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STILLE'S ANALYSIS AND SYNTHESIS OF THE MOUNTAIN STRUCTURES OF THE EARTH.

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Hans Stille, professor of geology and paleontology at the University of Göttingen, has been writing about the greater structures of the earth since 1909. The fifteen papers that he has produced in that time have now been brought together in improved and extended form and the whole wrought into a book entitled "Grundfragen der vergleichenden Tektonik."[1] It is the only work of its kind and is unquestionably the most philosophic treatise ever published on the tectonic features of the earth's crust. The book does not, however, describe the detailed orogenic structures of individual mountains, but only those structures concerned with the greater tectonic features, their categories, and the times of their making. But to understand mountains fully, especially their groupings and their times of origin, it is also necessary to know their complete history, which begins with the gathering of their sediments and does not end even with their orogenic culminations. On the other hand, why there are mountains and what their relations are to the greater movements in the earth's mass can not be comprehended until the epeirogenic movements are also discerned and understood, and this knowledge, in turn, is not obtainable without making an analysis of the oceanic transgressions and regressions over the continents. Through an analysis of all these records, Stille has arrived at a synthesis of the mountains that does him great credit.

As the subject matter is in itself most difficult, and as the facts themselves are often capable of more than one interpretation, the author seeks to use an exact language, which makes his descriptions very technical, and, for a non-German, most difficult to follow and especially to translate into English. Many more diagrams illustrating the structures described and

[1] Pp. viii + 443, 14 text figs., 1924. Berlin (Borntraeger).

more everyday German with the technical terms in parentheses or in headlines would have made such work easier and more precise.

The first part of the book (pp. 6-39) has to do with the fundamentals of tectonics; the second with the fundamentals of orogenesis and the larger features of individual mountain systems and their causal connections (pp. 40-280); the third with the fundamentals of epeirogenesis (pp. 281-386), which lead the author to seek for the causation of the spillings of the oceans over the continents; then follows a short chapter (pp. 387-399) which is a summation of the book; and finally there are three indices, to authors, places, and subjects.

Stille's great book opens with a study of geosynclines, and his usage of this term is in the widest generic sense, that is, he applies it to any sinking area, small or large, flexured or faulted, and having marine or continental deposits, finally regarding even the oceans as geosynclines. This is of course not the original conception of Hall, based on the Appalachian basin, but is the unfortunate extension that Dana finally gave to his own term geosyncline. Geosynclines, in a narrower sense, are, then, in the main the long-continuing sinking areas of the lithosphere, troughs like the Appalachian and Cordilleran and the mediterraneans. These are, in general, the mothers of future fold or fold-fault mountains, but Stille says not all of the geosynclines have had such progeny.

It seems to the reviewer that Stille, in using geosynclines in this wider sense, fails to work out a clear picture of what has obtained in the different orogenic areas, due to a difficulty under which all European geologists labor, in contrast to the simple problems facing their fellow workers in North America: the Europeans are working with Tethys—a mediterranean which is a *narrow ocean lying between continents* and which, when in orogenic labor, adds from its abyss to the adjacent continents; while Americans are dealing with *shallow basins which have always been parts of their continent* and which, during orogenesis, add nothing to the continent but on the contrary subtract from its greatness through their folding and faulting. This criticism becomes plainer when we point out that the Caledonian geosyncline also is not one in the American sense, but is a comparatively small mediterranean, lying, as Stille correctly says, between the continents of Eria and Fennosarmatia (Baltic Shield); accordingly, the geologic results are somewhat similar but less grand and less complicated than those of Tethys, though in both occur the decken structures that are never seen in similar extensive development in the typical geosynclines (Appalachian). When the Caledonian mediterranean was squeezed into land, seemingly through the approach of the two continents, the three parts were welded through the upfolding of the sea-way into one land mass; but when the Appalachian or even the greater Cordilleran geosyncline passed into mountains, North America was not enlarged nor united to another continent.

The study of tectonics, Stille says, has to do with the movements in the earth, and mainly with the lithosphere, or, better, the outer part of it sometimes called the tectonosphere. But tectonics in the wider sense also takes cognizance of the deeper plastic parts, for when these are in flowage, they carry along the outer stiff crust. From these plastic parts it is only a step to the more mobile magmas, and their movements are also tectonics in that they bring about changes in the form and position of the parts of the rigid outer surface of the earth.

Tectonics includes orogeny, which makes anticlines and synclines (= fold mountains), and epeirogeny, which creates geanticlines and geosynclines (= wide arches that are depressed-convex or concave). Expressed in tabular form, diastrophism appears thus:

Orogenic, of comparatively short geologic duration —episodes or revolutions	Gives rise to	Undulations: anticlines and synclines
Epeirogenic, of long geologic duration in anorogenic times—evolutions	" " "	Undations: geanticlines, plateaus, and continents, geosynclines and epeiric seas
Synorogenic, short in geologic duration	" " "	Accentuations of geanticlines during orogenic times
Synepeirogenic, short in geologic duration	" " "	Orogenic movements during anorogenic times

Before we can arrive at the fundamental meaning of the periodicity of the successive orogenic occurrences, we need to have, as the author correctly says, exact discernments concerning the time occurrences of the individual orogenies, and likewise we need to understand and distinguish the various movements of the seas during geologic time in order to derive a second fundamental conception, namely, the universality of epeirogenic times.

In the study of mountains, the first important step is to discern their time relation—the chronologic law (*Zeitgesetz*). Mountain making is of relatively rare occurrence when considered in relation to vast geologic time, but each orogenic phase, even though of relatively short duration, has more or less of a definite time significance. Orogeny may occur at the same time in the most widely separated regions of the earth (= *Gleichzeitigkeitgesetz*—law of contemporaneity). In certain areas an orogeny appears isolated and alone, and in others one to three or more may be superimposed in time.

On the basis of their internal structures, all tectonic mountains can be grouped into fold mountains and fault mountains, though transitions between these types occur. All mountain structures are consequences of upward directed movements in relation to sea-level, but fold mountains are due to lateral pressures, while fault mountains are in the main due to radial ones. The diminuendo of tectonic deformations goes from decken thrusts down through recumbent folds, fold-thrusts, folds, monoclinal blocks, to normal faults. More of this is expressed in the following table:

Fold-thrust mountains Alpine type	Overfold mountains. With greatly drawn out folds and overfolds and widely transported overthrust sheets (decken). According to Heim, the Alps are reduced to one-half to one-third of their original width.
	Fold mountains. Marked by foldings and secondarily by thrusts.
Fault mountains Germanic type	Fault-fold mountains. Characterized by faulting followed by some flexing and folding. A typical example is the Saxonian mountains.
	Block mountains (sometimes called table mountains). May or may not have the blocks tilted; little or no folding. Example: Great Basin ranges.
	Rump mountains. Originally of any of the above kinds, but leveled by vast erosion.
	Mountains of erosion and mountains of extrusion (volcanoes). Not of tectonic origin.

The first four types of mountains are conditioned by the degree of mobility or tectonic consolidation of the material

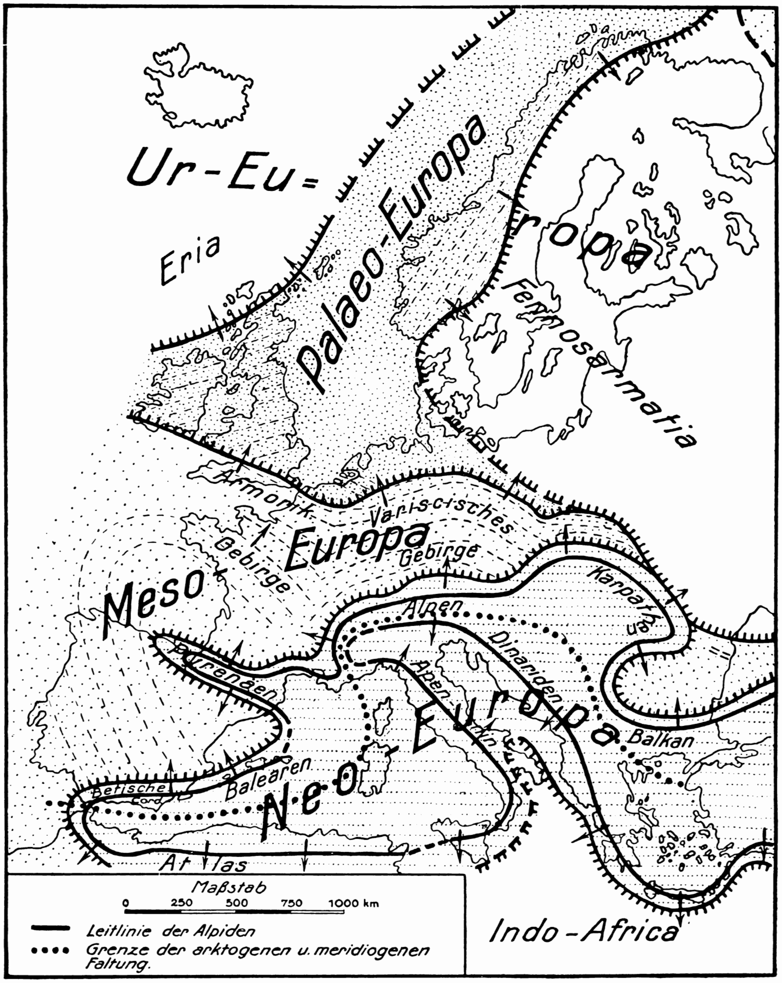

Fig. 1.—Successive tectonic zones of Europe. After Stille.

composing them at the time of their orogenesis, and fall into two main categories, namely:

Alpine type. Materials mobile because unconsolidated tectonically previous to orogenesis.

Germanic type. Materials resistant because stiffened by previous orogeny.

With the above as a basis, the mountains of Europe arrange themselves into four zones according to the degree of their tectonic consolidation (see Fig. 1). These are, from north to south,

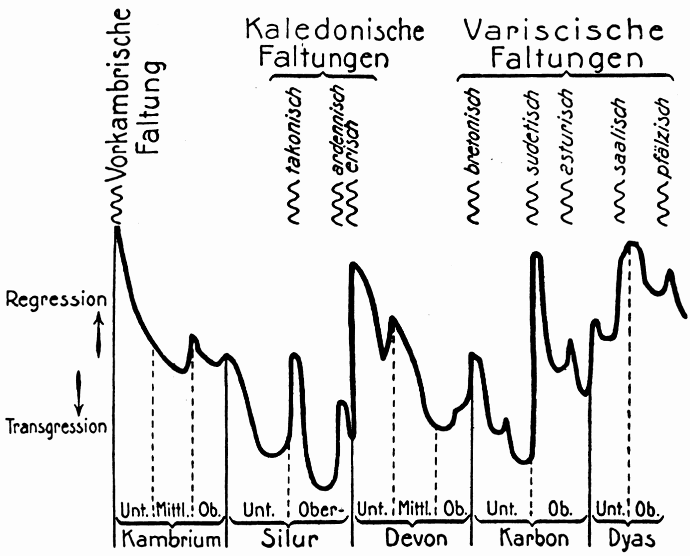

Fig. 2.—Times of Paleozoic orogenies and sea movements. After Stille.

Precambrian or ancient north Europe = Eria and Fennosarmatia.
Caledonian or old northwestern Europe. Thrust upon Eria and Fennosarmatia.
Variscian or medieval central Europe.
Alpine or youthful south Europe.

Northwestern Africa has similar zones of consolidation, but in the reverse order, that is, from south to north; between the two widely separated orogenic fields lies the remainder of Tethys, the present Mediterranean.

The orogenic law first defined by James Hall, namely, that the fold zones of the earth are the areas of thickest sedimentation, Stille holds is true not only for the Alpine type of mountains but for the fault-fold Germanic type as well. Geosynclines become the most mobile parts of the earth through their long continued sinking and the accumulation of essentially detrital deposits laid down in thin and thick beds of varying mobility. Eventually these areas attain geosynclinal maturity (*Reife*) and then through lateral pressures they are pushed into undulations. These folded and stiffened areas may regain their mobility through renewed geosynclinal sinking and sedimentation, and the new and old formations again undergo folding in a secondary maturity. The attainment of geosynclinal maturity is not determined by the conditions in the geosynclines themselves, but by forces outside of them. On the other hand, it may well be that the nature of the deposits is a factor in this, as, for instance, when thick-bedded limestones, dolomites, or sandstones, in well cemented and thick formations, are so resistant as to make for immobility and failure to fold through orogenesis.

Comparative tectonics reveals to Stille six orogenic laws. He finds that each orogenic time is of relatively short endurance in limited areas, or of world wide distribution, and furthermore, that each orogenic time appears simultaneously in the different regions of the earth. From these facts he deduces (1) the *law of orogenic contemporaneity.*

Since the Proterozoic, there have been at least thirty different orogenic times (phases of Stille). Three of these he combines into the Caledonides, embracing the time before the Middle Devonian. About those of the later Devonian he awaits further information. The next five orogenies, of later Paleozoic time, are embraced under the Variscides. All the remaining ones, eighteen to twenty in number, are included in the Alpides, or Saxonides, about half of them occurring in Mesozoic times (mainly Cretaceous) and the remainder in the Cenozoic.

It appears to the reviewer that Stille's grouping of the orogenies into three tectonic climaxes is clearly not a chronogenetic one, nor is it in harmony with the era culminations expressed in our geologic time-table. It is, for example, curious to see all Mesozoic and Cenozoic orogenies regarded as of one genetic culmination, and only somewhat less disconcerting to see his combination of the post-Devonian orogenies, with a culmination in the Permian. That the idea of grouping orogenies is as sound as that of grouping epochs into periods and these into eras needs no argument, and hence, for the present at least, it appears desirable to combine the individual orogenies into larger and larger categories in order to harmonize them with, or to show variances from, the climaxes expressed in our accepted time-table. For instance, Paleozoic time is certainly twice as long as subsequent geologic time, and yet its combined orogenies are made to appear in Stille's scheme as far less significant than, for example, those of the Mesozoic, which is a far shorter era. If, however, we note the greater orogenies according to their appearances in geologic time, we get climaxes in the Silurian, Devonian, and the greatest of all in the Pennsylvanian-Permian; then there are the culminations of the Jurassic followed by the Laramides of the late Cretaceous; and finally those of the Cenozoic are topped by the greatest movements of Miocene-Pliocene times, resulting in the Alpides. If, now, we make a curve of these orogenies according to their time and strength, we get small waves (the phases) that gather into another series of a higher order and these culminations appear with constantly increasing speed and tectonic importance. This speeding up of orogenic times has apparently been overlooked by all geologists. What does this striking fact of acceleration in tectonics mean? We get no answer from Stille because his plotting appears to have obscured this fact from his observations.

Now let us return to Stille's other four laws of tectonics. (2) The *law of contemporaneity of orogenic form* expresses the fact that all kinds of orogenic structure types can be made in one and the same tectonic time. In no sense do the categories of orogenic structures stand separated from each other, but all transition stages are known between the overfold mountains at one end and the block structures at the other. This fact brings out (3) the *law of the unity* (*Verknüpfung*) *of orogenic forms.*

(4) The *law of orogenic elevation* (*Hochbewegung*) holds that all fold, thrust-fold, and block mountains result from upward movements relative to sea-level. It also denies the assumption that block mountains arise through the downsinking of their blocks. (Is not this assumption contradicted by the structure of the Great Basin?) There is no fundamental difference between tangential pressures that make fold mountains and purely vertical orogeny that gives rise to block mountains.

(5) The *law of identity of orogenic force* holds that the same force gives rise to all kinds of orogeny. Secondary causes, such as isostasy, which is directly opposed to mountain making, and which is compensatory and local in effect, are of far less importance. The frequent tensional occurrences are also thus explained.

(6) The *law of conditioning of orogenic form* holds that the type of structure is determined primarily by the degree of mobility of the subsurface. Folding results from mobile ground, block faulting from resisting ground, salt plugs rise out of the very mobile salt beds, and the most mobile of all are the rising magmas. Again there are transition forms between these various categories. Accordingly, the structures in a given mountain range may be harmonious or inharmonious, and disharmony results from variably resisting masses pushing through and over one another.

The mobility of the crust varies during geologic time due to orogenic, epeirogenic, magmatic, and external consolidations. Folding and magmatic introductions stiffen the crust and often prevent refolding, and the oftener these recur the more resistant the crust becomes, until finally it is dead to mobility and resists all orogenic changes, but is still subject to epeirogenic movements. However, a stiffened area may be made mobile through becoming a new geosyncline.

The term "frame" (*Rahmen*), long in use by Stille, appears to the reviewer to be the same as Suess' foreland and shield. In front or outside of these lie the growing geosynclines. The latter at maturity go into orogens and are folded against the old land, which is thus enlarged by the encircling younger orogens. Again, new geosynclines may develop in front of the enlarged frame and in turn give rise to other orogens. In this way Europe has been built up through successive additions, first by the Caledonides, then by the Variscides, and finally by the Alpides. However, this does not include all of the tectonics of Europe, since within the vast frame there develop secondary geosynclines (*Sonderbecken*), which in the main have continental deposits, and secondary geanticlines (*Sonderschwellen*) as well. It is these secondary epeirogenic developments that are so characteristic of the Germanic type of mountains.

Nowhere does Stille appear to see the full significance of what Schuchert has called borderlands, structures that lie on the outer side (oceanward) of the true geosynclines. These have nothing to do with the forelands, the frame of Stille. In the genesis of Tethys, which has the tectonic significance of an ocean, similar but shorter and narrower and less long-enduring geanticlines arise time and again to the southward, one after the other, out of the deeps of this mediterranean, and eventually becoming parts of the orogens, are pushed northward and some appear to have gone into decken. Accordingly, such newly arisen lands are not to be homologized directly with borderlands, since the latter are far larger, and, what is most significant, have always been the outer parts of the continents and not additions to them raised out of the oceans, as are the lands born of Tethys. In the geography of to-day, comparable masses are the island arcs (Japan, etc.) of the western Pacific. But borderlands, as was said before, have always been parts of the continents and therefore are not the same as the island arcs of the present geography, but are geanticlines born of the oceans and mediterraneans. To distinguish the island arcs of geologic times from those of the present, and more especially from those of Tethys, it is here proposed to call them *paleoarcs*. If this hybrid be objected to, then we could speak of them as *ancient arcs* to distinguish them from the present island arcs.

We now come to one of the most vexed questions in orogenic interpretation, namely, were the mountains folded from one side or from both? Stille gradually approaches the answer to this question by relating the history of how our present knowledge of mountain origin has arisen, and in abbreviated form this is as follows: Von Buch, studying the Alps and the volcanoes of Italy, and also noting the common occurrence of crystalline cores in mountain ranges, concluded that volcanism was the cause of their symmetrical structures in that it was the rising granite masses that pushed into and thus folded the formations to the north and south. Seemingly it was De Beaumont who was the first (1829) to say that the mountains owe their origin primarily to shrinking of the earth's mass, and in 1852, noting the fanlike structure of Mont Blanc, he further concluded that it was lateral pressure from two sides that made the mountains, comparing this movement to the closing in of the jaws of a vise. The theory of pressure from one side only, giving rise to unsymmetric mountains, arose in America first in 1836 and in final form in 1868 in the Rogers brothers through their studies of the Appalachians. As early as 1842, H. D. Rogers pointed out the one-sided pressure seen here in the many parallel folds and the absence of a central granite axis, a condition very different from the symmetric structures so general in the mountains of Europe. Rogers attributed this one-sided pressure to wavelike pulsations from deep-seated magmas, a view which Dana altered by explaining that the push came from the subsiding oceans toward the continents, folding their margins through the addition of new land. The reviewer would add here that the first part of Dana's theory is now widely accepted, but that the second part has not stood the test of time; what the oceanic push has done is to shove inward the borderlands and thus crowd together and fold the strata of the geosynclines, while long afterward most of the borderlands have been broken down into the depths of the Atlantic and Pacific oceans.

In Europe the theory of one-sided tectonic pressure in fold mountain making was slow of acceptance, but eventually it gained very general adherence and especially through Suess, whose great classic, "Das Antlitz der Erde," was dominated by this theory. Even so, it left the Alps unexplained—"the sore spot in Suess' hypothesis"—since they are actually the type example of two-sided orogens, and Suess' idea that the Dinarides are but one-sided mountains pushed from the south and added to the Alpine arcs has not met with acceptance. The Caledonides of Norway and Scotland Stille regards as a beautiful example of a two-sided orogen, caused by the approach of Eria and Fennosarmatia. "The folding push accordingly works from the frame toward the geosyncline, and the folds arising out of it are recumbent toward the frame." These examples, he holds, make it clear that the overfolding toward these lands is not proof that the direction of pressure was also toward these lands, rather that each side of the mediterranean was squeezed outward in a more or less fanlike way as the two continents moved toward one another. Accordingly, the dip of the folds and the direction of the tectonic pressures are opposites of one another. Hobbs (since 1912) and Kober also hold that the one-sidedness of the mountains is due to pressures from the old lands (Rahmen), the underthrusting being toward the geosynclines. On the other hand, Haug points out that one-sidedness may also be explained in that one continental mass remains fixed while the other one moves toward it, and that one-sidedness need not always mean pressure from one side, but that pressures may come from either side of the geosynclines.

It may actually be, Stille concludes, that mountains are made through pressures from one side and from two sides as well. One-sided mountains rise out of wide sinking areas (oceans) near the periphery of the continents, but when continents are near each other and the separating sinking area is comparatively narrow, as in Tethys, there arise, through the inward movements of the continents (Africa and Europe), pressures, as in a closing vise, that may make for bordering mountains on either side of a medial unfolded seaway. In extreme cases, i.e., in a very narrow geosyncline, the whole may be pressed outward and folded fanwise as appears to have been the case in the Caledonian mediterranean, or in the geosyncline of the Pyrenees between the Central Plateau and the Siberian Meseta during the Alpine orogeny; and then one must regard one half of the fold-fan orogen as belonging to one continent and the other half to the other land.

One can not, therefore, correctly say that the orogenic pressures actually worked from one side or from two sides. If the basins between the continents are relatively small (Caledonian, Pyrenees, and in a certain sense also the Alps), then we have the phenomena of two-sided pressings; when, however, the basins are broad, then each of the margining lands will appear with one-sided pressures. The latter type is especially developed when the foldings occur along the margins of continents separated by wide oceans, since in this case one can not speak of two-sided mountains. It is evident from this that Stille does not agree with Kober in regarding the Appalachians as a two-sided orogen of which the outer half has broken down into the depths of the Atlantic.

In many instances, and more especially in the Mediterranean tectonic belt, the separate mountain ranges appear in general as one-sided orogens, but this is because the European side is nothing more than one part of a very wide two-sided tectonic zone, the other part of which lies in Africa. These conclusions of Stille will take on a somewhat different aspect when he keeps more in mind the presence of paleoarcs, since in some cases these have been squeezed to the north, and in others have been pushed upward and outward, causing fan-like structures. The tectonic labors of Tethys are ever so much more manifold, and hence decidedly more complicated, than are those of the Appalachian or even the Cordilleran geosyncline.

Epeirogeny has to do with the secular or long-continued movements affecting great tracts of the earth without disturbing their tectonic structures. The more recent of these movements are easy to see in the morphologic forms of the present lands and especially so in the epeirogenically elevated terraces that may be traced far and wide along the shore lines.

For older times the best clues to epeirogenic movements are to be obtained from paleogeographic maps that picture the transgressions and regressions of the oceans over the lands. This is one of the special features of Stille's work and he devotes much space to an analysis of the transgressions. The crust moves and so affects sea level, and while the movements of the oceans are in the main due to wide crustal movements, yet the strand-line is also elevated or depressed by changes in the topography of the land, which pull variously on the mobile waters; also to subtraction of water to make ice-sheets during glacial times, and to its return when they melt; to changes in earth rotation; and finally to the dumping of the detritals of the lands into the oceanic basins as sediments.

Stille does not find that Haug's "law of epeirogenic compensation" holds true, namely, that when the geosynclines (means mediterraneans) are filled with marine water there is compensation in regressions elsewhere, nor does it hold true for the reverse of these conditions. The "law" does hold in some cases, but in general, compensating movements do not exist. (There is complete discussion of this matter on pages 322-344.) In other words, there are times of dominantly marine and of dominantly land tendencies, and also orogenic times when the waters of the geosynclines are only partially removed, but these displaced waters do not result in floodings over the neutral or medial portions of the continents. Where, then, do these waters go? Stille thinks into other deepened geosynclines or into the oceans, which become the water asylums of the geocratic (land) times. During the anorogenic times, one or more or all of these asylums become shallowed and so bring on the great floodings of the lands.

The changes in the sea-level that bring on the transgressions during anorogenic times and the regressions during orogenic times are generally due to movements of the earth's crust, but may be accentuated, at least in part, by non-tectonic causes such as erosion and sedimentation. Stille finally concludes that the wide and slowly progressing marine transgressions, one or more of which are so characteristic of each geologic period, are phenomena of the long-enduring anorogenic times, and while the wide and quickened regressions occur mainly in orogenic times, they also take place in anorogenic epochs. Furthermore, during geocratic times the enlarged lands are on the average highest, while the areally diminished oceans are deepened; in other words, the relief of the crust is somewhat greater. On the other hand, during thalattocratic (flood) times, the smaller lands are lower, and the enlarged seas are less deep; in other words, there is less contrast in the earth's relief. Therefore the transgressions and regressions are in the main due to internal or epeirogenic crustal movements (undations) which are usually of world-wide distribution and everywhere nearly simultaneous; while the orogenic undulations are caused mainly by tangential pressures.

Finally, Stille says the epeirogenic force is nothing other than a weakened orogeny, the orogenic a strengthened epeirogeny; both are alike qualitatively and differ only quantitatively. The canon of the sea movements is at the same time the canon of the changing intensity of the tangential earth pressures, and from the sea movements is also derived the general pulsing of the crustal pressures.

Comparative tectonics shows that the more stable regions are subject to upward undations, while the more mobile areas are subject rather to downward ones. Hence it is not only a question of stability as such, but of relative stability in comparison with the neighboring areas. In this way is explained the accentuated sinking of the mobile regions on the borders of stable units, which leads to the so-called border deeps (*Saumtiefen*). The latter are therefore epeirogenic reactions of the geanticlines. The present deep-sea troughs and the old and young foredeeps are also to be regarded as border deeps, although we see here in addition some isostatic compensations.

Accordingly, tectonics is a function of

(1) the intensity of the tectonic force = pressure factor,
(2) the capability of reaction in the materials involved = composition factor,
(3) certain location relations = location factor.

In the main, however, the world of tectonic appearances is founded on the first two factors, namely, on the relationship between pressure and reaction ability.

What is the cause of tectonics? This fundamental question Stille does not discuss in his book, but the context shows that he is orthodox in holding that the earth is a shrinking mass. That this is actually his stand is clear from his address of 1922 entitled "Die Schrumpfung der Erde," in which he says, "The theory of a shrinking earth is not disproven; and still less has anything better been offered to replace it." Furthermore, ever since 1912 Stille has dissented from the view that mountains are made through orogenic causes; isostasy is a locally operating cause, while orogeny is cosmopolitan in appearance.

However, we must ask, Is the fundamental causation of tectonics so simple, and does the principle of isostasy play so small a rôle in the movements of the earth? Stille finished the writing of his book in September, 1924 and the reviewer received his presentation copy in June, 1925. Hence Stille could not have considered the epochal Halley lecture on "Radioactivity and the surface history of the earth" by Joly of Dublin, published in 1924 and appearing the next year in more extended form as "The surface history of the earth" (Oxford University Press); nor did he, apparently, take into consideration "The movements of the earth's surface crust" by the same author, which appeared in June, 1923. According to Joly, the reason why the earth has a rising and sinking surface is mainly because of (1) radioactivity and (2) isostasy. Through the breaking down of uranium and thorium within the earth, more heat is generated than can escape at the surface, and hence it accumulates in the "basalt substratum," which probably lies only a few tens of kilometers from the surface. Accordingly, the substratum is melted periodically, and then the granitic continents which have been buoyed up isostatically sink epeirogenically as the density of the substratum decreases, and the oceans spill widely over the continents. As the substratum expands through fusion, the crust is jointed by tensional forces and magma rises, filling and healing the fissured crust. When the substratum is more or less fluid, tidal forces also come into play and the crust lags in rotation, and thus with time the whole of the upper part of the substratum is cooled by the oceanic waters. Then the substratum again becomes solid and with increasing density the continents rise isostatically, causing the epeiric seas to regress into the oceanic basins. Not only this, but because of the shrinking and restiffened crust the greater and more subsiding oceanic areas press against the continents and thus squeeze together into mountains the more mobile areas, the geosynclines and mediterraneans.

We agree with Longwell that "Professor Joly has made an important contribution to the field of speculative geology. If the objection is raised that many unknown factors are involved, the answer may be made that the theory has a sound basis in recent scientific developments, and certainly it offers a reasonable explanation for more geologic factors than does any other theory known to the reviewer. The rhythmic submergence and emergence of continents; the periodicity of mountain making, and the localization of folded mountains; the larger facts of igneous geology; the apparent requirement of considerable mobility in the outer earth at certain periods: these and other large problems find at least a partial solution in this attractive hypothesis."[2]

The merits and weaknesses of Joly's arguments, Longwell goes on to say, are discussed by Holmes,[3] who "shows the improbability that the continents have ever floated freely in basaltic magma. He suggests that the basaltic layer is comparatively thin—40 kilometers or less—and lies directly above a peridotite zone which has a much smaller content of radioactive material. Fusion of the basaltic layer would then account for periodic disturbances, and at longer intervals simultaneous melting of the basalt and peridotite would produce a revolution."

Viewing Stille's more fundamental results in the light of the reviewer's knowledge of the diastrophisms of North America, and these in the light of the further studies of Joly and Holmes, it seems evident that the heretofore very vexed question as to what causes tectonics is about to be answered with more finality than ever before. As the earth is a heterogeneous mass, seemingly the accumulating radioactive substances must be locally variable in amount, letting down through isostatic compensations small portions of the crust, now here and now there, and at other places and times of wider molten conditions causing more and greater areal sinkings. On the other hand, when the substratum is more widely softened, tidal actions may set in, due to the moon's influence, the continents appear to shift in part, and these motions, along with those produced through solidification, bring on the more general times of orogenesis. Parenthetically it should be said, however, that Joly's theory of tidal drifting over a molten substratum is something very different from Wegener's improbable theory of continental drifting through a cold substratum, resulting, as he thinks, in differential drifting of the continents through thousands of miles.

Seemingly, then, it is the changes in the substratum—its differential swellings, consolidations, shrinkings, and driftings—plus the periodic rejuvenation of isostasy, plus some actual shrinking of the earth as a whole, that in the main bring on its diastrophism.

Peabody Museum, Yale University,
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[2] Longwell, C. R., this Journal, 11, 521-522, 1926.
[3] Holmes, A., Geol. Mag., **62**, 504-515, 529-544, 1925; **63**, 306-329, 1926.