GEOSYNCLINES: A FUNDAMENTAL CONCEPT IN GEOLOGY.

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PART I.

ABSTRACT. Existing uncertainty and confusion as to the application of the term "Geosyncline" made it appear desirable to re-examine critically the original definition and subsequent development of this concept. Approached from lithogenetic, orogenetic, and geotectonic viewpoints it is found to be significant in all these fields of geological studies. The complex nomenclature proposed for various types of geosynclines is reviewed and elements entering into a definition are considered. The complexity of the problem as revealed by recent work is such that a formal comprehensive definition and a restriction of proposed types of geosynclines to those properly included in the more general concept has to await the outcome of further field studies.

INTRODUCTION.

THE present study took its origin from informal discussions between Prof. E. S. Hills, of Melbourne University, and one of the authors (Glaessner) concerning the nature and history of geosynclinal areas in Australasia. These discussions were held early in 1943 and later in the same year Teichert was invited to coöperate in a general critical review of the whole problem. At one time or another all of us had been associated with studies of geosynclinal areas in Australasia and abroad, but we soon felt the lack of common ground as far as definitions of general concepts were concerned. It was, therefore, decided at an early stage to enter into a thorough analysis of the whole concept of geosynclines and its history.

Owing to pressure of other work Professor Hills withdrew from the project at an early stage, but has at all times been of assistance in numerous discussions on many aspects of the problems raised. We are also indebted to a number of colleagues abroad who helped considerably by sending their publications. Among them G. Marshall Kay, and R. J. Russell may be specially mentioned.

The bibliography at the end of the paper is not intended to be exhaustive, but is believed to contain all fundamental contributions with a bearing on major theoretical aspects of the problem of geosynclines. Many authors have stated and re-stated their opinions in more than one publication in which case we have generally been satisfied to quote from one or two papers which to us seemed to contain the fullest exposition of their views.

The glossary of terms applied to geosynclinal structures may serve for a general orientation of the reader. It will at the same time help to demonstrate the great complexity of the whole problem and the generally unsatisfactory present state of terminology.

I. THE ORIGINS OF THE CONCEPT OF GEOSYNCLINES.

(a)   James Hall

The year 1859 is an important date in the history of geological thought. It was the year of the publication of the third volume of James Hall's "Palaeontology of New York" in which that great geologist summed up the results of his work on the stratigraphy and structure of the Appalachian Mountains of Eastern North America. The northern Appalachians, particularly in the State of New York, where Hall worked, were then without doubt the geologically best known mountain system in the world, and the generalizations at which Hall arrived on the basis of his study of field relations and stratigraphy, soon caused wide-spread discussion. They have provided the starting point for all modern work on problems of mountain building.[1]

Hall described the most characteristic features of the Appalachian system, and with remarkable perspicacity he recognized that many of his conclusions would be applicable to other mountain systems in America and elsewhere.

First of all Hall pointed out that the thickness of Palaeo-

[1] It is true that Hall had formulated some of his ideas as early as 1857 when he presented them in an address before the Montreal meeting of the American Association for the Advancement of Science. However. this address was not published until 1883. Also, it appears that between 1857 and 1859 Hall must have clarified his ideas and enlarged his concepts, as the treatment of the subject in 1859 is more concise and more exhaustive. The year 1859 must therefore be taken as the starting point of the discussion.

zoic strata in the Appalachian Mountains was considerably greater than the thickness of beds of equivalent age in the Mississippi Valley; in other words the site of the Appalachians had been the site of maximum accumulation of sediments in Palaeozoic times. These sediments were predominantly clastic and had all been laid down in shallow water. This could have happened only if the area of sedimentation subsided at a rate sufficient to keep pace with sedimentation and Hall suggested that the yielding of the substratum in the area of sedimentation was caused by the increasing load of the sediments. Thus, a great synclinal structure was formed. Along the axis of this syncline the beds were folded into smaller synclines and anticlines. They were fractured and magma could thus intrude into them. Metamorphism due to folding and the increase in temperature at depth is also strongest along the centre.

On this basis Hall ventured to put forth the general conclusion that all great mountain chains represented such belts of greatest accumulation of sediments and he postulated that ultimately it would be found that the height of mountain ranges is more or less proportional to the thickness of sediments accumulated in them. Also, he suggested that since sedimentary series belonging to successive geological periods may be accumulated on top of each other, mountain ranges of greater height will be found to be younger and "to embrace the newer geological formations." The full range of Hall's generalizations and conclusions may be embodied in the following points:—

(1) Mountain ranges occupy elongated belts with a very great thickness of sediments. The younger the mountain range, the greater the thickness of the sediments.

(2) These sediments were deposited in shallow water (predominance of clastics) and their presence in these belts therefore indicates yielding of the crust so that eventually a large synclinal structure filled with shallow-water sediments was formed.

(3) The yielding of the crust is due to the ever increasing weight of the sedimentary load.

(4) The greatest amount of sediment is deposited in the vicinity of the land and the place of these great accumulations

of sediment is therefore determined by the course of pre-existing shore-lines.

(5)   Such belts of thick sediments are lines of strength in the earth's crust.

(6)   Folding is caused by the bending of the bottom of the synclinal structure.   To the same cause are due igneous intrusions and metamorphism. Folding, igneous activity, and metamorphism will thus be found mainly along the axial line of mountain ranges and will be found to die out towards both margins.

(7)   It follows that manifestations of internal forces such as fractures and intrusions are ultimately caused by external agencies.

(8)   The elevation of mountain chains is no local phenomenon. Mountain chains rise with the continents of which they form a part. This elevation is due to the accumulation of sediments on the neighbouring ocean floor. The ocean floor is subsiding under the load and the deep-seated material is squeezed sideways thus lifting the continents. Here Hall follows Herschell's earlier views to which full credit is given.

Some of Hall's generalizations are now generally recognized as facts, particularly those relating to the thickness and lithology of sediments in mountain belts (1 and 2). Other ideas appear surprisingly modern, although Hall is not generally credited with them and they are put forth in a crude form, e.g., the recognition of "central metamorphic belts" and the statement of the fact that the elevation of mountain ranges is not directly connected with the process of folding.

Yet other points in Hall's thesis are debated to this day, such as the question of the yielding of the crust under load.   Others are now obsolete, as e.g., the idea that belts of thick sediments form lines of strength, and some long forgotten suggestions have been revived in a more modernized form in quite recent times. Thus, the idea of a causal connection between the bending of the bottom of the "synclinal structure" and the folding of the beds is recognizable in Vening Meinesz' and Hess' theory of the "geotectocline" and the suggestion that pre-existing shore-lines (and thus drainage systems) determine the site of greatest accumulation of sediments has been restated in a similar form in recent years by Russell.

(b)   Early Discussions and Dana's Views

The general importance of Hall's deductions was soon realized, by contemporary geologists and the volumes of the AMERICAN JOURNAL OF SCIENCE during the fifteen years following the publication of Hall's work contain many articles in which these problems are discussed.

Hall very soon received the support of T. Sterry Hunt (1861) who fully concurred in the idea of subsidence in the basin of sedimentation being caused by the weight of the sediments, but who objected to certain other ideas, in particular to the explanation of folding as produced by simple downbending of the synclinal in which the sediments were accumulated. On the whole Hunt tried to combine Hall's theories with contractionist ideas by stating that the effects produced by contraction are chiefly exerted along the lines of greatest accumulation of sediments. This idea has, of course, been restated in various forms many times up to the present.

Other contributions, mostly in support of Hall, came from LeConte, Vose, and others, but the most important came from Dana who voiced his first criticism in a paper published in 1866. After briefly stating the principal points of Hall's views he emphasized that the "subsidence connected with the formation of the successive thick deposits of sediments in the Appalachian region was a *foot-per-foot movement*, that is, taking into view the grand result through the Palaeozoic, there was a foot of sinking for a foot of accumulation," even though he admitted that in details the sinking may have proceeded paroxysmically, with intervals or even reversed oscillations. Such fine reaction to increase in load of the crust seemed quite unlikely to Dana who believed that in places the crust is able to support high mountain masses. This was, as we know now, a mistaken notion. But even granting Hall's point Dana concluded that the hypothesis accounts for subsidence only, not for mountain uplift, and he wound up with the now famous dictum that Hall had promoted "a theory for the origin of mountains with the origin of mountains left out."

This remark drew a retort from Hunt some years later (1873) that neither he nor Hall had ever endeavoured to produce any theories of mountain building at all. Similarly Hall himself, in a postscript to his 1857 address (1883, p. 68)

somewhat resentfully rejects the suggestion that he had aimed at such a theory; he had been satisfied to state some very remarkable facts and he was not much interested in theorizing, "because such arguments are not always philosophical for want of a basis in facts and are always unsatisfactory as giving a very inadequate solution of the problem." Even the original address contained some scathing remarks (pp. 34-35) about theorists who easily attain heights which the "devoted laborer in science" can never hope to climb.

In 1873 Dana came out with a lengthy paper on the subject of mountain-building which must be considered in greater detail.

The starting point for Dana's tectonical theories was the division of the earth's crust into continental and oceanic areas which he regarded as a pattern inherited from the time of the formation of the first solid crust. According to Dana, this division is of fundamental importance, because the two types of crustal material react differently to lateral pressure set up by the contraction of the earth. Belts of accumulation of thick series of sediments come into existence along the borders of the continents where downward-bending areas are caused by lateral pressure. These basins Dana proposes to call *geosynclinals*; they provide receptacles for the accumulation of sediments. It is thus pointed out in strict opposition to Hall that sediments accumulate in these belts because here the crust subsides, not, as Hall would have it, that the crust subsides under the load.

It is important to note that Dana gives rather a wide scope to the conception of a "geosynclinal," emphasizing the accumulation of sediments as an essential characteristic. "A geosynclinal accompanied by sedimentary depositions, and ending in a catastrophe of plications and solidifications, are the essential steps, while metamorphism and igneous injections are incidental results." To illustrate his conception of a geosynclinal Dana gives three examples of sedimentary belts:—

(1) The Alleghany ranges, extending from New York to Alabama, with folded, unmetamorphosed sediments.

(2) The "Green Mountains," an intensely metamorphosed belt of western New England and eastern New York.

(3)   The Trias-Jura basin of Connecticut with its 4,000 feet of continental, unfolded sediments.

Later authors have usually overlooked the fact that Dana gave his original "geosynclinal" this rather wide meaning, though Kay (1945) has recently called attention to it. Basins of the third type were excluded by many from the definition of a geosyncline, until at a much later date the conception of "continental geosynclines" was reintroduced in application to the Rotliegende and Buntsandstein basins of Germany by Born, Leuchs, Brinkmann, and others, and would no doubt have received the sanction of the originator of the term "geosyncline."

Two further concepts of Dana's deserve special attention. Dana states that successive geosynclinals are formed in parallel belts, each succeeding one more or less outside the preceding one, and he also thinks that folding and igneous injections result in a stiffening of the crust and in the "annexation" of the geosynclinal to the more stable parts of the continents. The former idea was revived in a much modified fashion by Grabau, as the theory of the "migration of geosynclines"; the latter suggestion found wide-spread support, particularly among German writers, but also by others, under the heading of the "stabilization of the continents."

Dana's term "geosynclinal," later modified to *geosyncline*, has persisted to the present day, and, most authors while questioning details of interpretation, have been in substantial agreement in applying it in one way or another, to areas of heavy accumulation of sediments. It is unfortunate that the meaning of other terms suggested simultaneously by Dana has later been greatly changed.

Thus, *synclinorium* was proposed by Dana for the mountain system that originated from the folding of the sediments of a geosynclinal. It is now almost exclusively used for large downfolded areas, complicated by minor anticlines and synclines.[2]

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[2] As observed by O. T. Jones (1938, p. lxi) the misconception regarding this term probably arose through its misapplication by Van Hise (Journal Geol., 4, 1896, p. 319). By a peculiar further change in meaning structures of the type now, after Van Hise, generally known as "synclinorial" have been called "geosynclinal" by certain Australian writers (see H. Herman, Bull. Geol. Surv. Victoria, No. 47, 1923, p. 12).

The terms *"geanticlinal"* or *"anticlinorium"* were proposed by Dana synonymously for major "upward bendings" of the earth's crust, outside the geosynclinals; the Cincinnati uplift was given as a typical example. Later both terms came to be used for different types of structure and in an entirely different sense from that Dana had had in mind; *anticlinorium* for the opposite of a synclinorium (in its later changed meaning), *geanticline* for more than one feature, as will be explained below.

(c)   General Trends of Later Developments

The facts brought forward by Hall and Dana and the problems raised by them received wide attention in subsequent years, and their importance was realized, slowly at first, but more rapidly since the beginning of the present century. The concept of the geosyncline was much changed, often beyond recognition, and applied to many widely different types of earth structures. Eduard Suess rejected it altogether, in the mistaken view, however, that it was intended to apply to the great ocean basins of the present day. More recently, Haarmann (1930) proposed to abandon the term.

In general, however, it will be found that the term geosyncline was accepted as useful by the majority of geologists. The approach was made from several different angles and it is attempted in the following pages to bring out the main trends along which the ideas developed.

Some authors concentrated their attention on the sedimentary filling of the basins, more or less ignoring their later history. We might call this the *lithogenetic* approach. Others regarded the orogenetic history of the basins at least as equally essential, if not more important than the sedimentational development. This may be known as the *orogenetic* approach. Others again gave prominence to the *geotectonic* positions of the basins of sedimentation in their relation to other crustal units.

Depending on the method of approach authors arrived at concepts and classifications which seemingly differed widely, but differences were often more apparent than real. As some investigators attempted to combine two or all three methods of approach their names will appear repeatedly in different places in our story.

The germs of practically all later developments, however, are already contained in Hall's and Dana's papers. It has often been overlooked that both were concerned with major sedimentary accumulations, not *per se*, but in their relation to other areas of the earth's crust. A good deal of later confusion has been caused by attempts to regard the conception of the geosyncline in terms of absolute quantities and unassailable definitions which would make it easy to point out exactly what is a geosyncline and what is not. More often than not it was overlooked that a "geosyncline" as defined by the originators of the idea can only be considered in relation to neighbouring continental, oceanic, or other non-geosynclinal sedimentary areas, and to a given period of geological history. It follows that the "geosynclinal" nature of an area of sedimentation can only be determined by comparing its physical features and its history with that of adjacent areas of sedimentation and non-sedimentation. This is the very good reason why attempts to find a definition of a "geosyncline" in absolute terms by establishing definite standards independently based on either the nature and thickness of sediments or the orogenetic and igneous history, or its general position with regard to other crustal units, have been so contradictory and generally not very successful.

II.   LITHOGENETIC ASPECTS.

(a)   The Relation between Sedimentation and Subsidence

Subsidence due to accumulation or accumulation because of subsidence? Thesis and antithesis had been clearly stated by Hall and Dana. In a way it is peculiar that Hall's thesis was so largely discredited, because at the same time as isostatic adjustment under sedimentary load was being denied by tectonicists, yielding of rigid shields under the weight of ice-sheets was being generally accepted among students of the Pleistocene.

A number of geologists working on problems of the Gulf Coast of North America have in recent years re-stated Hall's views on subsidence in the most emphatic way. Thus Russell and Fisk write (1942): "The daily load of sediments deposited in the lower delta of the Mississippi River averages about two million tons. If distributed over such depths as exist

in the vicinity of the river's mouth this amount of inorganic material should cause an accretion of about 30 square miles of land each year. In fact the accumulation of locally derived organic materials should accelerate the gain far beyond that rate. A comparison of surveys about a century apart, however, indicates not the addition of 3,000 or more square miles of land surface in southern Louisiana but neither appreciable gain nor loss." The possibility that the bulk of the sediments might have been swept away by currents to be deposited elsewhere is discounted so that "it appears that most of the sediment accumulates near the river's mouth to thicken downward rather than build outward. The Earth's crust appears to yield under the load."

The geosynclinal character of the Gulf Coast area had first been advocated by Barton, Ritz and Hickey in 1933. They pointed out the great thickness (up to 30,000 feet) of sediments, with a zone of maximum accumulation approximately along the present coast line, and stated that sedimentation had been practically continuous since the beginning of the Tertiary. It is now known that sedimentation in the area started as early as Jurassic times.

The conception of the "Gulf Coast Geosyncline" received strong support from Russell (1936) in a paper which contains ample material on sedimentation, thickness, and submergence of the Mississippi delta, together with a general discussion of the theory of geosynclines which Russell winds up with the unreserved statement that "geosynclines are the result of sedimentation." Since sedimentation is at least partly determined by drainage conditions and since on the other hand mountain ranges are often found to occupy the sites of former geosynclines Russell advances the thesis that ultimately "drainage patterns determine future courses of mountains." These views are, of course, a return to Hall almost in the strictest and purest sense.

Lawson supported the general idea of subsidence under load for the Mississippi delta but his calculations (1942) led him to suggest that the initial depth of sea at the time of the commencement of sedimentation must have been about 13,000 feet. No such depth is, however, suggested by the nature of the sediments concerned which are all of shallow water type and Law-

son's argumentation would seem to indicate that there has been a component of active subsidence in the general downward movement of the Gulf Coast region.

An able and interesting review of the whole problem has recently been published by Storm (1945) who rightly says that "with its possibilities for enlightenment about such subjects as subsidence under load and the development of a geosyncline this mass of evidence is a unique offering from the Gulf Coast region to the science of geology."

Even depressions which are entirely filled with volcanic material have been compared to geosynclines. Thus, in West Greenland over 30,000 feet (10 km.) of plateau basalts have been erupted in Tertiary times and caused a depression of the crust which to Noe-Nygaard (1942) suggested an analogy to geosynclinal conditions.

The views of Dana according to which sediments accumulated where primary depressions in the earth's crust had been formed, has throughout the decades proved to be the much more popular thesis.

Since it is well known from other evidence that portions of the crust are oscillating in a vertical sense, it is obvious that oscillations help to create basins in which sediments can accumulate. The question that interests us here is under what circumstances and in what particular setting one will be justified in calling such depressions "geosynclines."

In 1924, Stille defined a geosyncline as a slowly ("secularly") subsiding area and took pains to explain that the sedimentary filling is not a necessary part of the definition, because the addition of sediments depends on factors unconnected with the fact of the existence of a slowly sinking area; where there is no source of sediments, no sediments can accumulate, so that in exceptional cases sedimentation may remain insignificant even in the presence of strong subsidence.

Similarly, Arkell (1936) spoke of geosynclines as "all long-continued down-flexured parts of the lithosphere." ("Their shape, the depth of water, and the nature of the neighbouring land or sea are secondary considerations").

Daly (1926) is among those who want to divest the term "geosyncline" of its sedimentational significance, restricting the use of the word to the actual depression in the crust. He

speaks of the sedimentary filling as "geosynclinal prism"—perhaps a not altogether fortunate term because a body whose height is only a tiny fraction of the dimensions of its base is not usually called a "prism."

Others recognized the necessity of considering the existence of major depressions apart from their sedimentational history, but preferred new and non-committal terms, such as Bucher's "furrows" (1933) and Haarmann's "geodepressions" (1930). To call such features geosynclines would indeed be too wide a departure, from the original meaning of the word, both in Hall's and in Dana's sense who both regarded the depression and its filling as an entity.

J. L. Rich (1938) spoke of "broad geo-basins"—another non-committal term for large sediment-filled unfolded depressions.

There is no doubt that the discussion about geosynclines received its greatest stimulus after Dana from the writings of Emile Haug, particularly from his paper published in 1900. Haug's ideas however present a new viewpoint and in many ways a departure from classical thoughts, although as we shall see Haug expressed himself far less dogmatically than it would appear from many quotations by later authors.

Haug referred back to an earlier observation by Suess who in 1875 had stated that in folded zones the sedimentary series are generally complete and of a pelagic type while in stable areas they are often incomplete and contain brackish intercalations. This, Haug concludes, would contradict Hall's statement on the shallow-water nature of geosynclinal sediments, but actually he believes both statements to be exaggerated, and suggests that in the majority of cases geosynclines were comparatively deep, though not abyssal seas. He proceeds to define his "bathyal" region of the oceans, now long accepted by oceanographers and geologists alike, as the part of the sea floor between 100 and 900 meters, and quotes numerous examples of geosynclinal sediments which in his opinion were deposited in this zone: graptolite shales, *Posidonomya* shales, *Dentalium* clays, *Aptychus* shales, dense and concretionary Ammonite limestone, and others. Haug pointed out that owing to the great depth range of the bathyal zone (800 m.) in which he assumed deposition to be homogeneous, minor oscil-

lations of the sea floor would not appreciably alter the character of the sediments. The accumulation of a great thickness of sediments of uniformly bathyal character would not, therefore, require the perfect balance between the rates of sedimentation and subsidence which would have to be assumed for deposits of a more limited depth zone. According to Haug this is another reason for considering many geosynclines as former comparatively deep troughs. He admits, however, the existence of shallow-water geosynclines such as the Paris Basin and refers to the "Tertiary geosynclines of the Rocky Mountains" as examples for infillng with freshwater deposits.

This may have prompted Glangeaud to speak of the "lacustrine geosyncline" of the Limagne, and if Arkell (1936) calls the Weald-Boulonnais Basin of Jurassic and Cretaceous sediments a geosyncline he may also find authority for this procedure in Haug.

With palaeogeography as the starting point of his investigation and with a depth zone assigned to typical geosynclinal deposits, Haug was naturally led to a search for equivalents of geosynclines in the present seas. This quest, in which he was followed by a number of later authors, appears to be based on a different concept from that of Hall and Dana who both believed that it would be impossible to recognize geosynclines, even if they were in existence today. The thesis that geosynclines do not exist at the present moment has also found its advocates. Thus, Stille, in his earlier writings, seems to assume that the earth at present passes through a non-geosynclinal phase, whereas Borissjak (1923) maintained that the earth has definitely passed the state of its development when geosynclines were formed and that the crust is now wholly consolidated. In his later writings, Stille also seems to be inclined towards this view.

Haug's use of the term "bathyal" has often been misinterpreted and it was later commonly used for the deposits of the continental slope. Cornelius (1925) and later also Tercier (1939) have pointed out that Haug included here deposits of the outer parts of the continental shelf and the upper part of the continental slope only.

That all, or at least some, deep sea troughs are geosynclines has been maintained by Haug, Kuenen, Tercier, and others.

Haug regarded entire oceans, especially the Atlantic, as geo-synclines. Fore-deeps were interpreted as geosynclines by Grabau and partly also by Kossmat. This author spoke of "relic Geosynclines" within young folded belts and similarly Born believed that geosynclines may be rejuvenated after folding (example: the present Mediterranean). Obrutschew carried the search still further. Accepting Schuchert's essentially geographic classification of geosynclines into mono-, poly-, mesogeosynclines, etc., he quoted present-day examples for every one of these types, but we are not aware that this procedure has been followed by anybody else.

Cornelius attempted to reconcile the views of Stille with those of Haug. Recognizing that not all of Stille's "sinking areas" were of the same quality, he proposed to distinguish between "first order geosynclines" and "second order geosynclines," the first of these categories corresponding more or less with the world-wide major geosynclines of Haug, the other referring to more local depressions. Cornelius thought that in first order geosynclines the rate of subsidence would as a rule be slow enough to allow sedimentation to keep pace with it. Also they would generally be submerged, although marine sedimentation is not an infallible criterion of first order geosynclines. The equilibrium may occasionally be disturbed, resulting either in the deposition of abyssal sediments or in the temporary filling up of the geosyncline.

Just as Hall's and Dana's concepts of the geosyncline were closely connected with current theories of the origin of the Appalachian folded zone, thus Haug's ideas soon became entangled in controversies over the origin of the Alps. During the decade following Haug's publications on geosynclines his views were interpreted as implying the continued exstence of a deep marine trough, with its greatest depth along its axis, in which the entire Mesozoic and Palaeogene sedimentary series of the Alps was deposited. The criticism of such over-simplified views did not, of course, "disprove the geosynclinal theory" as some writers seemed to believe. It led, however, to a clarification of important points.

(b)   The Concept of Mobility

Haug's idea of geosynclines as zones of bathyal sedimentation dominated the writings of European geologists for some

considerable time, although forces gathered to the attack as early as 1912.

In spite of many important differences Hall, Dana, Haug, and their followers and interpreters were on common ground in so far as they all regarded the sedimentational history of a geosyncline as a period of comparatively quiet and steady development. In opposition to these views Deecke published an article in 1912 in which he pointed out that the Mediterranean-Alpine region since the Carboniferous had not been a "uniform geosyncline," but on the contrary a highly mobile zone, full of archipelagoes, shallow seas, deep basins, and long troughs. The predominant sediments were not at all of the bathyal type; there was an abundance of sediments of clastic to coarse clastic type; and even in the case of many fine-grained sediments, limestones, etc., there was evidence of their having been deposited in quite shallow water. Needless to say that this view has been fully corroborated by later sediment-petrographical investigations among which those of Leuchs (1928 and other papers) may be mentioned. Deecke regarded the Alpine geosyncline as a zone of weakness in the earth's crust, characterized by great vertical mobility where "for unknown reasons" the Tertiary folding took place.

The theme was soon further developed by Dacqué (1915) who did not consider the character of the sediments as a necessarily distinctive feature of the geosynclines. Comparing the Jurassic in Alpine and extra-Alpine development he concluded that neither the thickness of the strata, nor the bathyal or eupelagic facies, nor the uniformity and continuity of sedimentation can be considered as typically geosynclinal. An essential feature of geosynclines is the alternation of slow subsidence and slow uplift. Deposits in geosynclines had very much the character of those in epicontinental seas and there is only a gradual quantitative difference in mobility between the two. The great amount of subsidence and the enormous uplifts in folded mountains are a measure of the high mobility of geosynclinal regions, but folding is only an extreme degree of mobility and not a necessary characteristic of geosynclines.

An able exposition of similar views was given in a little-known paper by Obrutschew in 1927 in which he regards general mobility as the most important feature of geosynclines.

This determines the variable nature of the sediments so that no definite type of rocks seems to be characteristic of these zones. He agrees with Dacqué and others that folding is not a necessary prerequisite of geosynclines.

Nothwithstanding Dacqué's emphasis on certain similarities between geosynclinal and extra-geosynclinal sedimentary series, there developed at about this time a growing recognition of the fact that areas commonly regarded as geosynclinal, as e.g., the Alps, contained certain types of sediments which were *not* found among the deposits of epicontinental seas. Research in this direction begins with the classical papers of Argand (1916) and Arbenz (1919). These new methods of investigation were greatly developed in subsequent years and applied successfully to earlier mountain systems, thus to the Hercynian by Fischer and others, to the Caledonian by Bailey, O. T. Jones and Backlund, and to the Archaean by Pettijohn in America, and Wegmann in Fennoscandia. These authors have placed particular emphasis on the occurrence in geosynclines of clastic sediments showing graded bedding, with rocks characterized by mixing of grain sizes from sand (or even coarser material) to clay grade (Greywacken) playing a major part in the sedimentary series of mobile zones. They have also insisted on the flysch-like character of many of the sediments of old mountain zones.

Tercier (1939) in a comprehensive discussion of the geological interpretation of Recent marine deposition in the East Indies and Central America reached the conclusion that from the point of view of sedimentation neither the distinction between neritic, bathyal and abyssal facies nor that between geosynclinal and epicontinental deposits is entirely satisfactory. He recognized the following fundamental area-types of sedimentation: (1) Paralic Shelf, (2) Epicontinental Shelf, (3) Geosynclines ("Areas of archipelagoes, of marginal seas with deep basins and of continental cordilleras bordering the oceans"), (4) Oceanic regions, (5) Continental regions.

Tercier described the general character of geosynclinal sedimentation in the following terms: It is connected with peculiar topographic conditions, such as strong mountainous relief and a variety of bathymetric conditions, with shelves

(marginal platforms) connected by narrow marine talus slopes with the abyssal zone. Sediments are coarse along the coasts, with a moderate development of equivalents of paralic and epicontinental types of deposits. These heterogenous neritic facies change rapidly into deep-water facies. Local conditions of these marine troughs make it generally impossible to distinguish among the deep-water deposits between bathyal and abyssal sediments. Geosynclinal deposits are generally marine, but vary in character and thickness, owing to rapid movements. Generally speaking, deposits of geosynclinal areas as defined by Tercier are thicker than epicontinental but less thick than paralic sediments. Only two examples of fossil geosynclinal deposits are given by Tercier, the Flysch (including "Wildflysch") facies and the facies of the Jurassic and Cretaceous in the Prealps and the Briançonnais zone of the French Alps. Tercier admits that the other types of sedimentation are often closely associated with geosynclinal sediments. Thus the Triassic of the Western Alps, the Molasse of the Alps and the Neogene of the East Indies are classed as paralic, the Triassic deposits of the Eastern Alps, together with the sediments of the Jura Mountains and of the North-west European basins are considered as epicontinental and the radiolarian rocks of the Alps are described as oceanic and abyssal. This indicates that the concept of geosynclines in a strictly sedimentational and palaeogeographic system of classification does not coincide with the use of the term in a geotectonic sense.

Tercier based his ideas partly on the researches of Kuenen in the East Indies (1930) who had strongly advocated the geosynclinal nature of the East Indies region with its strong relief due to great mobility. Kuenen's definition of a geosyncline as "any region in which the thickness of sediments is great" places the emphasis on the sedimentary filling and seems to invite comparison with neighbouring areas where the sediments are less thick.

It may be relevant in this connection to refer to Butts' recent exhaustive study of the Appalachian Valley of Virginia (1940) which represents one of the most detailed and most illuminating studies of a geosynclinal area ever undertaken. Butts concludes that "the sinking trough was filled

with sediments about as fast as it sank, so that the sea was relatively shallow most of the time. One can picture the Palaeozoic sea studded with low, sandy or muddy banks and scattered islands and fringed generally with low capes and peninsulas, all separated by shallow seas, straits, lagoons, and inlets. The variations in the thickness and the distribution of the formations would be explained by some such geological conditions. No such condition exists anywhere on the earth at present, partly because of relatively recent uplift of all continental masses with respect to sea-level, but the East Indian archipelago, or Australasia, perhaps comes nearest to it." On reading Butts' detailed descriptions, however, one cannot help feeling that most of the history of the Appalachian trough in Virginia has been considerably less violent than that of the East Indian archipelago.

(To be continued.)