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CERTAIN ASPECTS OF GEOLOGIC CLASSIFICATIONS AND CORRELATIONS[1]

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GENERAL CONCEPTS

OUR knowledge of the history of the earth has been developed gradually by fitting together the histories of small areas studied in detail. As the early geologists gradually became familiar with the rock formations of their own districts, they began to classify the strata in groups. Comparison of individual findings with those of geologists in other areas was particularly stimulating and led to more searching and critical study; correlations between different regions were attempted, and historical geology began to overspread political boundaries. In the course of time the full succession of rock systems came to be recognized and the broader outlines of the geologic history of Europe and North America became established.

[1] Address of the vice-president and chairman of the section on Geology and Geography, American Association for the Advancement of Science, Pittsburgh, December 31, 1934.

Rather notable it was that the rock systems built up from the stratigraphic sequences and fossil peculiarities of Europe were found to be applicable and useful also in North America, though three thousand miles of Atlantic Ocean lay between. Now the same rock systems and corresponding geologic periods do service the world over. Though great variation in local details is manifest, distant regions seem to have enough in common to make possible a general history of the earth in world-terms. Why this is possible, we can now understand.

We know that for long stretches of time the continental land masses have remained relatively free from diastrophic movements of the more declared sort, during which times erosion has lowered the lands and shallow epicontinental seas have spread widely over their reduced surfaces. Part of this spread of the seas has resulted directly from cutting down the lands and deposition of much of the eroded material in the oceans, thereby displacing an equivalent volume of water and causing a rise of sea-level. However modified in detail by local crustal movements, from which the earth is never free, as well as frequent eustatic fluctuating of sea-level, the general tendency toward continental inundation at such times is world wide. In these seas have accumulated the successions of sedimentary beds which constitute the marine phases of the rock systems. The sedimentary record developed at such times in such seas has, in general, been most nearly complete; it comprises, as a rule, the best-known portions of most rock systems and is most nearly comparable the world over. During these times of extensive transgression of the seas over low-lying continents, the climates have been largely oceanic in nature, mild and equable, and shallow-water marine life has prospered in an expansional phase. The marine faunas have then been as cosmopolitan as such faunas ever are. Consequently, given sufficient short-lived, rapid-traveling species, paleontologic correlations of the strata formed at such times are at their best, and these portions of the general earth story have been put together most correctly.

Had the relatively quiescent conditions of one of these periods been sufficiently quiet and persisted sufficiently long, the land masses would have been base-leveled and eventually submerged beneath ever-spreading seas. But, happily for land life, we find that after a long period of sea transgression, but before complete wearing down of the lands and final submergence was accomplished, a reversal of processes has invariably occurred. Recurring stresses have rejuvenated large portions of the continents and folded certain belts into mountain chains. Like the transgression of the sea, its regression is also far more than a local phenomenon.

We know that the principal belts of mountain building, such as those of the Caledonian, Hercynian, Alpine and Cordilleran orogenies, have been very long, arcuate strips, the last named of which reached fully a third of the way round the globe. Such long, winding belts of earth wrinkling tell of world stresses rather than local stresses, and imply a certain parallelism of major events over large areas. The diastrophic revolutions are thus of more or less cosmopolitan significance.

Very important for our problem, however, is the relation of general continental emergence to the more intensified orogenic earth distortions. It is natural enough to regard both relative uplift of continental areas and the much stronger deformation of particular belts as differently expressed results of the same earth stresses. One phase of this conception is the belief of some geologists that episodes of strong folding are genetically related to sinking of the ocean basins. On this question, however, there is no unanimity of opinion. But, as a rule, we find that general emergent conditions have been an accompaniment of the orogenic revolutions. To the emergences we owe the breaks in the stratigraphic sequence. Furthermore, we recognize that the orogenic revolutions have been characteristically short in duration compared with the times of relative quiescence and extended marine sedimentation. Accepting the generalization that the revolutions are accompanied by general emergences and important interruptions of the marine sedimentary record, they naturally serve as positive beats to mark off the long geologic periods of earth rhythm.

But because of the areal extent of a diastrophic revolution, exactly synchronous earth yielding in different portions of the globe is hardly to be expected. Indeed it would be strange if the resistance of the rocks were overcome at precisely the same time throughout the whole stretch of a major deformation. All the eggs in a nest do not hatch the same day. Although we recognize a general simultaneity, just how nearly synchronous the earth failure has commonly been throughout a belt of deformation is one of the important questions of geologic history, upon which more information is greatly needed. The problem of correlation would be less complex if each diastrophic revolution consisted of but a single pulsation, but instead it commonly consists of several distinct episodes or separate paroxysms of relatively short duration spaced between longer and quieter intervals. The relative intensity of the individual paroxysms may vary from place to place. Viewed in detail the problem of correlation appears very complicated, but viewed in larger units it becomes simpler because in many cases the whole revolution has occupied a span of time much less than that of either the geologic period immediately preceding or that immediately following, and the span of the revolution as a whole has been more or less contemporaneous over the globe.

The consequences of an episode of major deformation are far-reaching. Large areas of epicontinental sea bottom become land; in these marine sedimentation ceases, erosion occurs, and an unconformity eventually results. Climates become more diversified as oceanic conditions give place to continental conditions and severe mountain climates develop locally. Glaciation comes on in the more declared cases and extreme aridity may appear in places. Plants and animals are profoundly influenced by the changing environments. This whole combination of related changes has been attendant upon the diastrophism. In recognition of this, two decades ago, appeared the dictum:

"Diastrophism is the ultimate basis of classification and correlation."

The full accomplishment of these ramifying developments requires, however, a considerable length of time, and the changes do not progress everywhere at the same rate. Such is inevitable in the very nature of the case. Consequently, a close correlation of the individual steps in the progress of events over widely separated areas, while correct in many cases, is manifestly incorrect in other cases. Variability has characterized many of the links in the chain. Although certain changes, or certain steps of advancement, did not take place at the same time in different regions, nevertheless the diastrophic revolution, which inaugurated the changes, is the basic process upon which the rest are dependent. So it is that our geologic periods, though originally established primarily on stratigraphic and paleontologic grounds, are for the most part found to be delimited also by episodes of pronounced diastrophism. Since much of the globe has been involved to some extent in the diastrophism, our present geologic periods and rock systems are also of wide applicability and have become standard over the whole earth. But this does not mean that the future will see no changes in the periods as now outlined; there are not a few infelicities in our present classification; with increasing knowledge and a better understanding of the real significance of a geologic period, it is probable that important improvements will be made. Some of them are perhaps already in sight.

Pre-Cambrian Correlations

The nebular hypothesis of Laplace gave rise to the very simple picture of a hot molten globe which froze over on the surface and thereby gave rise to an original granitic crust which came to be called the primordial Archean and on which were laid down in succession the later sedimentary deposits. The Archean thus conceived was very clear-cut and definite. Now this distinctiveness has largely disappeared; water-laid sediments are among our oldest rocks, and where to place the upper limit of the Archean has become a matter of pronounced difference of opinion. Sir Charles Lyell's doctrine of uniformitarianism now applies as well to our earliest rock-revealed geologic history as to that of any later time, and if we could decipher the rocks beneath the oldest yet studied who can say that the doctrine would not still apply? The beginning of the familiar geologic processes on the globe is beyond our ken. A pre-Archean rock system is more than a possibility. Viewed in this light, the Archean system takes on a different aspect. Its lower limit must be passed over; but where shall its upper limit be drawn? This question leads to the principles of pre-Cambrian classification and correlation.

The great thicknesses of pre-Cambrian strata, like those of later ages, are naturally grouped into their larger units on the basis of pronounced unconformities. This is a practical procedure because the unconformities make natural divisions. Pre-Cambrian strata are also classified and correlated on the basis of large batholithic intrusions which cut across certain rock groups but do not penetrate other groups. This also is a practical field method of differentiating formations or groups of formations. We therefore ask ourselves: To what extent are time divisions based on granites merely a matter of practical convenience and to what extent do they have fundamental significance? Is there any relation between strong angular unconformities and batholithic intrusions?

For clearer understanding we turn to later and better-known eras of earth evolution. The later diastrophic revolutions reveal a common sequence of events. First is the well-known accumulation of many thousands of feet of sediments in a geosynclinal trough or belt of pronounced sinking. Secondly, after a long period of accumulation these weak sediments are compressed during a very much briefer interval of time into a folded mountain system. During a late stage of the strong folding process, but before the deformation ceases, large masses of acid magma characteristically intrude the heart of the folded mass. The rocks which have participated in the folding are cut across extensively by the invading magma and in places are strongly metamorphosed. Thirdly, the processes of erosion now proceed to reduce the mountains to lowlands; if the reduction goes far enough they uncover the intruded plutonic rocks in the core of the folded belt and they may bring the entire region to the condition of a peneplain. The first and third stages each occupy more time than the second. Subsequently, sedimentary deposits may again be laid upon the site of the former mountain system constituting an entirely new group of rock strata. The new rock system is thus separated from the older system, or systems, by a strong angular unconformity representing a long interval of time during which important events took place in the region.

In this problem the significant feature of the granite is that its injection occurred at the time of mountain-making between the earlier period of sedimentation and the later period of sedimentation. It therefore belongs to a part of the time interval represented by the unconformity between the two sedimentary systems and serves in a positive way to mark that interval. Consequently, a classification on the basis of the granite is essentially the same as a classification based on the unconformity.

The practical value of intruded granites in pre-Cambrian correlation lies in the fact that the batholithic masses are now exposed over considerable areas throughout much of the deeply denuded belt of correlative folding. They can thus be used rather generally along the grain of the folded structure in any one given structural province. Such structural provinces we know to be long in the direction of the axial lines of folding, but as a rule they are much more limited in width across the grain of the region. Recognition of their extent and limits is very important in pre-Cambrian correlations.

For a given province, such as the southern margin of the Canadian Shield, or at least important portions of it, the granite method of classifying rock systems is theoretically sound. In this particular province the three granites of widely different ages, the Laurentian, Algoman and Killarney, are practically and potentially of great assistance in unraveling and delimiting the pre-Cambrian systems. In actual application, however, a serious drawback arises from the fact that in many places, where exposures are limited, the correct identification of a particular granite is very difficult, though probably not beyond solution by our present field methods. The ultimate outcome at any rate looks hopeful.

But when an attempt is made to correlate, for example, the Archean of the southern border of the Canadian Shield with any group of rocks in the Piedmont area of the Atlantic states, the grounds for correlation by our present field methods are extremely insecure. Two different structural provinces are involved and while, according to our general conception, some relationship in the historical sequence of the two provinces is natural, we do not know the extent of such relationship. One or more of the three great pre-Cambrian diastrophic revolutions with batholithic intrusions may have occurred in the Canadian Shield, while only mild manifestations of quite a different sort affected the Appalachian Piedmont. Conversely, strong pre-Cambrian folding may have occurred in the Piedmont at a time when the Shield was but slightly involved. The so-called Archean of the Appalachian Piedmont therefore may, or may not, correspond to the recognized Archean of Lake Superior.

It has been common practise to designate as Archean the extensive granites of the Bighorn Mountains, those of the Front Range of Colorado and those of various other Rocky Mountain ranges. But, as a matter of fact, can we tell whether the granites which underlie the Cambrian sandstones in the Front Range of the Colorado Rockies are correlative of the Laurentian granite of the Canadian Shield, or of the Algoman granite, or of the Killarney granite, or whether they were intruded at some entirely different time or times? In the same way the Vishnu schists in the bottom of the Grand Canyon in Arizona are called Archean. But, after all, do ordinary field studies give us even the basis for a poor guess that these schists are in reality Archean, in the sense of being pre-Laurentian? These several regions lie far apart and apparently are different structural provinces. Similarly, the correlation of the Archean between continents, together with any attempted separation of the pre-Cambrian into Archeozoic and Proterozoic in distant lands on a time basis, faces like uncertainties. Ordinary geologic methods will help solve these problems, but it may be doubted whether they will solve them satisfactorily.

But there is in sight a method which offers good hopes of giving us the desired correlations. That method, apparently our chief hope in long-distance pre-Cambrian correlations, lies in the age determinations of intrusive rocks by measurement of the radioactive disintegration which has taken place within them since they were intruded. Time, measured in years, can be compared directly throughout the extent of the earth's surface. The major intrusions of acidic magma came with the diastrophic revolutions which were critical times of earth history and properly serve to mark off geologic periods. If their ages can be determined with a fair degree of accuracy we are on the road toward a satisfactory classification of the pre-Cambrian and the correlation of its major divisions in different structural provinces and on the different continents in so far as there has been a parallelism of events in the areas considered. Success in discovering the true relations will depend largely upon the accuracy of the time estimates.

How reliable are the radioactive determinations of the ages of intrusive rocks? This question is now being investigated critically by capable chemists and physicists in an effort to iron out the present discrepancies in the results obtained by different lines of attack. Progress seems assured and satisfactory results are apparently to be expected. Professor Lane informs me that in particularly favorable cases, which depend upon minerals high in uranium taken from freshly opened material, the probable error in age determination may be of the order of 5 per cent.

From geologic evidence, the Laurentian, Algoman and Killarney granites appear to be so different in age that radioactive age determinations should distinguish between them. We, therefore, have every reason to expect that identification and correlation on this basis will soon be possible. Such correlation obviously will not stop with the Canadian Shield, but comparisons should be possible with other granites of North America and those of other continents as well. From the granites as time markers, correlations may then be extended with varying degree of certainty to the associated sedimentary formations. At last we seem to be on the eve of general pre-Cambrian correlations on a basis which invites considerable confidence.

The utility of the method is of course not limited to the pre-Cambrian. Especially useful it should be in bringing the pre-Devonian history of the southern half of Africa into accord with the general history of the rest of the globe. In South Africa the oldest well-preserved fossils occur in Devonian strata; there the expression pre-Devonian has somewhat the same connotation as has pre-Cambrian in other continents; yet South Africa displays many important rock systems older than the Devonian, now known only by local names. Their proper placing in the established periods which do service elsewhere is greatly needed.

We may now return to our earlier question: Where shall the upper limit of the Archean be placed? In the several different positions in the rock column where it is now placed by different geologists we see the diversity of current opinion. For the Canadian Shield the choice lies between the Laurentian revolution and the Algoman revolution. Each has its advocates, and partisanship seems to depend primarily upon the portion of the shield with which the individual is most familiar. Geologists studying the Lake Superior region have been impressed with the great difference between the pre-Laurentian basement complex, which can be unscrambled with great difficulty, and the post-Laurentian metamorphosed sediments to which stratigraphic methods of investigation can be more successfully applied. On the other hand, to geologists working in eastern Ontario and Quebec, the Algoman revolution has seemed to have occasioned a greater break in the rock record than the Laurentian revolution. The question therefore becomes: Which revolution is more important in general earth history?

The secular trend in historical geology is from provincial points of view toward increasing cosmopolitanism as ever-widening areas of the globe are receiving detailed study. Local peculiarities are to be subordinated to those of more general application. In this spirit, though we may prefer one or the other of these revolutions for the close of the Archeozoic, we may well keep a somewhat open mind awaiting comparisons with other important pre-Cambrian areas as better correlations become possible. In the meantime we have Leith's suggestion that time equivalency in the pre-Cambrian be held in abeyance for the present and that instead the basis for the major divisions be rock types, as rocks of the Archean type and rocks of the Algonkian type. This has its uses. But by definition geology is the history of the earth and its inhabitants, and pre-Cambrian history will not be on a satisfactory basis until a fair degree of time equivalency has been established there as in the later history of the globe. Very close time equivalency, however, must not be expected nor implied by pre-Cambrian correlations. Possibly it may prove most practical to divide the pre-Cambrian only into a succession of rock systems and periods without attempting to group these into eras. In any case the large units are systems and not series as some of them are now so commonly called. The Lower Huronian and the Upper Huronian, for example, however they may be named, are each fully comparable to a typical Paleozoic system, either in duration of time, sedimentary successions or according to diastrophic cycles.

The Keweenawan Problem

The divergence of opinion in classifying the Keweenawan system of the Lake Superior region serves to illustrate another phase of the general problem of classification and correlation. Here a succession of lava flows totaling many thousands of feet was followed by waning volcanism and the deposition of a great series of subaerial clastic sediments, interbedded at first with flows, but continuing long after the flows ceased and the more pronounced deformative movements which produced the Lake Superior basin had largely come to an end. In Michigan and Wisconsin this thick succession of terrestrial conglomerates, sandstones and shales has long been known as the Upper Keweenawan. In Minnesota the apparent correlative was designated the Red Clastic series by Hall, Meinzer and Fuller in 1911. Both are overlain by the well-established marine St. Croixan series of the Upper Cambrian. As recently stated by Trowbridge and Atwater, geologists working from the older rocks upward in the stratigraphic column have included all the Keweenawan below the marine St. Croix series in the pre-Cambrian, whereas those working from the Paleozoic downward in the stratigraphic sequence, finding that the undoubted Upper Cambrian sandstones are not set off from the older clastics beneath by any very pronounced break, have not seen sufficient reason for separating the Upper Keweenawan from the Cambrian. Many of the latter have favored placing the Upper Keweenawan in the Cambrian and some have carried the idea further to include the entire Keweenawan in the Paleozoic.

In 1926 Stauffer was fortunate enough to obtain in well cuttings from the upper part of the Red Clastic series of Minnesota a few brachiopods and trilobites which resemble those found in the Middle Cambrian of Montana and Wyoming. The shales in which these fossils occur he confidently referred to the Middle Cambrian. Here indeed was an important step forward. An arm of the Middle Cambrian epicontinental sea, though perhaps only of transient duration, reached Minnesota and by its fossil record has served to date the upper beds of the Red Clastic series. Previous to the arrival of this sea a long period of non-marine deposition is indicated by the main mass of the Red Clastics.

The general picture now becomes clearer. The interval between the Proterozoic and the Paleozoic was characterized by an emergent North America. Late in the Proterozoic (following our present classification) prodigious floods of lava poured into the Lake Superior basin. Gradually the lava outwellings slackened and thousands of feet of continental clastic deposits, derived in part from erosion of the lavas, continued to fill the subsiding basin. Rejuvenation of the waste-supplying areas at the close of the Proterozoic would but increase the supply of detritus and prolong the depositional process. No notable break in the continuity of the series need have occurred. As the processes were entirely continental in nature and dependent largely upon sufficient relief of the land, changes in sea-level far removed from the Lake Superior region had little effect on them. Readvancing seas which started the deposition of the marine Lower Cambrian beds in many other parts of the globe need have caused no appreciable changes in these interior lands. Subaerial denudation and subaerial deposition would continue on during early Cambrian time, subject in general only to those changes which are inherent in the advance of peneplanation. We must recognize that, in such cases, it is entirely natural for provincial continental deposition of a more or less continuous sort to bridge the gaps between periods and even eras. Such linking land deposits have been formed at various times in various parts of the globe, producing a particularly troublesome type of classification problem. Finally the Middle Cambrian seas reached Minnesota and Later Cambrian seas spread over still more of the Lake Superior region. Marine sedimentation succeeded subaerial as the period advanced.

Thus a considerable portion of what has been called Keweenawan seems to have been deposited in Cambrian times. But the early portion of the great Keweenawan succession is very much older and has suffered moderate diastrophism. It is distinctly pre-Cambrian in type, though time classification by types is not necessarily conclusive, since types reveal prevailing conditions with greater certainty than they do specific time. Nevertheless, in the case in hand types do appear significant. We thus seem to have in this Lake Superior continental succession a lithologic record of the long interval between established Proterozoic and recognized Paleozoic of which, thus far, so little has been known. This fact alone adds not a little in interest and importance to further investigation of the various aspects of the problem.

The general nature of what has happened in this region is more or less clear, but for the purposes of classification where is the division between the Keweenawan and the Cambrian to be made? That is one of the immediate objectives. For the next step, however, present information is inadequate. Further directed study is necessary. Provisionally the division between the Keweenawan and the Cambrian may perhaps be placed at some break or pronounced change in the sedimentary sequence. According to Joseph Adler, some possibilities have already been noted in the Keweenaw Peninsula region. Ultimately the division may need to be modified for better accordance with the general diastrophic history of North America just preceding the Cambrian when the nature of the events which took place at that time shall be more fully understood.

THE PERMIAN

From the close of the Proterozoic we pass on to the close of the Paleozoic. The Permian is peculiarly the period of problems. Few times in the well-recorded history of the earth have been characterized by such critical happenings as the closing stages of the Paleozoic. Diastrophism of the most pronounced sort, glacial climates of surpassing intensity, an extraordinary development of red beds throughout the globe and profound biologic changes combined in climacteric fashion to make this a time of striking events and difficult problems.

The Hercynian revolution converted large areas of shallow sea into land and uplifted extensive tracts in various parts of the globe into lofty mountains, which together are thought to have been instrumental in bringing on diversified, continental climates of unsurpassed severity which, in turn, apparently led to extinction of many forms of life and a radical modification of others to meet the altered conditions. This chain of consequences was of a far-reaching sort, and the full sequence of events occupied a long time. The changes were slow in the aggregate, though profound. They came to be strongly in evidence in Pennsylvanian time and lasted in milder form into the Triassic. The intervening time during which these interrelated events took place is the Permian or Permo-Carboniferous. It was emphatically a time of transition, from the mid-Pennsylvanian to the Triassic, from the Paleozoic to the Mesozoic, from ancient to medieval life.

Shall this long time of transition be considered a regular geologic period, and, if so, shall it be placed in the Paleozoic or in the Mesozoic? If not an independent period, shall it be added to the Carboniferous or to the Triassic, or shall it be divided between them?

Questions such as these have been arising in the minds of geologists for some time and have led recently to a symposium before Section C of the British Association at the Bristol meeting on the validity of the Permian as a system, and to another discussion of the same general problem at the Sixteenth International Geological Congress in Washington. The diversity of expressed opinion has been very great. Some of the elements considered have been: The length of time represented; the evolutionary changes; distinctiveness of the fauna and flora; general usefulness and practical convenience; adherence to the original definition; redefinition on the basis of marine invertebrates; the break within the Rothliegende; possible fixing of limits according to episodes of the Hercynian revolution, etc. Including the Permian in the Carboniferous, it has been thought, would make that system too cumbrous; putting the Permian and Triassic together would make that system too unwieldy. Some students have favored partition of the present Permian; but most of those who have expressed views have preferred retention of the Permian in some form. In general the discussions from the standpoint of the practical stratigrapher have been thorough. The broader philosophical aspects of the problem, however, have received rather less consideration.

Geologic thought has now progressed to the point where the larger implications of the earth's past record are becoming clearer and more essential in an adequate understanding of the earth drama. It is now coming to be generally recognized that the Hercynian revolution in the Pennsylvanian, followed by extraordinary glacial climates and marked aridity in the later Pennsylvanian and Permian, was of great importance in bringing on the change from ancient life to medieval life. Obviously the biologic response to these exceptional physical conditions is rightly to be regarded as of prime consequence, but is it, after all, of greater importance than the chain of physical events which caused it? The more distinctive repression of the old order of life and rise of the new apparently started with one of the strong episodes of Hercynian deformation and the adverse climates. Inevitably, however, the process of elimination and readjustment extended through a considerable span of time. There were also further episodes of deformation with attendant consequences. Some forms of life disappeared early; other forms persisted longer; new forms, born of adversity in its varying degrees, came on the scene at different times and in different places.

Where to draw the line of division between the Paleozoic and the Mesozoic therefore involves the general question: Shall the new era commence with the most pronounced expression of the underlying physical phenomena and the beginning (or an early stage) of the biologic response, or shall it start only when the biologic response has progressed so far that the fauna and flora have become radically different from those which preceded? Shall the chain of transitional events be hooked on to the previous era as its dying phase, or shall it belong to the new era as its inauguration? Or shall it be divided between them? Whichever alternative we work toward, it is essential that we recognize properly the diverse elements involved in a satisfactory solution of the problem.

The appearance of new forms of life is generally regarded by paleontologists as of greater significance than the disappearance of lingering forms of old life. Viewing the problem in this light, we should naturally be inclined toward moving classification boundaries forward, or earlier in time, rather than in the reverse direction. In the present case this is toward the onset of the pronounced changes in physical environment which were seemingly so important in influencing the evolutionary progress among plants and animals. If we are correct in tracing the remarkable succession of physical changes of the Permian back to the exceptional display of diastrophism we naturally look to the diastrophism as the primary control.

But the problem is not simple. The diastrophism during this transitional time was episodic in character, recurring in several separate spasms. At the close of the Mississippian period occurred the Culmide disturbance which serves to divide the Carboniferous into Mississippian and Pennsylvanian. In Europe this has been termed the Sudetic deformation for, between the Dinantian and Middle Carboniferous, there was strong folding from the Vosges Mountains to the Sudetes. The importance of this division of geologic time is becoming increasingly apparent. It may be noted in passing that David and Süssmilch believe that the first of the late Paleozoic glaciations of Eastern Australia, which follows the Wallarobba (Culmide) disturbance, took place at about this time.

Particularly prominent also was the Asturian phase of the Hercynian revolution, occurring between the Westphalian and Stephanian epochs of Western Europe, or the Moscovian and Uralian of Eastern Europe. At that time arose great mountain chains across much of Central and Southern Europe and apparently South Central Asia as well. In this country strong deformation occurred in the Wichita-Arbuckle-Ouachita region, in the so-called Ancestral Rockies, and probably also in portions of the Appalachian system, approximately correlative with the European deformation.

Considerably later, following the Autunian (Lower

Rothliegende) came the Saalian deformative episode, notably in Central Europe, the Eastern Alps and the Ural Mountains. Extensive unconformities and important floral changes were associated with this episode. After the Dunkard, though we do not know just how soon after, was the main Appalachian revolution in the Eastern United States. This may well have been contemporaneous with the Saalian diastrophism of Europe, but the correlation has not been definitely established.

At the close of the Permian, as now delimited, came the Pfalzian episode of Stille in the Palatinate of Germany, and some neighboring areas. This diastrophic manifestation was feebler and more local than the others just mentioned.

(To be concluded)

OBITUARY

JOHN ALEXANDER MATHEWS

JOHN ALEXANDER MATHEWS died suddenly of a heart attack on January 11, 1935, at his home in Scarsdale. At the time of his death he was vice-president and director of research of the Crucible Steel Company of America and a metallurgist of world-wide repute.

For over thirty years he was in the first rank of American steel metallurgists and among his most notable achievements were the use of the electric furnace in the quantity manufacture of high quality steel, the improvement of high speed steel by the addition of vanadium in 1903 (Rex AA) whereby its cutting efficiency was trebled, the development of various vanadium steels, especially spring steels, and of oil-hardening magnet steels of chrome vanadium, and of corrosion- and heat-resisting steels and the so-called stainless steels.

Born at Washington, Pa., May 20, 1872, he took his B.S. degree at Washington and Jefferson College in 1893 and M.S. in 1896. Coming to Columbia University he obtained his A.M. in chemistry in 1895 and his Ph.D. in 1898. After instructing in the chemical department at Columbia for two years he was given the Barnard fellowship and with it went to the Royal School of Mines, London, in 1900, to study metallography under Sir William Roberts-Austen. It was there I first met him; we were the only two graduate students that year, had adjoining benches and were soon very good friends, for no one could resist his kindly and friendly manner and good fellowship; in fact, all the students in metallurgy used to drift over to his desk to hear about the States. Roberts-Austen thought so highly of him that he strongly recommended Mathews for one of the first Carnegie Scholarships of the British Iron and Steel Institute, which he received. Returning to Columbia in the fall of 1901 with me in tow, we worked in Henry Marion Howe's laboratory in the basement of Havemeyer Hall, Mathews on a series of alloy steels which were made for him at the Sanderson Steel Company at Syracuse, myself continuing the work I had begun with Roberts-Austen on the bronzes at the next bench. His report on this work was awarded the first Carnegie Gold Medal by the Iron and Steel Institute. Finishing this work he went to the Sanderson Brothers Steel Company, Syracuse, as metallurgist in 1902 and soon became assistant manager. From there he went in 1908 to the Halcomb Steel Company, Syracuse, of which he was operating manager and in 1913 president and general manager until 1920, when he became president of the Crucible Steel Company of America. Three years of being a president of a steel company was enough for any real scientist and so in 1923 he was promoted to what he considered a really satisfactory job, namely vice-president and director of research.

He served on numerous technical committees, notably that on aircraft engine forgings of the Bureau of Aircraft Production during the war, was for some time chairman of the Iron and Steel Committee of the American Institute of Mining Engineers, and of the Committee on Alloy Steels of the National Research Council, and did notable work on various committees of the Society for Testing Materials, etc. He was also a member of the Columbia School of Mines Advisory Committee and for several years gave an annual lecture to the pre-engineering class.

He was a clear, concise writer and published about 100 papers, chiefly on the constitution and properties of alloy steels. His worth was recognized by his associates. He received the Carnegie Gold Medal from the British Iron and Steel Institute in 1902, from Washington and Jefferson the honorary Sc.D. in 1903, the Hunt Gold Medal from the American Institute of Mining and Metallurgical Engineers in 1928, and was an honorary member of the American Society of Steel Treaters (now the American Society of Metals). In 1924 he was appointed the second Henry Marion Howe lecturer of the American Institute of Mining Engineers, succeeding Professor Albert Sauveur of Harvard.

It is so easy to tell what a man has done, to list his honors and publications, but how difficult to put in words what he really was. To those who knew him in public or private life or worked with him on committees or in the works that is not necessary, for his kindly personality and the charm of his company