

GEOSYNCLINES: A FUNDAMENTAL CONCEPT IN GEOLOGY.

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PART II.

III. OROGENETIC ASPECTS.

(a) Geosynclines and Folded Mountain Zones

The concept of geosynclines was established in close connection with investigations into the origin of mountain zones. James Hall considered folding as a direct result of subsidence during sedimentation and mountain building as a result of upwarping which reaches its maximum in the zone of thickest sedimentation. Although this does not explain the process of orogeny, it does point to a connection existing between two major features of the earth's crust, the visible mountain chains consisting of folded rocks and the inferred geosyncline which preceded them. The nature of this connection, the causal relation between these two elements, have been studied and discussed by numerous geologists since the time of James Hall.

Dana (1873) invoked folding of the geosyncline by lateral compression and expressed the view that mountains are formed by geanticlinal movements embracing a wider area than that of the geosyncline. It seems that subsequent authors did not fully appreciate the importance of this departure from Hall's theory of an automatic folding of geosynclines. Lawson (1942) has later expressed ideas somewhat similar to those of Hall by stating that folding could be expected to occur in a geosyncline as soon as the thickness of sediments had reached the order of about 40,000 feet.

Haug's work contains the generalization that mountain zones arise from geosynclines. It should be clearly understood that this does not mean that geosynclines are *necessarily* transformed into mountain chains. Even in its original form Haug's statement cannot be accepted without restriction. Argand (1924) recognized that in addition to "Chaines geosynclinaux" there exist "chaines de fond" "chaines de couverture" and "chaines liminaires," which are unconnected with geosynclines.

Schuchert (1923) stated that "geosynclines are destined to evolve into mountains." This was in agreement with Hall's but opposed to Dana's and Haug's views. Hall's statement

that deformation during deposition was the initial phase of the folding of sediments in a geosyncline received support recently from observations by Cornelius (1925), Pruvost (1930), Bärtling and others. This, however, does not prove the postulated causal connection between the development of a geosyncline and its subsequent transformation into a folded mountain chain. Stille, in 1924, believed that folding was a sign of maturity of geosynclines, but not every geosyncline was destined to become mature. Those that matured he called "mother geosynclines."

Kober (1928, p. 52) saw that his orogenetic zones or "orogenes" were related to the geosynclines of Dana and Haug but he was reluctant to consider the two concepts as entirely identical and used the expression "orogeosyncline" (or "orosyncline") for the sedimentary belt in the pre-orogenic stage. His term "orogene" was subsequently replaced by "tectogene" as the discussion centred on the concept of a folded zone as a structural feature rather than a mountain zone in a physiographic sense.

Is the mobility of the geosyncline identical with the mobility of the orogene (tectogene) or is the ultimate tectonic fate of the geosyncline determined by factors not directly related to its origin and early development? The answer to this question depends on the acceptance of one or the other of the numerous current hypotheses of mountain building. The only aspect to be considered here is the nature of those sedimentary basins which possess characteristic features of geosynclines but which are not affected by orogenic movements.

(b) Unfolded and Weakly Folded Geosynclines

Many later authors lost sight of the fact that Dana and Haug included among their examples of geosynclines many basins of deposition in which the sediments have remained unfolded or have undergone only weak folding. Dana mentioned specifically the tilted and faulted Triassic strata of Connecticut. Haug stated that the Scandinavian and Canadian massifs are separated from the zones of Hercynian and equivalent folding by depressions or shallow geosynclines which are characterized by peculiar facies and by undulating folding. He included the "subhercynic hills" among the examples

for this type of geosyncline and mentioned the Paris basin in the same connection. Stille (1924) supported this wider concept. He stated that folding is no essential prerequisite of a geosyncline and that no sharp distinction can be made between those that are folded and others that are not. He defined geosynclines simply as areas of secular (slow and long-continued) subsidence. We shall see that at a later stage he re-introduced the orogenetic approach when he began to differentiate between various types of geosynclines.

Obrutschew (1927) expressed the opinion that folding in a geosyncline depends only on stresses in the basement. The absence of such stresses in certain areas and at certain times explains, according to this author, why some geosynclines remained unfolded. In this connection, reference should be made to Grabau's work (1940) in which among many other important statements on geosynclines, he draws attention to continental geosynclines such as the Indo-Gangetic plain or the Hoang-ho delta. They are filled with great thicknesses of sediments but are essentially unfolded. A recently published graphic comparison between the reconstructed Appalachian trough and the Gulf Coast basin of deposition indicates the remarkable analogy between this area which is neither strongly folded nor a mountain zone and Hall's typical geosyncline (Storm 1945). Finally, Molengraaff (1920) and Umbgrove (1933) recognized in the East Indies marginal basins situated between the strongly folded zones and the stable areas. They are filled with thick series of sediments but are only weakly folded. Umbgrove proposed the term *Idiogeosyncline* for this type.

(c) Cyclic Development

During the last twenty years or so there developed a school of writers who attempted to amalgamate contrasting features and who by tracing "evolutionary trends" built up a unified deterministic picture of the geosyncline.

The germ of the idea is already clearly expressed in early writings by Stille (1913) and Tornquist (1916) that the history of geosynclines follows a predetermined uniform pattern from which there are few deviations in individual cases. Folding indicates that the geosyncline has reached a state of "maturity." The stages of the "evolution" of a geosyn-

cline as these authors see it may be indicated as follows:—
Evolutionary Stage—

1. Initial, presumably rapid, subsidence.
2. Long continued subsidence, mostly oscillatory, with accumulation of thick sedimentary series.

Revolutionary Stage—

3. Uplift of certain parts and finally of the entire geosyncline above sea-level so that it becomes a mountain chain.

Decay—

4. Fracturing and formation of horsts between which parts of the geosyncline sink back into the deep.

The question whether or not areas which have not completed the full cycle should be excluded from the definition of geosynclines is one that has been much debated in subsequent years. As has already been noted Stille, in 1924, gave a much more comprehensive definition of the term, but in still more recent writings (1936, 1940) he recognized the immense complexity of the problem by starting out on the path of multiple terminology (see below).

At this stage it is perhaps necessary to call attention to the fact that the conception of the "geanticline" had by now undergone considerable change at the hands of alpine writers. Haug, and following him, Argand and many others considered that preparatory to the folding of a geosyncline the floor of the latter was thrown into wide undulations. The rises were called "geanticlines" which separated "secondary geosynclines," all running more or less parallel along the trend of the main or primary geosyncline. Tornquist used "geanticline" both in Haug's and in Dana's sense, thus combining quite obviously unrelated features, but Stille in 1924 returned to the original definition of Dana.

The idea according to which all geosynclines complete evolutionary stages according to a predetermined pattern culminated in the writings of Bubnoff and of Kraus. Kraus distinguishes the following stages and illustrates them with examples from alpine geology³:

³In the following the terms preorogenic, kataorogenic, epiorogenic, and postorogenic are proposed to replace, respectively, Kraus' original terms "vororogen, tieforogen, hochorogen, nachorogen."

1. *Preorogenic stage.* Shallow sea with slightly undulating bottom relief. Generally quiet time, except for the slow sinking of the geosyncline. Compare eastern Alps during Triassic.

2. *Kataorogenic stage.* Increasing relief of the seabottom and accelerated subsidence of certain parts of the geosyncline. Flysch, the sediment of the later stages, when many swells have risen above sea-level and even new islands are being formed, is thus an "interanticlinal sediment of the archipelagos." To this stage belong basic, submarine extrusions which may already have started during the preorogenic stage. The seat of the forces responsible for this "mobilization" of the geosyncline must be looked for at depth, in the deeper more mobile parts of the crust.

This stage comes to an end at different times in different parts of the geosyncline, in the case of the Alps partly in the Middle Cretaceous (pre-Gosau), partly later, in the Middle Oligocene.

3. *Epiorogenic stage.* Characterized by Molasse—the detritus deposited partly in shallow seas, partly as lacustrine and fluviatile beds on the foreland. At the end of the kataorogenic stage there was already considerable relief above sea level. Now flysch sedimentation ceases, because the flysch troughs were elevated above sea level. The sea also recedes from the marginal parts of the rising mountain chain where swamps were formed (peat and brown coal formation). While the central mountains rise, the molasse troughs sink, and intrusions characterize this phase.

4. *Postorogenic stage.* This is the period of isostatic adjustment which leads to the formation of the present relief of the mountains.

H. Cloos follows the same line of thought when he (1936) speaks of the "almost mysterious" way in which the formation of folded and nappe mountains is preceded by the development of sedimentary troughs which are characterized by special facies and thickness conditions. "We know hardly any complete folded chain, which has not gone through these evolutionary stages. On the other hand, we know of hardly any unfolded sedimentary series which possesses all the characteristics of a geosyncline."

Finally we may have a translation from a recent paper by Bubnoff (1937) in which he states: "It seems to me that the turbulent and vicissitudinous history of these troughs is still more important than subsidence, for they were not at all continuously covered by deeper seas, but comprised shallow parts and island arcs which emerged and subsided in a certain, apparently regular, rhythm. Moreover, these were the places of violent, mostly submarine, volcanic activity during which predominantly basic rocks were erupted. These physico-geographical conditions led to a distinct type of rock formations in the troughs, fundamentally different from the normal rocks of the shallow epicontinental and shelf seas. *Firstly*, the thickness of the sediments is very much greater and may be 10 to 100 times that of the shelf sediments. *Secondly*, the rhythmical change of sand, clay, limestone is hardly or not at all found in the steadily sinking geosynclines, mostly we find thick uniform series predominantly shaly and slaty rocks, corresponding to the finer erosion products of the neighbouring mainland and often poor in carbonate rocks. A *third* characteristic is the intercalation of submarine lava flows of predominantly basaltic constitution which in this form are not found in shelf deposits."

The overstatement of the case will perhaps best appear from the inconsistency which tells us in one sentence that parts of the geosyncline emerge and subside in regular rhythms, and in another that no rhythmical changes in the sediments are observed because of the steady sinking of the geosyncline.

Although this school of writers has made valuable contributions to the study of certain important sedimentation areas, and has drawn attention to the significance of the close association between certain types of sediments and of intrusive rocks, it would seem that their conclusions have been driven too far and a very complex problem has been reduced to an over-simplified pattern.

IV. GEOTECTONIC ASPECTS.

A purely lithogenetic or orogenetic approach to the problem of the geosynclines involves the assumption that they lead an independent existence unrelated to other elements

of the earth's crust forming their actual surroundings. Since the beginning of this century, it has become increasingly clear that investigations into the relations between non-geosynclinal elements and geosynclines are essential for a proper understanding of this concept which proved to be much more complex than its initiators realized. More recently it was found that instead of a clear-cut two-fold division there exist numerous transitions in space and time between the main elements in geotectonic classification.

Dana was actually the first to take a dynamic rather than a purely static view of geosynclines, but it appears that little attention was paid to his remarks on the outward shifting of geosynclinal belts. Grabau (1919, a detailed paper published in 1924 is not now accessible to the writers) is properly credited with the first clear statement on the migration of geosynclines, although his conceptions differ materially from those of Dana.

Grabau, as opposed to Haug and others, distinguishes between geosynclines, or belts of concurrent deposition and subsidence parallel to the old land, and fore-deeps, or sub-oceanic areas of subsidence with a minimum of deposition. A consideration of a number of such geosynclines of various geological ages, and in various parts of the world, brings out the fact that on the folding of the strata of the geosyncline, and their elevation into a mountain chain, a new geosyncline came into existence, parallel to the earlier one, but within the region of the former old land, which supplied the material for the sediments of the preceding geosyncline. Thus the geosyncline migrates towards the old land. European examples are: The Molasse Channel, formed with the first folding of the Alps; the new geosyncline along the outer border of the newly formed Carpathians; and the similar late Tertiary geosyncline north of the Caucasus.

It will be seen that Dana conceived an outward migration of geosynclinal belts from the stable land masses, an idea which was later greatly developed by Stille, Born and others, whereas Grabau's "migration" takes place in the opposite direction. These inwardly displaced geosynclines are otherwise known as "foredeeps" whose origin is directly connected with the folding of the original geosynclines. Kossmat referred to them as "second order geosynclines."

It should also be noted that Grabau, unlike Haug, Schuchert and many others, does not refer to non-geosynclinal areas as "continents." The use of this ambiguous term is confusing. It is not the "continent" in its geographical connotation which is properly opposed to geosyncline but a continental nucleus in a geological sense for which Kober introduced the term *cratogene* (later altered to "craton" as opposed to his "orogene" ("tectogene")). Borissiak (1923) has argued that the geosynclines as well as the "shields" are continental and that they should both be opposed to oceanic basins. Stille however, recently referred to these basins as "low cratons."

In a study of certain features of the East Indian Archipelago, Molengraaff (1920) came to conclusions similar to those of Grabau. In the "marginal" geosynclines of this region folds originated more or less parallel to the shoreline of the continent and at some distance from the shore. "These folds may cause one or more rows of islands or a more or less continuous strip of land to emerge from the sea. Not seldom in such a case the folding process is attended with volcanic activity. The result may be that the portion of the geosyncline immediately bordering the continental shore, gets separated from the deeper ocean by a row of islands or a more continuous strip of land consisting of a system of one or more folded mountain-chains, which may even shut the inner portion of the geosyncline off completely, thus converting it perhaps into a fresh water lake for some time. It is evident then that the materials for sedimentation will be transported to the geosynclinal receptacle from two quarters, viz., from the continent and from the strip of land or mountain range newly emerged from the sea, whereas prior to the folding the geosynclinal belt received its sediments from one side only, viz., from the pre-existing continent."

Vening Meinesz, Umbgrove and Kuenen have developed those ideas in connection with their studies of gravity anomalies of this region and their geological and geotectonic interpretation. In the modern concept of the "geotectocline" (Hess) the differentiation between the highly folded zone corresponding to the main downfold of the crust and the marginal downwarped portion of the geosyncline which is only moderately folded assumes great theoretical and also

practical significance as clearly foreseen by Molengraaff. Important oil and coal deposits are located in such marginal geosynclinal troughs.

In historical sequence, however, the discussion on the geotectonic relations of the geosynclines took a more devious course. Schuchert (1923, p. 209f) vigorously attacked what he believed to be Haug's comprehensive theory of geosynclines. Overlooking the fact that Haug had recognized more than one type among his examples he stated:

"It has been shown that all of the geosynclines of North America form the inner sides of borderlands which are but the diastrophically active margins of the continents. Furthermore, that geosynclines are destined to evolve into mountains. This is the American theory of geosynclines and it is in direct opposition to the views of European geologists, especially as formulated by Haug in 1900. The fundamental differences between the two theories is that Haug places the geosynclines on the outer side of the continents in the areas of continental shelves. His studies centre in the history of Tethys, the greater Mediterranean, once extending from the Atlantic to the Pacific. This is a very deep and vast basin of the oceanic type, situated, however, between close-lying continents. Tethys was not, therefore, a geosyncline in the American sense, but a mediterranean or mesogeosyncline.

"To extend the meaning of the term geosyncline to all subsiding areas of sedimentary accumulation, to mediterranean and even to oceanic basins, as was done, it is true, for the first time by Dana, is to befog the brilliant idea of James Hall. Our understanding of geosynclines (both monogeosynclines and polygeosynclines) is that they are variably long and variably wide, very mobile, sinking areas that always originate within a continent. They are more or less long in geological development, and receive great quantities of sediments derived in the main from the borderlands. The more rapidly sinking side of a geosyncline is adjacent to the inner side of a borderland, while the subsidence becomes less and less towards the neutral area of the continent. Finally, when orogenic forces have converted the geosyncline into synclinal mountains, these either are the inner portion of the anticlinal borderlands or they occur on one or both sides of geanticlines. Mediterraneans are vastly greater

fields of diastrophism, with the longest and most intricate of geological histories."

In effect, Schuchert proposed to restrict the use of the term geosyncline to a structure which in its composition, history and regional setting was identical with Hall's type, i.e., the Appalachian zone of folding. Subsequent work has shown this zone to be more complex and its geological history to be as intricate as that of most other belts of folding (Kay, Balk, Cloos and Hietanen, *et al.*).

Huang, in a recent analysis of the structure of China (1945) found evidence for the existence of "epicontinental geosynclines"—"long narrow troughs bordered on both sides by large land masses which belonged to the same continent." Sedimentation in them was long-continued and their sediments as thick, or even thicker, than those of "intercontinental" geosynclines. Similar features were simply called "Intra-Geosynclines" by Du Toit (1938). It should be understood that "epicontinental geosynclines" are not necessarily entirely continental. They usually start as marine troughs and as they gradually become filled up, may contain continental sediments towards the later stages of their development.

Chamberlin (1924) has pointed out that the existing mountain range and also the folded ranges of earlier ages are located neither between continents as assumed by Haug (intercratonic) nor within continents as Schuchert's "true" geosynclines (intracratonic) but on their borders (marginal). According to Chamberlin the boundaries between continents and oceans which have not changed very profoundly in general position are the main zones of weakness and mobility. It will thus be seen that considerable uncertainty exists in regard to the geotectonic interpretation of the conception of geosynclines and mutually exclusive definitions have been given.

Progress in the clarification of concepts was made when the simple two-fold division of the earth's crust into stable areas (continents, shields, old lands) and mobile areas (geosynclines, belts of folding) was replaced by a more advanced geotectonic classification.

Bubnoff (1931) elaborating on his earlier thesis (1923) recognized shields, stable shelves, mobile shelves, geosynclines and oceanic troughs. Shields are generally rising; both types

of shelves alternate between continental conditions and shallow transgressions (with cyclic sedimentation) and may be distinguished by more or less strong faulting and folding. The eastern European platform is described as a typical stable shelf. Mobile shelves are developed in western Europe (area of saxonic germanotype folding).

Geosynclines are distinguished by a still higher degree of mobility. Orogenic movements in folded geosynclinal zones differ sharply in intensity from those observed in shelf areas and finally lead to great uplift. Even before the orogeny the area later to be occupied by folded mountains must have had a distinctive structure since it reacted differently to "epeirogenic" movements.

Mobility of structural elements depends not only on their strength but also on the intensity of mountain-building forces to which they are subjected. The development of marginal troughs may turn stable shelves or even shields into mobile shelves under the influence of orogeny in the adjoining geosynclines, as indicated by greater thickness of deposition, stronger folding and formation of certain characteristic mineral deposits such as oil and coal.

The North German Plain and the Donetz Basin are intermediate between geosynclines and mobile shelves but shallow water deposition and limited igneous activity bring them closer to the shelves. Oceanic basins are a fundamentally different type.

The question of the permanent nature of the four main types arises in this connection. Folded geosynclines lose their mobility; are often incorporated into shields but may be subsequently eroded and subject to shallow transgressions ("inhomogenous shelves" e.g., parts of the Hercynian mountains in Europe.) According to Stille progressive consolidation and growth of continents represents the fundamental "law" of the formation of the earth's crust. There are no direct observations to indicate whether this process is reversible (transformation of parts of continents into deep sea and formation of geosynclines in formerly stable areas). Bubnoff does not appear to accept this view. A. Born (1933) came to the conclusion that normally orogenesis is followed by breaking up of folded zones and formation of new geosynclinal zones of deposition incorporating parts of the earlier folded belt.

V. CLASSIFICATION OF GEOSYNCLINES.

The stage had now been reached when a considerable number of closely interrelated types of mobile zones could be recognized. In one sense or another they were all geosynclines. They were all more or less mobile, thick sedimentary series had been deposited in them, they were generally long and narrow in outline; most of them were folded or at least presented the same appearance as others in a stage preceding that of folding. Some of them were affected by characteristic types of igneous activity, others contained typical deposits of economic minerals. It can be fairly stated that the actualistic approach to this phenomenon was least successful: It was impossible to prove conclusively that any particular part of the present sea floor is, or is not, a geosyncline. It was obviously not a particular configuration of the ocean floor which made the concept geologically significant—its foundation was a thick mass of rock formed under certain conditions and interacting in a certain manner with its environment. A choice had now to be made between restricting the term to a few specific types, preferably those which the original authors of the concept had had in mind (principle of priority) or using it in a "generic" sense for a class of interrelated phenomena, distinguishing at the same time between them as far as practicable by means of new special terms.

The discussion on this point is still in progress but it appears that the second approach is favoured by those most actively engaged in the study of the subject.

This procedure was first adopted by Schuchert, though it would appear that his separation of monogeosynclines, polygeosynclines, parageosynclines and mesogeosynclines (or mediterraneans) rests on a geographical rather than on a geotectonical basis.

Stille as we have seen has generally favoured the application of the term geosyncline in a very wide sense, so as to cover all slowly subsiding areas of sedimentation (and even non-sedimentation) but in more recent publications he has clearly indicated a number of different types and stages of the development of geosynclines. In a study of geosynclinal history and folding of the North American Cordilleras (1936) Stille states that the Nevadian and Rocky Mountains zones are distinct units, separated by a ridge or zone of reduced subsidence which forms the boundary between pre-Cretaceous (Neva-

dic) folding in the West and Laramic folding in the East. The Nevadian zone which is further characterized by strong Late Palaeozoic to Jurassic vulcanism and synorogenic plutonism is described as *pliomagmatic* while to the Rocky Mountains zone which has hardly any geosynclinal vulcanism and only weak plutonism the term *miomagmatic* is applied.

In a publication which is not accessible to the present authors, Stille used the terms "Eugeosyncline" and "Miogeosyncline" for the Plio- and miomagmatic zones respectively. For these two kinds of sedimentary belts affected by "alpinotype" folding he proposed the wider term *orthoгеосyncline*. The geosynclinal areas formed in zones and phases of germanotype folding after consolidation of an earlier folded basement are distinguished as *parageosynclines* (see Kay, 1942).

Stille's concepts and classifications, based on the study of geosynclines in northwestern Europe and western North and South America, recently received strong support from the results of Marshall Kay's comprehensive analysis of the Alleghany and adjacent areas (1942). He states (1944, p. 461) that the American continent in early Palaeozoic time "is conceived as having the interior craton separated by flexures from the deeper sinking miogeosynclines, with more peripheral belts of eugeosynclines and linear islands. The theory of marginal volcanic troughs is supported by direct evidence and induction." It is easy to recognize in the "miogeosynclines" some of Bubnoff's mobile shelves and in the volcanic troughs eugeosynclines and island topography the conditions of Kraus' katarogenic stage in the Alps, Chamberlin's marginal zones of folding and some of Tercier's and Kuenen's typical geosynclinal conditions.

Kay (1942, p. 1644) makes it clear that although geosynclines as such are long-lived, the specific types are shifting laterally (cf. Grabau's "migration") and overlapping so that in a certain area the early Palaeozoic rocks may indicate eugeosynclinal and the late Palaeozoic rocks miogeosynclinal conditions. The Appalachian structural front lies "in the position of thick Paleozoic sediments" as Hall and Dana had found, but "it does not follow any recognized axis, flexure or trough of the Palaeozoic" (Kay, 1942, p. 1647). Instead of one Appalachian geosyncline, "there are geosynclines of several sorts and of different ages in the Appalachian region" (Kay, 1944, p. 462).

These include intracratonic semilenticular depressions filled with detrital material derived from uplifts beyond their margins. For these, Kay proposed the name *deltageosyncline*. This definition suggests that the Molasse zones of the Alps are *deltageosynclines*.

Kay continues the classification of "slowly subsiding areas of sedimentation" in the area of his studies by introducing the terms *autogeosyncline* for endogenetic rapidly sinking intracratonic basins which are separated from the less active tectonic zones (e.g., Michigan and Illinois basins), and *taphrogeosyncline* for rift-bounded depressions within the folded zone (e.g., Triassic of the Atlantic coast).

In a recently published abstract, Kay (1945) gives a summary of his classification with definitions of new terms.

"I. Linear geosynclines peripheral to the shield or craton—*orthogeosynclines*: (a) having volcanic rocks, cherts, and slates—*eugeosynclines*; coarser detritus from adjoining linear islands (Middle Ordovician, central New England to central Newfoundland); (b) lacking appreciable volcanics, clastics from craton (Cambrian of northern Rocky Mountains and Great Basin) or from uplifts in peripheral belts—*miogeosynclines*.

II. Geosynclines within the craton—*parageosynclines* of Stille (a) marginal geosynclines gaining principal detritus from uplifts in orthogeosynclinal belts—*deltageosynclines* (Upper Ordovician and Lower Silurian, central Appalachians); (b) isolated within the craton, without adjoining uplifts—*autogeosynclines* (Later Palaeozoic, Michigan basin); (c) similar but having complementing uplifts within the craton—*zeugogeosynclines* (late Pennsylvanian, northwestern Colorado).

III. Geosynclines of later cycles: (a) narrow, deep, peripheral geosynclines adjoining linear uplifts, lacking abundant volcanics—*epiugeosynclines* (Pennsylvanian, Nova Scotia); (b) fault-bounded geosynclines in tilt blocks and grabens—*taphrogeosynclines* (late Triassic, Connecticut); (c) deposits in synclinal consequent basins (Eocene, southwestern Wyoming); (d) geosynclines passing marginally into present coastal plains—*paraliageosynclines*, possibly *parageosynclines* of Schuchert—(Tertiary of Gulf Coast)."

VI. CONCLUSIONS.

It is desirable to re-state briefly a number of facts which have emerged from this historical account before attempting to look into the future and to predict further developments.

Firstly, the concept of geosynclines occupies a definite place in the theoretical and terminological apparatus of modern geology. Attempts to eliminate it have been rare indeed and have amounted to little more than the substitution, for various reasons, of new terms for the old idea.

Secondly, the concept as employed by modern writers does not differ essentially from that established by its originators. It was sufficiently wide in scope and deep in its foundations to cover most of the later developments and interpretation. It cannot be discarded on the grounds of later misuses or shifts in meaning of the original term; we have seen, in fact, that the germs of practically all later developments are already contained in Hall's and Dana's papers on the subject.

There is, however, a certain vagueness in this concept which makes it impossible at present to define a geosyncline in absolute terms and quantitative relations so as to decide once and for all what is a geosyncline and what is not. Recognizing it as an essential scientific concept implies, of course, that it will be ultimately so defined. Nevertheless, it is likely to remain not fully definable until further work is carried out. The discussions here reviewed have produced a number of elements which in our opinion will enter into a future formal and comprehensive definition.

The first group of such elements is embodied in the statement that geosynclines are represented in the earth's crust by *masses of sediments* deposited in elongated belts of regional extent, in other words, geosynclines are megatectonic features; their sediments developed in greater thickness than in adjoining areas and included, among others, certain specific types of sedimentary and igneous rocks which are not found elsewhere, formed under conditions of high crustal mobility. To regard as geosynclines as has been done by some, all slowly sinking down-flexured parts of the crust is obviously not helpful. Unless such depressions receive sediments, they leave no traces in the geological record and their existence cannot, therefore, be recognized. The whole concept would thus be deprived of practical significance.

The second group of attributes in which this vagueness is even more pronounced can be formulated as follows: Some of these masses of sediments have been folded to a varying degree and most of them have been transformed into folded mountain zones while some remained in an unfolded condition.

The third class of distinguishing features should incorporate the observation that the sites of geosynclines are neither immovable nor permanent but migrate within certain limits and that geosynclines undergo evolution which may be cyclic; they are at any given period of geologic time coexistent with and (in a manner as yet ill defined) spatially related to stable areas of predominantly rounded outline which have been named cratons and which form the nuclei of existing continents and of certain ocean basins.

The origin of geosynclines is still unknown. The views which have been expressed on the subject are based not so much on observed facts as on the authors' attitude to one or the other of the current and mutually exclusive hypotheses of mountain building and of the origin of continents on which no finality has yet been reached. Concerning the actual mechanism of the formation of geosynclines it would seem that the school of Gulf Coast geologists has produced such weighty arguments in favour of subsidence under load that the operation of this factor can no longer be doubted. On the other hand there is evidence for "autonomous" uplift and subsidence of parts of the crust which would make it possible for sedimentary accumulations to be formed as a result of active subsidence and uplift rather than of passive depression under the load of shifting products of erosion. Very probably neither Hall nor Dana were entirely right and geosynclines may owe their origin to either one or the other factor or a combination of both.

It would be futile to attempt, in conclusion of this review, to formulate a generally acceptable definition of the term *geosyncline* in order to cut short a discussion which under the stimulus of new discoveries of great importance is at present still actively proceeding. New facts in regional geology and structural history (Appalachian geosyncline), subsurface structure (Gulf Coast), geophysics (Western Pacific, East Indies, Himalaya), sedimentation, and other widely separated fields have been found only recently to have a profound bearing on the problem. They have not yet been fully applied to its solution.

Advances in the classification of observed features of the earth's crust are being made in many parts of the world and in this process the old concept of geosynclines will maintain its place. Further progress towards its final clarification will depend on more than indiscriminate world-wide extension of the use of nomenclatures primarily proposed either to fit local conditions or to express findings in terms of geotectonic hypotheses. In fact, the justification of the inclusion of some of the proposed borderline classes of geosynclines under this heading will depend on the outcome of more detailed comparative investigation of their features and geologic history, and the results of further field studies of the more remote geosynclinal areas of the world must be awaited.

VII. GLOSSARY.

Autogeosyncline (Kay)—“Isolated geosyncline within the craton, without adjoining uplifts.”

Deltageosyncline (Kay)—“Marginal geosyncline gaining principal detritus from uplifts in orthogeosynclinal belts.” Kay (1942) proposed to replace this term by “exogeosyncline.”

Epieugeosyncline (Kay)—“Narrow, deep, peripheral geosyncline, adjoining linear uplifts” in areas formerly eugeosynclinal.

Euogeosyncline (Stille)—Linear geosyncline peripheral to craton, having volcanic rocks, cherts, etc.

Exogeosyncline (Kay)—see *Deltageosyncline*.

Fossa (Du Toit)—“A geosynclinal depression developing all around a continent.”

Geo-Basin (Rich)—Large, unfolded basins with thick sediments.

Geodepression (Haarmann)—Major depression of the crust.

Geomonocline (Cloos)—Unilateral (marginal) geosyncline.

Geosynclinal (Dana)—Belt of accumulation of thick series of sediments along border of continents where downward bending is caused by lateral pressure.

Geosyncline:

Bilateral (Cloos)—Intracontinental geosynclines.

Continental (Stille *et al.*)—Geosyncline filled with continental (non-marine) deposits.

Epicontinental (Haung)—Geosyncline within a continent, filled with marine and continental deposits.

- First order* (Cornelius)—World-wide (alpine) major belt of geosynclines.
- Polycyclic* (Argand)—Geosyncline which has gone through more than one orogenetic cycle.
- Primary* (Haug)—Major undivided geosynclines.
- Secondary* (Haug)—Longitudinal subdivision of primary geosyncline.
- Second order* (Cornelius)—local depression, receiving little sediment.
- Second order* (Kossmat)—Fore-deeps.
- Sequent* (Schuchert)—Two or more parallel geosynclines which have evolved out of a primary geosyncline by formation of a geanticline (or geanticlines).
- Idiogeosyncline* (Umbgrove)—Marginal basin, short lived and weakly folded.
- Intra-geosyncline* (Du Toit)—Geosyncline within a continent.
- Mediterranean* = *Mesogeosyncline*.
- Merosyncline* (Bubnoff)—Parts of major geosynclines with independent mobility.
- Mesogeosyncline* (= *Mediterranean*) (Schuchert)—Deep complex geosyncline of oceanic type, situated between two close-lying continents.
- Miogeosyncline* (Stille)—Linear geosyncline, peripheral to craton, lacking volcanics.
- Mobile Shelf* (Bubnoff)—Area alternating between continental conditions and shallow transgressions, later strongly folded and faulted.
- Monogeosyncline* (Schuchert)—Simple geosyncline.
- Mother geosyncline* (Stille)—Geosyncline giving rise to folded mountain system.
- Orogeosyncline* (Kober)—Geosyncline giving rise to orogene.
- Orthogeosyncline* (Stille)—Linear geosyncline peripheral to craton.
- Parageosyncline* (Schuchert)—Recent marginal oceanic depression.
- Parageosyncline* (Stille)—Geosyncline developed within craton or stabilized area.
- Paraliageosyncline* (Kay)—“Geosyncline passing marginally into present coastal plain.”
- Polygeosyncline* (Schuchert)—Intra-continental compound geosyncline (= primary geosynclines subdivided by “geanticlines” into sequent geosynclines).

Taphrogeosyncline (Kay)—“Fault-bounded geosyncline in tilt block or graben.”

Zeugogeosyncline (Kay)—“Geosyncline within the craton, having complementary uplifts within the craton.”

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