GUIDEBOOK

29th Annual Field Conference of Pennsylvania Geologists

STATE COLLEGE, PA.

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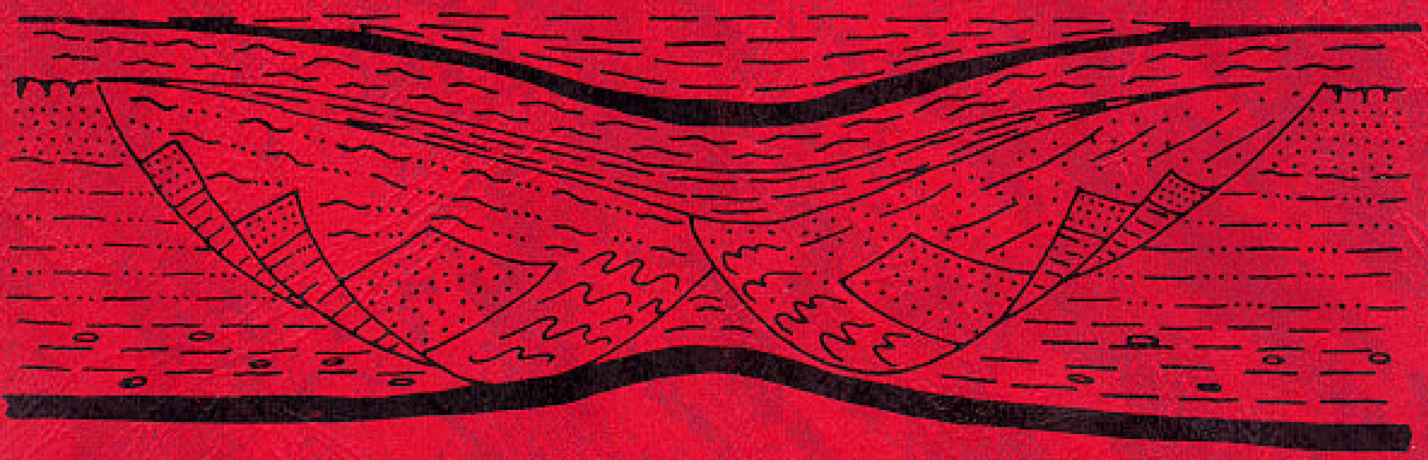

Host

The Pennsylvania State University

Department of Geology

Mineral Conservation Section

CYCLIC SEDIMENTATION IN THE CARBONIFEROUS OF WESTERN PENNSYLVANIA

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The Pennsylvania State University
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THE NATURE OF CYCLIC SEDIMENTATION IN THE CARBONIFEROUS OF WESTERN PENNSYLVANIA

E. G. Williams, Leader

Introduction

The rhythmic character of nature has held for man the most subtle fascination. From the periodic motion of planets to the turning of the seasons to the rise and fall of the national economy, man lives immersed in a multiplicity of rhythmic patterns, both natural and artificial. To a large extent progress in civilization has depended upon understanding the numerical form of rhythms. It is little wonder then, that cyclic phenomena in rocks have always attracted the interest of geologists. To my knowledge, the classic paper by Joseph Barrell, "Rhythms and Geologic Time," was the first extensive treatment of the significance of cyclicity in the rock record. Barrell was especially interested in analyzing both theoretical and actual manifestations of complexly interacting cycles of different amplitudes and frequencies. Barrell's most interesting conclusion was that rhythmic movements of base level, both tectonic and eustatic, resulted in more erosion than deposition. Hence, although the processes were cyclic in character, the resulting deposit, if preserved, need not be so.

One would imagine that after 40 years of rather intensive study, the character and genesis of Pennsylvanian cyclothems would now be a settled matter. But such is not the case. Instead, geologists working in the same areas cannot sometimes agree as to whether cyclothems exist at all, although the sequences resemble those described in the classical areas. The disputes seem to revolve

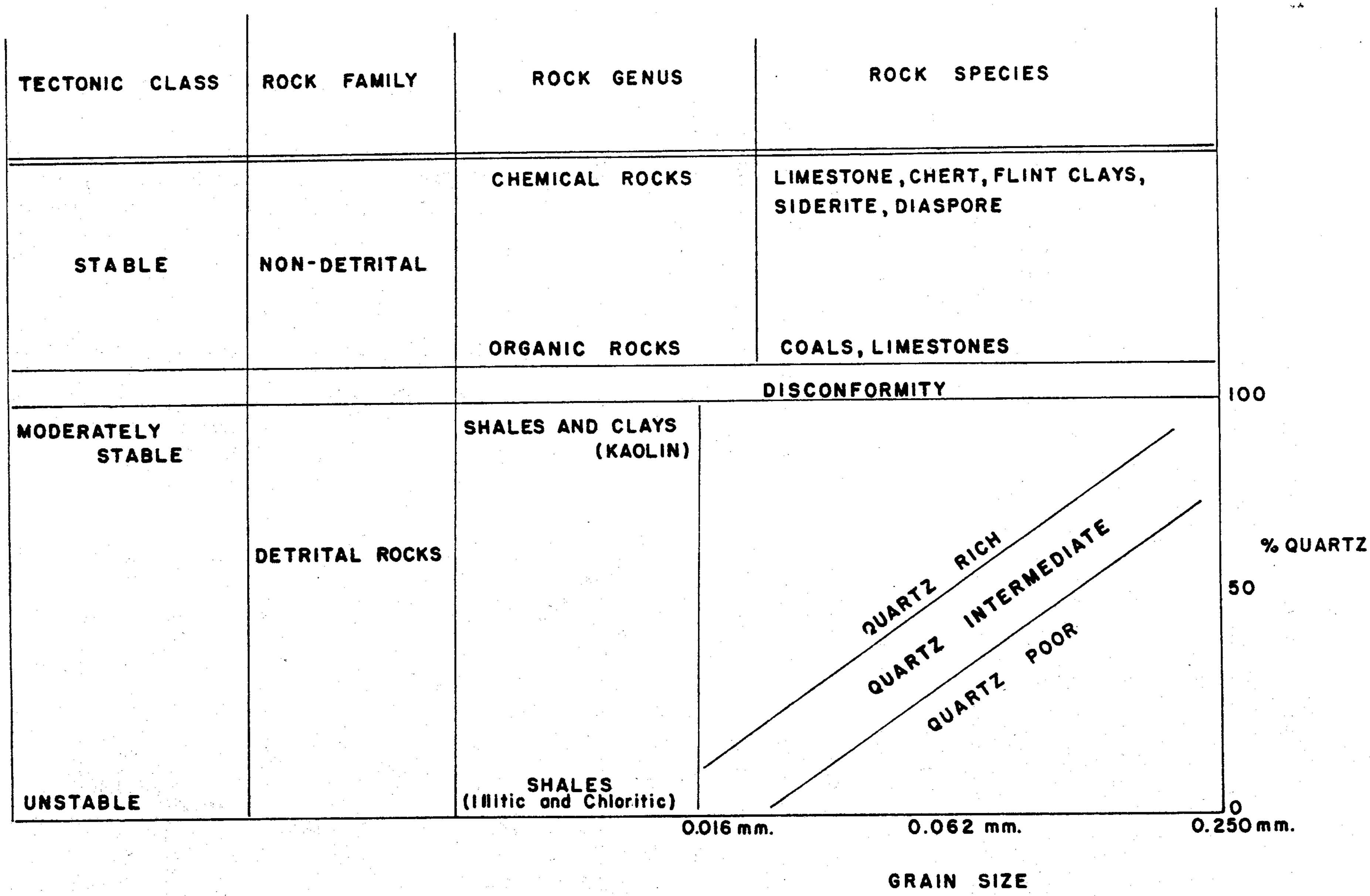


FIG. 1, CLASSIFICATION OF CARBONIFEROUS ROCKS about two points: (1) what are the stratigraphic and geographic limits of a cyclothem, and (2) assuming that boundaries or limits can be set, what is the fundamental arrangement or repetitive pattern, that is, what is the cyclic equation or formula?

Apart from questions concerning cyclicity, the origin of most Pennsylvanian sediments is imperfectly understood. Expecially troublesome are the origins of underclays, the depth of water of marine limestones and the environments of deposition of various types of sandstones.

The purpose of this field trip is to demonstrate the existence, character and genesis of cyclothems in the Carboniferous of western Pennsylvania. As examples we will use sections of marine, continental and mixed character. In order for the field observations to be meaningful, it is necessary to provide regional stratigraphic, paleogeographic and paleotectonic frameworks. The development of these frameworks does not necessarily depend upon the postulation of any cyclic concepts, and in fact, during the time most of the work was in progress, the investigators did not believe the Pennsylvanian rocks exhibited predictable cyclic aspects. However, as greater understanding of the frameworks developed and as the method of petrographic analysis improved, a cyclic pattern emerged. We believe this to be the most meaningful in classifying and interpreting the Pennsylvanian. In the process of expounding upon the cyclic concept, we must of necessity consider the problems of rock genesis.

The Genetic Cycle

A Carboniferous sedimentary cycle will be defined as a repetitive, complexly structured, three dimensional group of rocks, whose boundaries are ideally independent of rock type, environment of deposition and morphology.

The unifying principle of tectonics or base level stability is used to classify Carboniferous rocks (figure 1). The amount and rate of accumulation of detritus at a given point is a joint function of the rate of supply and the rate of subsidence (base level rise). A necessary condition for the formation of a chemical or organic rock is the absence of detrital material. Thus a chemical rock may form under conditions of rapid subsidence and low supply (basin is starved); slow subsidence and high supply (area is by-passed); or lastly, slow subsidence and low supply. The last condition is obviously the one in which chemical rocks are most likely to form.

The principle of stability can be used to further subdivide the detrital rocks. In areas of rapid subsidence, sediments will tend to be poorly sorted and have low quartz contents relative to their grain sizes, whereas sands deposited in more stable environments are likely to undergo more current action and winnowing and therefore have better sorting and higher relative quartz contents. Therefore, grain size and quartz content have been used to classify sandstones, the resulting groups being shown in the lower right hand quarter of figure 1.

In addition, the composition of shales and clays may also reflect base level tectonic variation. Kaolinitic shales, for example,

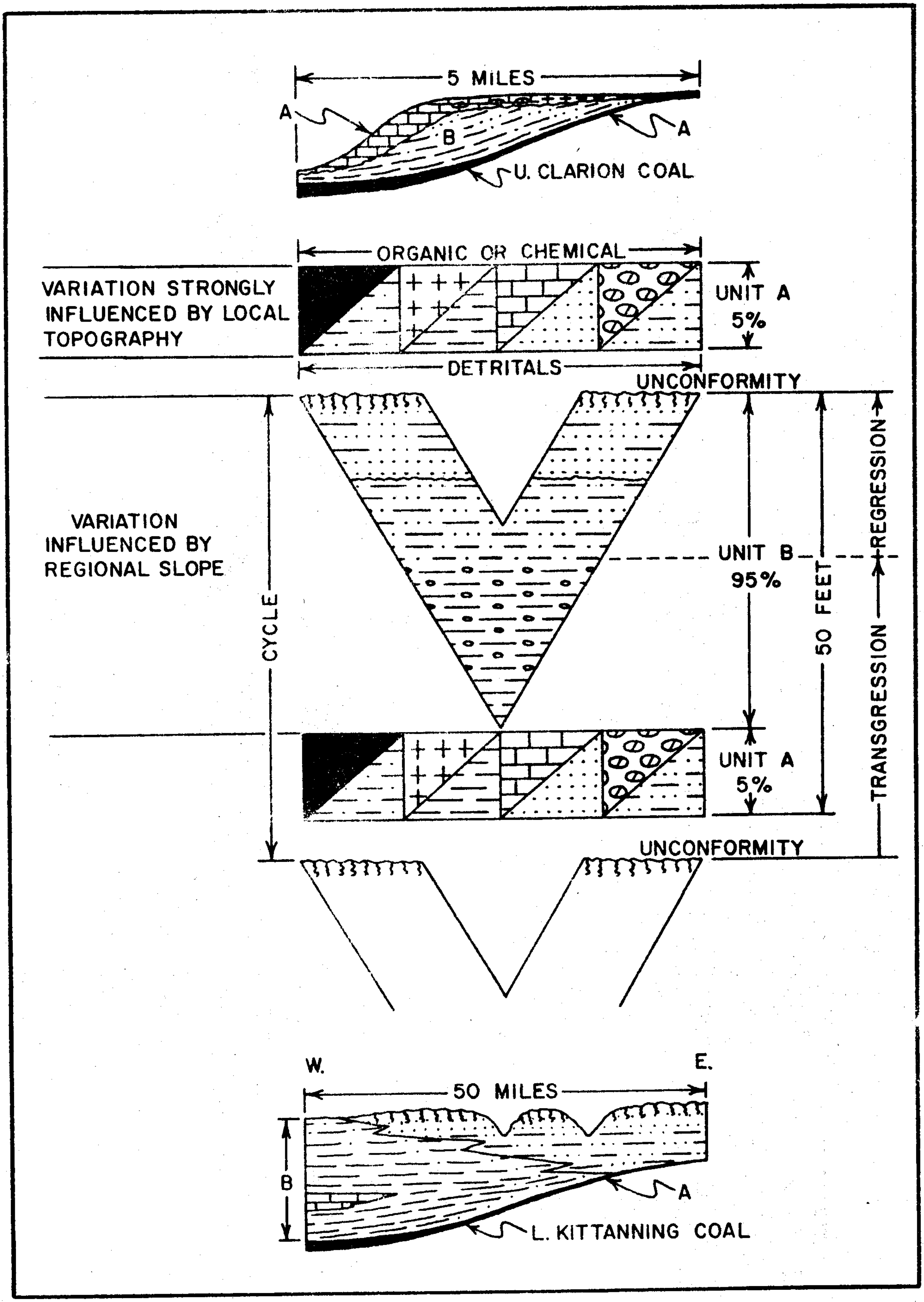


FIG. 2, GENERALIZED CYCLE

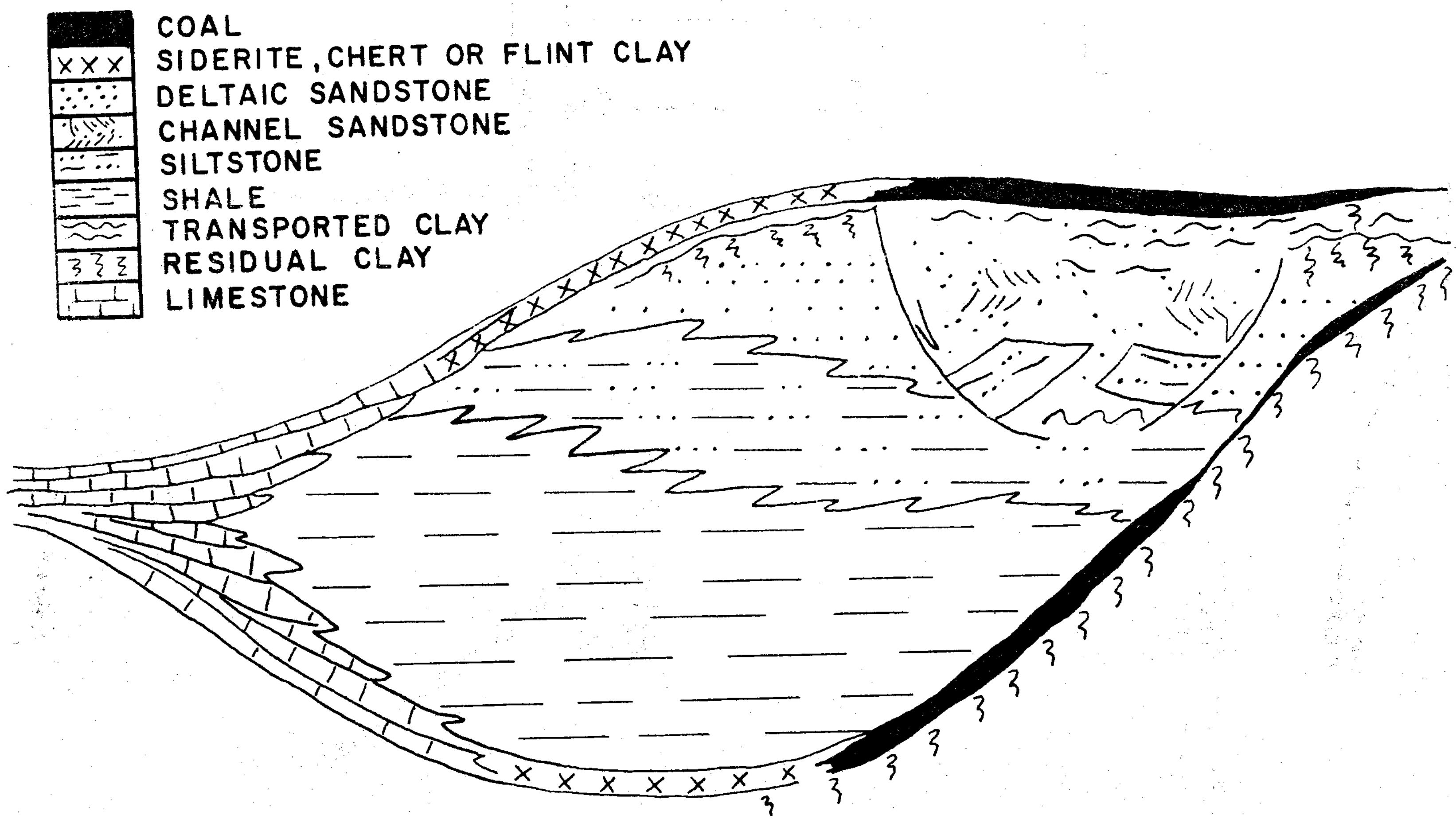


FIG. 3, IDEALIZED CYCLOTHEM

would tend to occur under conditions of greater stability than would illitic ones.

The main advantage of using a single, broad principle such as base level stability in classifying Carboniferous rocks, is that the dependence of correlation and cyclic interpretation on specific rock types is mitigated. The importance of this can be illustrated by the following deductions which can be made using the proposed classification:

1. Non-detrital or chemical rocks should show more frequent paleogeographic association with each other than with detrital rocks. Translated into more familiar terms, this means that in a tectonically stable environment, any or all of the chemical rocks may be present, the number and kind depending upon subtle chemical factors, such as pH and Eh.
2. Of the paleogeographic associations that sometimes occur between detrital and non-detrital rocks, the most frequently involved detrital classes should be those produced under conditions of moderate stability, that is, kaolinitic shales and clays and quartz-rich sandstones (beaches and bars).

The disconformity separating detrital from non-detrital rocks (figure 1) cannot be deduced completely from the rock classification. Field evidence demonstrates that the detrital and non-detrital rocks are frequently separated by disconformities. Therefore, by using the concept of stability together with the occurrence of disconformities as criteria for classification of Carboniferous rocks, we

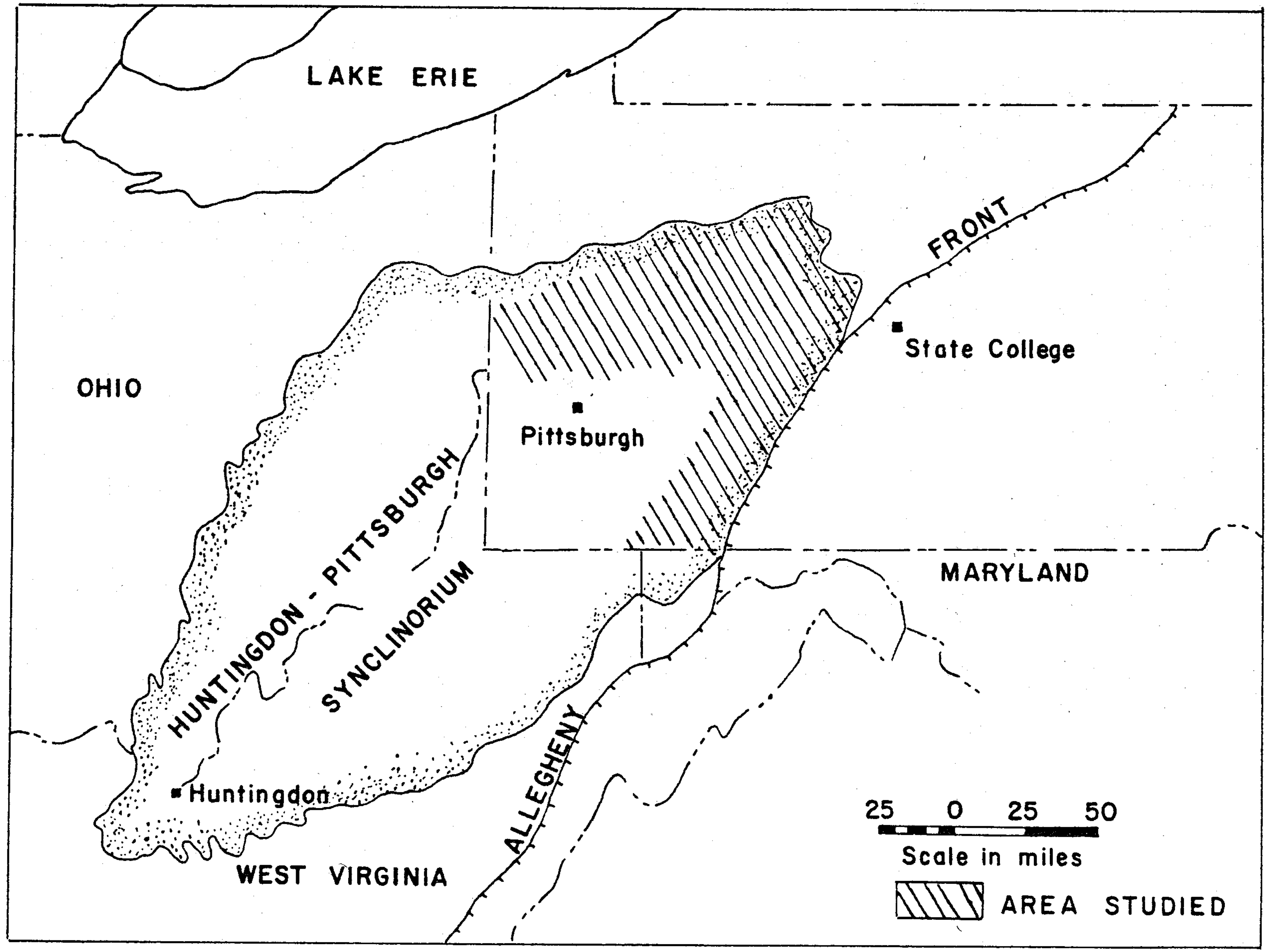


FIG. 4, GENERAL INDEX MAP OF APPALACHIAN COAL BASIN potentially should be able to recognize sedimentary patterns (cycles) which are represented by a wide variety of rock types.

Our concept of a genetic, Carboniferous cycle is illustrated in figure 2. The cycle is bounded by disconformities and consists of two complex units, labelled A and B. Unit A may contain eight different rock types which can be grouped into both chemical-organic and detrital classes. Coals, limestones, cherts and flint clays are typical sediments in the first group whereas sandstones, siltstones and illitic clays characterize the detrital group.

Unit A may be bounded by any of the listed rocks, the specific types depending upon base level variations and topographic conditions at a given locality. However, chemical-organic rocks usually form the upper boundary and detrital rocks the lower. Coal is the most common chemical-organic rock and illitic clay the most common detrital. The geographic and stratigraphic variations both within and between rock types are largely influenced by variation in elevation of the subjacent disconformity. Genetically, unit A is thought to represent a transgressive phase, either continental or marine, over dissected topography. As indicated above, continental rocks such as coals and clays predominate, although in some instances as shown in figure 2a, the entire unit may be composed of marine sediments.

Unit B, which extends from the top of the underlying chemical or organic rock, which typically forms the upper boundary of Unit A, to the overlying disconformity, has two distinguishing features. It is a prograded sequence, grading from fine shales at the bottom to interbedded sandstones and siltstones at the top. Lateral variation

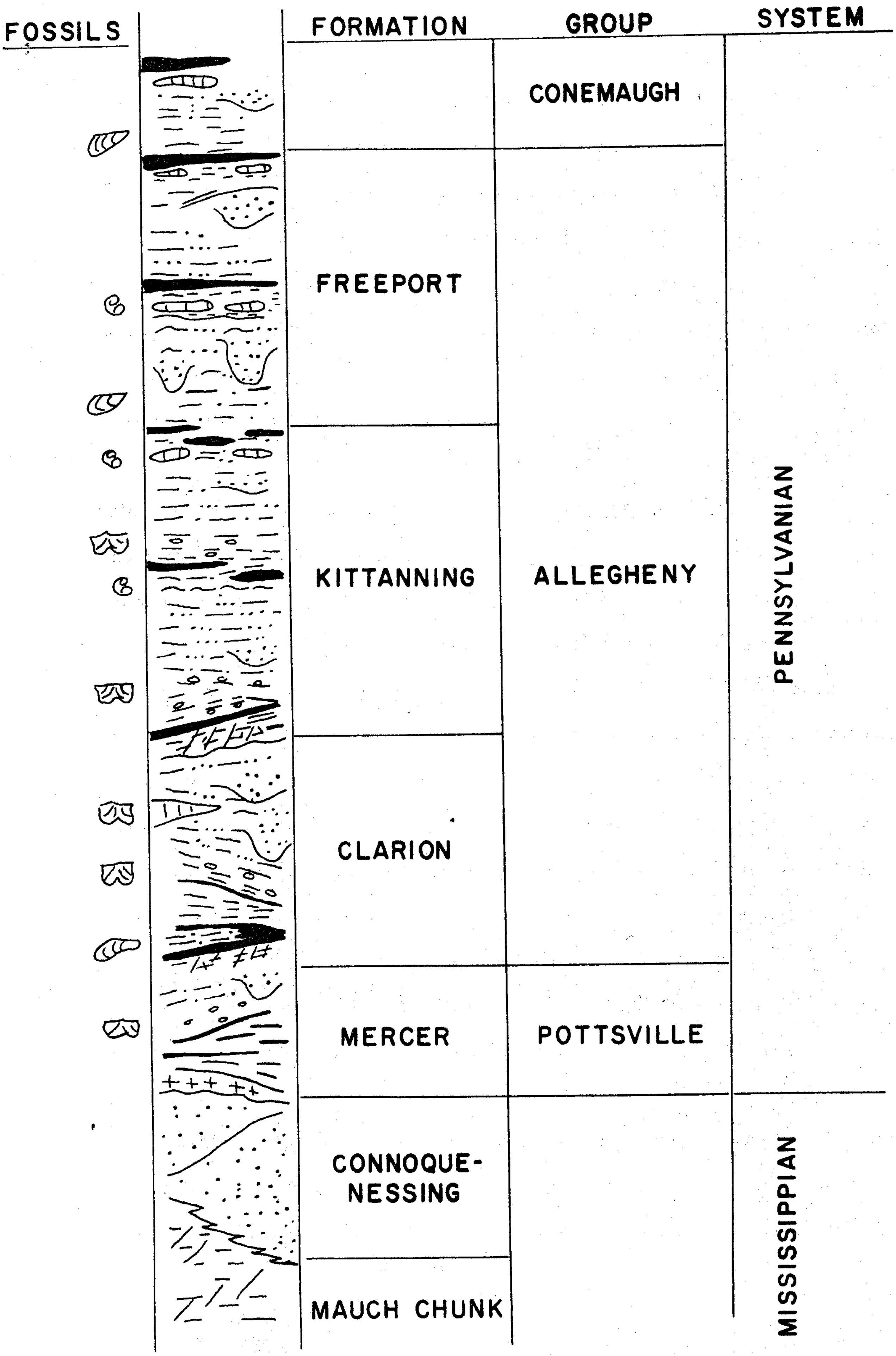


FIG. 5. GENERALIZED STRATIGRAPHIC SECTION OF ALLEGHENY
IN WESTERN PENNSYLVANIA

occurs at the regional level and is presumably controlled by a joint interaction of tectonics (subsidence) and eustatic sea level changes. An example of such regional variation is shown in figure 2b.

The second characteristic is that the original thickness is seldom observed, the unit having been removed to varying depths by the erosional processes which created the disconformity. The latter feature is present either as a surface or as a variable thickness of residual clay.

Unit B is dominantly regressive in character and probably represents the infilling of a sedimentary basin, either marine or continental, by the systematic encroachment of shallow-water deltaic sediments onto deeper water ones.

An ideal or conceptional cyclothem is illustrated in figure 3. It is ideal because it represents a synthesis of fragmentary analyses made at various stratigraphic and paleogeographic positions in the Pennsylvanian of the Appalachian Basin.

The cycle consists of a wedge of prograded detrital rocks which are completely enclosed by thinner, chemical-organic rocks. At one lateral extremity (figure 3) coals predominate, whereas limestones (chemical rocks) are best developed at the other end. Coal beds frequently rest on disconformities whereas limestones rarely do. Where disconformities are present, they bound the cycle; where absent, a chemical or organic rock forms the boundary.

The chemical rocks were formed under conditions of relative tectonic stability and during transgressive sedimentary phases. The detrital complex was produced during times of relative tectonic

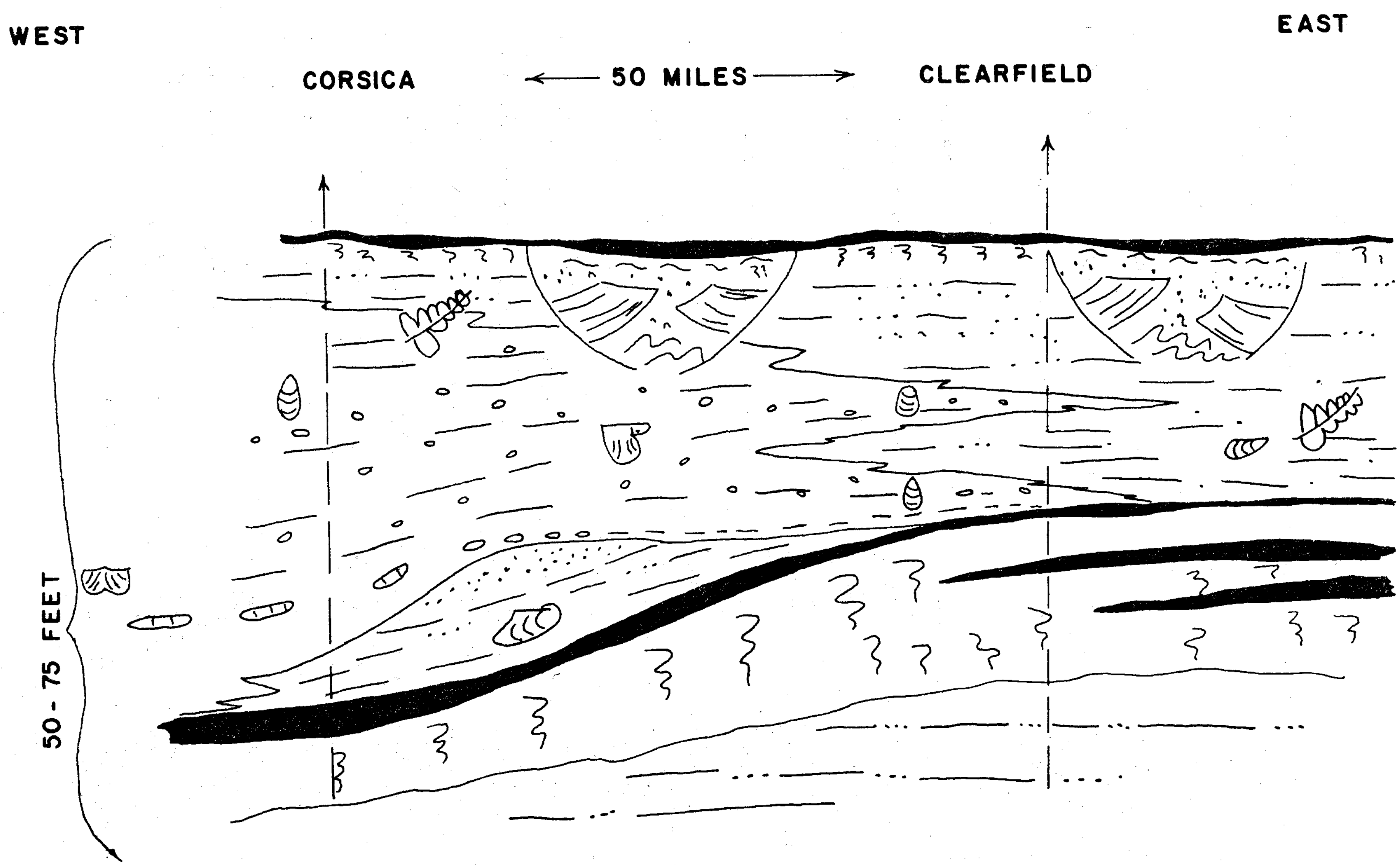


FIG. 6, DIAGRAMMATIC CROSS SECTION OF HAMDEN SHALE AND ASSOCIATED ROCKS (COLUMBIANA) instability (subsidence) and is largely regressive in character. The disconformities resulted from eustatic lowering of sea level. The cycle as drawn is independent of any general environmental connotations. For example, the limestone could be either marine or fresh water, etc.

Purpose and Philosophy of the Field Trip

The purpose of the trip is to provide conceptional and physical frameworks within which we can observe and reflect on some important aspects of Carboniferous sedimentation and stratigraphy. The conceptional framework is the genetic cycle and the physical frameworks involve aspects of stratigraphy, paleogeography and paleotectonics.

The specific problems or questions which we desire to illustrate and discuss are as follows:

1. Can the concept of the genetic cycle be meaningfully applied to rocks of both continental and marine origin? To attempt an answer we will examine the Freeport formation which is entirely of continental origin; the upper part of the Clarion formation (figure 2a), dominantly of marine origin; and lastly an interval which contains both continental and marine rocks, the lower part of the Kittanning formation (figure 2b).
2. Tectonic and topographic control of sedimentation. This involves the idea of differential subsidence on a subregional scale (tectonic sub-block concept

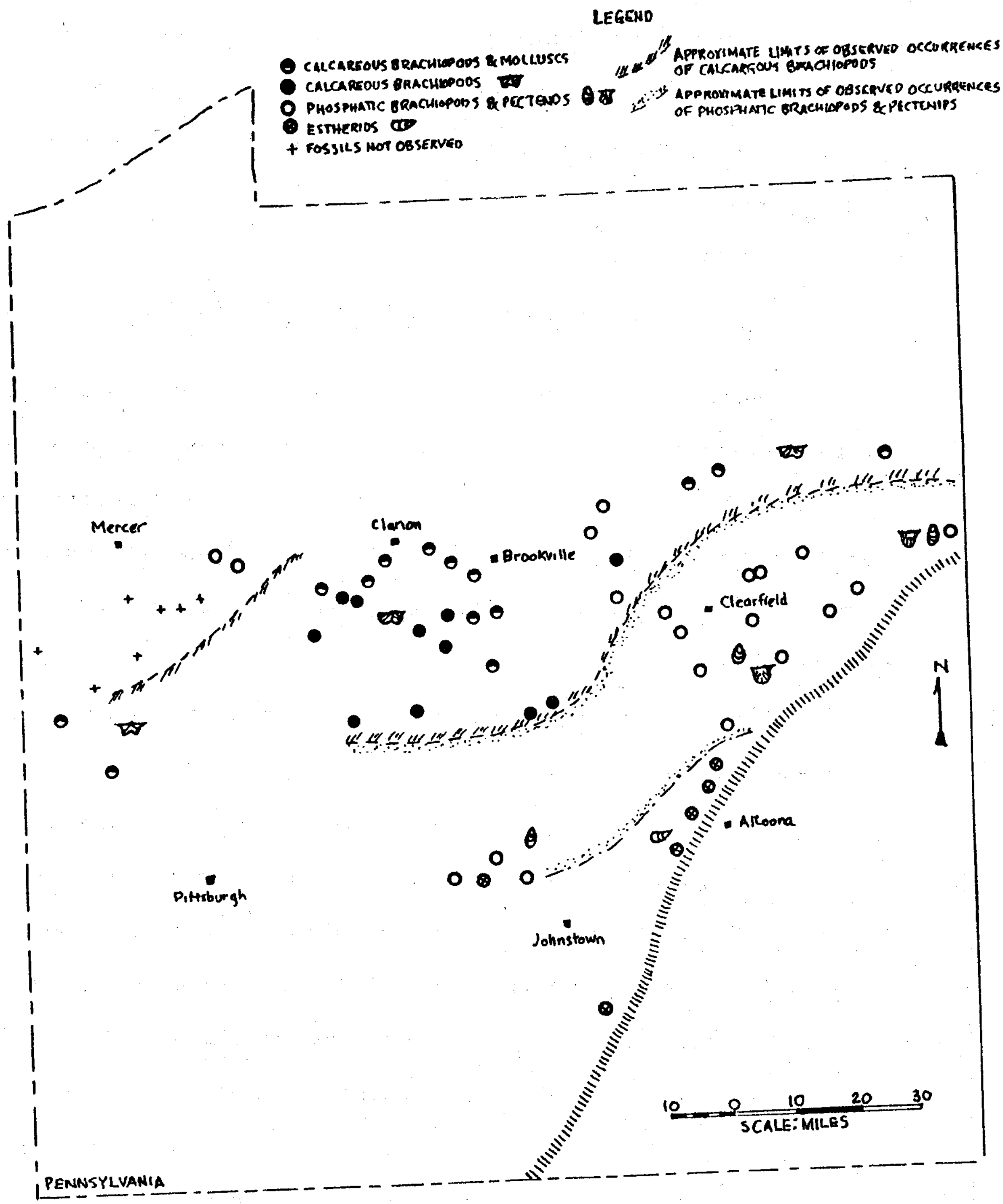


FIG. 7, BIOFACIES MAP OF MIDDLE MEMBER OF HAMDEN SHALE
(COLUMBIANA)

of Krynine) and secondly, the development of disconformities by eustatic changes of sea level.

3. The origin of underclays. This involves the concept of residual and transported clays and their relations to local paleotopography.
4. The origin of Carboniferous sandstones.

These four questions may be rephrased as follows: (1) Do cyclothems exist, or are they merely broad generalizations or abstract concepts? (2) If they exist, what are their limits and dimensions? (3) Assuming they exist and can be mapped, what is their origin?

Before these and related questions can be discussed, it is necessary to provide stratigraphic, paleogeographic and paleotectonic frameworks for selected intervals of the Allegheny. Following this, a discussion of individual localities will be given. These have been chosen so as to illustrate in a logical or connected manner, the evolution of our thinking concerning cyclic sedimentation.

General Stratigraphy of the Allegheny

The area to be examined lies in the northeastern extremity of the Pittsburgh-Huntington synclinorium (figure 4). A generalized stratigraphic section for this area is presented in figure 5, from which the following conclusions can be drawn:

1. The lower Allegheny and upper Pottsville formations are characterized by low-grade coals, high-grade

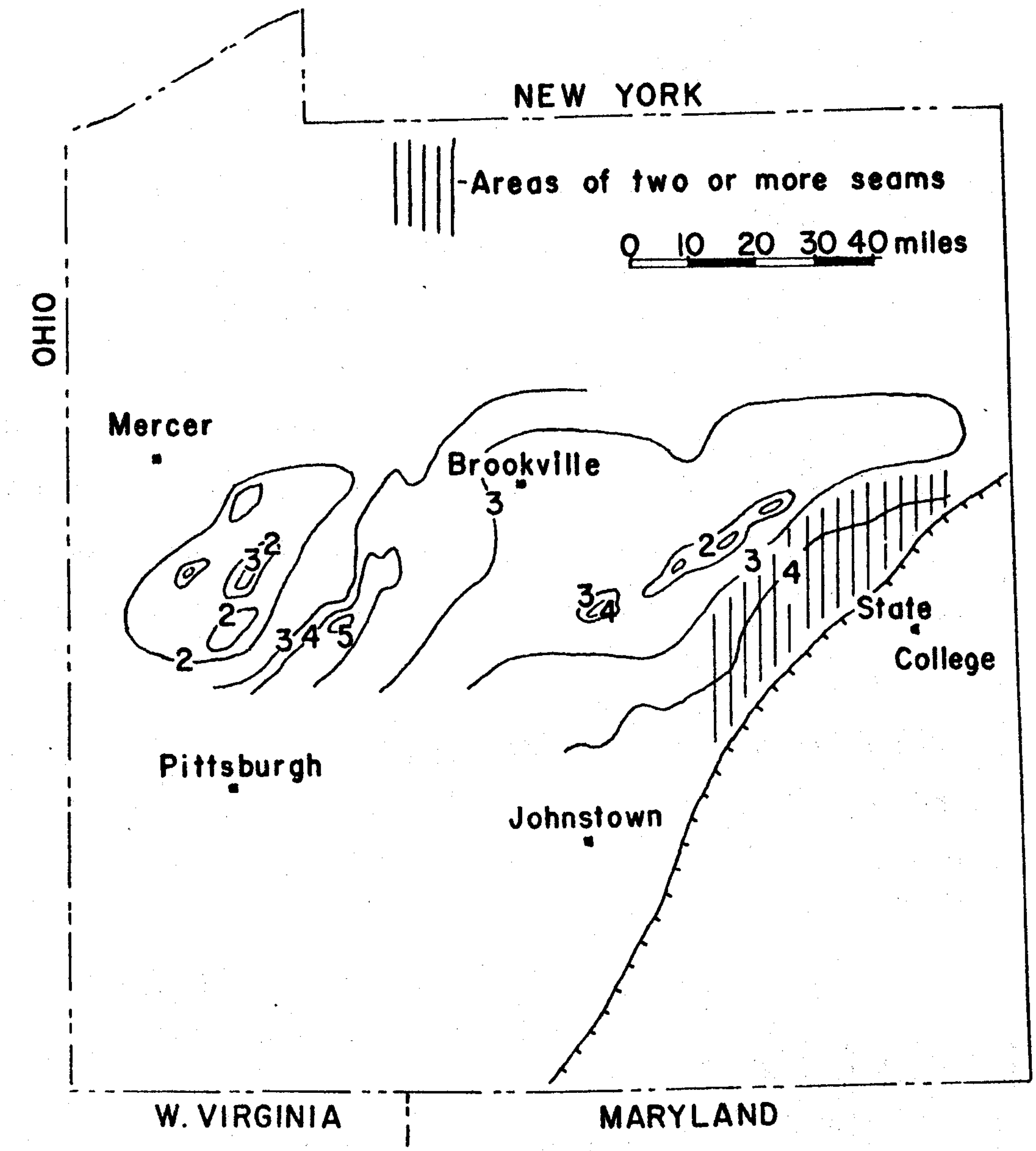


FIG. 8, ISOPACH MAP OF LOWER KITTANNING COAL underclays and the presence of well-developed marine shales and limestones. Variation in thickness and character of the rocks is great both at local and regional levels.

2. The upper Allegheny (Freeport formation) is characterized by relatively high-grade, persistent coals, low-grade clays, fresh water limestone and no marine beds. Variations in thickness and rock properties although variable, are less so than in lower Allegheny rocks.
3. The middle Allegheny (Kittanning formation) is intermediate in character.

Paleogeographic and Paleotectonic Frameworks

Introduction

The paleogeographic and paleotectonic frameworks for the Allegheny will be developed by regional analysis of two prominent marine beds of middle Allegheny age. These are the Columbiana shale and the Vanport limestone. The main conclusion to be demonstrated is that the regional paleogeographic patterns of both marine beds are tectonically controlled.

Lower Kittanning Cycle

Figure 6 is a northwest-southeast section across the Allegheny Plateau, illustrating the variation in the interval between the Lower Kittanning coal and the Washingtonville shale. This interval includes the marine Columbiana shale which is thickest and best developed in the central part of the area. The Columbiana rapidly thins and disappears to the northwest and southeast by intertongueing with sandstones and siltstones of deltaic origin. The Columbiana represents a transgressive-regressive marine sequence. The middle member, containing an abundant marine fauna, represents a period of marine stillstand and deepest water.

Figure 7 is a biofacies map of the middle member of the Columbiana and its lateral equivalents. The deepest water marine facies (calcareous brachiopods and mollusks) occurs in a central, northeast-southwest trending belt which is successively flanked on the northwest and southeast by shallow marine (sparse calcareous brachiopods), brackish (phosphatic brachiopods) and fresh water (estherids) biofacies. Of special importance is the fact that in the north, biofacies trends are east-northeast; in the central region north-northeast and in the western part, they are approximately east-west. This regional configuration or grain of the Columbiana biofacies is manifested in all other members of the Lower Kittanning cycle which have been mapped. For example, figure 8 is an isopach map of the Lower Kittanning coal which directly underlies the Columbiana. A comparison of figures 7 and 8 clearly shows that the configurations are similar. This is interpreted to mean that at least one common process was involved in the formation of both units. The most likely process was differential, tectonic subsidence.

Using all available stratigraphic, faunal and petrographic evidence, a paleogeographic map of Columbiana time has been constructed (figure 9). The Columbiana sea had a maximum depth of about 60 feet, and was eventually filled or shoaled by detrital sediments derived from the southeast and northwest. The near-shore sediments are of deltaic origin and consist of complexly related fluvial, lacustrine, paludal, lagoonal and channel environments.

Vanport and Clarion Cycles

The paleogeographic and paleotectonic patterns for the lower Allegheny are based on an analysis of the Vanport limestone and associated sediments. Figure 10 is an isopach map of the Vanport which shows the limestone to be thickest (20 feet) in a northwest-southeast trending belt which occupies the central part of the plateau. To the north, east and southwest, the Vanport thins by gradation into marine shale and chert. In the south, the Vanport passes below drainage.

The peculiar thickness configuration of the Vanport is attributed to differential subsidence and sedimentation. This is best seen by comparing figures 10 and 11. Note that in figure 11 the Vanport is thickest along an axis labelled "tectonic high" whereas the Clarion formation is thinnest. The thinning is accomplished by the gradual elimination of sandstones, coals and marine shales. The rate of thickening and thinning of the Vanport is related to the position of the limestone with respect to areas of detrital influx. In areas of abandoned deltaic lenses or wedges, such as "A" on figure 11, the Vanport is relatively thick whereas in areas of contemporaneous deltaic sedimentation (wedges C, D and E, Figure 11), the Vanport is thin or absent. Along the tectonic high the limestone reaches its greatest thickness. The critical factors which appear to control the variation in thickness and

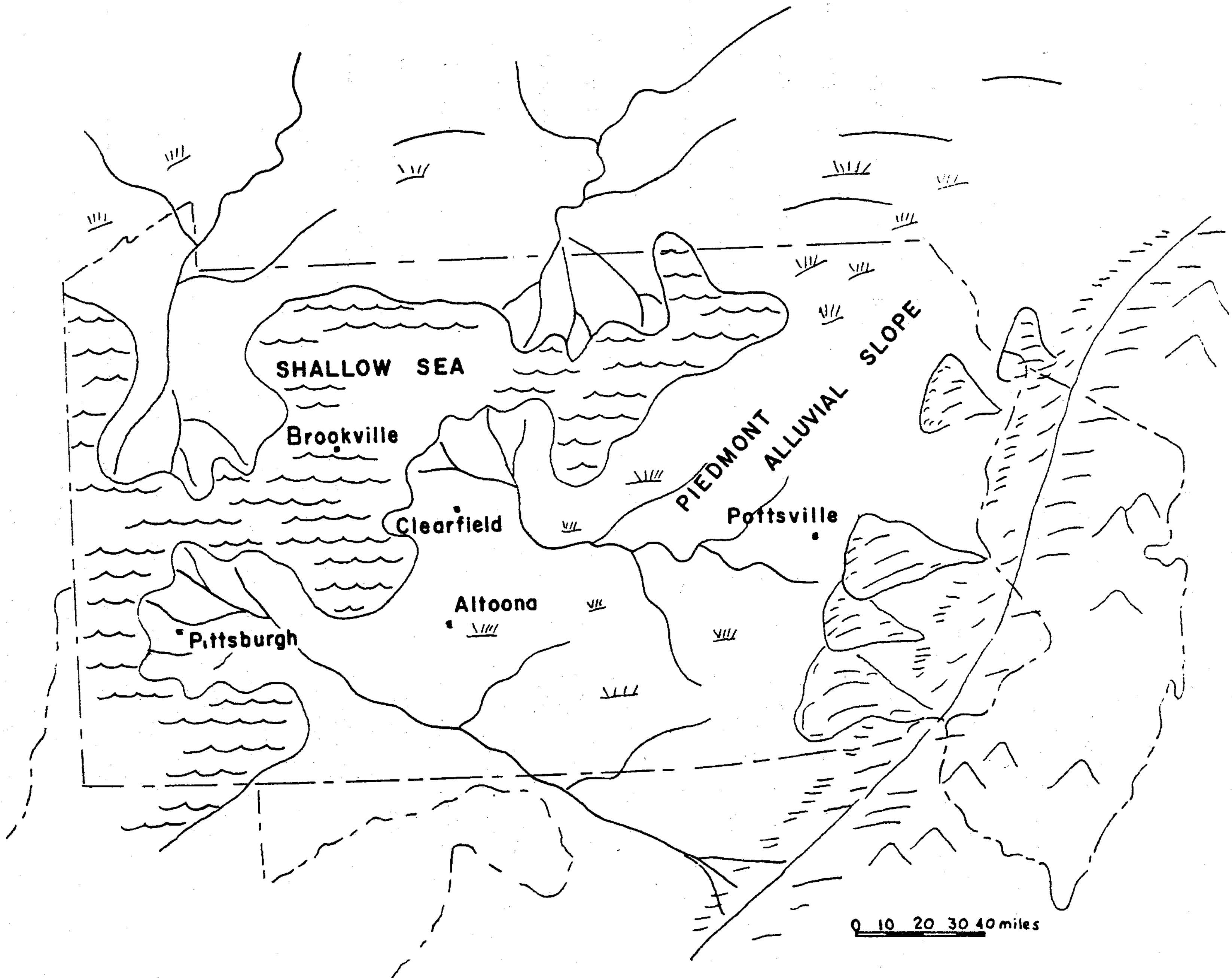


FIG. 9, PALEOGEOGRAPHIC MAP OF LOWER KITTANNING TIME

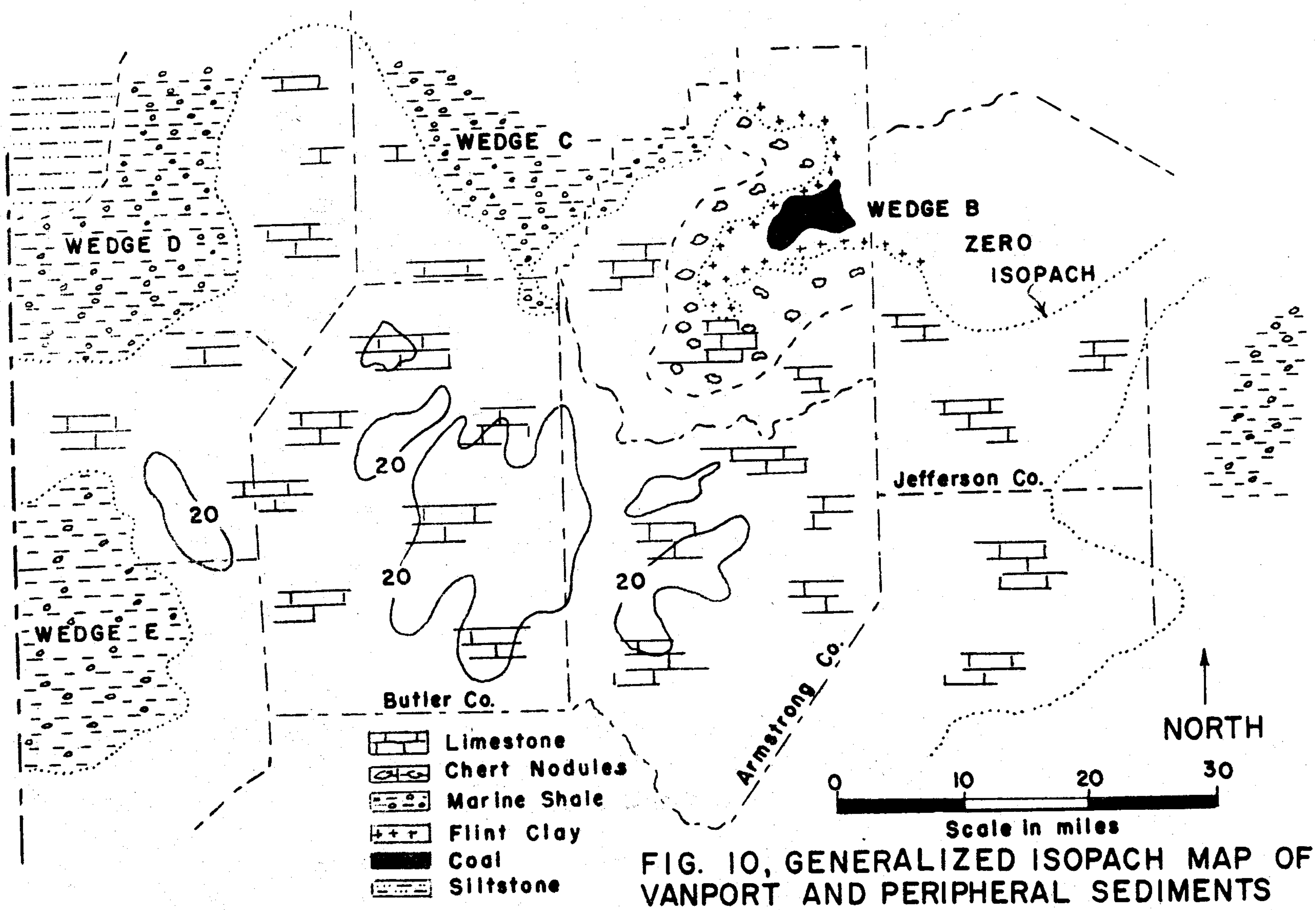
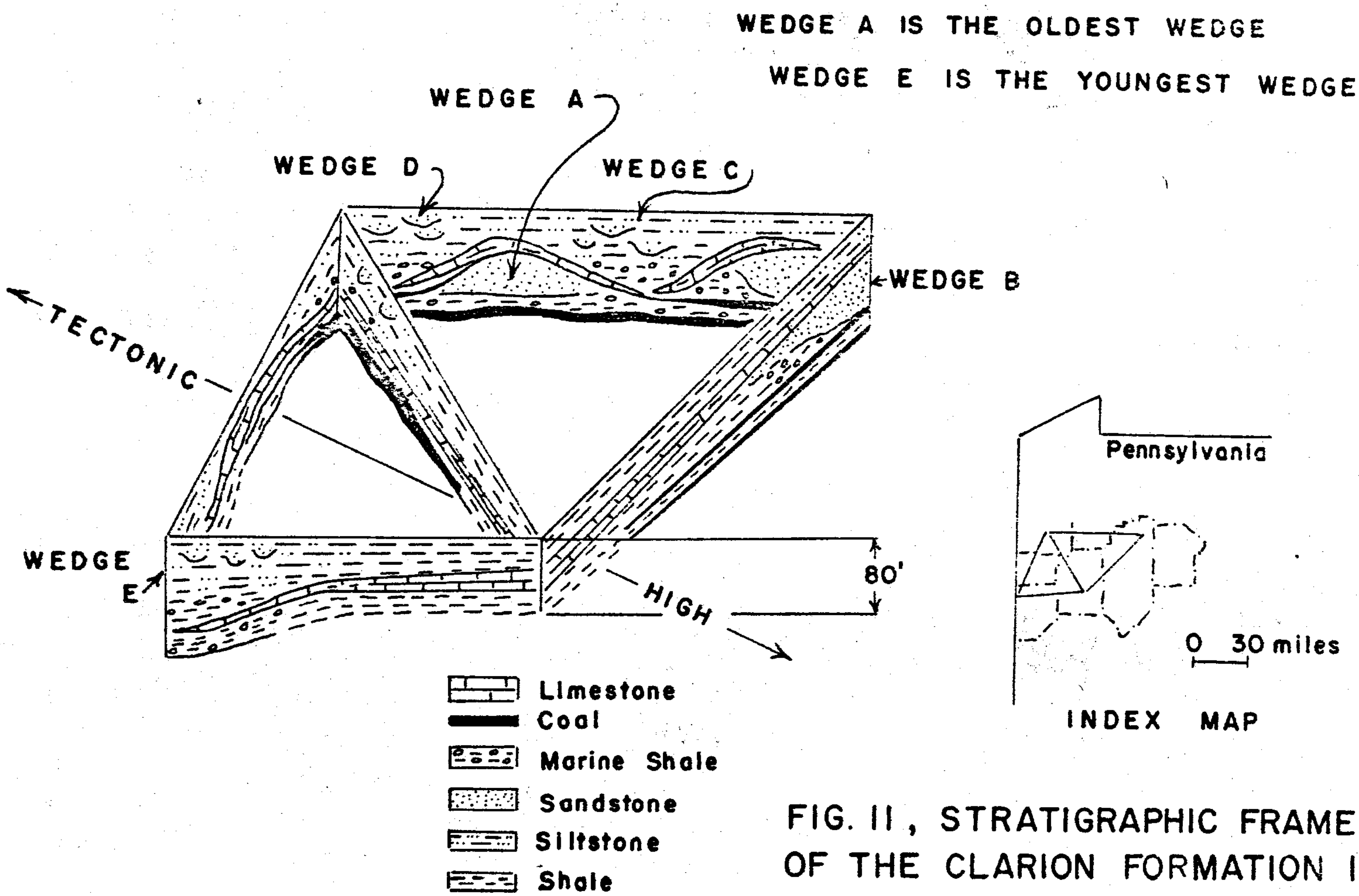


FIG. 10, GENERALIZED ISOPACH MAP OF VANPORT AND PERIPHERAL SEDIMENTS



INDEX MAP

FIG. II, STRATIGRAPHIC FRAMEWORK OF THE CLARION FORMATION IN WESTERN PENNSYLVANIA composition of the Vanport are depth of water and rate of subsidence. The former controls the chemistry and the latter factor affects rates of detrital influx.

As shown in figure 12, the Clarion coals are mainly confined to areas north and northeast of the tectonic or stable high. The association of thick limestones and thin coals or vice versa occurs on both local and regional levels. Limestone seems to require more stable conditions than coal. One reason may be that coal swamps are, in a sense, self perpetuating, that is, dense vegetation tends to inhibit detrital influxes and fosters reducing conditions.

In summary, reference to figures 11 and 13, shows that the paleogeographic and paleotectonic pattern during lower Allegheny time is one of relatively thick limestone accumulation along a northwest-southeast trending stable axis, and differential subsidence and detrital sedimentation in areas to the southwest, north and east. The peripheral detrital sediments accumulated in deltas which shifted both in time and space, the position of each delta being a complex function of differential subsidence and compaction.

Upper Freeport Cycle

The Freeport formation, as shown in figure 5, consists of continental sediments representing paludal, lacustrine and fluvial environments. Although some detailed work has been done on these rocks, it has not been sufficient to establish any well defined regional paleogeographic or paleotectonic patterns. Therefore, our attempts to apply cyclic concepts, largely developed in more marine sequences, to the interpretation of the Freeport continental sections must be

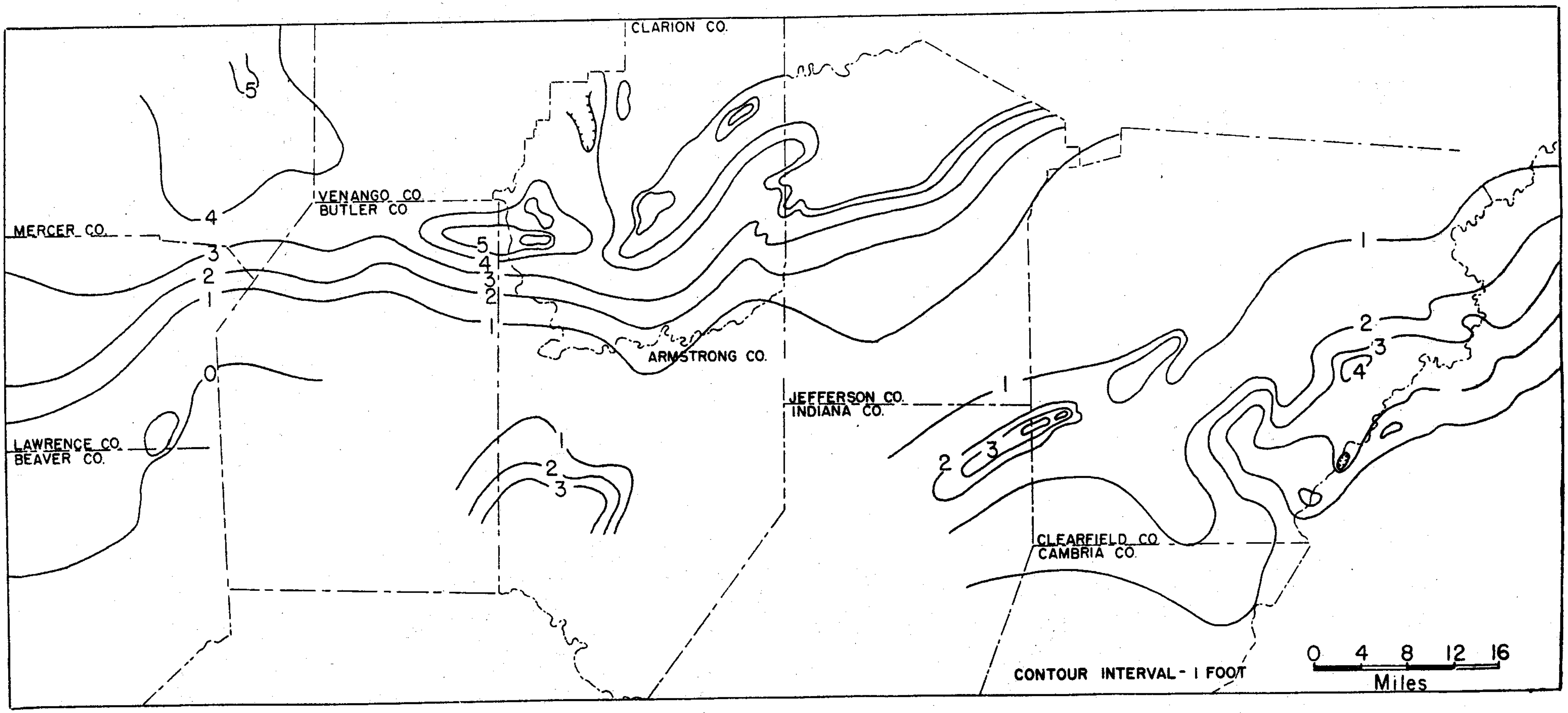


FIG. 12, ISOPACH MAP OF CLARION COALS

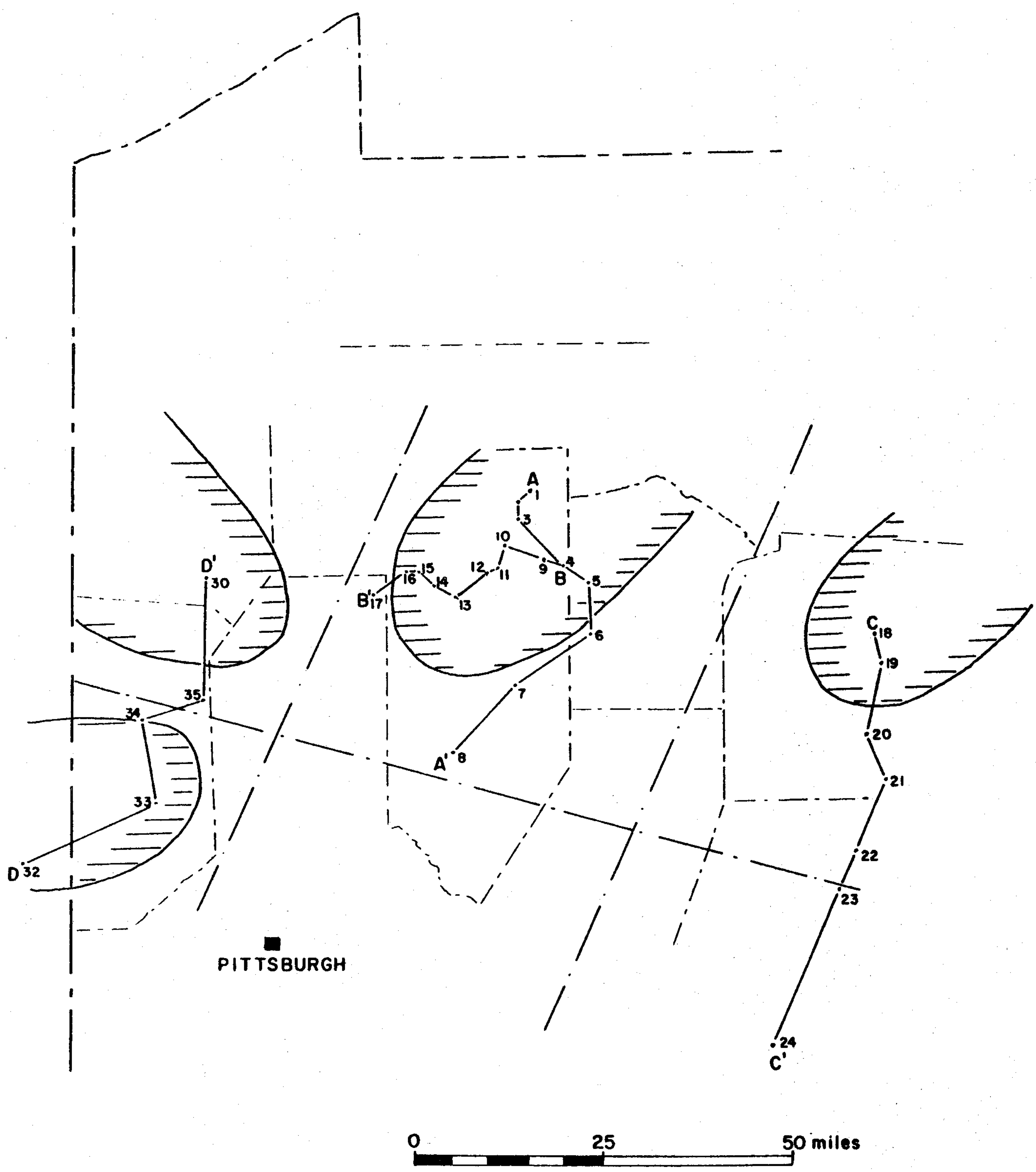


FIG. 13, CLARION TECTONIC MAP

considered as tentative and experimental. We justify the attempt on the basis that an understanding of the relationship between continental and marine cycles poses the greatest single problem for the coal stratigrapher. In effect, precise correlation between marine and continental areas of the Carboniferous cannot be accomplished until marine analogs are found in the continental areas or vice versa. And this implies a genetic interpretation based on phenomena common to both areas. This common denominator, which has been used to develop our rock classification, (figure 1) is the rate and amount of base level change, produced either by tectonic or eustatic processes.

Figure 13a is a generalized diagram of upper Allegheny rocks (includes most of the Freeport formation) in northeastern Clearfield County. Most of the cyclic elements observed in the marine cycles also can be found here. For example, a prograded sequence, analogous to unit "A" in the generalized cycle, everywhere occurs above the Upper Freeport coal. Directly above the coal is 10 to 15 feet of dark gray, well-bedded, estherid-bearing shale, which grades upward into interbedded siltstone and sandstone. A disconformity forms the upper boundary of the prograded sequence. In some places the erosion surface can be observed directly while in others it can be located conclusively by an analysis of slump phenomena. As in the marine cycles, the relief on the Freeport disconformity controls the location of slumping as well as the thickness and composition of subsequently formed sediments. For example, freshwater limestones are thickest in topographically low areas; and medium to coarse-grained sandstones are confined to areas of slumping.

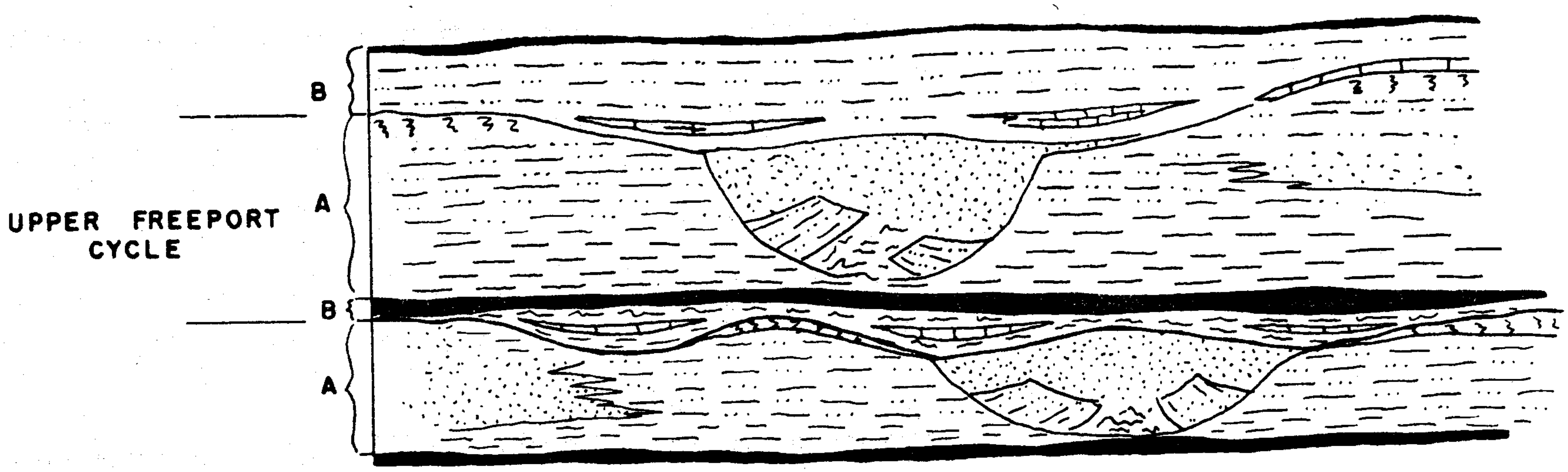


FIG. 13a, GENERALIZED DIAGRAM OF FREEPORT CYCLES N.E. OF SHAWVILLE, CLEARFIELD CO., PA.

Conclusions

The Allegheny cycles of western Pennsylvania, of both continental and marine origin, are believed to result from eustatic and tectonic changes in base level. The cycles consist of two complex units; a pro-graded sequence of shale, siltstone and sandstone, the proportions of which vary over regional and subregional levels (unit B, figure 2); and an underlying unit (A, figure 2) which consists of a complex of chemical, organic and detrital sediments, the variations of which take place at local levels, that is, over distances of several hundred feet to several miles. The units are separated by a disconformity, which, because of its wide areal extent, is interpreted to have been produced by eustatic lowering of base level. The relief on this erosion surface is controlled by the amount and temporal duration of base level drop. In turn, the kinds and arrangements of rocks in the overlying "A" unit are a joint function of the relief on the disconformity and the rate of base level rise. Because the joint action of these two factors produce a wide range in physical and chemical conditions, the number of sediment manifestations is correspondingly large. Hence, a typical or average arrangement has no meaning. The best that can be done is to show the relationships that exist between rock properties, depositional slope and the rate of base level change. Some of these relationships have been discussed in previous sections and will be illustrated in the field.

In the foregoing discussion of both marine and continental cycles, our attention has been focused on the disconformity and the rocks associated with it. In effect, the differences in the rocks are recognized, or at least magnified, by their spatial and temporal relationships to the erosion surface. But in most areas, the criteria for recognition of this surface will not be available (that is, direct truncation or indirect inference by analysis of slump blocks). Therefore, if our cycle concept is to be made operational, the methods of study should be reversed; the disconformity must be located by an analysis of the composition and texture of the rocks. And it is here that the future progress of the science of coal geology will reside. We have already made some progress in this direction. Analysis of clays, sandstones and limestones which are associated with the erosion surfaces have been partially completed. Details will be given at the appropriate places in the field.

References

The purpose of the guidebook is to provide a framework within which the field observations made on the trip may be discussed and debated. The text has not been referenced since it is not formally presented. However, because the discussions are based on the work of several people, some acknowledgement is desirable. The following is an anotated list of the most important works:

Bergenback, R. (1964) "Petrology and Geochemistry of the Vanport Limestone of Western Pennsylvania," unpublished PhD thesis, The Pennsylvania State University. The work demonstrates the quantitative relationships between the chemistry and petrography of a marine limestone and the depositional slopes upon which it was deposited. The use of carbon isotopes (C_{12}/C_{13}) in establishing paleogeographic and paleotectonic patterns is of special significance.

Ferm, J. C. (1962) "Petrology of Some Pennsylvanian Rocks," Jour. Sed. Pet., vol. 32, No. 1, pp. 104-123. The most significant article yet published on the classification and genetic interpretation of Carboniferous sandstones. Some of the results are incorporated in the classification shown in figure 1.

Ferm, J. C. and Williams, E. G. (1960) "Stratigraphic Variation in Some Allegheny Rocks of Western Pennsylvania," A.A.P.G. Bull., vol. 44, No. 4, pp. 495-497. This paper represents the first attempt to classify, on a sedimentalogical basis, the Allegheny rocks of western Pennsylvania.

Ferm, J. C. and Williams, E. G. (1964) "Paleogeography of the Lower Kittanning Cycle," Jour. Sed. Pet., (in press). All of the data on the regional paleogeography of the Lower Kittanning cycle was obtained from this paper.

Williams, E. G. (1960) "Marine and Fresh Water Fossiliferous Beds in the Pottsville and Allegheny Groups of Western Pennsylvania," Jour. Paleont., vol. 34, No. 5, pp. 908-922. This paper provides the basis for the gross, regional interpretation of the paleogeography of various Allegheny cycles.

Williams, E. G. (1960) "Relationship Between Stratigraphy and Petrography of Pottsville Sandstones and the Occurrence of High-Alumina Mercer Clay," Econ. Geol., vol 55, pp. 1291-1302.

Williams, E. G. and Griffiths, J. C. (1961) "Application of Statistical Methods in Prospecting for High Alumina Clay," Mineral Ind. Dept. Sta. Bull., No. 77, pp. 29-34. This paper and the previous paper deal with origin of the Mercer fire clay which will be discussed at stop 2 of the first day.

Williams, E. G. and Keith, M. L. (1963) "Relationship Between Sulfur in Coals and the Occurrence of Marine Roof Beds," Econ. Geol., vol. 58, pp. 720-729.

Williams, E. G. and Ferm, J. C. (1964) "Sedimentary Facies in Lower Allegheny Rocks of Western Pennsylvania," Jour. Sed. Pet. (in press). All of the diagrams and discussions of the Clarion cycles are taken from this work.

Williams, E. G., Guber, A. L. and Johnson, A. M. (1964) "The Age and Significance of Unconformities in the Carboniferous of Western Pennsylvania," submitted to the Journal of Geology. The criteria for recognition of disconformities by analysis of slump phenomena are presented in this work. Also, our latest ideas on cyclic sedimentation are discussed.

FIRST DAY

Locality 1

The Lower Kittanning cycle is well exposed at this locality (see figure 14 for location). The stratigraphic and paleogeographic positions of the section can be obtained by reference to figures 5, 6 and 9. The diagram of the railroad cut to be examined is shown in figure 15.

The main features, listed in order of discussion, are as follows:

1. Origin of underclays or "seatearths" below the Lower Kittanning coal beds.
2. Nature and significance of prograded sequence above Lower Kittanning coal.
3. Mechanism of slumping.
4. Origin of post slump sediments.
5. The significance of various diastems and disconformities observed in the mine.

The angular discordance between the lower bench of Lower Kittanning coal and the underlying siltstone, is good evidence that the clay which separates them is of residual origin. The fact that the clay is thicker and the coal thinner on the topographically highest part of the erosion surface means that the surface had this configuration during coal and clay formation.

The clays and silty claystones between the two Lower Kittanning coals are believed to be mainly of detrital origin. The evidence for

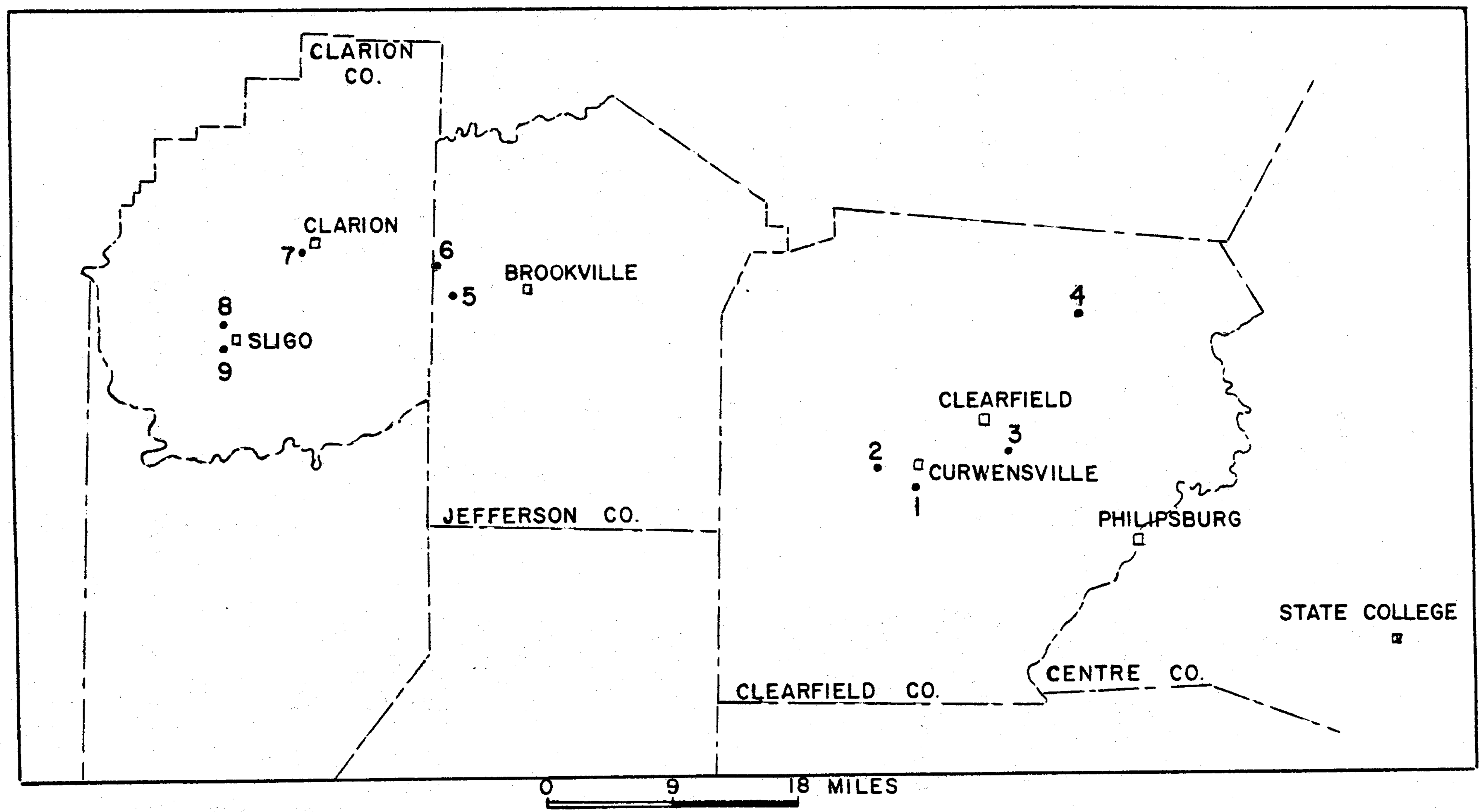


FIG. 14, INDEX MAP OF STOPS

this is that the sediments thin on the high and thicken into the lows whereas the upper bench of the Lower Kittanning maintains a relatively constant thickness across the outcrop. Thus by the time the peat was deposited, the topographic irregularities which influenced the thickness of the lower coal and clay had been obliterated by differential sedimentation. The difference in elevation of the upper coal is probably the result of differential compaction, which was greater in the lows.

The importance of the above observations is very great. It means that underclays are both transported and residual in origin, the latter occurring as weathered residuum along disconformities.

The prograded sequence at the left end of the mine, and extending from the top of the Lower Kittanning coal to the top of the sandstone, represents the eastern, near shore equivalents of the Columbiana shale. The lower six feet of shale contains Lingula and probably is of lagoonal or estuarine origin. The overlying siltstones and sandstones are believed to represent the subaqueous forsets and topsets of a shallow, westerly-migrating delta. The irregular discontinuity at the base of the sandstone is a scour surface, the sandstone itself being deposited in a tidal inlet or delta distributary.

In order to understand the mechanics of slumping and subsequent events, several observations are important. First, the slump blocks are paired, having rotated about curved slip surfaces toward a common center. This configuration requires that a depression, presumably a channel, must have existed in the area now occupied by contorted shale between the blocks. Secondly, when the blocks are rotated about the slip surfaces back to the pre-failure position, they

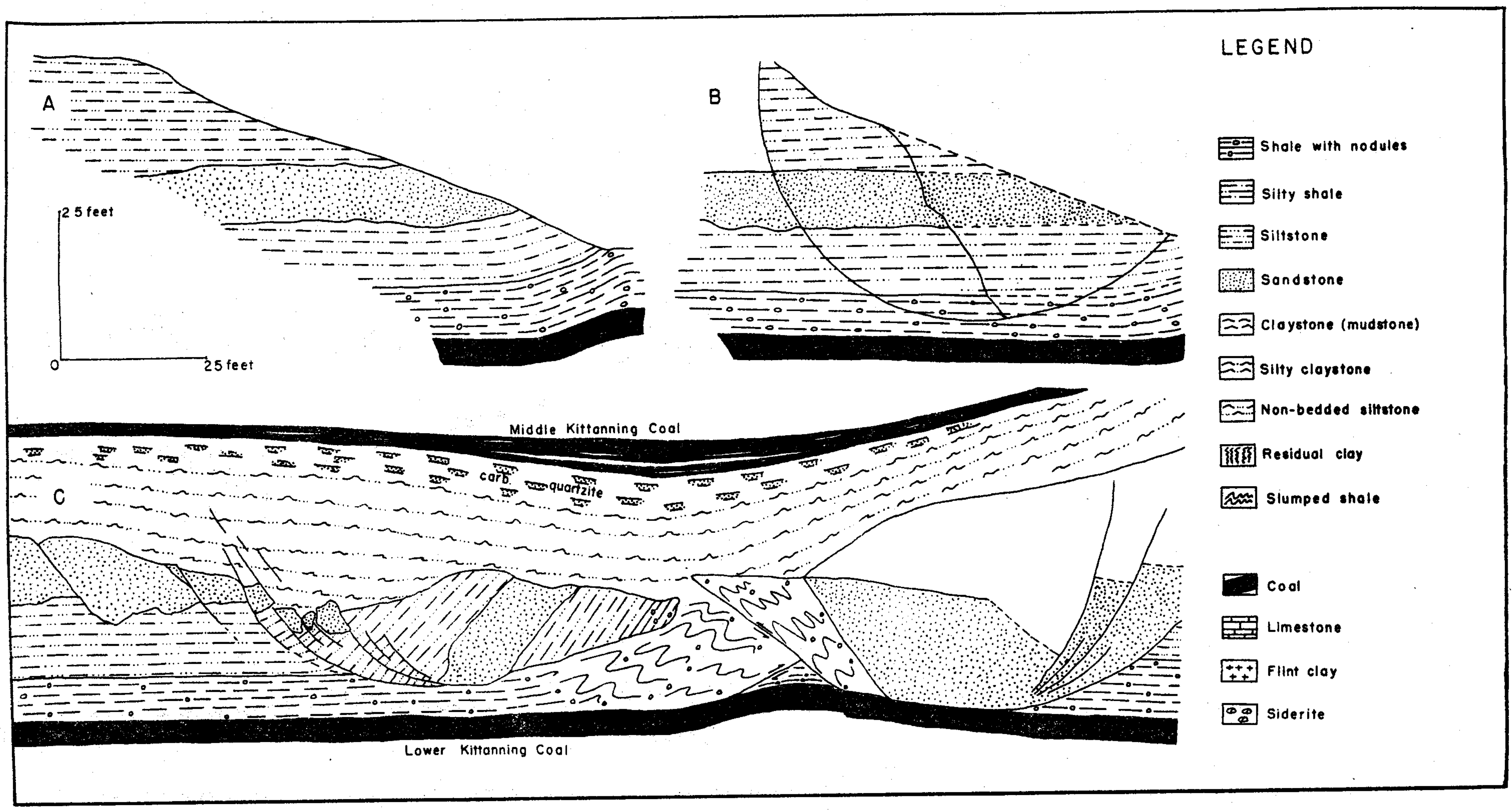


FIG. 15, DIAGRAM OF SLUMP STRUCTURES AT CURWENSVILLE project some 20 feet above the top of the adjacent, undeformed, prograded sequence. This clearly indicates that erosion has taken place in these adjacent areas, even though the beds there appear conformable.

Using this information, the history of slumping and subsequent events are reconstructed in figure 16. Briefly, the history is as follows: after the prograded sequence was deposited, base level was lowered (probably by drop in sea level) and streams were incised to maximum depths of about 50 feet. The channel walls were unstable which resulted in the development of sets of paired, rotational faults, along which the banks slumped into the deeper part of the channel. The interfluves were then lowered by processes of mass wastage and sheet wash and the eroded material deposited in the channel as colluvium. During this process, residual soils developed on the higher parts of the interfluve areas. When relief was reduced from 50 feet to about 5 feet, drainage was sufficiently impeded so that swamps and peat could develop. This peat now forms the Middle Kittanning coal.

Interpreting the sequence of rocks by the cyclic concepts described in figure 2, the Lower Kittanning cyclothem is encompassed by the two disconformities. Since the lower disconformity is represented by the residual clay below the first bench of Lower Kittanning coal, it is immaterial whether the boundary is placed at the top or bottom of the clay. We prefer to place it at the base of the residual clay. In places where the residual clay is absent, as is the case in areas of slumping, the disconformity must be reconstructed by analysing the mechanism of slumping. In the Lower Kittanning cycle, the coals and associated

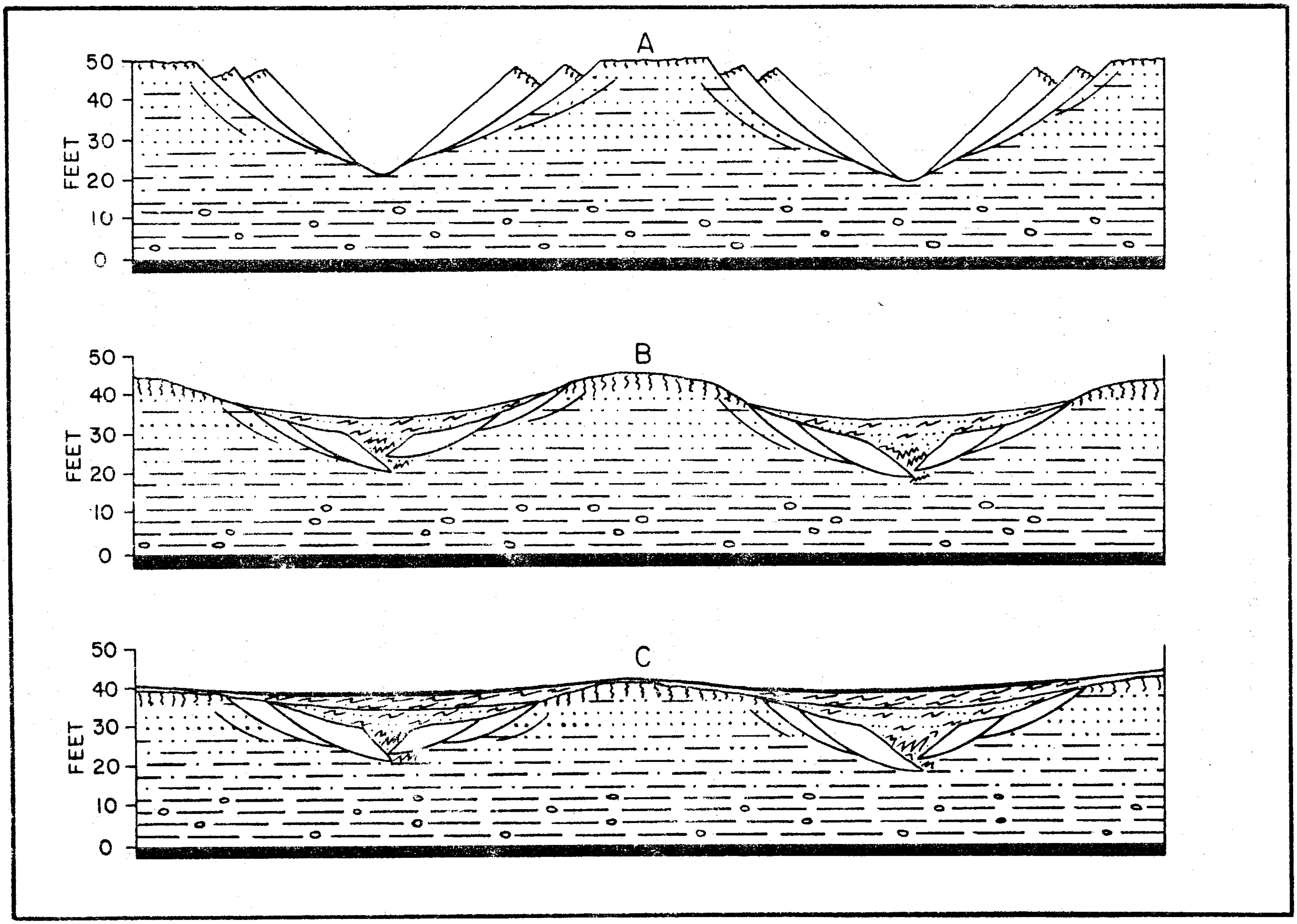


FIG. 16, HISTORY OF EROSION AND SLUMPING underclays constitute the "A" or transgressive continental phase and the prograded sequence represents the "B" or transgressive-regressive marine phase.

Locality 2

At this locality (see figure 14 for location) the nature of the Mississippian-Pennsylvanian unconformity will be examined.

The unconformity has a relief at this locality of about 10 feet. All of the Lower and Middle Pottsville are missing, and the Upper Pottsville is represented only by 15 feet of high alumina clay. As shown in figure 16a, the more elevated parts of the unconformity (regionally) are overlain by flint and diaspore clay whereas in the lower parts, massive, coarse grained sandstone is the principle rock type. It is believed that the variation in elevation of the unconformity is a causative factor in controlling the location and character of the clay. The higher areas were subjected to more intense leaching and less detrital influx.

Flint and diaspore clays are unique and interesting deposits. Flint clay is a fine-grained, well-crystallized kaolinite, $Al_4(OH)_8Si_4O_{10}$; the formula for diaspore is $Al_2O_3.H_2O$. Commercial deposits of these clays are found at only two areas in the United States, namely, Clinton and adjacent counties in western Pennsylvania and in south central Missouri. In both areas the clays are related to the Mississippian-Pennsylvanian unconformity.

Keller, et al (1954) believes that both diaspore and flint clay were formed under intense and prolonged leaching of a clay substrate in swamps which were slightly acid. Differences in alumina content of the clays are a function of the intensity and duration of leaching process. Presumably, Keller feels that the initial clay substances were detrital clays, illite and kaolinite.

Weitz (1959), who studied the high alumina clays of Clearfield

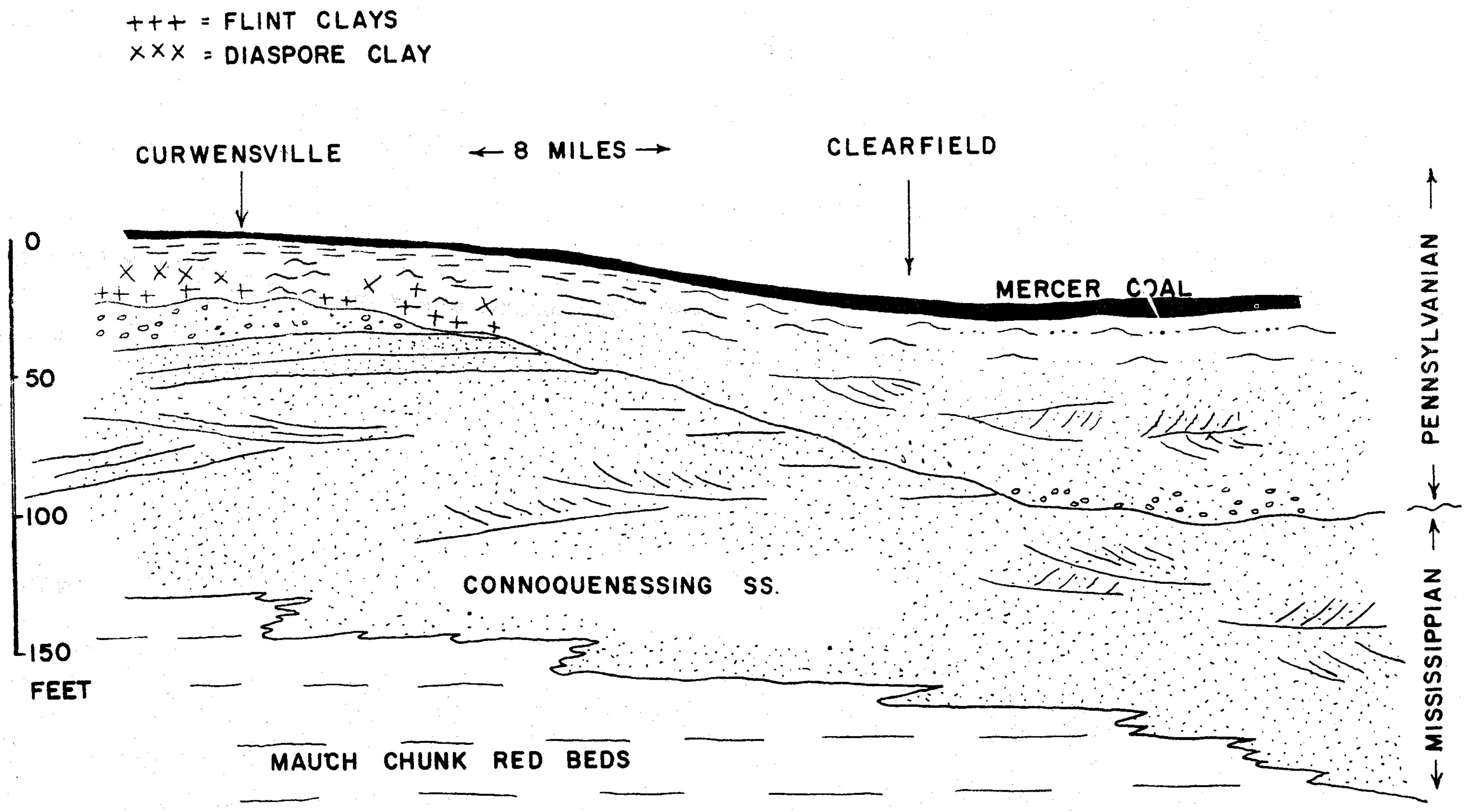


FIG.16 a, STRATIGRAPHIC CROSS SECTION OF MERCER AND ASSOCIATED ROCKS

County, believed they were formed by normal sedimentary processes. The flint and diaspore clays were deposited as gels in swampy environments, areas where detrital sediments could not penetrate.

Williams and Ferm (1964) conclude that flint clays were deposited in brackish environments in water draining from coastal swamps. In one instance, at least, a flint clay has been correlated with a marine limestone.

References Cited at Locality 2

Keller, W. D., Westcott, J. F. and Bledsoe, A. O., (1954) "The Origin of Missouri Fire Clays," Natl. Research Council Pub. 327, Clays and Clay Minerals, pp. 7-46.

Weitz, J. H. (1954) "The Mercer Fire Clay in Clinton and Centre Counties," unpublished PhD thesis, The Pennsylvania State University.

Williams, E. G. and Ferm, J. C. (1954) "Sedimentary Facies in Lower Allegheny Rocks of Western Pennsylvania," Jour. Sed. Pet., (in press).

Locality 3

A complete section of the Clarion formation is exposed at this place (see figure 14 for location). The regional stratigraphic relationships are shown in figure 17 (section 19 was measured in this mine) and figure 13, the latter showing the position of the areas of greater subsidence. This is clearly shown in figure 17, which illustrates the southward thinning of the entire Clarion formation by a coalesence of the coals and a disappearance of sandstones and siltstones.

A pronounced disconformity occurs below the middle coal shown in figures 18 and 19 (location of sections given in figure 20). Between sections 7 and 9, slumping has obliterated the disconformity. The geometry of the slump blocks suggests that a channel once existed in the area now occupied by contorted shale. Of special importance is the fact that the configuration of the disconformity controls variation in thickness of the Upper Clarion coal and overlying marine shale. The uniform thickness of the uppermost Clarion coal demonstrates that by this time the effects of the disconformity have been obliterated.

The azimuth of the original channel axis is drawn on figure 20. Note that it closely parallels the regional structural dip. This parallelism characterizes almost all of the slumped channels which have been observed in the eastern part of the Allegheny Plateau. This might suggest a causative connection between growing structures and the orientation of the channels. However, since regional paleoslopes parallel regional structures, no definite causative connections have yet been established.

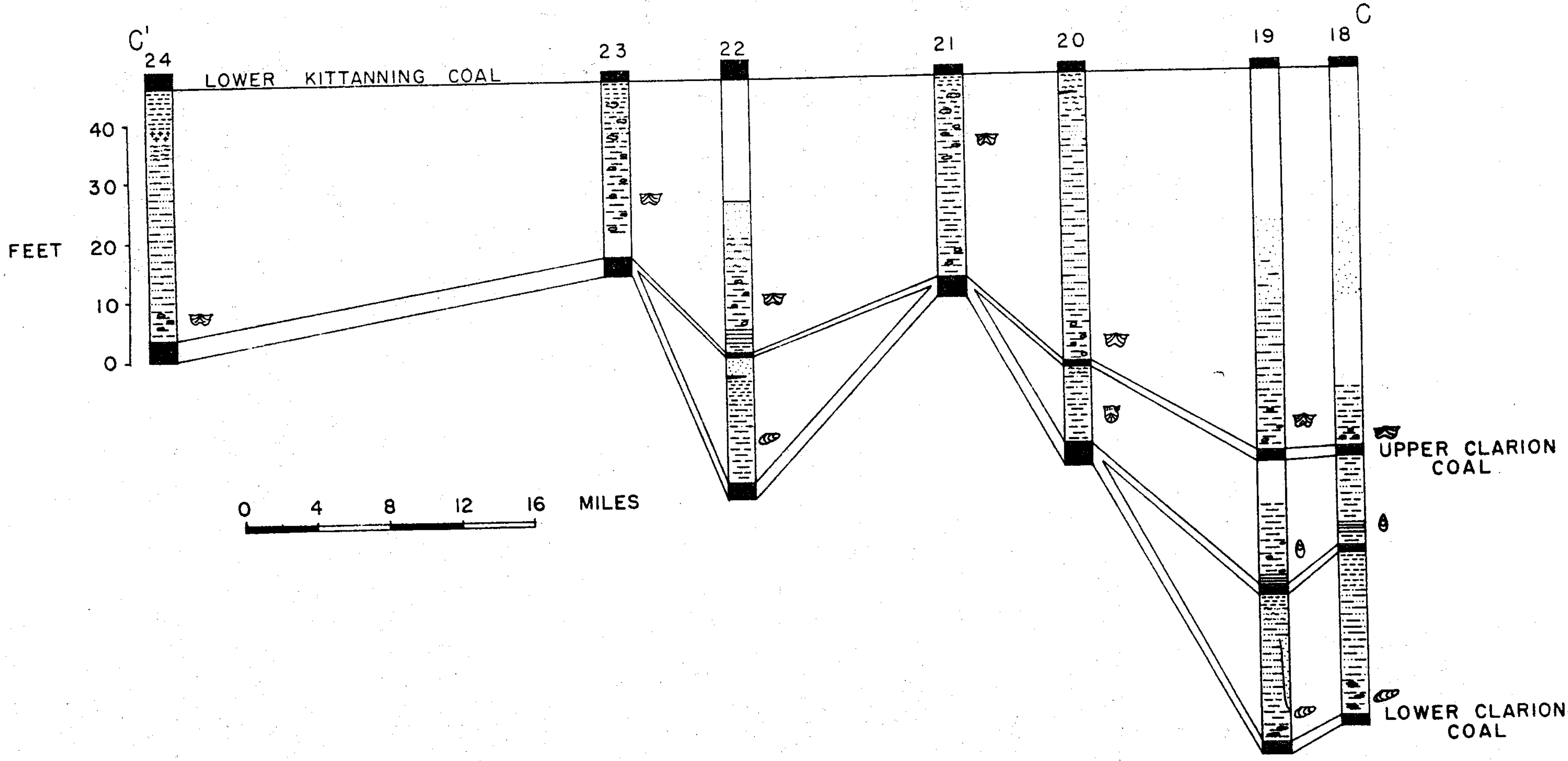


FIG. 17, STRATIGRAPHIC CROSS SECTION OF CLARION FORMATION (C'C)

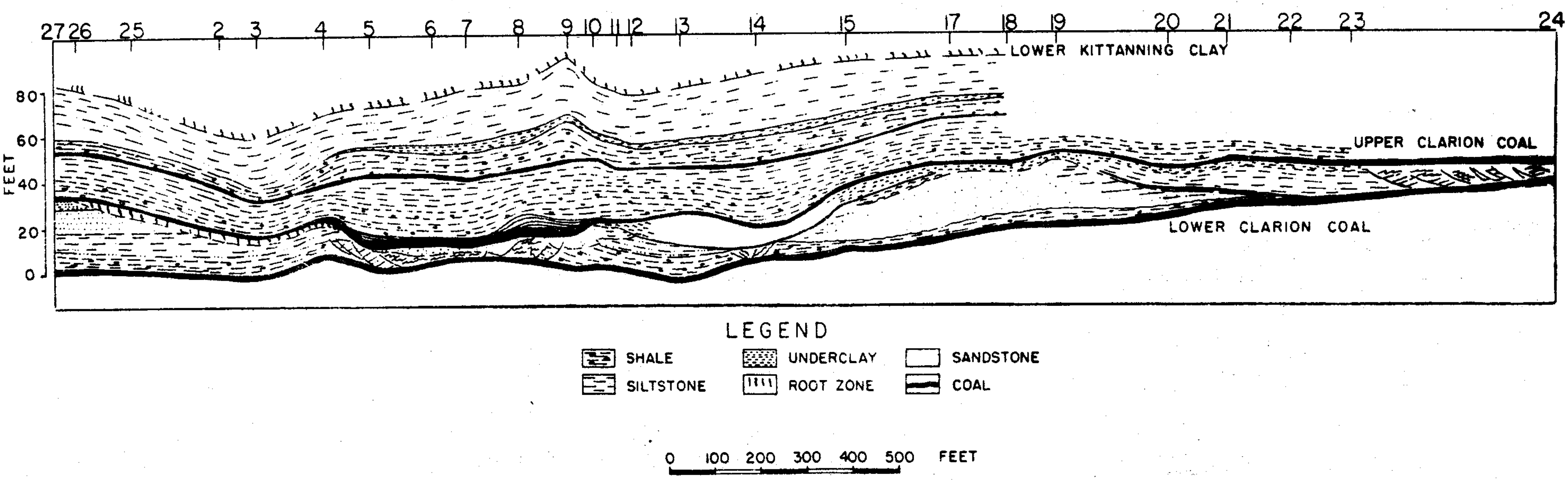


FIG. 18, DIAGRAM OF CLARION FORMATION AT KREBS (N.W. MINE)

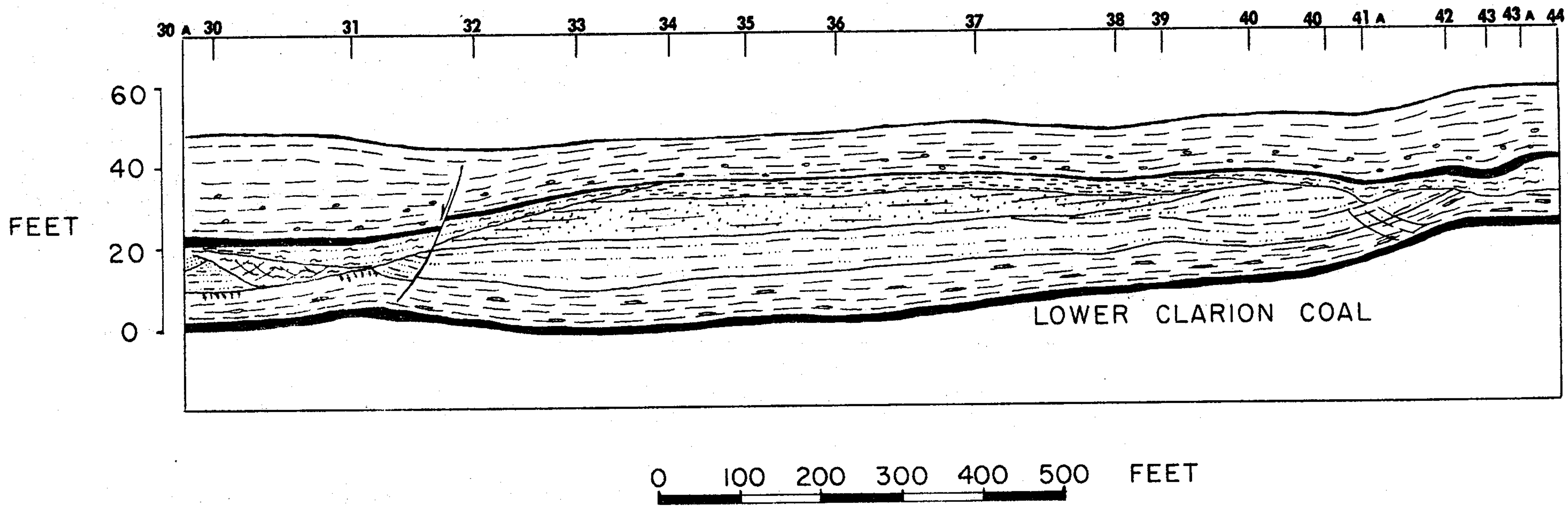


FIG. 19, DIAGRAM OF CLARION FORMATION AT KREBS
(S.E. MINE)

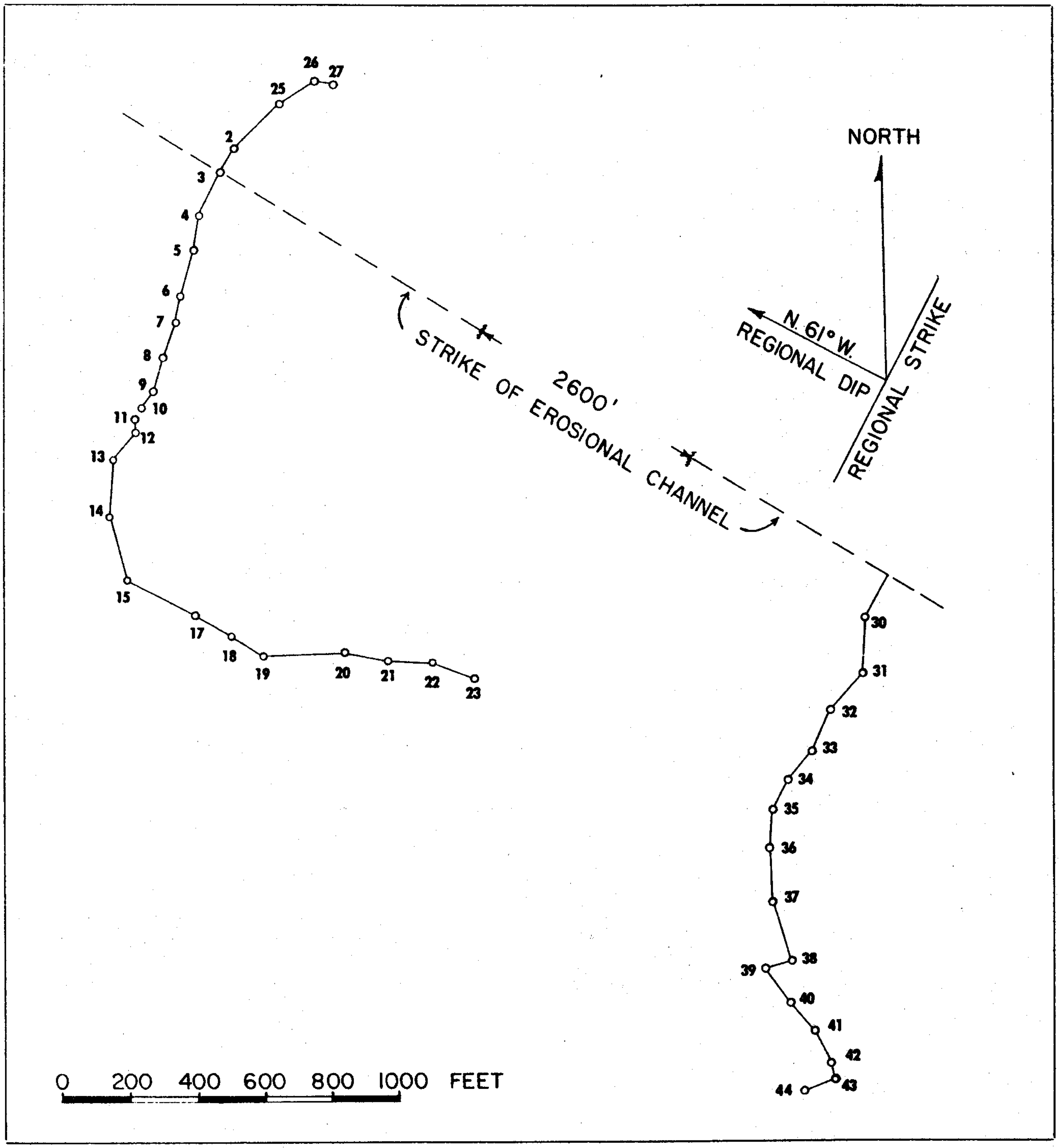


FIG. 20, SECTION LOCATIONS AT KREBS

Locality 4

(See figure 14 for location, and figures 22 and 23 for geological details). The purpose of this stop is to compare and contrast the Upper Freeport cycle (continental in origin) with those cycles, such as the Lower Kittanning and Vanport, which contain both marine and continental beds.

The Upper Freeport cycle encompasses the rocks between two disconformities. The lower disconformity is located at the base of the fresh water limestone below the Upper Freeport coal. This surface is best observed at sections 4, 8, 9, 13 and 14, which are shown on figure 22. At other localities, the lower disconformity is not obvious, and has been provisionally located by analysis of clay minerals.

The upper disconformity is present in all sections shown on figure 22. It is everywhere overlain by 20-40 feet of sandstone, which is frequently coarse grained or pebbly in the lower part, finer grained in the middle and upper parts. The coarser grained rocks are relatively thick-bedded (1-3 feet) whereas the finer grained upper phases are thin-bedded (1-6 inches). Shallow festoon cross-bedding is characteristic of these thin-bedded phases. The sandstone is definitely of continental origin, but its exact mode of formation is uncertain. However, certain aspects of its genesis may be obtained from an analysis of the slump blocks which can be observed at sections 5, 6 and 7, figure 22.

The slumps are represented by four or five blocks which have been rotated counter clockwise along curved slip or fault planes (figure 23). The slip planes strike northwest-southeast, and the direction of rotation is to the southwest. These relations require the

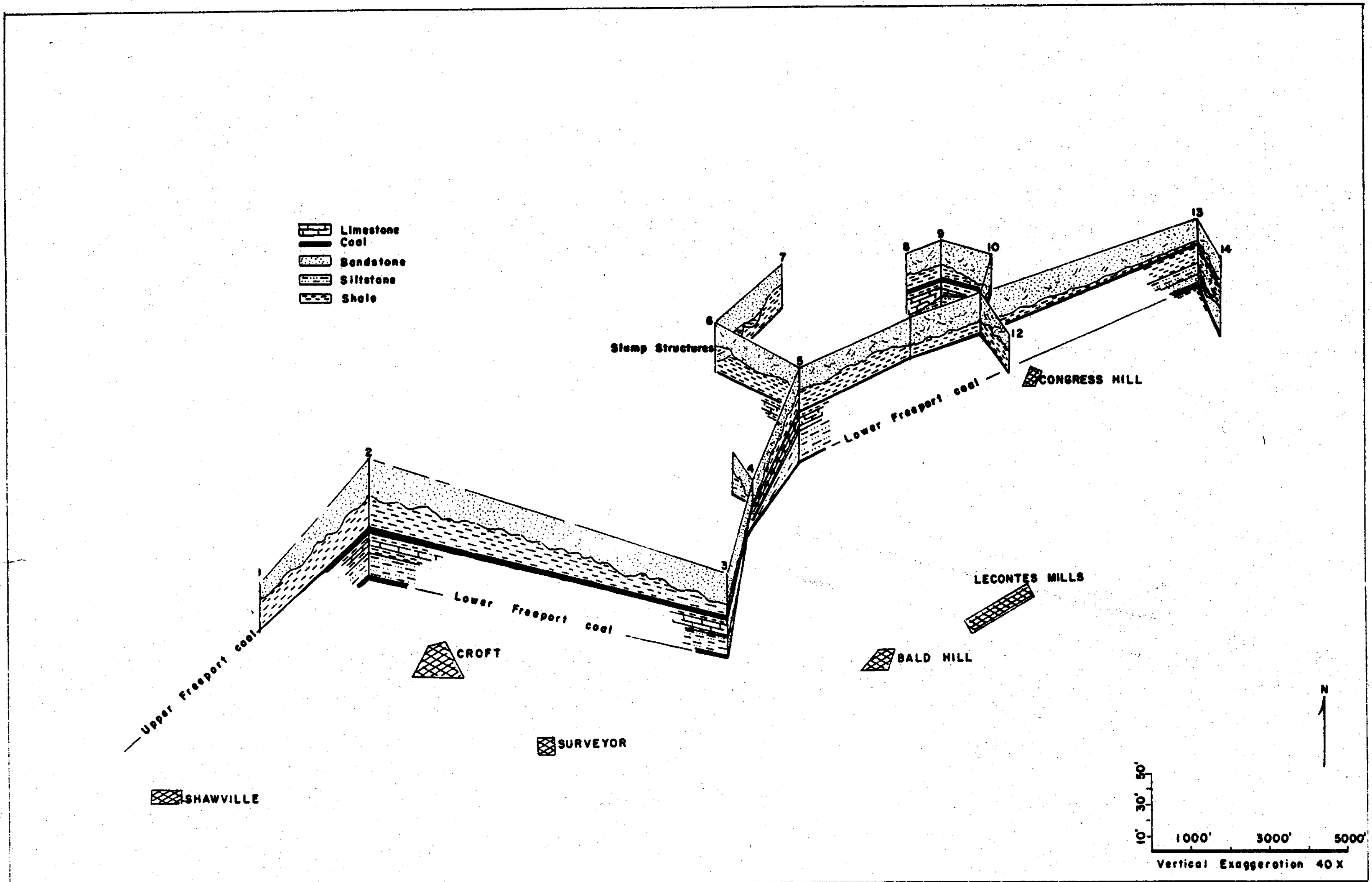


FIG.22, PANEL DIAGRAM SHOWING FREEPORT FORMATION IN NORTHERN PART OF LECONTES MILLS 7 1/2' QUADRANGLE

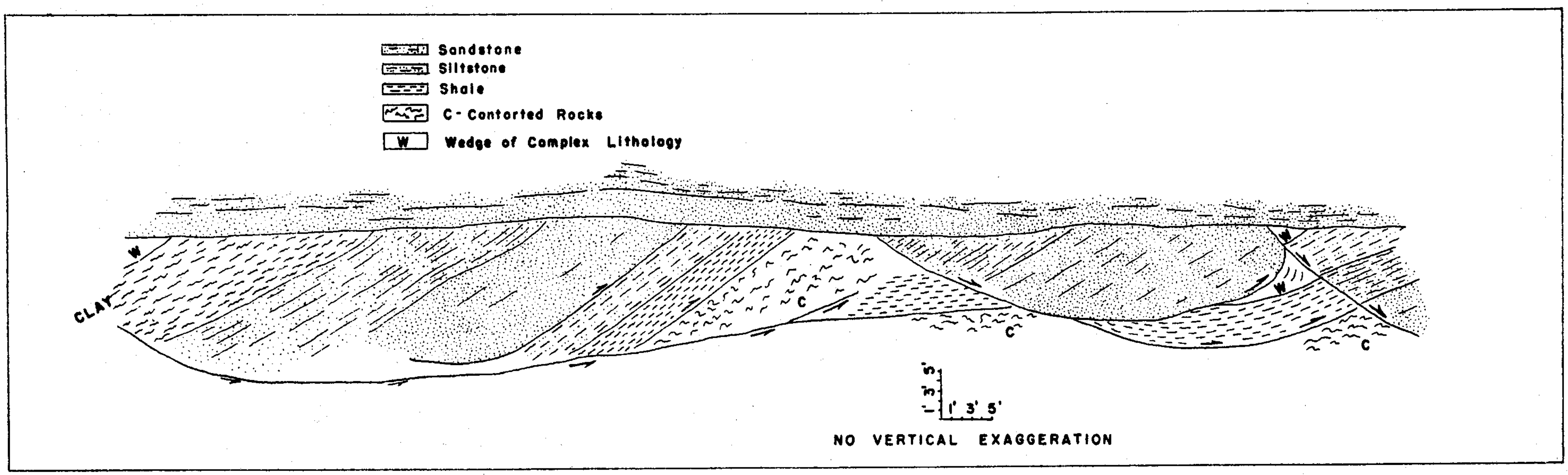


FIG. 23,SLUMP STRUCTURES IN UPPER FREEPORT CYCLE existance (during Freeport time) of an area of reduced sediment load parallel to and southwest of the panel between sections 5 and 6. Presumably this was a northwest-southeast stream channel, the axis of which might have been at section 4. The geometry of the blocks suggests that the slumps developed sequentially and that each preceding block was partially eroded before the following slump could occur.

Some estimate of the original thickness and character of sediment deposited after coal formation (Upper Freeport) and prior to erosion and slumping can be obtained from an examination of the slump blocks. The block at the extreme left in figure 23 contains the greatest stratigraphic thickness, approximately 40 feet. Since the lower part of the block has been considerably deformed, this is a minimum figure. Using this value, we estimate that the channel into which the blocks rotated had a depth of about 30 feet.

The stratigraphic sequence in the slump blocks is similiar to those outside the areas of slumping and channeling. It consists of dark gray shale grading upward into siltstone and fine grained sandstone.

From the foregoing observations, we conclude that the concepts of cyclic sedimentation developed in dominently marine sequences can be successfully used to interpret sequences that are of continental origin. And the most important common element in all cycles, regardless of their environmental character, is the presence of disconformities which separate two basically different kinds of stratigraphic units.

SECOND DAY (Stops 5-9)

The purpose of the second day is to examine and contrast the marine phases of the Kittanning and Clarion cycles with the more continental and brackish phases which were observed in Clearfield County on the first day. Because the marine cycles can be more precisely zoned and correlated, we are better able to analyse the independent and combined effects of the various factors primarily responsible for sediment variation, namely, differential tectonic subsidence, eustatic base level changes and the effects of local relief. The effects of differential compaction are also more obvious in the marine areas.

We plan to examine parts of three cycles -- the Lower Kittanning, the Vanport and the Upper Clarion. The geographic locations of the stops are given in figure 14; the paleogeographic position may be obtained by comparing the index map, figure 14 with figures 9 and 10. These latter maps illustrate the distribution of the most marine parts of the Lower Kittanning and Vanport cycles respectively.

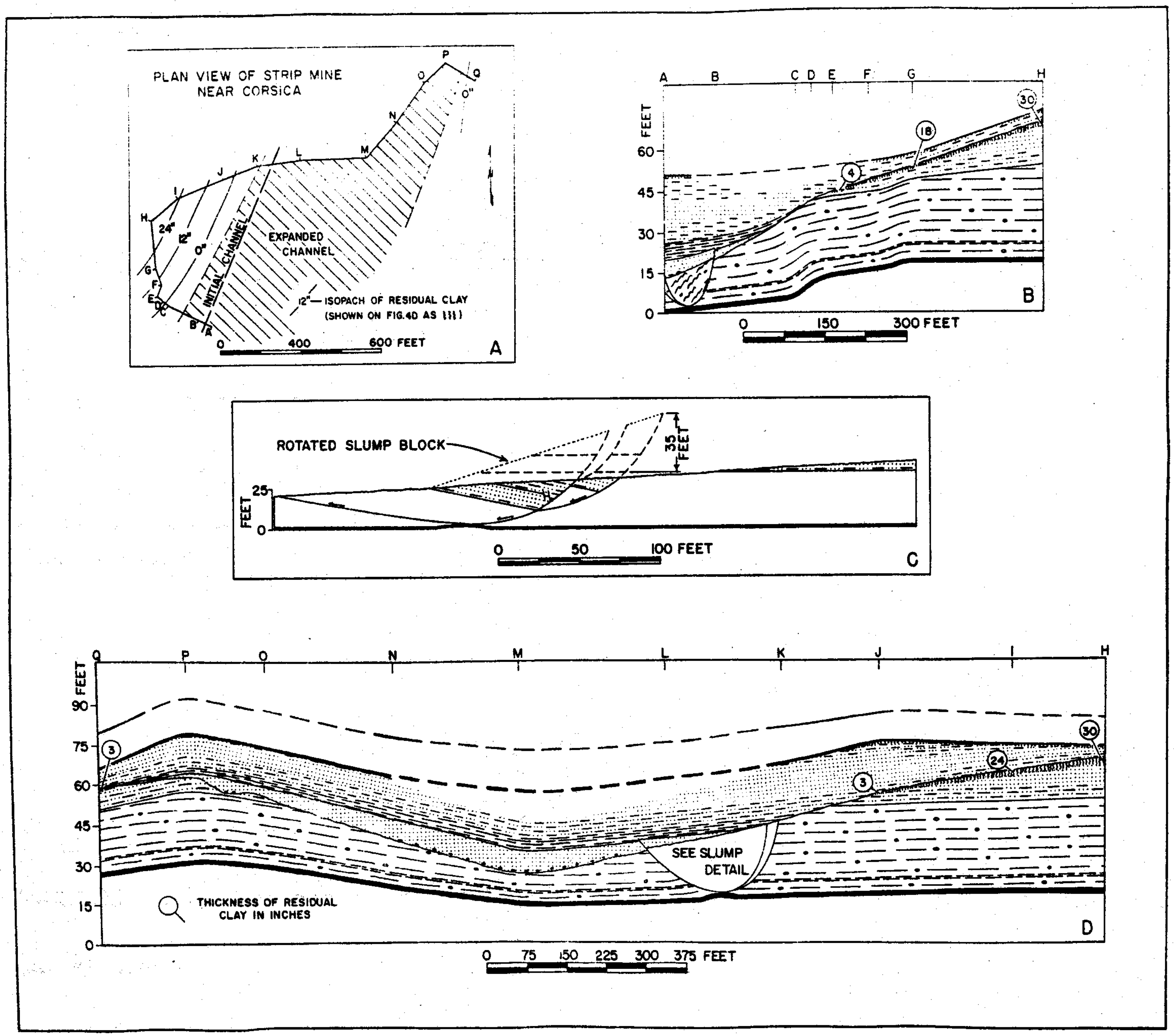


FIG. 24, SLUMP STRUCTURES AT CORSICA

Locality 5

The marine facies of the Columbiana shale is well developed at this locality (see figure 14 for location). The stratigraphic and paleogeographic relations can be observed in figures 6 and 9 respectively.

As shown in figure 6, the Columbiana at this locality consists of three members, which respectively record marine transgression, stillstand (deepest water) and marine regression. The lower, transgressive unit consists of moderately well-bedded shales which contain Lingula in the lower part and calcareous brachiopods toward the top. The middle member is a soft, non-bedded shale with an abundant marine fauna (calcareous brachiopods and mollusks). The estimated depth of water for the middle member is approximately 50 feet. The upper member is about 20 to 25 feet thick and consists of poorly bedded shales with siderite nodules. Calcareous brachiopods occur at the base, Lingula near the top.

The Columbiana shale grades upward into 15 to 25 feet of thin-bedded siltstone and fine grained sandstone, which are believed to represent a delta distributary environment.

As shown in figure 24, the Columbiana is truncated by a disconformity. Initially the erosion surface had considerably more relief, at which time rotational slumping occurred. Of considerable importance is the fact that if the slump blocks are rotated back to their pre-failure position, they stand 35 feet above the eroded Columbiana surface. This means that at least this much erosion has taken place in the non-slumped areas. The erosional interval is now represented by several feet of residual clay.

Locality 6

(See figure 14 for locations). This section resembles some of those observed at locality 5 south of Corsica. (For example, see section H, figure 24). The main reason for visiting the present locality is that the disconformity and associated residual clay, features which form the upper boundary of the Lower Kittanning cycle, are more clearly visible and continuously exposed than at locality 5. By comparing localities 5 and 6 with other nearby sections we will try to give a more complete picture of post-erosion sedimentation, which is mainly concerned with the origin of the so called "channel sandstones."

Localities 7 and 8

(See figure 14 for locations). Sections measured at locality 7 are shown as numbers 11 and 12, figure 25; the one measured at locality 8 is represented by number 13, figure 25. The two stops plus examination of relevant maps and cross-sections provide the data for demonstrating several conclusions. The first is that the immediate or proximate cause of sediment variation is the angle of slope upon which the sediment was deposited; these slopes are first formed by erosion caused by eustatic lowering of sea-level and subsequently modified by the processes of differential sedimentation and compaction. And secondly, all variations produced by local relief may be modified by a more regional process, differential, tectonic subsidence. The effect of this process on the thickness of Clarion cycles is shown in figure 13, which outlines the areas of greatest accumulation of detritals during Clarion time. We have called these areas tectonic subblocks, realizing that not all of the observed variation is tectonically controlled.

We shall study the north central subblock as shown in figure 13. The stratigraphic cross-sections A-A' (figure 26) and B-B' (figure 25) define the north-south and east-west variation respectively across the block.

As shown in figure 26, the entire Clarion formation thins from north to south (section line A-A' located on figure 13). This is accomplished by the thinning of coals and intervening detrital units.

Of special importance is the fact that the Vanport limestone thickens in the direction of detrital thinning. And this condition

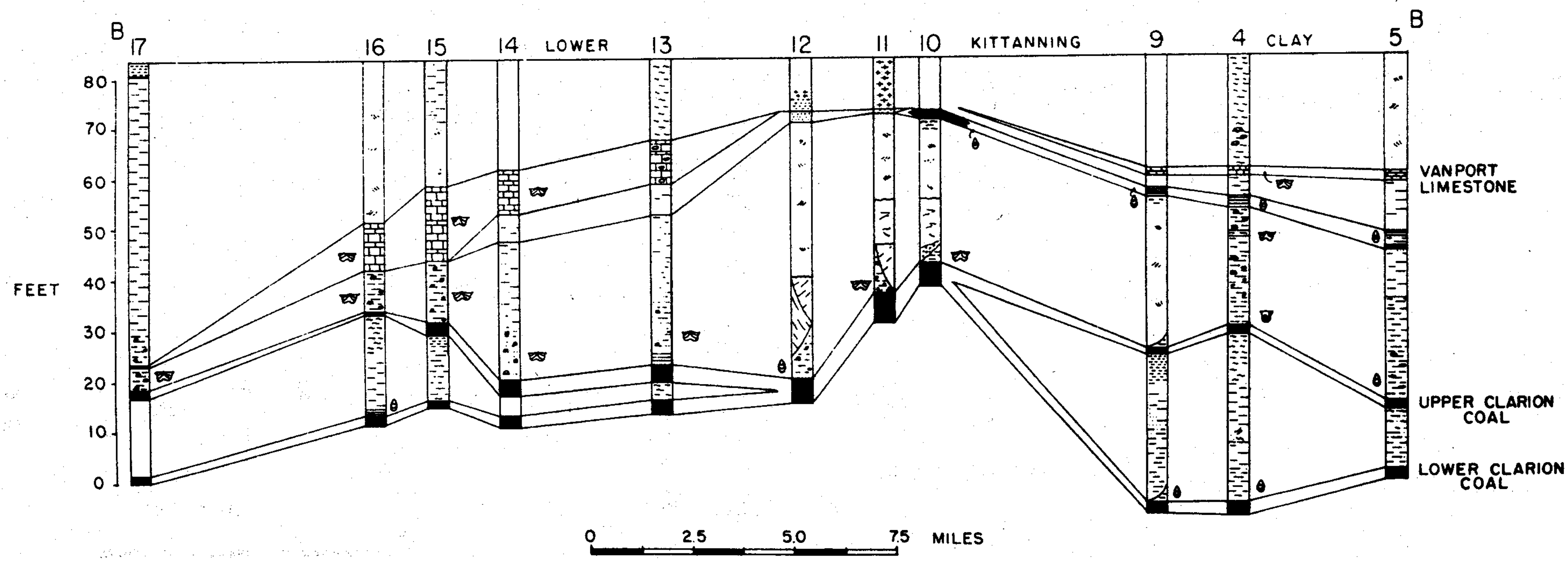


FIG. 25, STRATIGRAPHIC CROSS SECTION (B-B') OF CLARION FORMATION

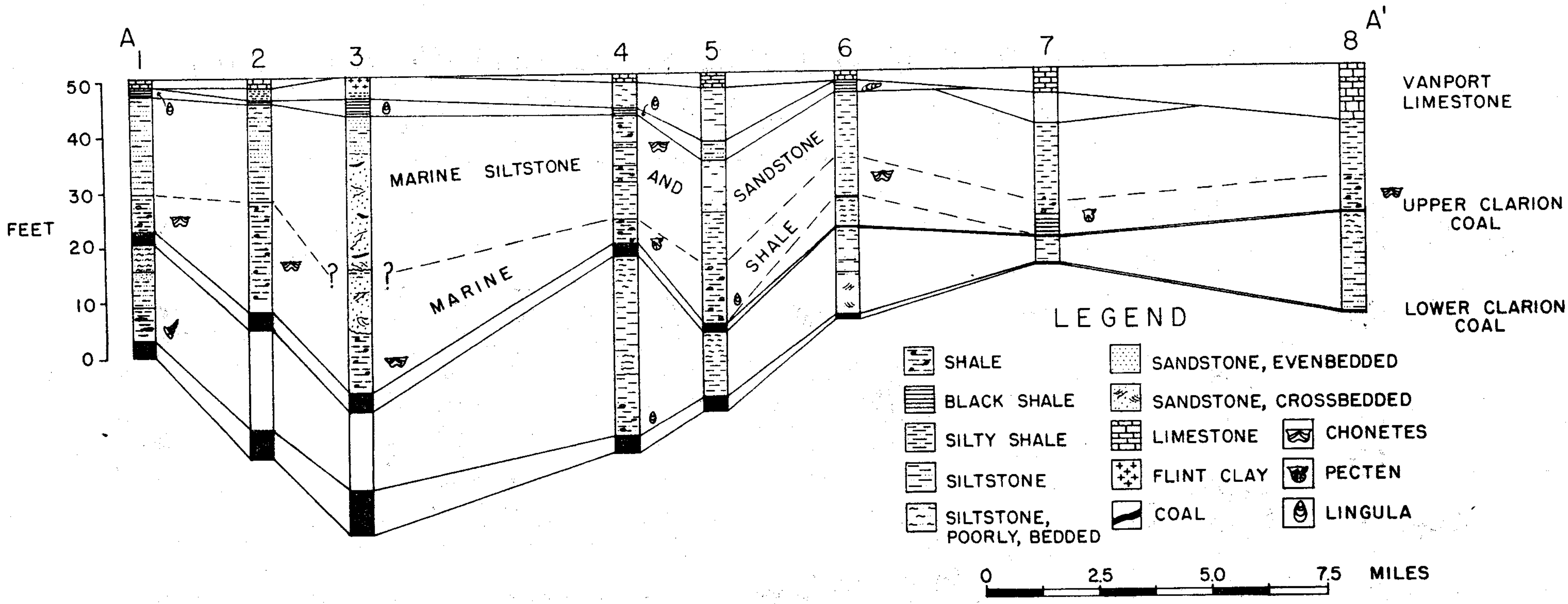


FIG. 26, STRATIGRAPHIC CROSS SECTION (A-A') OF CLARION FORMATION prevails in any north-south cross section in which the Vanport is known to occur. The association of relatively thick-limestones with thin coals and thin detritals, and the association of thick coals and thick detrital sections are believed to result from differential subsidence; the thick limestone accumulating in areas of slow subsidence, whereas, the detritals were trapped and deposited in more rapidly subsiding areas to the north and south. As will be shown later, the same associations can be produced in other ways, namely as a function of local topography or relief. But that explanation cannot be invoked to explain the regional variations described above.

Further evidence for the tectonic control of sedimentation is provided by the rather peculiar thickness patterns of the Vanport limestone along the Pennsylvania-Ohio border, (see figure 10). Reference to the detailed Vanport isopach of the area, figure 27, and the stratigraphic cross section, figure 28, provide the main evidence for differential subsidence.

The area of thickest Vanport, which occurs in central Lawrence County, is interpreted to have undergone less subsidence than the areas to the north and south. In these latter areas, the Vanport rapidly gives way to relatively thick sections of marine shale and siltstone. The limestone is very pure where it is thick and quite impure where thin; the impurities consist of clay (mainly illitic), pyrite and organic matter, the latter two components suggesting reducing conditions. We suggest that these data can be explained by postulating that as the Vanport sea advanced into Pennsylvania from the west, detrital sands and clays (derived from both northern and southern sources) were

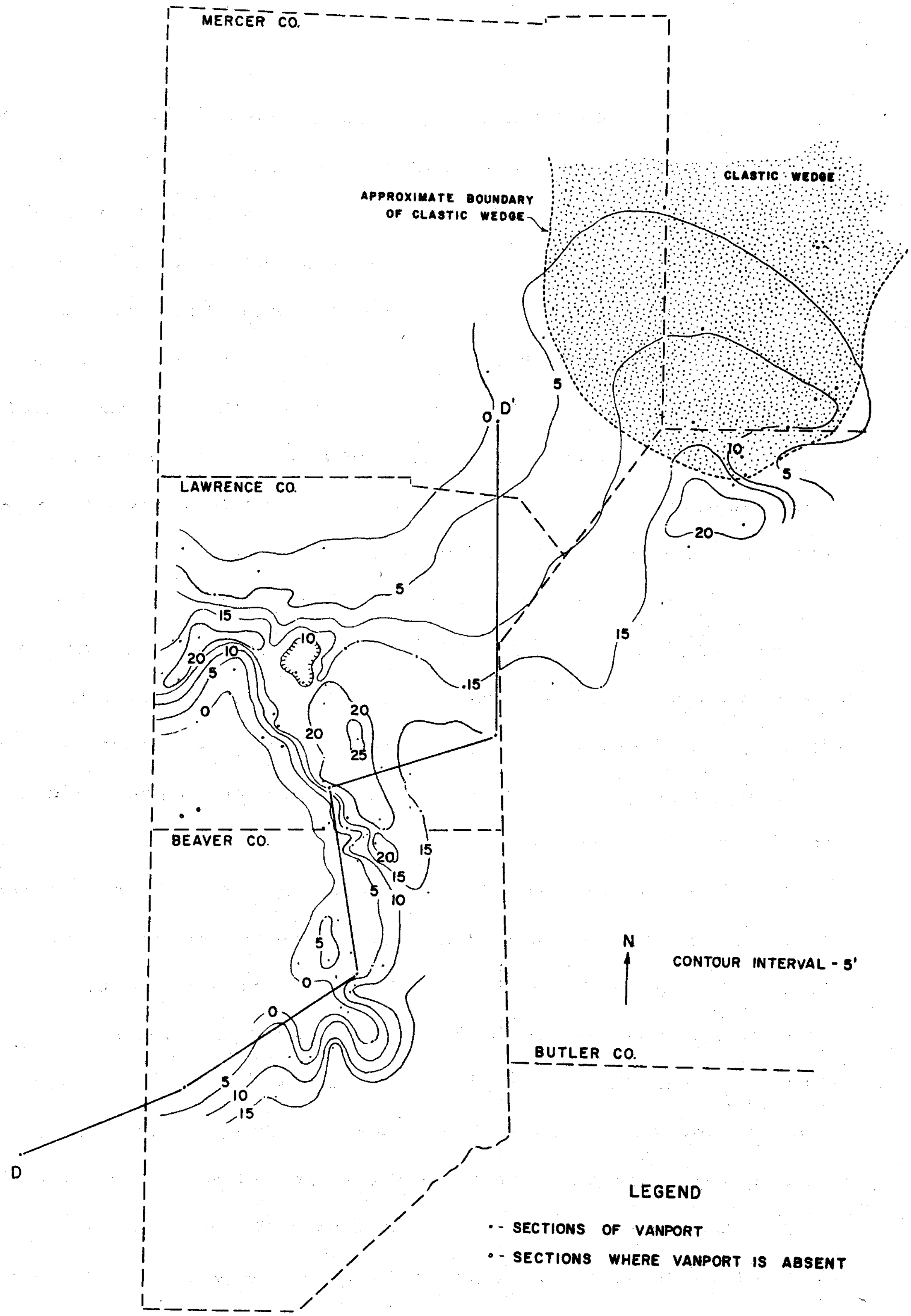


FIG. 27, ISOPACH MAP OF THE VANPORT LIMESTONE IN EXTREME WESTERN PENNA.

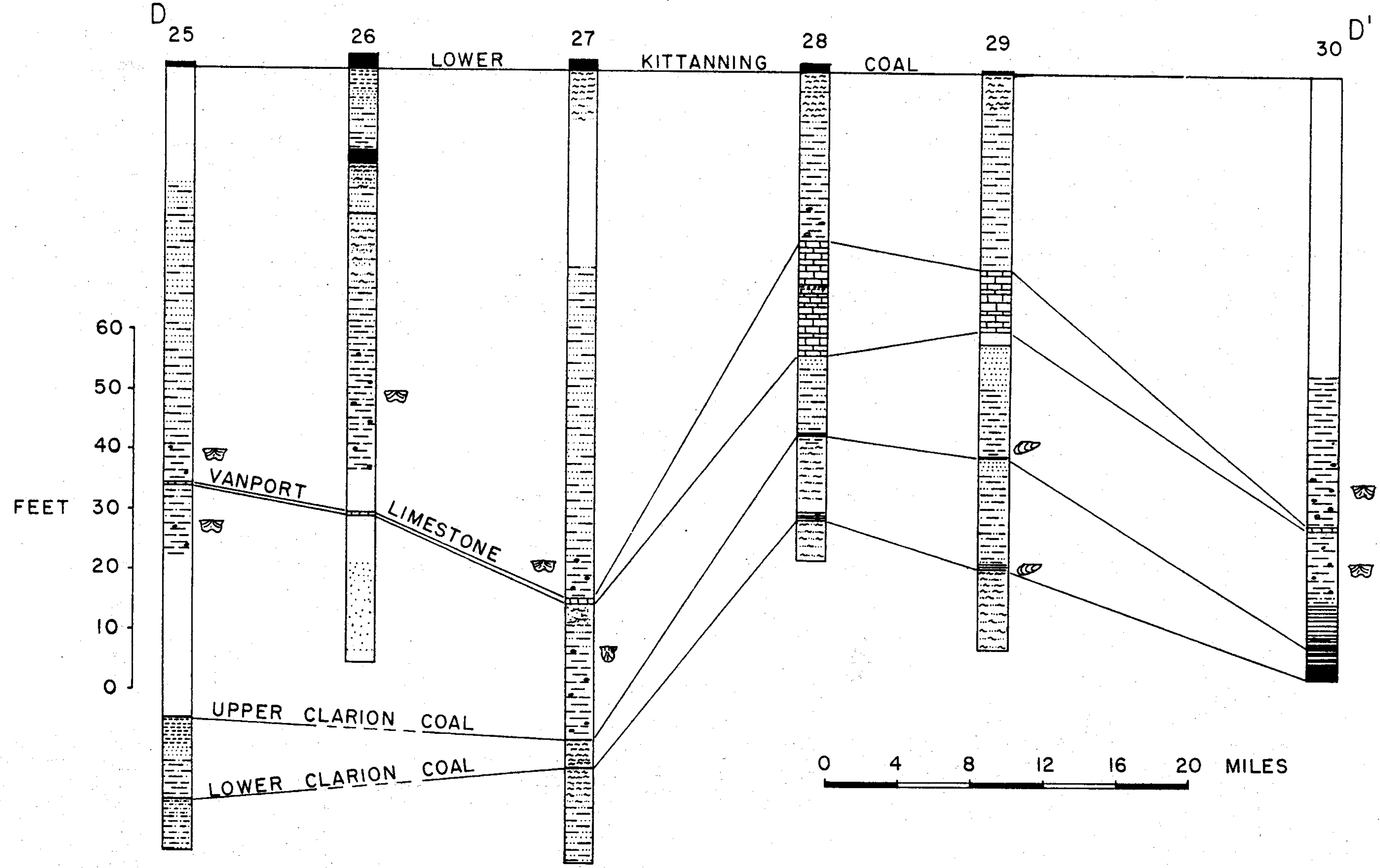


FIG. 28, STRATIGRAPHIC CROSS SECTION OF CLARION FORMATION (D-D') trapped in subsiding areas, while at the same time calcium carbonate accumulated in more stable, detrital-free, oxidizing areas in central Lawrence County.

The east-west variation in the thickness and composition of the Clarion cycles is however, much more difficult to analyze. It is probably a complex function of differential subsidence as well as differential compaction, erosion and sedimentation. Since chemical rocks, such as limestone, are sensitive to relatively small environmental changes, and furthermore since chemistry of water will be shown to be an indirect function of slope, an analysis of the former might give some information about the angles and rate of change of the latter. Accordingly we will analyse the Vanport in the Clarion area. Our purpose in making stops 7 and 8 is to check the conclusions resulting from the analysis.

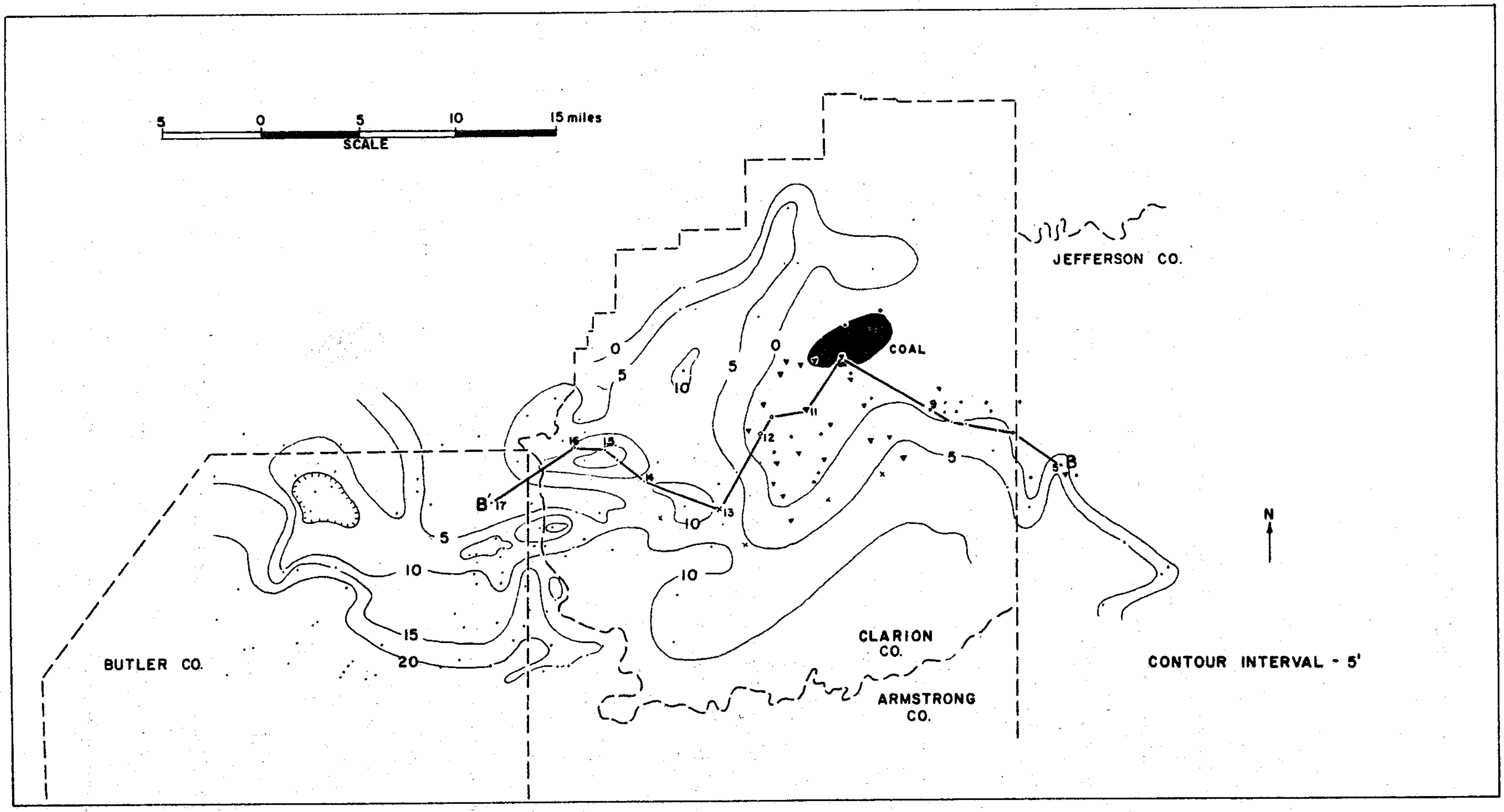
We contend that, if the base of the Lower Kittanning coal or clay is used as a datum (as in figure 25), then the line connecting the base of the Vanport limestone or equivalent rocks represents the ancient topography upon which those rocks were deposited. And furthermore, as shown in figure 25, if the Vanport is equivalent in age to the coal bed at section 10, then the coal bed represents the approximate position of sea level during Vanport time. If these two interpretations are accepted, then the depth of water in which the Vanport limestone was deposited can be computed for the various sections. These depths for sections shown on figure 25 are as follows:

Section	Depth (feet)
12	0
13	5
14	10
15	14
16	20
17	50

Chemical and mineralogical analysis of the Vanport plus chemical theory strongly support the above interpretations. Limestone precipitation is inhibited in strongly reducing environments or where the pH is below 7. The former condition prevailed at section 17, the latter at section 12. The systematic change (sections 15 to 11, figures 25 and 29): limestone, cherty limestone, chert, cherty flint clay is also explained as a function of distance from shore and hence increasing depth.

Therefore, assuming that the line below the Vanport on figure 25 is a depositional surface, the question of interest is then, how was it produced? Analysis of slump blocks in sections 11 and 12, figure 25, shows that the blocks contain somewhat thicker sequences than in adjacent non slumped areas. This demonstrates the probable existance of a disconformity between the Vanport and underlying marine sandstone in sections 13 and 14. The configuration of the upper surface of the sandstone in sections 10, 11 and 12 is obviously produced by differential sedimentation and compaction.

The character of the lower contact of the Vanport at sections 15, 16 and 17 is not obvious. Reference to figures 30 and 31 is instructive however. In the westernmost cross section of figure 30, the Vanport directly overlies the Upper Clarion coal (see also figure 31).



LEGEND

- · - SECTIONS OF VANPORT
- ∘ - SECTIONS WHERE VANPORT IS ABSENT
- ▾ - FLINT CLAY
- x - CHERTY LIMESTONE

FIG. 29, ISOPACH MAP OF VANPORT LIMESTONE IN CLARION CO.

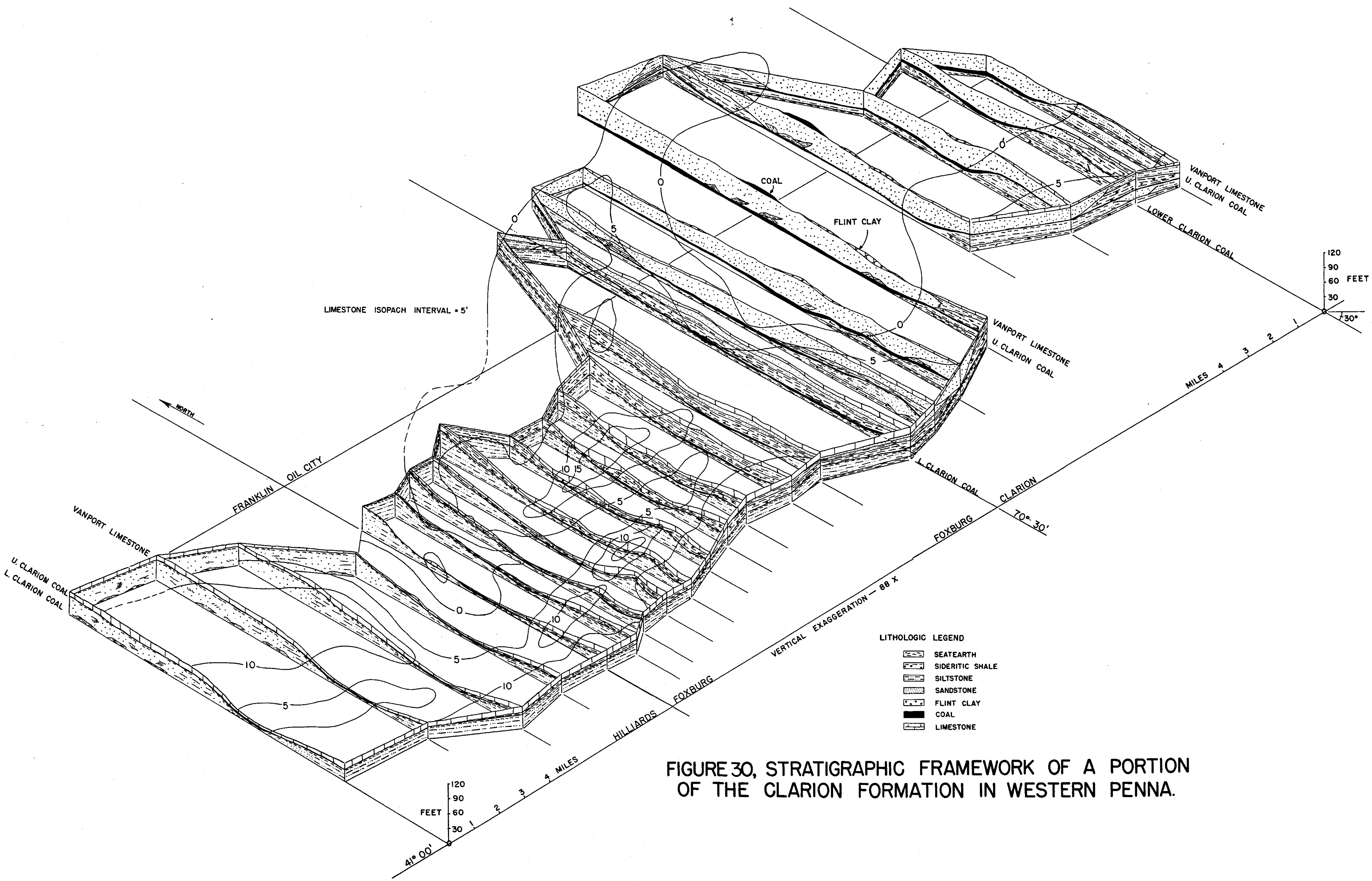


FIGURE 30, STRATIGRAPHIC FRAMEWORK OF A PORTION OF THE CLARION FORMATION IN WESTERN PENNA.

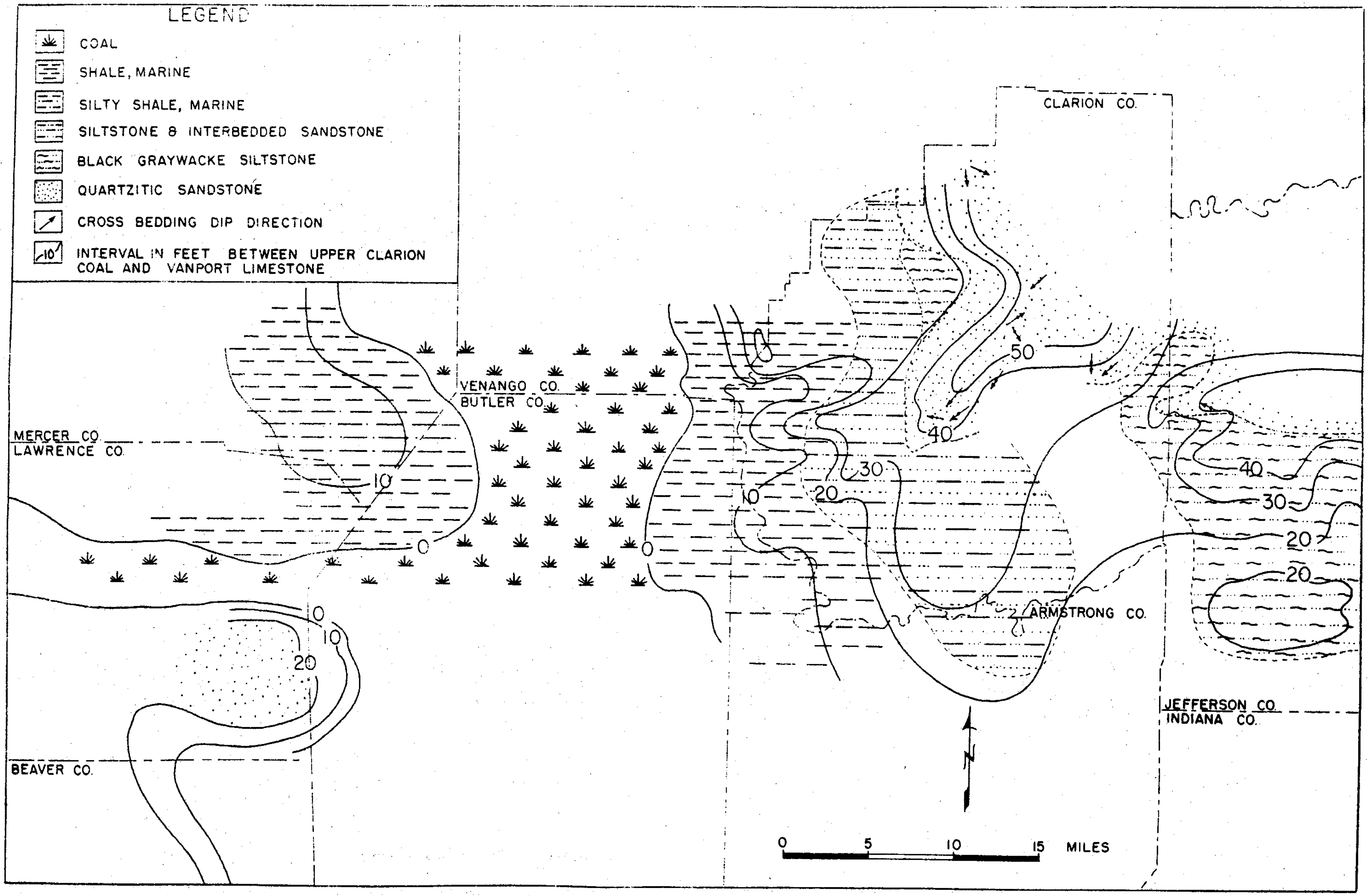


FIG. 31 MAP OF ROCK TYPES OCCURRING DIRECTLY BELOW VANPORT LS.

It is apparent that the thickness of these two units bears a strong relation to the elevation of the disconformity below the Upper Clarion coal, namely the coal is thick in the lows whereas the Vanport is thick on the highs. This is in accord with principles previously explained. This relationship obtains to within several miles of the border of the Foxburg-Clarion quadrangles. At this point 10-20 feet of sediment occur between the Vanport and the Upper Clarion coal, an amount sufficient to completely obliterate the topographic effects of the lower disconformity. Five miles eastward, the Vanport thickness is inversely related to the thickness of the underlying sandstone. From these relationships we conclude that the area in the Hilliards quadrangle (figure 30) was receiving little or no detrital sediment at the same time areas to the northeast in the Clarion quadrangle were receiving relatively large amounts of sand and clay.

In effect, the detrital materials were trapped in the eastern part of the area. To account for this phenomenon, we believe that some differential subsidence must have occurred and this is our reason, among others, for calling the detrital wedges shown in figure 13, tectonic subblocks. Of course, our argument would be refuted if it could be shown that the lower boundary of the Vanport everywhere rested on an erosion surface. If this were true, in the sections discussed above, then the two disconformities must coalesce in the western part of the area (figure 30), a condition which is possible but unlikely.

We conclude that the east-west variation in the thickness, composition and configuration of the Clarion cycles is a complex and variable function of differential erosion, sedimentation and compaction.

Locality 9

(See figure 14 for geographic location, figure 32, section 5 for stratigraphic position). This locality deals with the origin of the lower member of the Columbiana marine shale. As you recall, at Corsica, which paleogeographically was located in the center of the Columbiana embayment, the Columbiana consisted of three marine shale members (see section 9, figure 32 and figure 6). These members were interpreted to represent transgressive, stillstand and regressive phases of marine sedimentation. However, toward the northwest and southeast, the lower member rapidly thickens, becomes coarser grained and contains only fresh or brackish water fossils. (Sections 4 and 10, figure 32 show the maximum development). Near the extremities of the area, sections 1 and 14, the lower member is either thin or absent. In areas, such as sections 3, 4 and 5 and 10 and 11 in figure 32, the upper part of the member consists of from 10-20 feet of interbedded sandstone and siltstone which grades downward into laminated siltstone and shale, the latter containing the pelecypod, Anthraconata, as well as some carbonized plant remains.

The origin of the sandstones is especially important because of their anamolous stratigraphic and paleogeographic positions. With respect to the latter, they occur near the center of a marine basin and have no visible shoreward connection. Stratigraphically, they represent an interruption in a normal transgressive and regressive marine sequence. In effect, the lower member resembles the "B" unit of the generalized cycle, except that it is not bounded by a disconformity. If the character and structure of the "B" unit is primarily related to base level rise, it is apparent that some other process has acted conjointly with base level change to produce the observed character of the lower member. In order to make some guesses as to the nature of the additional process, we need to draw some environmental conclusions concerning the sandstone and associated sediments.

The sandstone is unique in several respects; relative to its grain size (fine sand and coarse silt) it is the most quartz-rich of any Pennsylvanian sandstone (refer to figure 1); in its upper part it contains marine fossils and exhibits well developed ripple marks. We interpret these data to mean that the upper part of the sandstone is of marine origin, either a beach or bar deposit. The lower part of the sandstone and the underlying shales might be either brackish or fresh water origin, depending upon the environmental interpretation one gives to Anthraconata. If they are of fresh water origin, then the lower member probably was deposited in large lakes, formed in depressions developed on the Lower Kittanning coal prior to marine advance. And during the latter process, the lacustrine depoits were reworked to form the sand beaches. On the other hand, if the rocks were deposited in brackish water, they may represent tidal deltas. But in either case, there must have been some reworking by marine processes to produce the upper sandstone.

The regional distribution of thickness and composition of the lower member of the Columbiana parallels the regional configuration of other mapped units of the Lower Kittanning cycle (figures 7 and 8). We conclude that this paleogeographic parallelism of units, which have dissimiliar origins, is largely controlled by differential, tectonic subsidence.

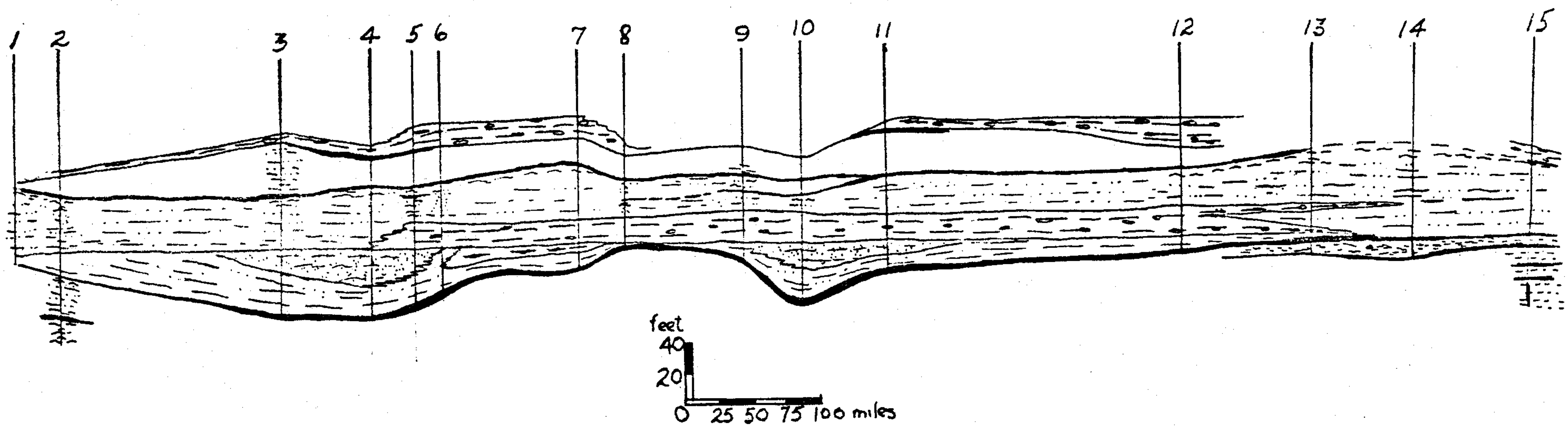


FIG. 32, STRATIGRAPHIC CROSS SECTION OF KITTANNING ROCKS