TECTONIC AFFINITIES BETWEEN EUROPEAN AND NORTH AMERICAN MOUNTAIN SYSTEMS[1]

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In the vicinity of New York, the Appalachians may be divided into two parts, of which the northern connects with the Caledonids, and the southern with the Hercynids (Variscids) of Europe. In the European Hercynids three belts are joined in a single dynamic unit: (1) the generating Moldanubian belt in the south; (2) the sparsely preserved belts, with metamorphosed thrust-sheet structure (Erzgebirge, Spessart); and (3) the belt of nonmetamorphosed folds (Rhinish Schiefergebirge, Harz). In the American Hercynids, the so-called Paleozoic geosyncline corresponds to the third belt of Europe. The crystalline basement rocks, in the southeast, adjoin the geosyncline as the second belt. The crystalline facies and the wide-spread thrust-sheet and over-thrust structures in these regions lead to the assumption that a generating belt, corresponding to the Moldanubian, was adjoined. Counter movements at the inner border, and in the interior of the mountains are of a different sort, and cannot be regarded as wing activities symmetrically opposed to the main movement. As in the European Hercynids, so, also, in the American representatives, the granites are indigenous to the crystalline belt, and are pushed outward from it.

On the basis of their general structure, the Hercynian Appal-

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lacians are to be regarded as continental border-mountains, comparable to the Andean chains of both Americas. The associated continent, however, was not Laurentia, but an ancient land-mass which lay in the lap of the present Atlantic ocean. Through pressure the chain became welded to Laurentia, as the Alps were welded to the fragments of the Hercynids, and the European Caledonids to the Fennoscandian shield.

The Caledonian Appalachians, to the north of New York, seem to connect with the Scottish Caledonids. The Moine over-thrust is a continuation of Logan's line, according to Bailey. The area extending eastward from Logan's line, to the sea, appears to be a basement fold made up of various ruin remains.

The angular crossing of Caledonids and Hercynids, on both sides of the Atlantic ocean, furnishes, in conjunction with a variety of stratigraphic relationships, the most significant indication of the former connection of North America with Europe, in the sense of Wegener.

In their oldest mountain relationships, America and Europe display the two end parts of a belt the evident connection of which has been obliterated, much after the fashion of the beginning and end of a delivered lecture in hand. Before first announcement of such connection by Marcel Bertrand, there were determined the ancient resemblances, and the modern accordances, on both sides of the Atlantic, of the Carbonic stratal sequence of the most recent folded belt. When both parts show disjointed sections of structure, better understanding of the restored comparison may be expected. An exchange of views from different quarters of the world is the chief objective of our gatherings; and when here I am able to weigh the matters of the other side of the Atlantic's tried experience with those obtained by me now from the literature of the described regions; so, if you please, what here is statement is not presented so much as categorical assertion as mere inquiry.

Originally suggested by Bertrand,[2] Termier [3] has already pointed out that the northern, and particularly the Canadian, part of the Appalachians are Caledonids; while beyond the transgressing sedimentation began with the sandstones of the Devonic. Still more emphatically has Bailey [4] shown the resemblance of the Acadian

2 Bull. Geol. Soc. France, (3), t. XV, p. 423, 1887.
3 Comptes Rendus, Acad. Sci. Paris, t. CLVII, p. 621, 1913.
4 Rept. British Assoc. Adv. Sci., 96th meet., Sec. C., p. 57, 1929.

Paleozoics to the English Caledonids, the relations of the Lewisian gneisses with the Laurentian basement-complex, and the long recognized similarity of the Durness limestones of the northwest Scottish over-thrust with the Beekmantown limestones of the foreland of the Appalachians. Consequently, the great Moine over-thrust must correspond to the sharp over-thrust of the Logan line, which extends from the St. Lawrence River, across Lake Champlain, nearly to New York city. From Scandinavia, the Caledonids trend obliquely towards the Hercynian (Variscian) arch. The broad interval is occupied by the Sudetian, towards the west, until, in the south of England, at the Bristol channel, and in Ireland, they cross each other in both directions. In the New England states, such crossing is repeated. Bailey, especially, has stressed the significance of this phenomenon in support there of Wegener's hypothesis of continental drift. Likewise, Van der Gracht [5] also adopts the Bailey view. In consequence of this relation, the New York region becomes one of the best known key-points on the globe for the understanding of geological events in general.

Even, as in the southern hemisphere, according to Du Toit,[6] the Devonic phases of the South American Pampas mountains are comparable to the South African Cape mountains, the older Paleozoics extend over the region between American and Great Britain Caledonids. According to Howell,[7] one can hardly be more astonished in earth history than at the similarity of facies between the Cambric formations of New Foundland and of southern England. The similarity of the vulcanic series in the "Old Red" (Devonic) of New Foundland and of Scotland has been especially noted by Howard.[8]

The two-fold character of the Appalachians has been already indicated in its main outlines. North of the compression at New York, arching begins, which continues unbrokenly to the mouth of the St. Lawrence River. Instead of broad, uncovered, folded, and over-thrust structures of the extensive Appalachian over-lap, follow the sharply bordered and narrowly stepped over-thrusts, one upon another, on the Logan line, which, towards the unfolded Paleozoics abruptly delimits the shield. According to Keith,[9]

5 K. Akad. Wetensch. Amsterdam Verh., Afd. Naturk., Deel. XXVII, No. 3, 1931.
6 Geology of South Africa, p. 194, 1926.
7 Bull. Geol. Soc. America, Vol. XXXI, p. 214, 1920.
8 *Ibid.*, Vol. XXXVII, p. 475, 1920.
9 Bull. Geol. Soc. America, Vol. XXXIV, p. 309, 1923.

Woodworth,[10] and others, the tectonic character of this interruption at the Logan line is of another kind, as is that of the peculiar Appalachian folded belt between Oklahoma and Pennsylvania.

The European Hercynids (Variscids) can only be connected with the Appalachians south of New York. They are designated here as the American Hercynids, or Variscids. The Appalachians north of New York must be correlated with the European Caledonids.

The European and American Hercynids may be briefly compared. Van der Gracht[11] prolongs the American Hercynids, through the Ouachita and Wichita mountains, quite to their mergence with the Rocky mountains, near Marathon, Texas. The Appalachians between New York and the Mississippi River lowland, form one of the greatest continuous folded belts in the world. The European segment is not unbroken, while it is transformed after folding into lofty blocks. Dislocations of different systems divide it, and it is converged on centers. The best known are in the northwest, which have been designated the "Karpinsky Breaks," the disappearance of a dismemberment which the Asiatic continent contributed to the mosaic of European appanages where they extended to the south. They are the result of surrounded movements which divided the interior of Asia into the "Blockschollengebirge" of Obrutschew,[12] or the basement fold of Argand,[13] and therefore have produced the modern relief. The American portion of the cross fracturing has vanished. Before all, we must return to the fact that the European part is unknown because of the Mesozoic sunken areas of the surrounding horste.

The disadvantage, occasioned by the destruction of a single belt, is off-set by the upraising of the dislocated parts, and by the potential, extensive relief characteristic of the crystalline parts of the mountains. In consequence of this, in the European Hercynids, the entire extent of the dynamic unity is surveyed. Through the assistence of the ground-plan produced, the following belts are distinguished: (1) A known generative base, through subsequent tectonic re-crystallization of the Moldanubian region of the Bohemian *massif*, and the lost ruins of the Black Forest, the Voges, and the Central plateaux of France; (2) the indeed scarcely preserved,

10 *Ibid.*, Vol. XXXIV, p. 253, 1923.
11 K. Akad. Wetensch. Amsterdam Verh., Afd. Naturk., Deel XXVII, No. 3, 1931.
12 Fortschr. Geol. u. Palä, Heft 15, Berlin, 1926.
13 Comptes Rendus, XIIIth Cong. Geol. Internat., pp. 171-372, Bruxelles, 1924.

yet clearly recognizable, belt of the metamorphosed folds and coverings in the Erzgebirge and in the Spessart; and (3) the belt of non-metamorphosed folds of the Thuringian Forest, of the Herz, and of the Rhinish Schiefergebirge.

For the American Hercynids, Keith has advanced the idea that all of the crystallines and pre-Cambric mountains, including their granitic cores, from the border of the younger coverings to the sea, belong to a great mountain system the full extent of which is not visible. He has conveyed, in part, further, the idea that the late Paleozoic revolution was shared by contact metamorphism of Carbonic granites, with the production of crystalline schists.

All that is to be expected, when the relations between the Appalachians and the American Variscian arch are better known, regards an age comparison of the fold phases. Thus, the "geosyncline" accords with another belt of unmetamorphosed fold and thrust-sheet tectonics, and in the added belt must be preserved the arch of a metamorphosed thrust-sheet and fold-structure. If the comparison hitherto made be valid, it follows, without doubt, that a mighty disturbance had taken place. This may today be entirely, or partly, broken away from the continent, but once must have been driven before, and partly have overcome other belts. By its loosened under-surface the out-welling granitic magma was allowed to push upward.

It is to be expected that, as in the Alps, and the European Hercynids (Variscids), likewise in the Appalachians, the dynamic initial focus for mountain upheaval must be sought in the crystalline core.

The crystalline facies itself is instructive. According to Knopf & Jonas, a single northwest movement controlled the Appalachian crystallines, from Trenton to Alabama. It is best expressed in the vast sedimentary succession of the "fore-deep." Indeed, from this, as especially distinct in the crystalline facies, one recognizes that the unmetamorphosed folded belt is tectonically intimately united with the fore-deep, and is altogether unrelated to the opposite lying Laurentian foreland, to the supposititious limits of the geosyncline.

According to all the descriptions, also, both main belts of the Appalachians are relatively simply constructed, in spite of their great length and breadth in comparison with the crystalline belts of the Alps and of the Variscids. Jonas arraigns the crystallines of the Appalachians in three, flat, over-thrust plates. The border of the Blue Ridge, Martic, and Pine-Mountain-Appomattox over-thrusts which, when viewed at a distance, resemble somewhat extensions of the great Alpine thrust-sheets, or the two, unlike mountain-masses dividing the Moldanubian-Silesian over-thrust.

The affectation of both parts with progressive metamorphism, as the polymetamorphic development of many rocks, is described by Knopf & Jonas as coming in. But in spite of greater variety of example, and despite the great breadth of the regions, the intensity of the metamorphism itself remains within narrow limits, as in the crystallines of the European Variscids and the Alps. The facial succession extends from garnet-, staurolite-, and also cyanite-bearing, biotite-oligoclase gneisses to albite-, chlorite-, and sericite-gneisses and phyllites. These consequently come within the scope of dynamic metamorphism. After regional transformation, schists of this kind belong in the class of secondary alteration during burial. Likewise, also, tremolite becomes a characteristic mineral of marble in the deeper stress zone.

As in the Erzgebirge, and in the core of the Alpine schists, cordierite is wanting, and with this the whole group of demetamorphosed rocks which characterize the Moldanubian sector of the Variscid orogenetic unit; under which are included the lime-silicate felsites, with augite, plagioclase, scapolite, the granulites, and pyroxene-granulites. While sillimanite, the dynamically formed mineral of the depths, does not appear in the crystallines of the southern Appalachians.

Between the various garnet-, staurolite-, and cyanite-bearing gneisses and mica-schists, and albite gneisses of the Alps there occur yet original traces of preserved unmetamorphosed rock, which escaped the changes in the middle and upper levels. Likewise, many cases are shown thereupon that retrograde metamorphism takes place to such great extent that one is turned to general assumption. The primitive mountains of different ages and orogenies, with the accompanying intrusive bodies, have been observed through the Alpine effects in dynamic metamorphism, by their graduations. Yet, because of the original rock conditions controlling the boundaries, they are distinct.

Regarding the crystalline thrust-sheet structure, according to the presentation of Knopf & Jonas, it is shown that a similar, encompassing tectonic history obtains for the crystallines of the Appalachians. As I have repeatedly emphasized, the thrust-sheet structure, with its crystalline facies, cannot develop through free, independent movement of a rock-mass, but only under pressure of exposed "generating centers."

Such conditions must once have existed over at least a part of the Appalachian crystallines, and in the back-ground. Thus Knopf & Jonas [14] have assumed great change in explanation of the metamorphism.

From this every one knows that the whole crystalline complex encountered is patterned. It is not permitted now to say in which particular region it thereby may be already much folded through slipping one upon another. From this view-point, one must judge the great Glenarm series from its stratigraphic rather than its tectonic aspects, as an extensively glided, unmetamorphosed stratal consequence of the "geosynclinal."

The essential tendency of the entire structure of the crystalline sort is measured by the distribution of the gneisses, and the associated schists. Sharply defined gneiss-domes, or arches, as are the rule in the structure plan of the Erzgebirge, the Pennines of the Alps, and the Moravian fenster, are not noted in the Appalachians.

Indeed, the gneiss-arch does not play a very important rôle in the structure of any of the three mountain systems mentioned. In the Erzgebirge it is displayed in a well-developed thrust-sheet system, in which the sedimentary gneiss (gray gneiss), in manifold, ramifying light-colored intrusions occur. In the Pennines of the Tauer, and in the Moravian mountains, the resisting granitic masses give rise, in the midst of slaty sediments, to the form of the dome, and likewise the "fensters of the Joch." The Tauer gneisses are, in fact, intrusions in an older phase of similar mountains. They are, through later developments, overcome and are formed from the gneiss-arch. In the Moravian granites the delay causes all the heterogeneous Moldanubian centers, a similar slaty structure, and transformation to a dome.

The domes of the Erzgebirge were formed in the depths. The medial crystallization since it took place under movement, was accompanied by the formation of richer and more abundant mica-flakes and garnets. Then the metamorphism, after extending out-

14 Bull. Geol. Soc. America, Vol. XXXV, p. 355, 1924.

ward gradually into the higher thrust-sheets, affected the gneisses in the slaty covering in other places (erroneously), as syntectonic intrusions with contact borders. Likewise here the resisting granitic mass controlled the cause of the doming where it also is drawn out to higher level, and is thrust aside as it nears the original Moravian and Pennine granite-gneiss dome. As evidence there occurs no cordierite in the gneisses of the Erzgebirge.

Altogether otherwise does the Baltimore gneiss, or Carolina gneiss, appear as the basis of the Appalachian crystallines. This shows post-tectonic recrystallization at somewhat higher temperatures. The structure is truly crystalloblastic, with unbroken twinning plates of orthoclase, abundant myrmekite, quartz, orthoclase as filled blotches at the angles, tattered, scattered biotite, and small garnets. The type of crystallization reminds one of the so-called quartz-granulites of the Moine, in the Scottish highlands, in which the biotite is still more loosely and sparingly distributed.

It follows, on the contrary, if, in the changed biotite and in the quartz-feldspar mosaic, sedimentation is indicated, whether it is presented through injection, "lit-par-lit," or whether refinement takes place somewhere through alternation, or banding, of previously formed gliding-planes. With deep, post-tectonic crystallization, and therefore with a considerable gap in the metamorphism associated, the impaired Glenarm series becomes a reality. Knopf & Jonas[15] say: "It is possible that the Baltimore gneiss remained an inert mass so far as later metamorphosing influences were concerned."

Nevertheless, the Baltimore gneiss is reduced tectonically to vast connected ruins, and is displaced to unknown extent. This is affirmed by the zones of strongly cataclastic structure, and particularly by the intrusions of Hartley augen-gneiss in the Baltimore gneiss, in which remains preserved nearby crushed quartz and microcline, as well as some biotite, in part shredded or fringed. Deformation phenomena are indicated near it, also, through the presence of muscovite scales.

Perhaps the relation between the Baltimore gneiss and the Hartley augen-gneiss resembles that between the gray, sedimentary gneiss and the intrusions of so-called "red gneiss," in the Erzgebirge. There, indeed, the metamorphism, in deep conformable

15 Bull. U. S. Geol. Surv., No. 799, p. 130, 1929.

streaks seems to have taken place, with the development of coarse-scaled muscovite forms and without cataclastic phenomena.

The thrust-sheet and over-thrust tectonics are illuminating. The change and gradation of the crystalline facies within the Glenarm series shows in repeated thrusting, and allows also here to be clearly seen a notable thrust-sheet slipping. The faults in the basal conglomerates, included in the rest of the Setter quartzite, or formation, the well-marked structural discordance against the Baltimore gneiss, and, most important of all, the marked alteration of the fragments, or inclusions, in the Baltimore gneiss, permit the conclusion to be drawn, that the whole Glenarm series is distinct from the Baltimore gneiss. The same seems to be true for the Paleozoics. The immediate superposition of the Cambric strata upon the true pre-Cambric rocks of the Mine Ridge anticline cannot be observed on account of poor exposure. The metamorphism is almost solely confined to the controlling facies in the Wissahickon formation. It increases towards the south, that is, in the direction towards the interior of the mountains, where one, in imagination, restores the orogenics to its full width seawards. The relations remind one of the Silesian belt of the Sudetsian. There is a sedimentary succession of Devonic quartzites, grauwackes, and limestones, formed through shearing, into a transgressive plate for a tectonic thrust-sheet. This, increasing metamorphism, towards the west, or towards the interior of the mountains, according to Kölbl,[16] indicates that here the thrust-sheet near the forward face of the higher thrust-sheets and the generating Moldanubian center, is passed over.

In the European Hercynids, the over-thrusts which occur are not so often repeated as in the Martic over-thrusting. This view applies similarly to the Alps where, in the Grisonids, and in the Austrids of the sedimentary trough of a growing center, not only once, but in repeated thrust-sheets, thrust-movement is overcome, and only a narrow belt, similar to the Helvet with the added Flysch, close to the border of the ancient foreland, remained uncovered by the higher thrust-sheets. The old intrusions, under the advancing thrust-sheets, extend to the core of the arch.

Likewise, in the Erzgebirge and in the Spessart, the belt of the metamorphosed arch and thrust-sheet tectonics is between the un-

16 Mitt. Geol. Gesell. Wien, XXII Bd., p. 65, 1929.

metamorphosed belt and the stacked up core, and is similarly strongly compressed.

The unmetamorphosed folded belt west of the Ardennes, in Cornwall and in Brittany, is narrowly restive. Perhaps occurs here an approach to the structural style of the New York region. Also, here, towards the true Caledonids, the broad tract of Paleozoic folds disappears. Possibly there develops the sort of forelands in the structural style that exists in the Alpine-Carpathian arch. Here occurs the narrowest stationary thrust-sheets, the closest compression of the oldest and youngest fore-deeps, the Variscian fragments, the Rhinish horsts, and the Bohemian *massif*, together. When the borders give way backward the mountains of the Russian plateau may be reached, the single thrust-sheets are wider, stepped one on another, and sink in part under the Hungarian plains.

There appears also an Appalachian Hercynian folding in strongest contrast, where it rises before the Caledonids in the vicinity of New York, on the one side, and on the other side of the Atlantic, in Cornwall, Ireland and Brittany. In the west, in the Laurentian shield, and in the east, in the Scandinavian plateau, the sedimentary belt of the Hercynids is again broader. In America there is formed a transgression of the Dinantian, strongly marked, and for its expression correspondingly occurs on the geological map chiefly as a few deep-seated, post-Culm (post Dinantian) tectonics.

The distribution of the batholiths belongs to the structural plan as a whole. In the more complete European parts the granites, in the innermost belt, are normal, and from here extend out into the folded belt. Some extensions (intrusions) have reached the unmetamorphosed belt in the Harz, and in the foundations of the Rhinish Schiefergebirge, under Eifel vulcanism. Only rarely do the intrusions penetrate to the outer border of the mountains. This distribution is repeated in the Alps, in the Cordilleras of both Americas, and in other mountains, and obtain therewith the rank of a structural plan of greater orogenic governing law.

Very clearly does this apply to the Appalachians. The broad belt of synclinal sediments remained open and was not overcome subsequently by the compressing crystallines. Their connections remained firm, and were not broken by batholythic intrusions. Certain older granitic after-thrusts, as for example, the Hartley augen-gneiss, occur in the folded structure, and by means of it are altered in form and metamorphosed. Also, the Columbia granite, in the Appomattox thrust-plate, is drawn out into augen-gneiss and granite mylonite.

Syntectonic intrusions I cannot recognize. Post-tectonic granites can occur here, as in the European Hercynids, but not as a feature of mountain-building.

The irregular outlines, and the lack of order in distribution of the mountain masses, do not appear here, as in the Alps, to be carried near to the outer border of the mountains referred to, as observed by Jonas.[17] Besides, there are, in part, post-tectonic granites of very different ages. Further, such as present early a sheared structure, developed at the same time as the metamorphism, gives rise to another, which is cut through by the over-thrust plates (Martic and Appomattox). Again, others are younger and slip obliquely over the great interrupted plane. The youngest, under the great bodies, in Alabama, Georgia, the Carolinas, and Virginia, are Carbonic. The different ranks of the slaty cleavage indicate different geological ages. Similar relations obtain in Europe. Here, again, the granite intrusions, vary greatly, from the same grano-diorite stock, and from an early orogen, old Paleozoic, to a late orogen, post-Culm, indeed, in the latest thrusting in the Erzgebirge to a possibly post-orogenetic Permian time. Doubtless the Permian porphyry developed already from a similar magmatic source.[18]

Counter movements are noteworthy. Within the great, connected crystalline masses of the inner Appalachians the unity character which controls the structure of the outer belt disappears with the thick sedimental covering in the fore-deep that is to be. Dissimilar resistences enter into the problem from different directions. Northwestern ruins are met with, and are particularly striking in a belt which reaches from Alabama and North Carolina to Massachusetts, and are certainly most abundant on the borders of the batholith. Keith observes hereon on the fan-structure, but notes that the belts with northwestern ruins are not separated as observed belts.

Movements in the inner border, or within the mountains, are widely spread. They are, indeed, dissimilar, and no cases of symmetrical counterparts to the outer borders are known.

17 Bull. Geol. Soc. America, Vol. XXXV, p. 503, 1924.
18 Intrusiontectonik und Wandertectonik im variszischen Gebirge, p. 238, Berlin, 1926.

In the Appalachians one cannot expect such movements as occur in the great reversed disturbances on the south border of the Pennines, in the Grisonids and east Alpine (Insubrian) basement, or in the obliquely faulted "Insubrian Line." The continued or supplementary, compression, which is not present in the Appalachians, is the cause of these movements. Their irregularity proves that they are not related to the chief folding stage, and that they can arise as corresponding counterparts of the principal folding. Therefore, the "Insubrian basement" belongs to a later phase of the folded structure; the "Insubrian Line," indeed, is a great, steeply overturned belt, which, according to Cornelius & Furlani,[19] intercepts the folds. The north-folded, post-Culm disturbances of the upper Rhinish horst (Schwarzwald and Voges) lie not in a true orogen but in a generating center of the Moldanubian mass.

Likewise, in other instances, it may be shown that the supplementary compression of the folded belt can indicate the same sort of movements of which a surficial amount appears as a symmetrical counterpart of the main movement.

Neither in the Appalachians can occasional movements be derived from a symmetrical foundation. Possibly the crystallines of the eastern Appalachians include part of a belt of intrusive tectonics. The ruined active part is made up after the plan of the best-preserved European foldings.

There exist no orgenics in which two similar fore-deeps of a central belt are symmetrical with reference to corresponding sedimentations.

The Appalachians are best considered as continental-border mountains. It is immaterial that south of New York the great fold is conceded to be fragmentary, in a certain sense as a separated border band, emerging from under the coastal plain seaward, to make up the principal platform of the structure, as that, in similar sense, is pointed out by Keith[20] and by Woodworth.[21] In reality the Appalachians do not properly belong to the primeval North American continent, but were attached to it from without, while the Alps were composed of fragments of the Variscids, and these from Caledonid ruins.

After union of their foundations and development of beltal

19 Denksch. K. Akad. Wiss. Wien, Math-Nat. Kl., CIII, 1930.
20 Bull. Geol. Soc. America, Vol. XXXIV, p. 309, 1923.
21 *Ibid.*, p. 253, 1923.

arrangement, the Hercynian Appalachians aligned themselves with the continental-border mountains, much as they appear in the younger chains of the Cordilleras of both Americas, clearly and properly in appearance. The chief characteristics are: That towards the outer border, in the so-called geosyncline, were thick, patched-together bodies of sediments of the opened-up sea-bottom, and that towards the inner border, towards the crystalline belt, intrusions increased.

The Appalachians are piled up here and there on the Laurentia. The border-shell of the continental mass was already incorporated during the later mountain-building, as a Carbonic outer belt. But the continent, of that day, related to the continental-border mountains, lay in the position of the present Atlantic ocean.

The Appalachians have no similar counterpart in the Rocky mountains. These constitute the true border mountains of Laurentia. Their main mass belongs to the continent, and there sets up its arched border. In the west, this annexed, truely orogenetic, folded tract lay in great part under the sea, beyond the Pacific coast. The distinguishing feature for the continental part of the mountains is here, as in the South American Andes, the related, little folded, stratal succession, the long extended grano-dioritic batholiths, and the younger and youngest over-flattened and over-inclined vulcanism, with laccoliths in the little distorted stratal succession of the eastern border.

Concerning the Appalachians north of New York, the proof that they so apparently rank with the Hercynian southern sector, seems to me premature. The abundant observations, which are contained in the extensive literature, permit it not yet to be joined as a typical orogenetic belt sequence. The deep-seated difference in the foundations of both mountain sectors is not to be overlooked.

In a comparison of the northern Appalachians with the Caledonids of Great Britain, Bailey shows a stratigraphic relation between the Paleozoics of the two regions. He opines that disposition of the Canadian Appalachians and the the Gaspè sandstones, considered of Early Devonic age on the ground of the plant remains, is well founded. Therefore, there was also a similar kind of transgression on both sides of the Atlantic. He refers again, lately, to the relationship of the northwestern Scottish older Paleozoics with the Dungess limestones of Laurentia. In the chief supplementary relations, the Moine over-thrust has included additions of over-thrust folds on the Logan line, from the mouth of the St. Lawrence to the Hudson River at New York. The disturbed belt does not extend over the entire distance regularly. Compared with the three-fold, stepped over-thrust in the Champlain valley, in which four facies of older Paleozoics are brought together, the great Moine over-thrust seems simple, despite the fact of the presence of a number of minor thrusts there. The visible thrust-breadth, of 16 kilometers, in the Moine over-thrust, represents only a fractional part there, since the Moine and the Daldradian, by their movement over the Lewisian, are brought together.

True orthogenetic structure of the Scottish Caledonids appears in the southeast imposed upon thrust-sheet folds. This is illustrated especially by the researches of Bailey.[22] The Moinean is united tectonically with the Daldradian, and these again with the unmetamorphosed folded structures in south Scotland and in England. First, post-Siluric sediments were deposited over the crushed mountain areas, "Old Red" sandstones of Devonic age. The tectonic revolution which, perhaps in Siluric times, the Daldradian, as a metamorpho-tectonic unit, called into being, and with the Moine was folded, encroached upon the oldest early Paleozoics and pre-Cambric thrust-sheets of the Lewisian, where this was found in its immediate neighborhood. A wider interspace must have separated, at this formative period, both of these fundamentally different structures from each other.

The broad belt of pattern-folds, in the so-called "Appalachian geosynclinal" does not continue to the Logan line. A wide, moved west thrust is here replaced by a number of flat movement-planes, the shifting extending eastward far into the interior of the mountains. It produced there, in the crystallines, in Connecticut, Massachusetts, and Vermont, belts of retrograde metamorphism and mylonitic intercalations as an accompaniment of the greater thrust-planes. The Taconic chain, with the hundred-fold overturn minor folds is likewise, towards the west, piled up, and corresponds probably to a squeezed belt.

The great tract which is followed, as it were, as a mobile land, from the arch at the Logan line, in New Foundland on to the

22 Quart. Jour. Geol. Soc. London, Vol. LXXVIII, p. 82, 1922.

Hudson River at New York, shows no beltic succession parallel to the folds, such as occur in the mobile tract of the Hercynian Appalachians. It is composed of dissimilar structural elements. Extended folded belts, with close resemblance to the English older Paleozoics, are confined to the Canadian Appalachians. The Atlantic coast of Nova Scotia is attended, in part, by little metamorphosed pre-Cambrics, and extensive, fossiliferous Silurics.

The crystallines, diversified as are those in the southern Appalachians, find wide distribution in the New England states. These include abundant cata-gneisses (the so-called nethermost deep stages of Becke and Grubenmann), of the character of eruptive gneiss (groups of the Becket gneiss), such as the biotite- and plagioclase-rich sedimentary gneisses, schists, marbles, etc. To that end come yet more or less anciently altered, deep-seated masses, as granites, grano-diorites, diorites, gabbros, and the like. Repeatedly, as in the similarity of the schist-formation as a whole, is it compared with the Grenville series of Canada, by Barrell, Emerson,[23] Agar,[24] and others.

Farther to the southwest, lie, in the Hudson and Housatonic highlands, a similar, flatly disposed, widely extended body of schists, over Cambro-Ordovicic marbles, and of Poughquay quartzites over pre-Cambric ortho-gneisses. By Balk[25] the structures of these regions are described as resembling those of the the Alps, of the Erzgebirge, and of other regions with notable thrust-sheet structures. These lead to the supposition that also in these regions higher thrust-sheets once existed there. Prindle & Knopf[26] picture the northwesterly following transition tract with diaphtoritic and mylonitic layers, which circumstance points to the youngest, widely notable thrust of the manifoldly effected basement mountains.

The Canadian Caledonids unite a close stratigraphic relation of older Paleozoics with other folded belts of the Caledonids of Great Britain. The left-over space, shifted from the Logan arch, cannot be compared with the European Caledonids. The varied facies of base mountains in the south have no close counterpart in Europe. Neither the Moine, with its quartz-granulites, nor the thrust-sheet folded structure of the Dalradians appear to be represented in America.

23 Bull. U. S. Geol. Surv., No. 597, p. 394, 1917.
24 Am. Jour. Sci., (5), Vol. XVII, p. 197, 1929.
25 Proc. National Acad. Sci., Vol. XV, p. 616, 1932.
26 Am. Jour. Aci., (5), Vol. XXIV, p. 257, 1932.

Such, out of the ruins of the Caledonids and the ancient structures of united fragments of the Earth's crust are stacked against the Logan line, and in it they are made use of in increasing extent by the deep-seated orogenetic model. In its original state appear all the moved masses as great parent folds, or as a fold of depth, in the sense of Argand.[27] Because of the proportionally small influence of the sedimentary succession, lying in the outer folded belt, there appears to be supported, in comparison with the southern Appalachians, nothing of the nature of the "barren over-thrust," or the "charriage à sec." in the sense of Argand.[28] The Scottish Moine over-thrust illustrates this type very plainly. In their basal folding, block mountains take the place of the ancient crystalline mountains, and there is suppressed only a little of the chiefly marine sedimentary succession.

In conclusion: The essential facts which support, with greatest weight, the connection of Europe and North America, in the sense of Wegener, and as is already emphasized by Bailey, are the striking angular crossing, on both sides of the Atlantic, of the Caledonids and the Hercynids; further, the sharp separation of the European Acadian faunal province from the Canadian shield; and the reappearance of the Laurentian facies in the Scottish Moine over-thrust, which thereby may be added to the Logan line. They permit of scarcely any other explanation for the relations in general. In single, yet hindering, widely departing differences the combination dissappears on both coasts. Perhaps, as between Africa and South America, there are connecting sectors lost between Europe and North America.

From survey of the ever-growing literature a universal question is asked. The most important explanation to be expected is clearly one concerning the regions on the boundary, and to the north of our populous city, and in a larger global aspect, to which our view, full of hope for contemporary civilization, reaches beyond the sea, calls for, now, the particular geological problem which, when once solved, is for better understanding of the fundamental tectonic movements of the Earth.

27 Beitr. Geol. Karte Schweiz, p. 1, 1911.
28 Comptes Rendus, XIII Cong. Geol. Intern. p. 222, Bruxelles, 1924.