The Palæozoic Mountain Systems of Europe and America.[1]

By E. B. Bailey.

TWO factors are involved in the geological classification of folded mountains, namely, date and position. One-half of the surface of Europe has escaped mountain deformation since the dawn of the Cambrian. This area, which we may call Baltica, has its base on the Urals and its apex in South Wales.

Two Palæozoic mountain chains meet in South Wales about the western angle of Baltica. In 1887 Suess named the older of them Caledonian, out of compliment to Scotland. It runs north-east and its folded, cleaved, and broken rocks appear at the surface in many parts of the British Isles, in most of Norway and along much of the Swedish frontier. They frequently include marine representatives of the Cambrian, Ordovician, and Silurian; but the Devonian, where developed within the Caledonian belt of Britain and Scandinavia, and often in adjacent districts, is of continental or, in other words, of Old Red Sandstone facies; and is later than the more violent of the mountain disturbances.

Near Girvan we find, in addition to the post-Silurian unconformity, another of intra-Ordovician date, sufficiently important to bring Upper Llandeilo conglomerates on to Arenig plutonic intrusions. This earlier unconformity disappears with amazing rapidity towards the south-east; but north-westwards it increases in scope, while in the same direction the post-Silurian unconformity fails.

The evidence for these propositions lies partly in the Southern Uplands and partly in exposures to the north-west. The interpretation of the Southern Uplands is one of the miracles of science. We owe it to Lapworth, an English schoolmaster attracted to Galashiels by the charm of Scott's romances. During the seventies of last century Lapworth demonstrated that the hitherto despised graptolites furnish an extraordinarily sensitive time-scale for Ordovician and Silurian stratigraphy. This led him on to the discovery that many of the rock groups that pass with broken complication through the tightly compressed steep isoclinal folding of the district change profoundly in thickness and character from south-east to north-west.

The total thickness of the Upper Llandeilo, Caradoc, and Llandovery at Moffat in the centre of the Southern Uplands is given by Peach and Horne as 220 feet, consisting of black graptolitic shale and unfossiliferous mudstone. At Girvan, which is only 25 miles to the north-west in cross-strike measurement, these same formations are reckoned as more than 4800 feet thick, and their constituents include conspicuous conglomerates, grits, flags, grey shales, shelly beds, and one 60-foot limestone, in addition to subordinate intercalations of black graptolitic shales. The coarse deposits mark an approach to a coast line lying to the north-west, and their material contains much recognisable debris of Arenig cherts, lavas, and intrusions that must have formed part of a land surface in that direction. The great thickness of such shallow-water marine sediments indicates long-continued subsidence of the sea bottom, preparatory, as it were, to mountain upheaval.

The most impressive geological phenomenon in Scandinavia is the marginal over-riding of Baltica by the Caledonian mountains. It is best displayed in the province of Jämtland, where there are comparatively wide exposures of fossiliferous Cambrian, Ordovician, and Silurian. These formations lie undisturbed in the south-eastern part of their outcrop. Gradually, north-westwards, tranquillity is replaced by isoclinal folding, small-scale thrusting, and intense distributed shearing. Above lies the great Scandinavian thrust-mass or 'nappe,' the cause and origin of all the trouble.

When, in 1888, Törnebohm first propounded his overthrust theory of the Scandinavian Chain, he mentioned sixty miles as a minimum displacement, and compared this estimate with the half-mile of overthrusting previously described by himself from Dalsland and with Peach and Horne's ten miles from the North-west Highlands of Scotland. In 1896, by which time he had received important help from Högbom, he was able to demonstrate that the Scandinavian thrusting exceeds eighty miles.

The North-west Highlands of Scotland show the opposite margin of the Caledonian Chain to that studied by Törnebohm in Jämtland. A British audience knows full well the history of discovery in this wonderful region. Peach and Horne's lucid and beautifully illustrated descriptions, dating from 1884, 1888, and 1907, have, in Suess's words, "rendered our northern mountains transparent." The fossiliferous sediments of Durness, over which the Moine crystalline schists are thrust, are of Cambrian and probably Lower Ordovician age. They are essentially a quartzite-limestone (largely dolomite) succession, and in lithological character and fossil content they belong much more nearly to North America than to the rest of Britain.

The Atlantic seaboard of North America, southwards from Newfoundland, is constituted of Palæozoic mountains, locally concealed beneath a coastal spread of Cretaceous and Tertiary rocks. American geologists call their ancient mountains the Appalachian System. To European eyes they appear as a complex of two systems, rather than as a single system; but for the moment we may let this pass. Beyond the Appalachian Mountains lies an enormous interior region, the Laurentia of Suess, which, like Baltica, has remained unaffected by folding since late pre-Cambrian days.

The age and relations of the portion of the Appalachian complex, which borders the St. Lawrence Lowlands of Laurentia, justifies our grouping it with the Caledonian System. It was Marcel Bertrand who, in 1887, saw that the Appalachian Mountains, as a whole, could be partitioned among the two great Palæozoic systems that, on our side of the water, meet in South

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Wales. In Newfoundland, Canada, and northern New England the Appalachian Mountains belong to the Caledonian System, in the sense that their main movements were completed before the close of the Devonian period.

On Dec. 31, 1860, Logan addressed a long letter to Barrande, and told him how he had been forced to recognise a zone, situated on the mountain front, where older rocks are habitually overthrust upon younger. He actually laid down the course of his postulated thrust all along its Canadian outcrop from Lake Champlain to the extremity of Gaspé. On this account the Champlain—St. Lawrence thrust-zone is often spoken of as the Logan Line.

Logan was of course only applying a familiar direction, came to rest at its foot. The fossils of the two sets of deposits are as distinct as the rocks themselves, and this has led certain distinguished palæontologists to postulate continuous land barriers, or isthmuses, separating the two fields of accumulation. On the other hand, I think it can be established that the limestone of the one field has repeatedly landslipped down upon the mud of the other; in which case the division cannot have been an isthmus, but merely a submarine slope.

My conception of the Logan Slope is a slight modification of Logan's original. Let us picture the slope, not as a rigid feature of pre-Cambrian date, eventually obliterated by Palæozoic sedimentation, but as tectonic in origin and inter-

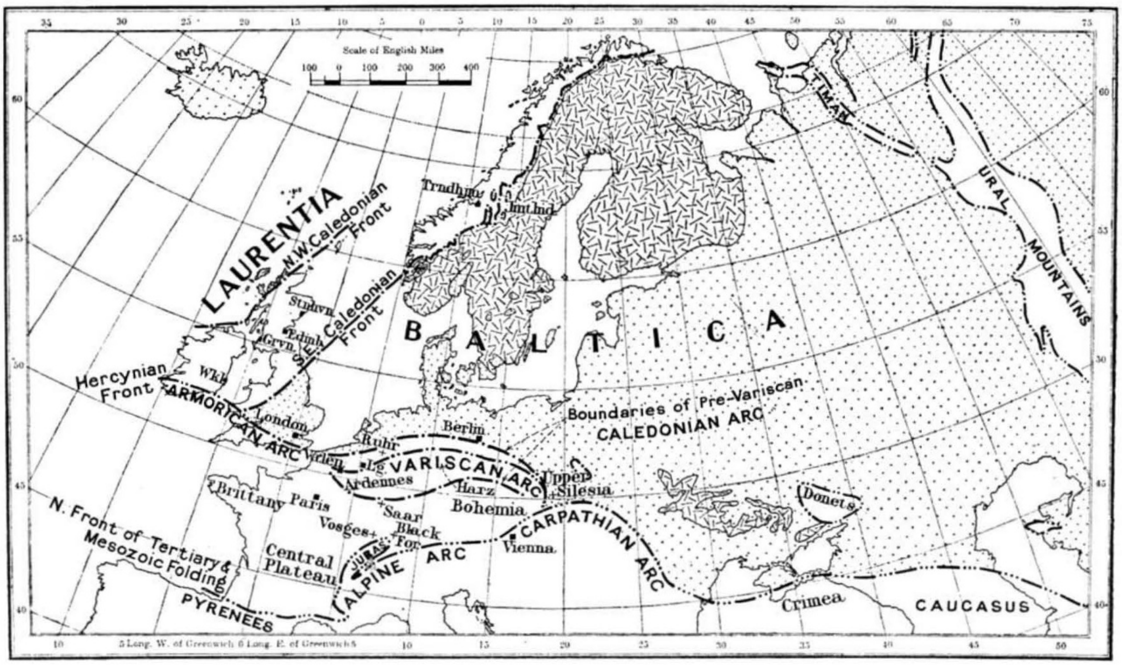

FIG. 1.—Tectonic map of Europe. The ornamented regions (Baltica, Laurentia, etc.) have remained unaffected by mountain-folding since pre-Cambrian times. Their pre-Cambrian outcrops are shown by ticks, Cambrian and later by stipple. Contractions are used for Black Forest, Edinburgh, Girvan, Jämtland, Liège, Stonehaven, Trondhjem, Valenciennes, Wicklow.

principle; for, in the States, thrusts had been described by the brothers Rogers so early as 1842, and, in the Alps, by Escher in 1841. Still, there can be no question that Logan's letter to Barrande furnishes one of the main landmarks of tectonic science.

Logan also recognised that the north-westward frontal thrusting of the Caledonian Mountains of Canada followed a much older line of slope, leading down south-eastwards from the platform of Laurentia to the comparative depths of the Caledonian sea bottom. He gave his theoretical slope a double function. First of all it had to act as a boundary to early sedimentation, and then as a guide to later thrusting and folding. There is, however, another aspect of Logan's Slope that has not, I think, attracted sufficient attention. This slope, when completely submerged, seems to have furnished a dividing line between clear-water Ordovician limestones (American facies), that grew on its top to the north-west, and muds and sands (Caledonian facies) that, creeping from the opposite

mittently renewed by hinged subsidence. Earthquakes connected with the intermittent renewal were probably responsible for the landslips to which I have just alluded. It is well known that most of the major earthquakes of to-day originate on submarine slopes, and that important submarine landslips precipitated by such earthquakes have been described, for example, in connexion with the Tokyo disaster of 1923. Of late years Kendall has reawakened British students to the possibility of recognising earthquake phenomena in the records of the past. I believe that a story of recurrent earthquakes is written in the submarine landslip-deposits of the Logan Slope.

If now we cast our minds back to the change of facies that Lapworth recognised in the Southern Uplands of Scotland, we find it on the whole of more gradual type than that characteristic of Canada. In the Southern Upland sea, mechanical sediment travelled down a tectonic slope, and change of facies depended upon the arrest of coarse material by deep water. In the Canadian sea, mechanical sediment reached the foot of a tectonic slope up which it was unable to climb. In both cases we notice subsidence preceding mountain elevation—an idea which had its beginnings in a publication of Hall's on the Appalachians, dated 1859, and its subsequent development more especially in the writings of Dana and Haug.

In 1887, the later of the two great Palæozoic chains that meet in South Wales received a double name from Suess. He distinguished along its course a couple of congruent mountain arcs with an inflectional junction of their fronts (syntaxis) northern front of the Hercynian Mountains has provided a favourite theme among tectonists from the days of Dumont and Rogers, 1832 and 1849. In 1877, Cornet and Briart, and in 1879, Gosselet, announced large-scale overthrusting, the first of the kind to be recognised in European Palæozoic chains. Of recent years, much the most delightful addition to our knowledge of the ground has been afforded by Fourmarier's 1905 interpretation of the Window of Theux, south of Liège.

The preparatory hinged subsidence that we have met with in the history of the Caledonian Chain, in southern Scotland and again in Canada, reappears

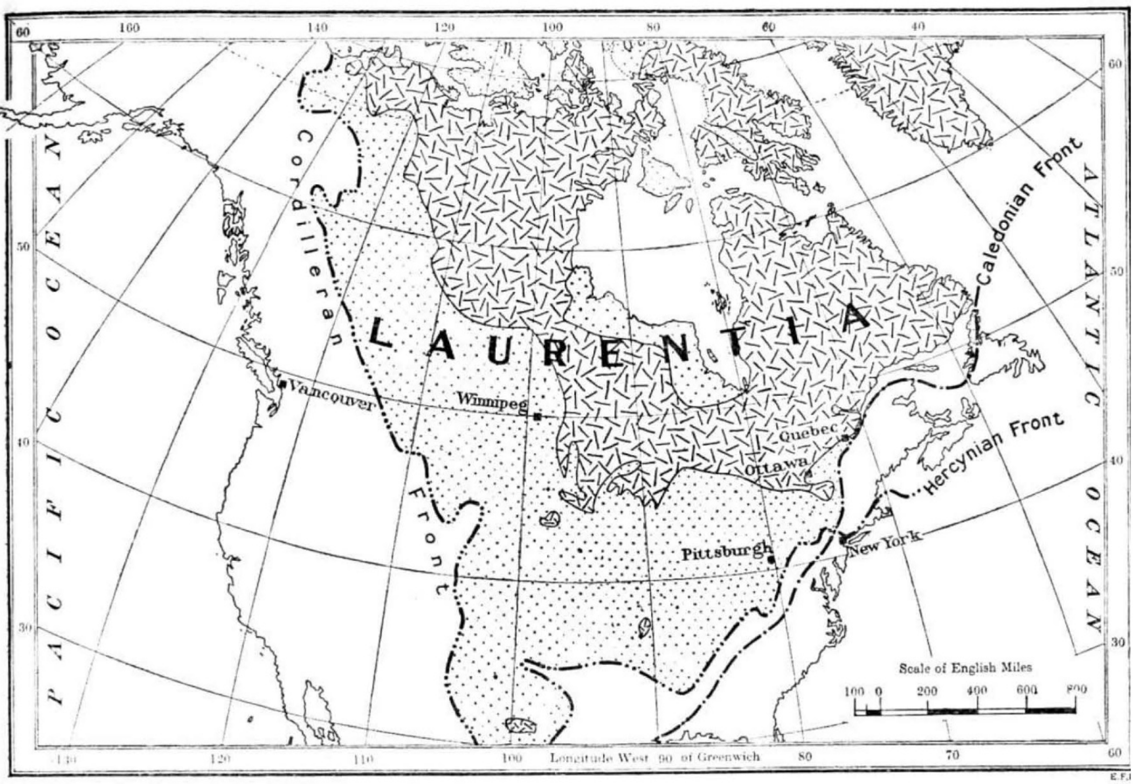

FIG. 2.—Tectonic map of North America. The ornamented region (Laurentia) has remained unaffected by mountain-folding since pre-Cambrian times; its pre-Cambrian outcrops are shown by ticks, Cambrian and later by stipple. The western cordillera is of Mesozoic and Tertiary date.

near Valenciennes on the Franco-Belgian border. The eastern arc he called Variscan, the western Armorican. The names are based on the Latin for the Bavarian town of Hof, *Curia Variscorum*, and for the French province of Brittany, *Armorica*. The meeting of the two arcs near Valenciennes is closely comparable with the meeting of the Carpathians and Alps near Vienna.

The date of the Armorican and Variscan folding varies somewhat according to locality, but lies either within, or at latest shortly after the close of, the Carboniferous. Bertrand, publishing the same year as Suess, classed these mountains on a purely age basis, as part of his Hercynian System (called after the Harz). Unfortunately, Bertrand's name Hercynian was preoccupied; but I propose to use it in his sense in the present description.

The Franco-Belgio-German coalfield at the in the Hercynian record of western Europe. Broadly speaking, the Devonian of the Hercynian Foreland is continental (Old Red Sandstone), while that of the Hercynian Mountains is marine. Evidently the marine Devonian gathered on a tectonic slope that, descending southwards to the site of the future mountains, was constantly renewed by subsidence.

The contrast between the foreland and the mountain region is particularly striking along the Franco-Belgian front of the chain, even when we make allowance for exaggeration by overthrusting. The Lower Devonian and the lower part of the Middle Devonian of the thrust region sometimes total 17,000 feet, while both divisions are absent in the over-ridden foreland to the north. The line at which this great mass of sediment fails is known as the Condroz Crest. I prefer to speak of it, when concerned with its pre-thrust character, as the Condroz Slope.

During Lower Carboniferous times, marine transgression submerged the Hercynian Foreland far and wide. A northern continent persisted, but its waste was retained along a deltaic belt that stretched through southern Scotland and northern Ireland. Accordingly, clear shallow waters covered much of the foreland in Belgium, England, and Ireland, where it encouraged the growth of Carboniferous Limestone. At the same time, the interior Hercynian zone, lying to the south, showed signs of mountain development, and its uplifted portions furnished sand and mud to the contiguous sea. It is almost certain that the northward travel of the Hercynian mud was checked by a successor of the Condroz Slope leading down from the shallow waters of the submerged foreland to the foredeep of the growing chain.

Without attempting to sketch this history even in outline, let us pass on to Millstone Grit times, when a slackening in the general subsidence of the foreland allowed deltas from the persistent northern continent to join with others from the growing southern mountains. They met upon the site of the erstwhile Carboniferous Limestone Sea and thereafter placed Scotland in frequent communication with contemporary land regions in France and Germany. Just at this critical time, as Kidston and Traquair have shown, the land flora and estuarine fish fauna of Scotland underwent a remarkably sudden alteration; whereas the fauna of the open sea showed no corresponding change.

The new flora that all at once appeared in Scotland, is one that has been demonstrated by Potonié and others to have arisen in a normal gradual fashion on the deltas fronting the nascent Hercynian Mountains; and I attribute its abrupt introduction into Scotland to migration across the confluent southern and northern deltas of the Millstone Grit. The contemporaneous renovation of the estuarine fish fauna of Scotland can also be explained by the meeting of the deltas, since this event made Scottish rivers tributary to the general drainage system of western Europe.

There is another aspect of the deltaic apron of the Hercynian Mountains which used to appeal insistently to the imagination of Marcel Bertrand. This deltaic accumulation gathered in the frontal depression of the growing Hercynian Chain, and to-day it furnishes the greatest belt of coalfields in the whole of Europe. We know it in Upper Silesia and again in the Ruhr, Belgium, north-east France, Dover, Somerset, and South Wales.

The phenomenon of mountain crossing receives two independent illustrations along the course of the Hercynian Mountains of western Europe. In Upper Silesia the front of the Hercynian Chain emerges from beneath the Carpathians, while in the British Isles it obliterates for the time being the south-westward continuation of the Caledonian Chain. Where the Carpathians and Alps have trespassed upon the domain of the Hercynian Mountains the latter had already been buried beneath an unconformable cover of Mesozoic and Tertiary marine sediments. Similarly, where the Hercynian front crosses the Caledonian Chain in Ireland, the new mountains, at the present level of denudation, consist of Devonian and Carboniferous sediments.

In America, from New York southwards, the north-west front of the Appalachian complex consists of folded and often overthrust Palæozoic sediments that extend upwards into Coal Measures. This belt it was that gave the brothers Rogers material for their ever-famous address delivered in 1842 before the American Association of Geologists. The last great movement seems to have been in the early Permian. Accordingly, Marcel Bertrand, in 1887, placed this frontal Pennsylvanian belt of the Appalachian Complex in his Hercynian System.

The most interesting peculiarity of the Hercynian System in America is its penetration to Laurentia, to the north-west foreland of the Caledonian System. The crossing of the chains, begun in the British Isles, is completed in New England. The actual front of the Hercynian Chain cannot be mapped with precision in the American part of the zone of crossing, because the critical district has been largely denuded of its Carboniferous rocks. At the same time, important Carboniferous outliers do occur in the southern States of New England and are strongly folded; whereas the Carboniferous spreads of the maritime provinces of Canada are tolerably undisturbed. The best known of the New England outcrops crosses Rhode Island, and its prevailing rocks are conglomerate, arkose and slate. Though folded, cleaved, and cut by granite and pegmatite, the Rhode Island Carboniferous agrees with that of Canada in being unconformable to the Caledonian disturbances.

Where at last the Hercynian Mountain front steps clear of its Caledonian predecessor, one encounters a sedimentary superposition of facies that is quite unknown in Europe. In Pennsylvania there is an immense concordant succession from Cambrian to Carboniferous. In the cores of anticlines we find our Durness (Beekmantown) Limestone, because we stand on the north-west foreland of the Caledonian Chain. In the hearts of synclines we discover Upper Carboniferous Coal Measures (Pennsylvanian) derived from the waste of the growing Hercynian Mountains, and we follow Bertrand in our thoughts to South Wales, the Ruhr, and Upper Silesia.

The study that we have made of mountain chains with their folds and their thrusts, which individually may be of the order of 100 miles, involves a recognition of some type of continental drift. Of late years Wegener has developed this idea on a particularly grand scale. He has accounted for many recognised correspondences in the geology of the two sides of the Atlantic by supposing that the ocean has flowed in between the Old World and the New, as the two continental masses, with geological slowness, drifted asunder. One cannot help feeling that Wegener may perhaps be telling us the truth. The available evidence is crude and ambiguous; but it is certainly startling to be confronted on the coasts of Britain and America with what read like complementary renderings of a single theme: the crossing of Caledonian Mountains by Hercynian.