An Alternative to the Cyclical Theory of Pennsylvanian Deposition and Classification in the Eastern Interior Province

By Gilbert H Cady

Completed January 18,1943

An Alternative to the Cyclical Theory of Pennsylvanian Deposition and Classification in the Eastern Interior Province

By Gilbert H Cady

I. The General Character of the Pennsylvanian Succession

The Pennsylvanian System in the Eastern Interior Province has a total thickness in the order of 3,000 feet. It consists of sedimentary rocks of great variety and of at least 40 beds of coal, most of which are generally less than 2 feet thick. Most of the individual beds composing the Coal Measures are less than a score of feet thick, and some, particularly the coal beds, are fairly wide spread. None, however, is known to extend uninterruptedly across the province. A considerable number of beds of sandstone, sandy shale, or siltstone may locally be several times their usual thickness, at these places having the form of narrow abruptly thickened lenses with relatively great longitudinal extension and a more or less conglomeratic constitution at the base. These are interpreted as "channel" deposits.

Although individual beds commonly vary lithologically from place to place, the persistence of certain peculiarities has been regarded as characteristics of some beds over wide areas. Hence similarly has been regarded as criterion correlation at widely separated localities between which of certain beds, outcrop, if continuous tracing is impossible. This is most strikingly and probably quite validly illustrated by the remarkable continuity of the bedded impurity in the Herrin (No.6) coal bed known as the "blue band", the persistence of which greatly aids in the identification of this bed. Similarly persistent are the lithological peculiarities of the earthy, dark-gray limestone cap-rock of this same coal bed. Many other examples of correct or supposed correct correlation could be cited.

However, since the character of sedimentary conditions in the Penn Illinois province were fairly limited in range / variation and similar conditions often repeated in time and place considerable unjustified matching of beds has probably taken

examples could be given of individual beds maintaining persistent lithologic characteristics over wide areas of the Illinois coal basin. Lithologic similarity has ~~been~~ found ~~useful, at least for~~ very commonly provided the for at least "suggestive" correlations of beds across nearly the extreme extension of the province. Unfortunately the suggestions since it often cannot be immediately refuted often becomes accepted as facts in spite / absence of actual proof of the accuracy of the suggestion. ~~Although~~ there is considerable diversity in lithologic composition of the Pennsylvanian beds, and the specific many possessing some measure of individuality, nevertheless it has been proposed to ~~they can be conveniently~~ classify them ~~classified~~ into about 10 general categories ~~varieties~~ of strata, viz.: (1) sandy beds: sandstone, sandy shale, or siltstone; (2) clay-limestone (fresh-water limestone); (3) slip-fracture clay ("underclay; with rootlets. coal beds; including "smut" bands → shales; (1) non-marine, fossiliferous (plants), gray; "soapstone", or "white lip" clay); (4) coal; (5) fine-grained laminated shale ("soapstone"); (6) limestone (1): very earthy, impure, laminated, small fossils if any, (false cap-rock) earthy, impure limestone ("false cap-rock"); (7) black (2) shale: black, commonly fissile well laminated, ~~usually fissile~~, ~~shale~~; ("slate"); (8) marine limestone (3): pure to very at least or earth, usually fairly blocky and solid, rather rarely well bedded, but occasionally so, fossiliferous; "cap rock" ("cap-rock") of varying degrees of purity; and (9) shale (3): marine, fine, dark (black) to gray, usually lightens upward; ~~fine-grained black to gray marine shale, commonly becoming~~ coarser and less definitely marine if ~~it attains a thickness~~ thick of 15 to 20 feet or more. This generalization ignores strata of not uncommon occurrence ~~Strata are rarely encountered~~ that or else places them without consideration of the peculiarment special lithologic development / in the category cannot be placed in one or other of these categories. ~~Furthermore~~, As has been frequently pointed out by other writers, these various elements of the succession are ~~commonly~~, and at least apparently, commonly arranged in the sequence as listed above. It is stated that This sequence of beds, although in varying completeness, appears to be repeated many times within the Pennsylvanian system in the Eastern Interior Province.

The character and thickness of these sedimentary so called "cyclical" units sequences are not uniform throughout the stratigraphic range of the Pennsylvanian system, in the ~~Illinois~~ eastern interior ~~province~~ nor either the geographic or stratigraphic range of the Pennsylvanian system in the Eastern Interior Province

Furthermore the completeness of the ~~cyclical~~ cyclical sequence varies considerably in different parts of the Illinois basin. For example although Udden pointed out a conspicuous repetition of succession in the Peoria in 1906 - an analogous arrangement in the same group of beds was apparently regarded as existing in the Bellevelle region described in 1915? by the same author. His ~~work~~ work was not until geological studies by the present survey were extended into the same Peoria region that the ~~so~~ cyclical conception of stratigraphic arrangement was again taken up - and applied with various success to other parts of the State

In certain parts of the succession several coal beds will lie relatively closely spaced and elsewhere the coal beds are much more widely separated. Where the coal beds are widely spaced a large proportion of the intervening material consists of sandstone and sandy shale; on the other hand, in parts of the succession where the coal beds are relatively closely spaced sandy beds will usually be absent but for ~~or very thin~~. In such places the strata separating the coal beds will consist of shale and limestone (beds 2 to 9) with the upper shale (9) also ~~usually~~ of abbreviated thickness.

The sandstones or sandy shale beds (1) exhibit the greatest but not the only important irregularity in the Pennsylvanian succession in the Eastern Interior Province. The predominating stratigraphic relationship of successive Pennsylvanian beds is that of conformity. In contrast with this common relationship is the irregular contact that commonly exists at the base of each successive sandy member (1). These sandy strata may grade conformably into less sandy shales below (9) without evidence of a sedimentary hiatus; but whenever the sandy member (1) consists of sandstone rather than of sandy shale, and in places even when it consists of sandy shale, the contact is usually abrupt and the contact surface irregular, not uncommonly cutting across the bedding of the underlying strata in places even to a considerable depth, truncating such strata, thus displaying unconformable relationships in text-book fashion.

In the Eastern Interior Province none of these "sub-sandstone" unconformities is known to ~~the~~ be sufficiently widespread to have been generally regarded as diastrophically significant and as a suitable basis for the stratigraphic subdivision of the Pennsylvanian system. On the other hand, until relatively recently this system in this province has generally been regarded as representing

essentially interrupted and continuous deposition. Subdivision of the system into groups has been largely a matter of convenience and ~~reference~~ primarily for the purpose of establishing a stratigraphic classification corresponding to an equally ~~essentially~~ arbitrary earlier classification of the system in the Appalachian Province. Classification in neither area has been possible on a diastrophic basis because of the essential continuity of the depositional record, an absence of evidence of significant faunal ~~and~~ or floral breaks. Modification of the grouping and boundaries in the Appalachian Province might be expected to be followed by corresponding modification in the Eastern Interior Province, unless diastrophic basis for separate classification is discovered.

But other stratigraphic irregularities occur in addition to the one at the base of the sandstone (1)

Considerable irregularity ~~also~~ characterizes the distribution and occurrence of the fine gray shale ("soapstone") (5) which in places ~~lies~~ intervenes between the coal bed (4) and the black shale ("slate") (7) which is commonly present as one of the "roof" elements in the coal mines of the province. This shale (5) locally called "soapstone" or "white-top", is distinctly lenticular in its general depositional form, as it is thought, owing to its dismemberment by some erosional agency. It appears to have been quite commonly the first material to have spread over the coal bed and in general to be of non-marine origin. Certain of the small bodies of "soapstone" were very definitely the filling of small depressions or channels in the surface of the peat deposit. The occurrence of plant fossils above coal beds is almost entirely restricted to ~~occurrences of~~ this shale (5).

The gray shale (5) attains thicknesses of 25 feet or more in places over some coal beds, and the width of the shale body may be several miles. This is the case above the Harrisburg

(No.5) coal bed in central and eastern Saline County, and also above Herrin (No.6) coal bed in the Franklin-Williamson counties mining district. In other places the gray shale lenses may be only a few feet wide and but a few feet thick at the center of the lense. In some instances the deposition of the gray shale was started before the accumulation of the coal had ceased, so that it occurs as lenses in the upper part of the coal bed.

The "false cap-rock" (6) commonly designated by the miners by a much less dignified name, appears to be little more than a very calcareous variety of shale commonly known by the miners term "clod". Because of its greater "lime" content it is somewhat stronger than clod; on the other hand its highly argillaceous content results in a rock considerably weaker than most cap-rock limestone. This "false cap-rock" appears to be more characteristics of some coal beds than others, but observations by the writer and his associates show that it is a relatively common element in the stratigraphic sequence. It has been seen above a number of coal beds, so that identification of a coal bed on the basis of its association with a "false cap-rock" type of limestone is scarcely justified. It is usually found to be discontinuous in distribution.

The black shale ("slate") (7) and limestone cap-rock(8) next in the sequence above the "false cap-rock"(6) may lie directly upon the coal bed (4), for beds intervening in the typical sequence are commonly absent, and they may actually be seen in mines or in outcrop to overlap the lenses of gray shale (5) and "false cap-rock"(6). ~~when these are present~~. When the bodies of gray shale are broad and thick, so that falls of roof in mines do not extend to the top of such shale layers, the continuity of the black shale and cap-rock over such lenses cannot always be demonstrated ~~except by drilling~~. However, above certain coal beds

as, for example, the Harrisburg (No.5) coal bed in Saline County, the records of drill holes and of shafts show that the black shale (7) and cap-rock limestone (8) elements of the typical succession are not present where the gray shale (5) is thick, although they are known to rise on the flanks of the shale lens.

II. The cyclothem or cyclical formation

The cyclical theory of sedimentation as applied to the interpretation of Pennsylvanian sedimentary sequence has become more than simply ~~the~~ a recognition of a cyclical sequence of deposition. The cyclical arrangement has become invested with important diastrophic significance. Each repeated sequence, cyclical formation, or cyclothem is regarded as a stratigraphic unit theoretically possessing a standard quota of typical components consisting of the nine elements listed in an earlier paragraph (p.2), with unconfromable relationships at the top and bottom. Each cyclothem is a formational unit, definitely isolated, owing to diastrophic changes, from preceding and succeeding cyclothems.

A correlation of sedimentary expression with diastrophic events is welcome as an explanation of the depositional events of any geologic period. It would be particularly welcome as an explanation of the sedimentary history of the Pennsylvanian period, because the strata of this time have in general been unresponsive to detailed rational organization. Consequently the cyclical concept has been widely and even enthusiastically accepted as a satisfactory basis for the subdivision and classification of the Pennsylvanian succession in the Eastern Interior Province. However, the existence of relationships not in agreement with this concept cannot be regarded as impossible in view of the limited extent of observation permitted by outcrops, in view of the restricted area of observation upon which the initial ennunciation of the theory was based.

and the necessity of substituting inference for observation for ~~over~~ much of the Illinois coal basin where the arrangement of beds is revealed only by cores, drill cuttings, and logs of drill holes. ~~Even~~ Since stratigraphic relationships observed in outcrops are not always similarly interpreted by independent observors, how much more is this likely to be true of when data are drillers' logs.

So long as considerable uncertainty exists concerning the stratigraphic relationships within the Pennsylvanian System of the Eastern Interior Province, it is important that a variety of working hypotheses be maintained in explanation of the relationships observed. The discussion that follows brings into the field of consideration a concept of stratigraphic relationships within the Pennsylvanian System that has developed from the writer's observation and study of the Pennsylvanian succession and his dissatisfaction with the cyclical formation concept as a solution of the stratigraphic perplexities of the Pennsylvanian System in the Middle West.

III. The nature of Pennsylvanian sedimentation in the Eastern Interior Province

The existence of numerous similar sequences of strata does not in itself establish the existence of cyclical formations or cyclothems. The existence of repeated sequences is a matter of observation; the existence of cyclical formations or cyclothems, on the other hand, is a matter of interpretation and rationalization based upon premises, which in turn may be a matter of opinion rather than a matter of fact. The interpretation that will be placed upon repeated sequences as a classification unit stems from the particular philosophy of Pennsylvanian sedimentation that is favored. This philosophy will be established not entirely by the order of sedimentary sequence but also by

other relationships existing within the Pennsylvanian depositional area. The general nature of Pennsylvanian sedimentation in the interior and Appalachian provinces is therefore of great importance in developing an acceptable interpretation of the course of Pennsylvanian sedimentation.

Although at present the various interior provinces of Pennsylvanian beds are isolated from one another by intervening areas of older rocks, continuity of these beds was probably general, at least during a considerable part of Pennsylvanian time. The isolation of the different provinces is the result of post-Pennsylvanian deformation and erosion. The present basin-like structure and form of the Illinois coal field is very largely post-Pennsylvanian in date of origin and the pattern of areal distribution of beds, particularly beds of Carbondale and McLeansboro age is imposed determined by erosional rather than by depositional limitations.

The interior Pennsylvanian depositional area appears to have been extensive, extending from the Appalachian region on the east to Kansas, Oklahoma, and Nebraska on the west. Marine conditions usually prevailed in the western interior provinces and farther west, whereas in the Appalachian province terrestrial, shallow water, mainly non-marine environment was the rule.

The intermediate position of the Illinois Pennsylvanian area between the Western Interior and Appalachian provinces was of prime importance in determining the depositional sequence. In the former province limestone and shale are the predominating components of the succession, with coal beds relatively few in number but very widespread. There are few sandstone beds and these are predominately of the "channel" type. In the Appalachian Province, in contrast, sediments were predominantly

sandy

sandy with limestone beds relatively rare. Coal beds, on the other hand are relatively numerous, many being of limited extent, and bifurcation of coal beds is not unkown.

Because of the intermediate position of the Eastern Interior Province in the Pennsylvanian depositional area, the character of Pennsylvanian sedimentation varied from time to time as conditions dominant in the adjacent provinces alternately prevailed in the intermediate region. Conditions favorable for plant growth and the accumulation of plant debris existed more frequently in the east ~~and~~ than in the west, hence many more coal beds are found in the east. On the other hand limestone deposition was more frequent in the west than in the east. However, certain coal beds and certain limestones appear to have had very wide distribution extending very widely across the depositional area repr sented by the three provinces.

The sedimentary sequence in the Appalachian Province does not display a characteristic cyclical ~~sequence~~ succession such as that found in the Pennsylvanian succession ~~in~~ of the Illinois basin because of the usual absence of marine beds. The strata consist in general of sandstone, sandy shale, and coal beds, the latter usually having an underclay; generally black shales or "slates", limestones, and calcareous shales, so common in the Eastern and Western Interior provinces are lacking.

In the Western Interior Province the succession is somewhat more varied and a cyclical arrangement is more in evidence inasmuch as marine limestones and shales, black "slates" coal beds and underclays are commonly present. The presence of even three varieties of strata provides a better basis for establishing a prevailing order of sequence

than is provided by a simple alternation of two general types of beds - sandstone and coal such as is generally found in the Appalachian Province, except along the northern margin where there is a greater variety of strata. The Illinois coal field occupying an intermediate position between an area in which sediments were predominantly marine and one in which they were predominantly non-marine, as a result was characterized by a transitional or intermediate type of depositional ~~sequence~~succession.

Predominant among the eastern type of sediments are sandstones and conglomerates, particularly the quartz pebble conglomerates of the "Pottsville" type. Of next importance are probably the coal beds, which in the East are prevailingly of low sulphur and relatively low ash content. Furthermore many of the coal beds are of relatively limited extent, and the splitting of beds is not unusual. Underclays, commonly refractory and true fire clays underlie many of the coal beds, and in the base of such clays the stigmaria type of sandstone, or ganister sandstone, is of common occurrence. Where the coal beds are not overlain by sandstone, fine textured gray shale, often containing plant fossils, is the roof material. This fine textured shale may grade upward into a sandy shale and then into sandstone, or it may terminate abruptly at the base of coarse "channel" type sandstone mass with an uneven lower surface. This is the general character of the Pennsylvanian succession in southeastern Kentucky and Tennessee in the heart of the Appalachian Province.

In the Western Interior Province of Kansas and Missouri the succession consists predominately of shale and limestone, with relatively thin beds of coal, beneath which there are usually underclays, usually more or less calcareous and non-refractory. Intervening between the coal beds and the limestones there are usually black carbonaceous shales not uncommonly with a fissle structure. Sandstones are the exception but such as occur are likely to be of the "channel" type. In the basal part of the underclays there is commonly a concentration of calcareous matter forming the underclay type of limestone commonly but unjustifiably designated as "freshwater" limestone.

Evidence points to the probability that coal beds present in the western province are the continuation of beds found in the Appalachian Province. It is reasonable to believe that if land conditions which qualified to support forest growth existed in the part of the depositional area where marine conditions predominated, they must have existed on the landward borders of such areas. On the other hand the existence of land conditions at any time within the Appalachian province does not carry the converse implication that land condition continued westward into the marine province.

It is equally reasonable to believe that marine limestone beds found within the Pennsylvanian succession of the Appalachian Province were probably more or less continuous with marine beds of the western province. In both cases, however, it is difficult to present actual proof of original continuity or even to establish precise correlations because of the complete dissection of the original depositional area

into a series of disconnected basins.

There are at least two ways in which the transitional relationship of the Eastern Interior Pennsylvanian Province with respect to the marine and non-marine depositional provinces to the west and to the east respectively is manifested:

1) In the lower ("Pottsville") Pennsylvanian beds of the Eastern Interior Province represented by the Caseyville and the lower part of the Tradewater groups the succession at least in southern Illinois is characteristically Appalachian in character. The strata in general appear to be non-marine in ~~character~~ origin,- sandstones, quartz-pebble conglomerates, gray shales commonly with plant fossils, and coal beds, the latter being characteristically lenticular and hence of limited areal extent. Black "slates", limestones, and marine shales are present, if at all, only locally. Undoubtedly while these beds were being deposited in southern Illinois shales were being deposited in the marine areas of deposition farther west, but attempts to correlate individual beds of the non-marine environment with individual beds of the marine depositional area must be regarded as highly speculative.

2) At about the beginning of Allegheny (Carbondale) time conditions in the Illinois basin seem to have changed somewhat and the marine, highly calcareous waters of the western sea began to have relatively frequent access to the eastern depositional area across the present position of the Eastern Interior Province and the Illinois coal field. From the time of the deposition of the Seville limestone, the cap-rock of the Rock Island (No.1) coal bed conditions favorable to marine limestone deposition appears to have prevailed within the Ill-

inois basin, at lea t for short periods of time, whereas at other times the depositional evironment was non-marine and of the Appalachian type. In general it will be found that when sediments representing both types of environment of the same depositional period are present in the Illinois coal basin, those of the non-marine type will be found in the eastern and southeastern part of the basin and those of the marine type in the western part.

This variation in the character of beds across the Illinois coal basin is attended by a regional thickening of the Pennsylvanian system in the direction of the major source of the sediments, that is to the south and southeast. Such thickening should not be ascribed to the effect of the Illinois basin structure, since this is not an initial depositional form. The component beds within the Illinois Basin are truncated on all sides and originally extended to an unknown distance beyond their present areal boundaries, probably in continuity with beds in adjacent provinces to the east and to the west.

Should this picture of the depositional relationships within the Eastern Interior Province be even approximately correct interest attaches to evidence of the possible manner of interbedding of the marine and non-marine elements of the succession.

For any relatively small unit of the Pennsylvanian succession, the stratigraphic boundaries of which are definitely defined for a considerable part of the depositional area by widespread beds, it can be assumed that there was essential contemporaneity of origin for this particular group of strata within the specific large area. The position of the Herrin

(No.6) coal bed and that of the La Salle (No.2) coal bed is reasonably well established in both the Eastern and Western Interior provinces in Western Kentucky, Indiana, Illinois, Iowa, Missouri, and Kansas. Within this stratigraphic unit the position of the Harrisburg (No.5) coal bed can also be widely traced; so that the larger unit can readily be subdivided into two well defined units, each of which is a relatively small part of the Pennsylvanian succession. Together they comprise the upper part of the Carbondale Group as recently defined.

There is undoubtedly a progressive increase in the thickness of this part of the Carbondale Group from west to east across the western and eastern interior provinces. In the west the succession includes relatively little sandstone except for "channel" sandstones such as have been described in western Illinois and eastern Missouri, whereas in southeastern Illinois and western Kentucky there is much sandstone and also more numerous coal beds than are found farther west. Inasmuch as this was one depositional area, as is indicated by the widespread extension of at least three important coal beds, it is reasonable to believe that the two kinds of deposition were essentially contemporaneous and that here and there there was overlapping and interfingering of depositional facies. This possibility provides a basis for the interpretation of the stratigraphic sequence of Pennsylvanian beds at variance with that implied by the recognition of cyclothem formations or cyclothems.

The sandstones and an intermediate coal bed No.5A lying between the Herrin (No.6) and Harrisburg (No.5) coal beds in Saline and Gallatin counties, Illinois are represented by limestone and marine shales farther west in Randolph County, since so far as can be observed, deposition was continuous in the latter county. The sandstones are not, therefore, correctly regarded as fundamentally separate phases of deposition reflecting peculiar diastrophic events. They are not truly cyclical in character but are of geographical or facies significance.

The assumption that because the sandstones of the Pennsylvanian System are characterized by an uneven basal surface the successive sequences must therefore represent diastrophic formational units is unwarranted if the succession is complete and continuous in localities where only the marine type of deposition prevailed. To establish cyclothems as valid formational units proof must be advanced of unconformable relationships between successive layers in the marine sequence at positions corresponding to those of postulated unconformities in the transitional type of succession as herein described.

Besides the concept of unconformity that is implied by the cyclothem arrangement there is the further assumption, of doubtful validity, that the sandstone member and its accompanying unconformable relationships to underlying beds always occupies the same position in the repeated sequence. It may be pointed out that the sandstone, coal bed, and intervening underclay in the eastern depositional area always occupy the same general relative positions. The sand-

stone and underclay appear to be the natural foundation of a coal bed and such surfaces seem to have been formed with much greater frequency in the Appalachian region than in the interior provinces, and at times to have extended westward into the region characteristically dominated by marine environment with mud and limestone the prevailing type of sediment. Thus tongues of sand, and beds of vegetable debris accumulated upon such sandy layers, from time to time extended westward and northward into that part of the depositional area where marine conditions usually prevailed, taking the place of deposition which otherwise would have consisted of mud or limestone. The fact that beds of coal are characteristically underlain by a sequence of underclay and sandy beds gives the resulting sequence the appearance of cyclical order, whereas it may actually be an abbreviated sandstone-coal sequence intercalated within what would elsewhere be regarded as a standard cyclical sequence of larger stratigraphic scope.

This point may be illustrated by returning again to the variations in the succession between Harrisburg (No.5) and Herrin (No.6) coal beds in southern Illinois. In southern Gallatin County and in adjacent parts of Saline County these two coal beds are separated by from 100 to 125 feet of strata. The intervening rocks, if interpreted from the standpoint of cyclical classification , appear to consist of two complete depositional sequences. On the cyclothem basis one complete and two partial cyclothems are represented - the upper part of the No.5 cyclothem, the No.5A cyclothem, and the lower part of the No.6 cyclothem. The cyclothem sequence in each case is essentially complete except that the clay-limestone member(2)

is likely to be represented by a ganister-like"stigmarian" sandstone.

In western Williamson County and farther west in Perry and Randolph counties the interval between the No.5 and No.6 coal beds is reduced to 25 feet or less, and the succession consists of black shale (black"slate") above the No.5 coal bed, limestone cap-rock, gray marine shale, underclay containing clay limestone, and the underclay of No.6 coal bed. There is no indication of the presence of No.5A coal bed, except very locally, and no sandstone, and no positive evidence of unconformable relationships between successive strata.

Thus, within a distance of about 25 miles the succession changes remarkably between No.5 and No.6 coal beds owing to the fact that the non-marine depositional province at certain times extended into but not entirely across the southern end of the Illinois coal basin.

If the writer understands the implications of the cyclothem theory correctly the No.5A cyclothem, if it is absent in Perry and Randolph counties, should be represented at least by an unconformity. Therefore the shale limestone sequence to the west should display evidence of at least one and possibly two unconformities,- one representing the base of the No.6 cyclothem and the other the base of the No. 5A cyclothem. Actually the deposition appears to have been uninterrupted and continuous. It appears, therefore, that while a considerable thickness of sandstone and a bed of coal accumulated to the east, limestone and marine shale accumulated in a marine environment to the west.

The outcrop of these strata is discontinuous across the transitional belt and the critical positions may be concealed, but at any rate it has not been determined at just what horizon in the shorter succession coal No.5A and its accompanying cyclical group of beds are interposed. In view of the absence of unconformable relations between beds in the shorter succession it is not apparent how the additional beds can be interposed in a manner consistent with the cyclothem concept of formational units. ~~Indeed~~ Hence it seems appropriate to inquire whether the position of the non marine beds,- sandstone (1), underclay (3),coal bed (4), and "soapstone"(5), conforms to any fundamental rule with respect to the position in the series of marine beds in which they will appear. The sandstone-coal non-marine facies of deposition may be more correctly pictured as shifting back and forth across the transitional or intermediate depositional area in such a way as to interrupt the marine deposition at any place. Whenever such marine deposition is interrupted the proponents of the cyclothem concept declare that a new cyclothem is constituted, whereas possibly only a little distance farther west no such interruption took place and marine deposition continued uninterruptedly.

In the Western Interior Province coal beds although relatively thin are very widespread and because such beds are relatively few in number they provide the basis for relatively few cyclical formations having similar sequence. If such index coal beds are traced eastward it will be found that more and more coal beds and associated sandstone layers inter-

pose between the successive index beds, and yet the continuity of deposition where the succession is more abbreviated indicates that the time represented by several cyclothems in the eastern part of the depositional area may be represented by a single cyclothem in the western part.

The critical consideration in evaluating the cyclothem concept of the stratigraphic classification of the Pennsylvanian system in the Interior Province is the validity of the unconformity between successive sedimentary sequences. If the unconformities are real and of the conventional type a basis for diastrophic subdivision into formations exists, otherwise some other interpretation may be more correct.

Undoubtedly wherever channel types of sandstone layers are present their undersurfaces lie unaccordant upon the beds below. Not uncommonly such unaccordance is impressive cutting across several beds, including even limestone beds, to a depth of 50 to 75 feet or more in extreme cases below the position of the base of the sandstone at points either side of the channel. In general, however, the transverse dimension of such channels is relatively small, that is in the order of a mile or less, and they actually compose only a small part of the total area of the sandstone layer. Whenever occasion calls for demonstration of the stratigraphic relations of the sandstone elements of the succession attention is almost surely to be directed to the more intrinsically interesting situations where channel conditions prevail rather than to those or regularity and conformity. Yet it is doubtful whether the more conspicuous unconformable relations of the channel phases of the sandstones

with underlying beds may reasonably be regarded as less of significance diastrophically than the more widespread conformity of sandy beds with underlying beds elsewhere than in the channel areas.

A conventional diastrophic unconformity at the base of each Pennsylvanian sandstone implies that a period of uplift and erosion marked the close of each depositional period. This was followed by sedimentation in the valleys and their eventual complete filling as sandy sediment buried both the valleys and the intervening watershed between adjacent valleys.

Certain implications derive from such a course of events: Erosion would be greatest in the valley tracts, but the upland watersheds would be longest exposed to weathering and to accessibility to plant growth. In view of the wide prevalence of vegetative growth during and throughout the Pennsylvanian period it is reasonable to believe that plants probably would have invaded any land surface very rapidly. However, even if conditions favoring the preservation and accumulation of the products of plant growth did not exist, the surfaces which were exposed should display some evidence in the nature of fossil soils that there had been plant growth. The stratigraphic implications of unconformity of the conventional diastrophic type are such that proof is required not only of widespread erosion or angular contact of successive depositional groups but also of erosion, weathering, soil formation, or peat accumulation on intervalley surfaces before the fact of such unconformity can be accepted unreservedly.

Furthermore, the cyclothem theory postulates alternating positive and negative displacements of the shore line of such a nature that the effect of each negative movement (sea invasion) exceeded the effect of each preceding positive movement (sea withdrawal). Thus whereas the sum total effect was that of progressive subsidence, the progression was accomplished by emergences of relatively small scope which were always followed by submergences of somewhat larger scope. Hence the coal bed of any cyclothem was always vertically higher than the coal bed of the preceding cyclothem. It might and probably would have been otherwise had this see-saw type of movement actually taken place, for it is not apparent why, nor does it seem probable that, the amount of submergence should in every case exceed the amount of preceding emergence in view of the many times such movement would have had to take place.

At least until recently the explanation most commonly advanced for the channel sandstones and their accompanying unconformities interpreted them as the equivalent of river channel accumulations formed in the distributaries of streams on deltas or sub-montain alluvial plains. Deposition of sediment in a periodically subsiding area would build up alluvial areas at or near sea level during periods of comparative stability which were probably long continued. Across such plains rivers, or even marine currents if the surface lay slightly below sea level, would be forced to shift masses of relatively coarse sediments, cutting and filling almost simultaneously in the finer sediments below. Such channels might very well extend considerably below the base of deposits of the same age accumulating outside the channels.

The depositional interrelationships of the eastern, non-marine, and the western, marine, areas of sedimentation are not readily understood because of the incompleteness of knowledge concerning the distribution of variations in Pennsylvanian sediments throughout the depositional area. It would be presumptious to regard any theory of Pennsylvanian stratigraphic classification as more than a working hypothesis in view of the many uncertainties of information. However, it seems evident that the two depositional areas represent contemporaneous facies of sedimentation.

There is evidence, likewise, that at certain times the shore line moved far westward and that at such times immense spreads of low lying land were occupied by forest growth and forest swamps where forest peat accumulated. The stratigraphic interrelationships between the eastern and western depositional provinces must be read in the record of sedimentary rocks that followed these periods of peat accumulation and terrestrial environment, each of which appears to have been followed by the return of marine waters over more or less of the area which had long been land.

following coal bed accumulation

With the cessation of plant growth, or sometime thereafter there usually followed in the eastern part of the depositional area in each case the deposition of fine mud, silt, or sand. Apparently, as would be expected the coarser sediments lie nearer their source in a more landward position. In the western part of the depositional area the initial sediments, after a period of organic accumulation in the nature of peat, consisted of sour black mud. As subsidence proceeded the black muds advanced eastward but did not continue any great distance over the previously deposited gray shale and away from the coal bed from which apparently it derived most of its carbonaceous content. Hence the black shale or "slate" is not likely to continue across bodies of relatively thick "soapstone".

In the eastern part of the depositional area the gray mud ~~shale~~ gradually becames coarser and sandier until the prevailing material consisted of sand. In the seaward part of the area the material deposited consisted of increasing amounts of calcareous debris derived from marine fauna. Such deposits generally continued eastward as far as did the pr ceding black mud deposits, but in general did not overlap the black shale and extend onto the area in which the gray mud or soapstone was the prevailing type of deposition. It seems probable, therefore, that the period of gray shale deposition in the eastern depositional area was essentially contemporaneous with the period of black shale and limestone deposition in the west. Subsidence apparently essentially came to an end after the deposition of the cap-rock limestone, with the result that the succeeding deposits consisted of sandy beds representing the gradual extension of river and lagoon prevailingly fresh water deposits outward into the

marine portion of the depositional area.

Within the eastern depositional area clastic sediments usually alternated with peat accumulations, but the peat beds were not in all cases nearly coextensive with the depositional area. There were streams carrying sediments seaward which expanded the delta-like depositional area until an extensive surface at or nearly at sea level was formed upon which plants and forest swamps could be widespread. The amount of filling ~~required~~ in the area of marine deposition necessary to restore conditions that would permit extensive plant growth depended largely upon the amount of subsidence which brought an end to the various periods of widespread forest swamps. Actually at certain times the amount of subsidence appears to have been relatively slight and the required amount of sedimentation also relatively small. Hence several widespread coal bed may lie relatively close together, as in the case of the coal beds near the top of the Carbondale formation. On the other hand such periods of successive subsidences of small dimension were followed by a more imposing subsidence, and the subsequent thick blanket of sediments consisting largely of sandy muds and sands.

This picture is one which implies essentially continuous deposition within the depositional area with the possibility at least, of peat accumulation taking place continuously at some place or other . Only occasionally did conditions favor extensive, widespread continuity of the Pennsylvanian forest swamps, possibly less than a score of times. At such times the sequence of events was essentially the same in areas where the record of events is supplied by either the marine or by the non-marine type of sediments . In the intermediate area represented by the Eastern

Interior Province greater irregularity obtains because of the intermittant overlapping of the sedimentary provinces.

Two depositional facies oscillated back and forth across the transitional zone of the Eastern Interior Province. Sedimentation or peat accumulation seems to have been essentially continuous in both marine and fresh water or terrestrial areas and the boundary between the two depositional provinces to have been continually shifting back and forth. Hence the interfingering of the sandy facies into the beds of the marine facies may have taken place at any position.

In the eastern province each period of sandstone accumulation seems to have terminated in a peat deposit or at least a "coal hroizon". This arrangement provides the only basis for separating the eastern succession into individual sedimentary units. The extension of certain of the sandy layers and the overlying associated coal beds westward, in a few instances far westward, provides the only really substantial basis for the postulation of a "cyclical" sequence. All other beds, except for the non-marine shale or "soapstone" that overlies the coal beds in many places, are marine. Wherever such non-marine beds including the coal bed, interrupt the marine succession the effect of a cyclical sequence is produced by the mere fact that non-marine beds of a fairly definite type are succeeded by marine beds. Accordingly a continuous, that is a conformable, marine succession made up of several components may be separated into two or more groups of marine beds because of the intercalation of one or more sandstone and coal bed groups. There seems to be no rule which determines in which part of a marine sequence the additional non-marine beds will appear. The intercalated non-marine beds

must have been deposited or accumulated contemporaneously with the marine beds deposited a short distance westward.

In the desire to establish the existence of diastrophic formational units the proponents of the cyclothem concept of Pennsylvanian stratigraphic classification have assigned to the sandy non-marine beds a position harmonizing with the implications of the hypothesis and providing a basis for the conventional sequence. It is suggested, however, that the supposed conventional position of the sandy beds is only apparent and that departures from the conventional order, commonly explained by local omission of certain elements, are actually indicative of the irregular, unsystematic oscillatory relationship between two parts of the depositional area.

It is fully realized that the concept of Pennsylvanian sedimentation herein proposed lacks the convincing naive simplicity of that theory which organizes the Pennsylvanian system into groups of diastrophic formations composed of similar beds similarly ordered. The concept of cyclical formations reduced problems of Pennsylvanian stratigraphy to an alluring pattern of classification that attracts acceptance of those not too critical of conflicting details. However, there are those familiar with the complex composition of the Pennsylvanian sedimentary succession who are unable to read in the record of the rocks that simplicity of organization demanded by the cyclothem concept. They doubt the adequacy of the evidence to support the diastrophic implications of the theory, preferring to believe that the sedimentary record is one of progressive periodic subsidence; they are also impressed with important exceptions to the sedimentary sequence declared to be standard; and finally they regard as significant

the intermediate position of the Ea tern Interior Province between and area of marine deposition on the west and an area of non-marine deposition on the eaat. In this last relationship they find a possible solution of the alternation of marine and non-marine beds that provides the basis for the so-called cyclical formational units in the Eastern Interior Province.