	*a.* E.N.E. and W.S.W.
	b. N. and S.
(4) Pre-Pliocene	E. and W.

The interest attaching to this paper will be very considerably increased if we view the facts here recapitulated in connexion with the theory of mountain-making first enunciated by Hall, and subsequently elaborated by the American geologists Dana, Sterry Hunt, Le Conte and others. The theory referred to may be briefly stated as follows. In the formation of a mountain mass the first important operation of which we have any evidence is the accumulation of a vast thickness of sedimentary deposits accompanied by a slow subsidence of the earth's crust. At a certain point, owing to the weakening of the floor on which the sedimentary deposits were first thrown down, the lateral pressure due to the secular cooling of the earth operates upon the sedimentary mass, which thereby becomes "folded, profoundly broken, shoved along, fractured and pressed into a narrow space" (Dana, Manual of Geology, page 749). To the downward bending of the earth's crust Professor Dana has applied the term *Geosynclinal*, and to the mountain mass which results from the breaking up of the sedimentary deposits formed in a geosynclinal he has applied the term *synclinorium*. The theory here sketched out appears to be applicable to all great mountain ranges. I would extend it still further, however, and use it to account for all the great systems of folds which are revealed by a study of the structure of the earth's crust, whether these systems occur in mountain ranges or not. Thus it seems to me that the four great systems of earth movements referred to in the present paper are strictly in accordance with this theory. The metamorphosed Pre-Cambrian rocks of N.W. of Scotland, the S.W. of Wales and Malvern, represent, it is believed, a great accumulation of sedimentary material; the geosynclinal which accompanied the formation of this material was broken up before the Cambrian period, and in this breaking up the rocks were folded and metamorphosed, and the existing strike determined. The lateral pressure acted, as we have seen, from the N.E. and S.W., and therefore, according to our theory, the original sedimentation should have been greatest along N.W. and S.E. lines. The second great period of sedimentation was the Cambrian of Sedgwick, this was broken up in Pre-Silurian (Sedgwick) times by pressure from N.W. and S.E. The maximum sedimentation in this case should have been in a N.E. and S.W. direction. The third great period of sedimentation was brought to a close by the formation of our Coal-measures, and this was followed as before by folding and contortion. Here, however, we cannot say that the folds follow any *one* course or direction; two parallel courses appear to be indicated. The earth movements in the Tertiary period followed on sedimentation, which reached its maximum in Central Europe, and which culminated in the formation of the Alpine range.

V.—Aqueous Vapour in Relation to Perpetual Snow.

By James Croll, LL.D., F.R.S.

SOME twelve years ago I gave (Phil. Mag. March, 1867, "Climate and Time," p. 548) what appears to me to be the true explanation of that apparently paradoxical fact observed by Mr. Glaisher, that the difference of reading between a thermometer exposed to