

ANALYSIS OF SOME RECENT GEOSYNCLINAL THEORY

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ABSTRACT. "Geosyncline" was invented by Dana in 1873. It was defined as "a down-bending of the crust"; the context supplied the connotation that a mountain chain would eventually arise from sediments accumulated in such a down-bending. However, "geosyncline" has not yet been adequately defined.

Stille's 1940 classification of geosynclines was introduced into America by Kay in 1942. Stille's two principal classes are based upon capacity to be folded. Highly foldable geosynclines are orthogeosynclines; weakly foldable, parageosynclines. Orthogeosynclines include eugeosynclines and miogeosynclines, distinguished by position, time of folding, and magmatism. Eugeosynclines supposedly determine the sites of autochthonous palingenic bathylithic magma. However, bathyliths occur also in so-called miogeosynclines, which necessitates the auxiliary hypothesis that magmas can travel laterally from their eugeosynclinal place of origin to a miogeosynclinal environment. Recent absolute age determinations on bathyliths render this hypothesis untenable.

Lawson maintained that geosynclines do not collapse until they have accumulated a critical thickness—approximately 40,000 feet. Nevertheless, geosynclines have been shown to fail under loads of 10,000 feet or less. The *maximum* thickness of accumulation appears to be 40,000 feet; consequently this limit suggests that stratigraphic thicknesses estimated to exceed 40,000 feet require reduction.

In 1944 Stille introduced the concept of "regeneration," meaning thereby restoration of the orthogeosynclinal state in ancient fold-belts. This idea has stimulated, among other things, active interest in the fate of ore deposits in regenerated orthogeosynclines. Critical evidence of the effects of regeneration on the dispersal of pre-existent ores is given by the isotopic composition of leads in galenas formed during successive orogenies.

ORIGIN OF THE TERM GEOSYNCLINE

The term geosyncline, as Goguel remarked in 1952, has had a brilliant career ever since its invention by Dana in 1873. In 1940, several kinds of geosynclines were defined and named by Stille, who also devised a classification for them. Shortly afterward, many more kinds of geosynclines were distinguished and named by Kay. It is proposed here to analyze the content of the more widely used of these terms and to show their impact on other major problems of geology, such as the origin of primary and palingenic magmas and the origin and classification of ore deposits.

The *idea* that a trough containing a thick accumulation of sediments was destined to become the site of a future mountain chain was originally formulated by James Hall, State Paleontologist of New York, in his presidential address to the American Association for the Advancement of Science in 1857, and was presented at greater length in 1859 in volume 3 of the New York Geological Survey (Hall, 1859).

The *name* was created by Dana in 1873 (Dana, 1873, p. 430) in the form of "geosynclinal". Dana, however, gave the term no comprehensive definition. He defined geosynclinal briefly in a footnote on page 430: "from the Greek *ge.* the *Earth.* and *synclinal.* it being a bend in the Earth's crust". The definition was given incidentally while Dana was explaining how the Allegheny Range was formed:

The making of the Allegheny Range was carried forward at first through a long-continued subsidence—a *geosynclinal* (not a true geosynclinal since the rocks of the bending crust may have had in them many true or simple synclinals as well as anticlinals), and a consequent accumulation of sediments, which occupied the whole of Paleozoic time.

The mountain range formed from the folding of such a geosynclinal accumula-

tion was called a synclinorium, from *synclinal* and the Greek *oros*, mountain. Etymologically better, it should have been termed a "geosynclinorium". Both Dana and Hall before him were mainly concerned with the problem of mountain-making. Hall, in finally publishing his presidential address in 1882 (Hall, 1882, p. 68) expressly affirmed that the address of 1857 was intended to show "that mountain ranges were coincident with lines of great sedimentary accumulation". Thereby the idea became implanted in geology that a geosyncline and its accumulation of sediments predestines a future fold chain. This idea can fittingly be called, with perfect etymology, the "geosynclinorial theory" of Hall and Dana.

RELATION OF GEOSYNCLINES TO OROGENY

In the theory of mountain-making based upon the geosyncline, Dana recognized two stages: (1) in which a "preparatory" geosyncline was gradually deepening and concurrently accumulated a great thickness of sediments, the building material of the future mountain range; and (2) the mountain-making events—the folding and faulting of the accumulated strata. In the final edition of his *Manual of Geology*, Dana (1895, p. 357) wrote:

The knowledge of the Appalachian facts led Professor James Hall to suggest in 1859 that a similar trough of deposition preceded the up-turning in all cases of mountain-making. It was the first statement of this grand principle in orography.

Thus by 1895 the idea had become established that all geosynclines that had been the loci of heavy sedimentation are "preparatory" geosynclines, and that such geosynclines are consequently the sites from which future mountain chains will arise. A great principle of orogenesis had indeed been stated, but no generally satisfactory definition of geosyncline had then been formulated, nor has one yet been produced.

MEANING OF THE TERM GEOSYNCLINE

Definitions range widely. Stille (1924, p. 6; 1940, p. 164) says that a geosyncline, in the broadest usage, is a secularly sinking basin of sedimentation. He adds that the formation of a fold-range from a geosynclinal accumulation is not necessary to the concept "geosyncline", thereby departing from the original ideas of Hall and Dana. On the other hand, Termier and Termier (1956, p. 2) in a treatise of world-wide scope define a geosyncline thus: it is a subsiding zone that, as a rule, has received a thick sedimentary accumulation, has then been subjected to regional metamorphism and to orogenic phases, and finally is transformed into a chain of mountains.

In 1936 "pliomagmatic" and "miomagmatic" were proposed by Stille (1936) to characterize certain types of geosynclines. Regions such as the Nevadan realm of North America that are characterized by strong volcanism during sedimentary accumulation and by synorogenic plutonism during the subsequent deformation were called "pliomagmatic". These terms, so the author insisted, are to be applied only to geosynclines that had been capable of being closely folded or, to use his own words, they are to be used to characterize the "alpinotype" condition of a region and not its subsequent "germanotype" condition after it had become consolidated and was no longer capable of being folded and closely appressed.

In 1940 "pliomagmatic geosyncline" was shortened by Stille (1940) to "eugeosyncline" and "miomagmatic geosyncline" to "miogeosyncline". The content of the terms was also amplified. The terms were defined in a book entitled "Einführung in den Bau Amerikas" published in 1940 (Stille, 1940). The volume contains also a valuable glossary of terms. World War II had already begun, and so far as known to Dr. Stille¹, only four copies of the volume reached the United States of America. Shortly afterwards the whole stock at Borntraeger was destroyed during an air raid on Berlin.

STILLE'S CLASSIFICATION OF GEOSYNCLINES

Stille's terms first appeared in American literature in a paper by Marshall Kay (1942, p. 1642). In a footnote to that paper on p. 1642, the following classification of geosynclines was presented, as given by Stille in a letter written to Kay in German under date of May 24, 1941. As translated here by me the Stille classification reads:

- I. Orthogeosynclines (alpinotype geosynclines) comprising
 - a. Eugeosynclinal zones (pliomagmatic mother zones of the internides)².
 - b. Miogeosynclinal zones (miomagmatic mother zones of the externides)³.
- II. Parageosynclines (germanotype geosynclines upon already consolidated basements).

To which Kay added: "the terms eugeosyncline and miogeosyncline have been defined recently (Stille, 1940⁴, p. 15)".

The term "parageosyncline" had previously been used by Schuchert (1923, p. 199) in another sense, but it had not come into use. The choice of the term parageosyncline by Stille was hardly felicitous, since "para" is used in so many senses in geologic terminology. As in Stille's definition parageosyncline is defined as being situated upon an already consolidated basement, in other words, upon the craton, "intracratonic or supracratonic geosyncline" would have been preferable.

The terms formulated by Stille in 1940 were adopted by Kay in 1942. To them Kay added other terms to specifically designate the geosynclines of many kinds that he proposed to distinguish. Although no one has yet been able to give a generally acceptable definition of "geosyncline", we now have thirty or more variants of the unsatisfactorily defined concept.

As commonly used in America, the terms eugeosyncline and miogeosyncline are purely descriptive. Eugeosyncline is employed to designate a thick stratigraphic section, i.e., measurable in thousands of feet, that contains abundant contemporaneous volcanic rocks. Miogeosyncline is used to signify a thick stratigraphic section devoid or nearly devoid of contemporaneous volcanic

¹ Letter to the writer (A.K.) under date of June 2, 1959.

² Internides: The inner and therefore the older zones of alpinotype fold chains.

³ Externides: The outer and therefore the younger zones of alpinotype fold chains. In geosynclinal chains on the borders of continents the externides are on the continental side.

⁴ Originally cited in error by Kay as 1941. The definitions referred to were not given.

rocks. Paleogeographic and stratigraphic evidence of alleged geosynclines are generally sketchy or are not given.

In a recent publication that is easily available Stille (1958, p. 284) again defined "orthogeosynclines" (an overall category that, as already mentioned, comprises both eugeosynclines and miogeosynclines) as those mobile zones of the Earth's crust in which have been concentrated the alpinotype foldings and the shortening of the crust thereby produced. While "eugeosyncline" and "miogeosyncline" were becoming widely used in America, the author of the terms came to use them only sparingly or not at all. In a masterly synthesis of the late Paleozoic Variscan orogeny as it affected the continent of Europe—a monograph of 138 pages,—Stille (1951) employs neither term; instead "inner Variscan (Innenvariszikum)" and "outer Variscan (Aussenvariszikum)" are used to distinguish these portions of the geosynclinal system "on the basis of time of folding, intensity of folding, and magmatism".⁵

Many authors in employing the terms eugeosyncline and miogeosyncline casually explain that miogeosyncline means "less of a geosyncline", but they do not explain what is meant by "less of a geosyncline". In the words of Stille (1940, p. 656), who created the term, miogeosynclinal zones are

more peripheral, generally miomagmatic or amagmatic elongate belts of a geosynclinal system, which manifest a certain 'lesser geosynclinality' in that they commonly become folded only after their neighboring eugeosynclinal zones have become folded.

The power to make such a distinction obviously requires a correct and comprehensive knowledge of the geologic history of the geosynclinal system in question.

MAGMATISM AND OROGENY IN RELATION TO GEOSYNCLINES

Initial magmatism, meaning thereby the eruption of lavas and the intrusion of related dikes, sills, and stocks during the accumulation of a geosynclinal prism, is regarded as characteristic of an orthogeosynclinal system. This igneous activity is specifically termed by Stille "initial magmatism". Such magmatism does not characterize all zones of an orthogeosyncline, however. Typically, initial magmatism is absent from the outer zones of an orthogeosynclinal system; that is, it is absent in those zones that during the collapse of the geosyncline become folded only during the later phases of a polyphase orogeny. In this usage the term "orthogeosyncline" includes; (1) the idea of "full geosynclinal (eugeosynclinal) state", which is characterized by the attributes of high geosynclinality, one of which is manifested most obviously by initial magmatism; and (2) a "lesser geosynclinal" state, in which initial magmatism has not participated. According to Stille, the eugeosynclinal zones have in general been folded first and have therefore been folded far more strongly than those portions of the orthogeosynclinal system that were folded later. The eugeosynclinal zones, which are the loci of initial magmatism, are said to have been as a rule the principal loci of synorogenic plutonic intrusions, but as shown later, this generalization needs considerable qualification. The eugeosynclinal zones are thus likely to be doubly pliomagmatic in contrast to the miomagmatic or amagmatic outer zones. The reason for this, according to

⁵ Letter to the writer, June 2, 1959.

Stille, is that the closely folded belt produced during the deformation of the geosyncline sinks so deeply that the lower portion fuses to form palingenic sialic magma. After the upper portion of the folded belt has become rigidified—when it has attained a quasi-cratonic state—it may become the locus of “subsequent magmatism”, marked by eruption of consanguineous sialic lavas and the intrusion of subvolcanic plutons. Therefore the original geosynclinal zone can be characterized as pliomagmatic on a third count.

The term eugeosyncline therefore embodies three features: (1) the eugeosyncline is that portion of a geosynclinal system which was the first to be folded; (2) it comprises the portion of higher mobility, i.e., the capacity to be folded and closely appressed; and (3) it is the locus of abundant igneous activity, both during the preparatory stage of the geosyncline and its subsequent conversion into a folded tract, or orogen as it was named by Kober (1921, p. 21). The orogen, as Kober ventured to emphasize, is from one-third to one-half narrower than the original geosyncline. “Orogen” has at least this advantage over “geosyncline”, it is one stage nearer factual reality than is “geosyncline”, in which the contained load is inferred to have been the necessary condition determining that a fold-chain has arisen from it.

Special insight, often of a predictive nature, has become linked to the term eugeosyncline. As early as 1942 Kay announced that the eugeosynclines become the loci of bathylithic intrusion of granites. “Why”, asks King (1959, p. 147) “are granitic rocks characteristically emplaced only in the former geosynclinal areas?” The idea underlying this question is a variant of an earlier generalization. Said Browne (1932, p. 135) “Wherever a bathylith outcrops we may infer the former presence, on or over that spot, of a series of geosynclinal sediments, terrestrial or marine, during whose folding and elevation the intrusion of the bathylith took place”. As of 1959 we can rephrase Browne’s generalization thus: “Wherever a bathylith outcrops we may infer the former presence, on or over that spot, of a series of *eugeosynclinal* rocks.”

On several counts, however, even the revised generalization is too inclusive. Bathyliths occur also in non-orogenic regions, as exemplified by the Rand granite of the Bushveld Igneous Complex, the granite comprising a mass of 5000 square miles in area; and by the Rapakivi mass near Viborg, Finland, 6400 square miles in area. Furthermore, bathyliths do occur in what have been called miogeosynclines, such as the Idaho bathylith of 18,000 square miles, the Boulder bathylith of Montana of 1200 square miles, the bathyliths of the Philipsburg district, Montana (Emmons and Calkins, 1913), and the large granitic stocks of almost bathylithic dimensions in the Wasatch Range, stocks which penetrate the thick amagmatic series of sedimentary rocks that accumulated in the Wasatch geosyncline.

The occurrence of large bathyliths in the Rocky Mountain region was regarded as anomalous by Stille. The folding was weak; consequently downfolding plus isostatic sinking was inferred to have been not deep enough to cause fusion of the geosynclinal prism. Because the magma could therefore not have been formed subjacently, it was considered to have moved in laterally from a supposed locus of generation farther west. The idea of eastward migration of magma had previously been advanced by Lindgren on other grounds.

Stille calls bathylithic intrusion of this kind "allochthonous synorogenic plutonism fed by the lateral migration of sialic magma." In an account of the Boulder bathylith (Knopf, 1957, p. 88) I presented these ideas without comment, believing them to be highly interesting but unsupported by compelling evidence. Since that time reliable age datings by the K-Ar method have become available. They demonstrate clearly that eastward migration of magma in time is *not* supported by the evidence; for example, the granites in the Coast Ranges of California are 80 to 90 m.y. old; the granites of the foothill region of the Sierra Nevada are 140 m.y. old; the granites of the higher Sierra Nevada are 80 to 90 m.y. old; and the Boulder bathylith, far to the east in Montana, is also 80 m.y. old.

CRITIQUES OF THE GEOSYNCLINAL DOCTRINE

Some recent critiques of the geosynclinal doctrine should be noted. Goguel, (1952) after commenting that Dana's term "geosynclinal" has had a brilliant, not to say dazzling, (*éclatant*) career, finds that it is impossible to give a precise meaning to the content of that concept. The essential idea implied by the term is that the sediments in a geosyncline are very much thicker in the folded zone than elsewhere. "But", added Goguel, "the other characteristics of sedimentary accumulations called geosynclinal vary with the author". It takes no worldwide survey of geologic literature to find this statement amply confirmed.

The Appalachian geosyncline, as is well known, is the type geosyncline. However, the great increase in knowledge of the region, including the many absolute age determinations recently made, which fix the dates of metamorphism and bathylithic intrusion beyond argument, show that the geologic history of the region differs greatly from that of the orthodox belief. When the recognition by Kay (1944, p. 462) that "there are geosynclines of several sorts and of differing ages in the Appalachian region", becomes generally accepted a great advance will have been made.

RECOGNITION OF MODERN GEOSYNCLINES

As has often been pointed out, the fundamental principle of orogeny that a geosyncline and its load of sediments predestines a future fold chain would prevent us from recognizing a modern geosyncline that has not yet been folded.

Nevertheless, it is probable that modern geosynclines can be recognized, but no criteria have yet been established by which to determine whether or not such modern geosynclines are "preparatory geosynclines" out of which fold-chains will eventually arise.

Kossmat (1936) thought that the basin of the Adriatic Sea is a typical geosyncline, still sinking. Kuenen (1935) considered the Timor trough and its continuation as a geosyncline to be a "modern geosyncline" in the act of formation.

The Gulf Coast region of Louisiana and Texas is considered by many geologists to be a modern geosyncline, despite its failure to agree with the orthodox conception of what the type geosyncline—the Appalachian—was like. To Bucher (1951) the so-called Gulf Coast geosyncline is a particularly fine representative of a modern geosyncline; to Lawson (1942) it has the most

significant feature of a geosyncline, namely the heavy load of sediments acquired *pari passu* with subsidence, i. e., the belt of excessive sedimentation which as emphasized by Hall, the founder of the geosynclinal theory, was the factor determining the site of the future mountain range.

According to Crouch (1959, p. 1290), however, the Gulf Coast "geosyncline" is in the unfortunate state that "none of the requirements for a geosyncline can be substantiated at this time; that is, no regional reversal of dip and no thinning of beds can be demonstrated". Finally, we may cite King (1959, p. 82), who believes that the Gulf Coast deposits do not differ very fundamentally from those of the Appalachian geosyncline, and that the differences "are mainly the result of differences between the internal geography of the continent in Paleozoic and Cenozoic time".

THE CRITICAL LIMIT OF THE FILLING OF A GEOSYNCLINE

In a series of papers beginning in 1927, Lawson (1927) advanced the idea that the sedimentary trough collapses only after the filling has reached a certain critical limit, which he placed at approximately 40,000 feet. Earlier however, Schuchert (1923, p. 208), having inductively examined the recorded field evidence of the failure of geosynclines, concluded that the thickness of the sediments accumulated in a geosyncline appears to have nothing to do with the time when the sediments were folded; in some folded belts the sediments appear to have been less than 10,000 feet thick.

Goguel in his *Traité de Tectonique* (1952, p. 23) goes even further than Schuchert, pointing out that we know of basins containing exceptionally thick sediments that have not been folded, as well as folded zones in which the sedimentary series are of feeble thickness.

Of still greater importance, because supported by examples, is the evidence cited by Lees (1952, p. 4). He finds that deep exploratory borings have shown that, contrary to expectation, many sequences of sedimentary rocks in flat-lying or very gently folded foreland areas are even thicker than their equivalents in the strongly folded or thrust mountain belt.

According to a remarkable summary account by Browne (1947, p. 635), the Tasman geosyncline of eastern Australia, because of its length (2000 miles), its duration in time (the whole of the Paleozoic), and its eventful history, "must surely rank as one of the greatest of its kind that the world has ever seen". The geosyncline was subjected in its various parts to five major orogenies, all of which were accompanied by granitic intrusion. The fourth of these orogenies, the Kanimblan, occurred near the end of Mississippian time. It is considered to be the greatest in the history of the Tasman geosyncline. The folding extended 2000 miles in length and affected the paralic zone and some of the marine zone of the geosyncline over a total width of 600 miles. The Kanimblan folding, although as a rule comparatively gentle, was followed by bathylithic intrusion in many of the areas affected (David and Browne, 1950, p. 319). Yet the thickness of the Devonian and Carboniferous beds that were folded is reported to be less than 10,000 feet.

In view of these statements by Schuchert, Goguel, Lees, David and Browne, it appears probable that Lawson's term "critical limit" must be

changed to mean not that folding failed to ensue until the sedimentary filling of the geosyncline reached 40,000 feet in thickness, but that no sequence (sedimentary or volcanic) can exceed about 40,000 feet in thickness without being folded. The following geosynclines are reported to have contained accumulations aggregating 40,000 feet before being folded: Appalachian; Llanorian (35,000 feet); Eastern Venezuelan; and Wasatch, Utah. On the other hand, geosynclinal sections that are reported to be much thicker than 40,000 feet prove on careful restudy to be generally, if not invariably, far thinner than originally announced.

RESTORATION OF THE ORTHOGEOSYNCLINAL CONDITION

An important new concept was introduced by Stille (1944, p. 195) into geosynclinal theory. An account of this idea was later (Stille, 1955) given in English. The concept is called "regeneration" or the restoration of the geosynclinal state. During regeneration a folded tract recovers the orthogeosynclinality that had been lost by the operation of preceding orogenic processes. When such regeneration takes place it affects not only the structures in the crust, but even more the magmatic relationships. An unexpected result of the introduction of this concept into geosynclinal theory has been the powerful stimulus it has exerted on theories of the origin of ore deposits.

In 1921 de Launay (1921, p. 333) pointed out that the fold chains of France are built upon the ruins of older fold-chains. Said he: "Nature has acted here just as does man who forever continues to build upon the preceding ruins". The Alps stand upon the ruins of a Variscan chain, and the Variscan chain stands upon the ruins of a still older chain, probably of Assyntian construction at the end of the Precambrian, and possibly on a still older one, according to Stille (1951).

The earliest recognition of this general idea, so far as known to me, is by P. Termier (1903). He pointed out that the Alpine geosyncline was established upon a zone that already had been folded before the deposition of the Carboniferous coal measures, and that the axis of the geosyncline is essentially parallel to the Variscan folds. However, in the Mont Blanc region, where at least four phases of folding have occurred, the axes of the youngest folding of the mid-Tertiary Alpine orogeny are not parallel to those of the older folding (Oulianoff, 1934, p. 125). Such axial divergence between the Alpine and older folding is evidence to Stille (1951, p. 41) that the Alps arose out of a regenerated orthogeosyncline and not from a residual portion of a Variscan or older geosyncline.

According to the French view, a fold-chain in the course of time is reduced to a peneplain, from which by subsidence, sedimentation, and folding a new chain will arise. A geotectonic cycle thus begins with a peneplain and ends with a peneplain. De Launay's generalization has been amplified so as to say that most mountain chains are built upon the ruins of older chains. In that generalization doubtless resides the explanation of why "the basement of all geosynclines is found to be a continental area" (Kuenen, 1950, p. 145). Earlier, Kuenen (1935) already had announced that geosynclinal troughs invariably develop on continental areas underlain by a thick sialic crust. Logically then,

the conclusion follows that throughout geologic time the development of such troughs was a consequence of restoration or recovery of orthogeosynclinality.

Exploration of our oldest Precambrian terranes may possibly in time supply us with evidence that there have been geosynclinal troughs which had not been developed from continental material. These geosynclines will probably fall into the class of ensimatic geosynclines, which in theory contain an accumulation consisting of effusive rocks that were poured out on a sima floor (Wells, 1949).

The Alps have long been recognized to stand on the ruins of older mountains: on Variscan (Hercynian) of late Paleozoic age and in part on still older remnants, probably of late Precambrian age (Assyntian). The region affected by the Tertiary Alpine orogeny is not a residual portion of the Variscan geosyncline or of a pre-Variscan geosyncline but is a regenerated orthogeosyncline. The restoration of foldability to the extreme degree shown by Alpine folding is unsurpassed in any of the world's orogenic belts.

An example recently recognized in Australia is described by Hills, (Hills, 1956). The Adelaidean geosyncline, of late Precambrian and early Paleozoic infilling, is a geosyncline that lies between blocks of cratonic basement, which had previously been strongly and universally folded.

REGENERATION IN ITS APPLICABILITY TO ORE DEPOSITS

The concept of the recovery of geosynclinality has led Schneiderhöhn (1952) to formulate a new classification of ore deposits, which is based on (1) the older magmatologic considerations, (2) the newer geotectonic ideas of Stille, and (3) the role of metamorphism as developed by Clar, Angel, and Friedrich. In this classification:

Class I comprises essentially the deposits formed in a primary orogen by fluids of magmatic derivation,

Class II regenerated ore deposits, comprise deposits of Class I whose constituents were put in circulation again during geotectonic regeneration of the primary orogen and were deposited in higher and younger parts of the Earth's crust.

These ideas have led to great intellectual activity. Space does not permit further discussion, but I must content myself with a brief mention of an extraordinarily penetrating account of the application of Schneiderhöhn's ideas by Smirnov (1959) to the ore deposits of the Caucasus. In that region tectonic, magmatic, and metallogenic processes took place during the Caledonian, Variscan, and Mesozoic-Cenozoic (Alpide) orogenies. Molybdenum deposits were formed during all three orogenies. At first sight this thrice repeated formation of molybdenum deposits would seem to support Schneiderhöhn's hypothesis. However, the first two metallogenic epochs produced only insignificant molybdenum deposits, but during the Alpide epoch important ore bodies were formed. The conclusion that the not inconsiderable number of Alpidic ore deposits of the Caucasus were formed according to the scheme of regeneration from the very small number of older deposits "is completely impossible". The same rule holds for the other metals. The reserves of lead and zinc in the known

Alpide ore deposits are at least 15 to 20 times larger than those in the Variscan deposits. It is therefore improbable that the lead and zinc in the Alpide deposits were derived from the Variscan deposits. This conclusion of Smirnov is independently confirmed by the differing isotopic composition of the lead in the galenas of the deposits of both ages.

Isotopic Composition of Leads

	Pb ²⁰⁸ /Pb ²⁰⁴	Pb ²⁰⁷ /Pb ²⁰⁴	Pb ²⁰⁶ /Pb ²⁰⁴
Variscan	18.02	15.22	37.31
Alpide	18.60	16.08	39.13

The Variscan lead corresponds well in isotopic composition with that of normal late Paleozoic lead, and the Alpide lead with normal Tertiary lead.

However, many examples in which the isotopic composition of a lead does not correspond with its geologic age have become known. In the late Mesozoic ore deposits of Bisbee, Arizona, the lead has an isotopic composition indicative of Precambrian age (Bain, 1952). Manifestly, the late Mesozoic ore-forming solutions had acquired from somewhere in depth lead that had previously been deposited in Precambrian time, had carried it upward, and had redeposited it in rocks higher in the crust. Many more examples of such "anomalous leads", as they are termed by Russell, et al. (1954, p. 305) could be cited; however, the geologic explanation of their anomalous compositions is still in the realm of the future.

REFERENCES CITED

- Bain, G. W., 1952, The age of the "Lower Cretaceous" from Bisbee, Arizona uraninite: *Econ. Geology*, v. 47, p. 305-315.
- Browne, W. R., 1932, Notes on bathyliths and some of their implications: *Royal Soc. New South Wales Jour. and Proc.*, v. 65, p. 112-144.
- , 1947, A short history of the Tasman geosyncline of eastern Australia: *Science Progress*, v. 35, p. 623-637.
- Bucher, W. H., 1951, Fundamental properties of orogenic belts: *Am. Geophys. Union Trans.*, v. 32, p. 514-517.
- Crouch, R. W., 1959, Inspissation of post-Oligocene sediments in southern Louisiana: *Geol. Soc. America Bull.*, v. 70, p. 1283-1292.
- Dana, J. D., 1873, On some results of the Earth's contraction from cooling, including a discussion of the origin of mountains and the nature of the Earth's interior, Part I: *AM. JOUR. SCI.*, ser. 3, v. 5, no. 30, art. 46, p. 423-443.
- , 1895, *Manual of geology*, 4th ed.: New York, American Book Co., p. 380-386.
- David, T. W. E., and Browne, W. R., 1950, *Geology of the Commonwealth of Australia*: London, Edward Arnold and Co., v. 1, 747 p.
- de Launay, Louis, 1921, *Géologie de la France*: Paris, Librairie Armand Colin, p. 333.
- Emmons, W. H., and Calkins, F. C., 1913, *Geology and ore deposits of the Philipsburg quadrangle, Montana*: U. S. Geol. Survey Prof. Paper 78, 271 p.
- Goguel, Jean, 1952, *Traité de tectonique*: Paris, Masson et Cie, 383 p.
- Hall, James, 1859, Descriptions and figures of the organic remains of the Lower Helderberg group and the Oriskany sandstone: *New York Geol. Survey, Palaeontology*, v. 3, p. 66-96.
- , 1882, Contributions to the geological history of the American continent: Salem, Mass., Salem Press, p. 29-69.
- Hills, E. S., 1956, The tectonic style of Australia, in Stille, Hans, *Geotektonisches Symposium*: Stuttgart, F. Enke, p. 343-344.

- Kay, Marshall, 1942, Development of the northern Allegheny synclinorium and adjacent regions: *Geol. Soc. America Bull.*, v. 53, p. 1601-1658.
- , 1944, Geosynclines in continental development: *Science*, v. 99, p. 461-462.
- King, P. B., 1959, *The evolution of North America*: Princeton, New Jersey, Princeton Univ. Press, 190 p.
- Knopf, Adolph, 1957, The Boulder batholith of Montana: *AM. JOUR. SCI.*, v. 255, p. 81-103.
- Kober, L., 1921, *Der Bau der Erde*, 1st ed.: Berlin, Gebrüder Borntraeger, p. 21.
- Kossmat, F., 1936, *Paläogeographie und Tektonik*: Berlin, Gebrüder Borntraeger, 414 p.
- Kuenen, P. H., 1935, The Snellius Expedition in the eastern part of the Netherlands—East Indies 1929-1930, in *Scientific results of the Snellius Expedition*, v. 5, pt. 1, p. 54-55: Utrecht, Kemink & Son.
- , 1950, *Marine geology*: New York, John Wiley and Sons, 568 p.
- Lawson, A. C., 1927, Folded mountains and isostasy: *Geol. Soc. America Bull.*, v. 38, p. 253-274.
- , 1942, Mississippi delta—a study in isostasy: *Geol. Soc. America Bull.*, v. 53, p. 1231-1254.
- Lees, G. M., 1952, Foreland folding: *Geol. Soc. London Quart. Jour.*, v. 108, p. 10-34.
- Oulianoff, Nicolas, 1934, Massifs hercyniens du Mont Blanc et des Aiguilles Rouges: *Geol. Führer der Schweiz*, fasc. 2, p. 121-129.
- Russell, R. D., Farquhar, R. M., Cumming, G. L., and Wilson, J. T., 1954, Dating galenas by means of their isotopic constitutions: *Am. Geophys. Union Trans.*, v. 35, p. 301-309.
- Schneiderhöhn, Hans, 1952, Genetische Erzlagerstätten-Gliederung auf geotektonische Grundlage: *Neues Jahrb. Mineralogie Mitt.*, p. 47-63, 65-89.
- Schuchert, Charles, 1923, Sites and nature of the North American geosynclines: *Geol. Soc. America Bull.*, v. 34, p. 151-229.
- Smirnov, W. L., 1959, Ueber regenerierte Erzlagerstätten: *Zeitschr. angew. Geologie*, Band 5, p. 280-282.
- Stille, Hans, 1924, *Grundfragen der vergleichende Tektonik*: Berlin, Gebrüder Borntraeger, 443 p.
- , 1936, Die Entwicklung des amerikanischen Kordillereensystem in Zeit und Raum: *Preuss. Akad. Wiss. Sitzungsber., Phys.-Math. Kl.*, Band 15, p. 114-155.
- , 1940, Einführung in den Bau Amerikas: Berlin, Gebrüder Borntraeger, 717 p.
- , 1944, Geotektonische Gliederung der Erdgeschichte: *Preuss. Akad. Wiss. Abh., Naturw. Kl.*, no. 11, 77 p.
- , 1951, Das mitteleuropäische variszische Grundgebirge im Bilde des gesamteuropäischen: *Geol. Landesanst., Geol. Jahrb. Beihefte*, Heft 2, 138 p.
- , 1955, Recent deformation of the Earth's crust in the light of those of earlier epochs, in *Poldervaart, Arie (ed.), Crust of the earth—a symposium*: *Geol. Soc. America Spec. Paper* 62, p. 171-192.
- , 1958, Einiges ueber die Weltozeane und ihre Umrahmungsräume: *Geologie, Jahrg.* 7, p. 284-306.
- Termier, Pierre, 1903, Les nappes des Alpes et la synthèse des Alpes: *Soc. géol. France Bull.*, v. 3, p. 711-765.
- Termier, Henri, and Termier, Geneviève, 1956, *L'évolution de la Lithosphère*; I, Petrogenèse: Paris, Masson et Cie, 653 p.
- Wells, F. G., 1949, Ensimatic and ensialic geosynclines: *Geol. Soc. America Bull.*, v. 60, p. 1927.