To the Graduate Council:

I am submitting herewith a thesis written by Steven Clinton Minkin entitled "Pennsylvanian Deltaic Sediments of the Northern Cumberland Plateau, Tennessee." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Geology.

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Thesis
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PENNSYLVANIAN DELTAIC SEDIMENTS OF THE NORTHERN CUMBERLAND PLATEAU, TENNESSEE

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Steven Clinton Minkin

March 1977

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ACKNOWLEDGMENTS

The writer is indebted to Dr. Garrett Briggs who supervised the field work and academic preparation of this study; thanks are also due to Dr. Robert E. McLaughlin for his instruction in paleontologic principles. I wish also to acknowledge Dr. Robert C. Milici and Mr. John F. White for instruction in the field. Thanks are due to the Department of Geology at Memphis State University for the use of their photographic equipment and to Mr. Hugh D. Faust who enthusiastically allowed this study to be conducted on his land. Special thanks are given to Melissa C. Minkin for help in editing.

ABSTRACT

Pennsylvanian sediments exposed by recent strip-mining in the Emory River Valley northwest of Oak Ridge, Tennessee, were studied to determine the nature and history of their deposition. The 600 foot sequence of flat-lying, layered sediments, part of the Redoak Mountain, Vowell Mountain, and Cross Mountain Formations (upper Pottsville) were examined to establish the lateral and vertical relationships of the several lithologies and to interpret their depositional environments as indicated by primary sedimentary features and constituent fossil faunas and floras.

The Pennsylvanian sediments of Tennessee's Northern Cumberland Plateau (total thickness approximately 4000 feet) represent a westwardly prograding delta system formed by rivers draining the rising Appalachian highlands. The 600 foot studied interval represents a small prograding delta lobe which underwent a gradual change from the lower delta plain through the upper delta plain punctuated by numerous, relatively short-lived marine invasions.

The lowermost interval (Big Mary horizon) is indicative of the lower delta region, a paleoenvironment characterized by wide, shallow distributaries, thin levees, and large interdistributary bays. Diverse marine fauna inhabited the shallow, more restricted areas of the interdistributary bay. The open bay environment served as a collecting basin for channel overbank sediments. Continuous progradation of the distributary system seaward established the upper delta plain environment (Pewee,

Rock Spring intervals), a region characterized by thick levees, point bars, alluvial channels, forested backswamps and thick splay sequences. Overlying the terrestrially dominated Rock Spring interval are the marine bay fill sequences of the Grassy Spring horizons. The change from the upper delta plain to the interdistributary bay environment represents abandonment of the lobe, a cessation of sediment supply and subsequent delta lobe decay.

The delta system represented by the study interval prograded into a cratonic basin characterized by a shallow, epeiric sea that exhibited relatively slow subsidence. The sediment source area was close, and volumes of sediment were periodically fed into the delta which accounted for rapid growth of the distributary system. Compaction of the fine-grained sediments in the marine bays provided subsiding troughs favorable for diversion of the distributary channel. A new delta system began prograding into the interdistributary basin while the abandoned delta lobe became a favorable site for peat accumulation prior to subsidence and inundation by the sea.

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I. INTRODUCTION

Recent strip mining near Wartburg, Tennessee, has exposed middle and lower Pennsylvanian sediments deposited by a rapidly prograding delta system. The sequence of layered sediments is approximately 200 ml thick and includes the Redoak Mountain, Vowell Mountain, and Cross Mountain Formations. The principal lithologies are coal, shale, siltstone, sandstone, conglomerate, limestone, and ironstone.

The proposed deltaic model for this sequence is based on field study of depositional facies, bed morphology, and primary sedimentary structures observed along laterally continuous outcrops. Photographic highwall panoramas were utilized to delineate each of these depositional features. Sedimentary interpretations of the deltaic subenvironments are based on comparisons of features identified in the study area with similar features of modern and ancient analogs described in the literature.

Several physiographic features of the ancient delta plain (e.g., subaerial levee, deltaic distributary, point-bar, etc.) were recognized and described as the result of studying the lateral facies relationships. In addition, the study of the vertical succession of sediment types reveals the different phases of Pennsylvanian delta construction and destruction. A complete cycle of delta construction and subsequent marine transgression could be observed in the stratigraphic section of the study area. The general framework of delta progradation or decay is observed by the vertical changes of sedimentary facies. The lateral

facies relationships indicate the specific fluviodeltaic features of each phase of the delta cycle.

II. PURPOSE AND METHODS OF STUDY

The primary objective of this study is to construct a depositional model for Redoak Mountain, Vowell Mountain and Cross Mountain Formations in Tennessee's Northern Cumberland Plateau. This study may then be used as a general guide for future study in this region.

To date, there have been no detailed published works concerning the depositional environment of the coal-bearing strata underlying this region (a distinct physiographic province of Tennessee including five counties with a total area of over 3000 square km). Most published information is confined to coal reserve estimates, chemical analyses, and production figures.

The general procedure of study was to describe the lateral/vertical relationships of the rock units representing differing depositional environments in six strip mining terraces. Photographic panoramas were made of each highwall which contained an important suite of sedimentary features. Line drawings made from each panorama highlight major bed forms and their lateral variations. These sedimentary facies diagrams provided cross sections on which detailed descriptions were plotted in the field. During the construction of the cross sectional diagrams and assembly of the field data, a survey of the literature provided a comparison of cross sections of Carboniferous coal-bearing sequences elsewhere with modern analogues.

The processes interpreted from the late Paleozoic deltaic sections are very similar to those which govern sedimentation in modern deltas

(Donaldson, 1974). Rapid subsidence of the delta plain allows burial and preservation of large amounts of sediment. For this reason, entire subenvironments of the ancient delta may be preserved in the sedimentary record. Therefore, the exposure of depositional features, preserved in their entirety, and a knowledge of modern processes allows the worker to reconstruct a detailed model for an ancient sedimentary sequence. Morgan (1970b) underscores the value of mapping depositional facies along continuously exposed mining outcrops. Lateral and vertical lithologic variations can be studied more effectively in many cases in continuous exposures rather than in bore holes made through modern deltaic sequences (Ferm et al., 1971). Strip mines (along several horizons in the study section) provide uninterrupted cross sections of deltaic features, and thus allow the development of a detailed environmental reconstruction for these rocks.

The plates included in the Appendix are a combination of the reduced sedimentary facies diagrams and photographic panoramas.

The interpretations proposed in this study are based primarily on the interrelation of depositional facies as illustrated in these plates. The reduced horizontal scale of the cross sections of the sedimentary facies are ideal for paleoenvironmental reconstruction because bed morphology characteristic of certain subenvironments is exaggerated and the individual features are more easily discerned. Also, these sketches provide an excellent base on which to plot further detail in the field.

III. LOCATION AND TOPOGRAPHY

The study area is located at the headwaters of the Emory River along the Morgan County line, Tennessee (Figure 1), on the north slope of the valley. The horizontal strata investigated are located in the Wartburg basin of the Northern Cumberland Plateau (Figure 2). The geographic setting forms a series of ridges that coincide with the three-way juncture of Morgan, Scott, and Anderson counties (Figures 3 and 4). The field area lies in the southeastern part of Morgan County and is characterized by steep plateau mountains and ridges reaching 2000 feet (600 m) in relief. This topography was produced by the deep dissection and headwater erosion of streams into uplifted horizontal layers.

The outcrops consist of highwalls at six strip mining levels extending from Sandy Gap Mountain southeastward along Ligias Ridge to the headwaters of Emory River (Figure 3).

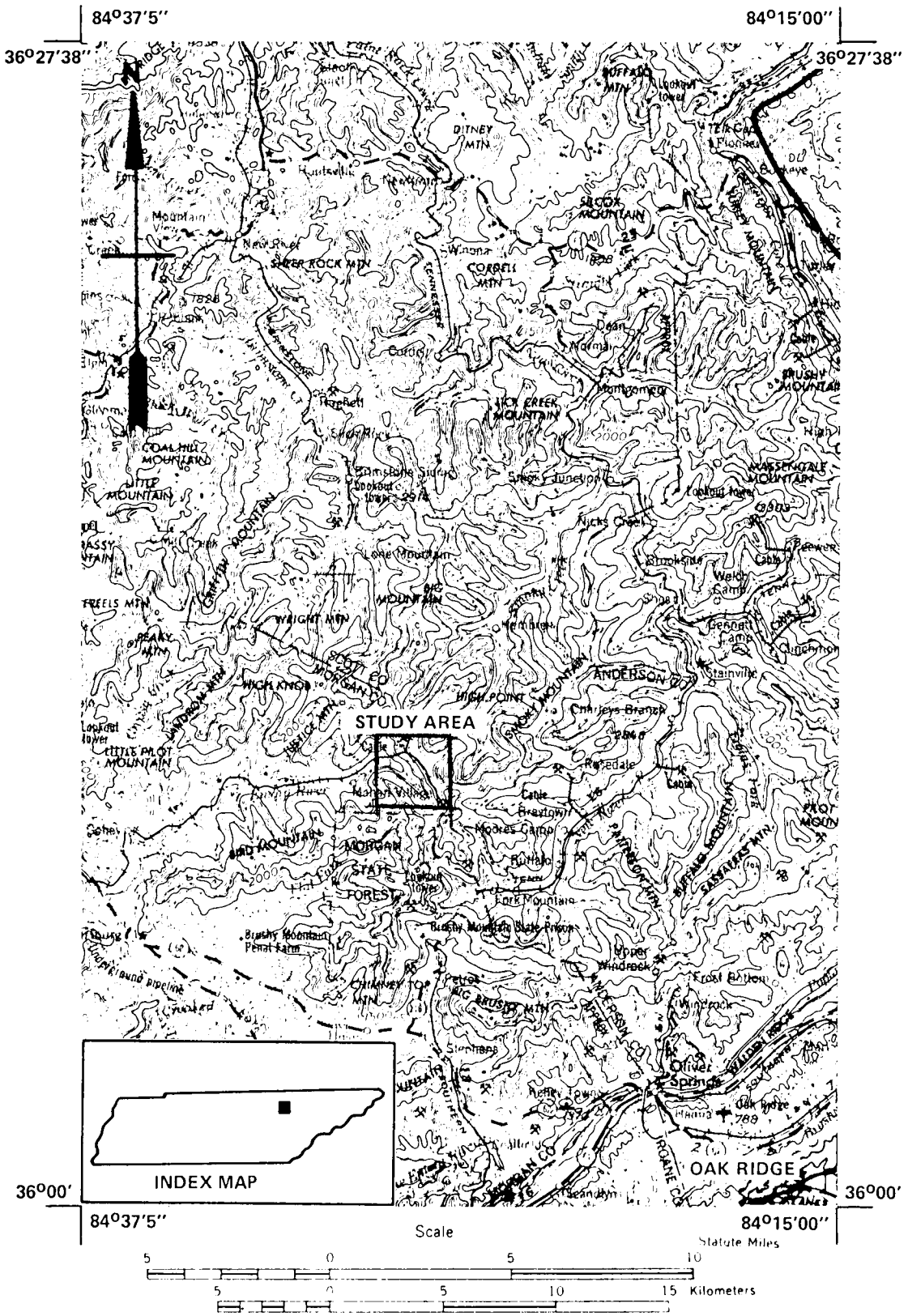

Figure 1. Location of the Study Area.

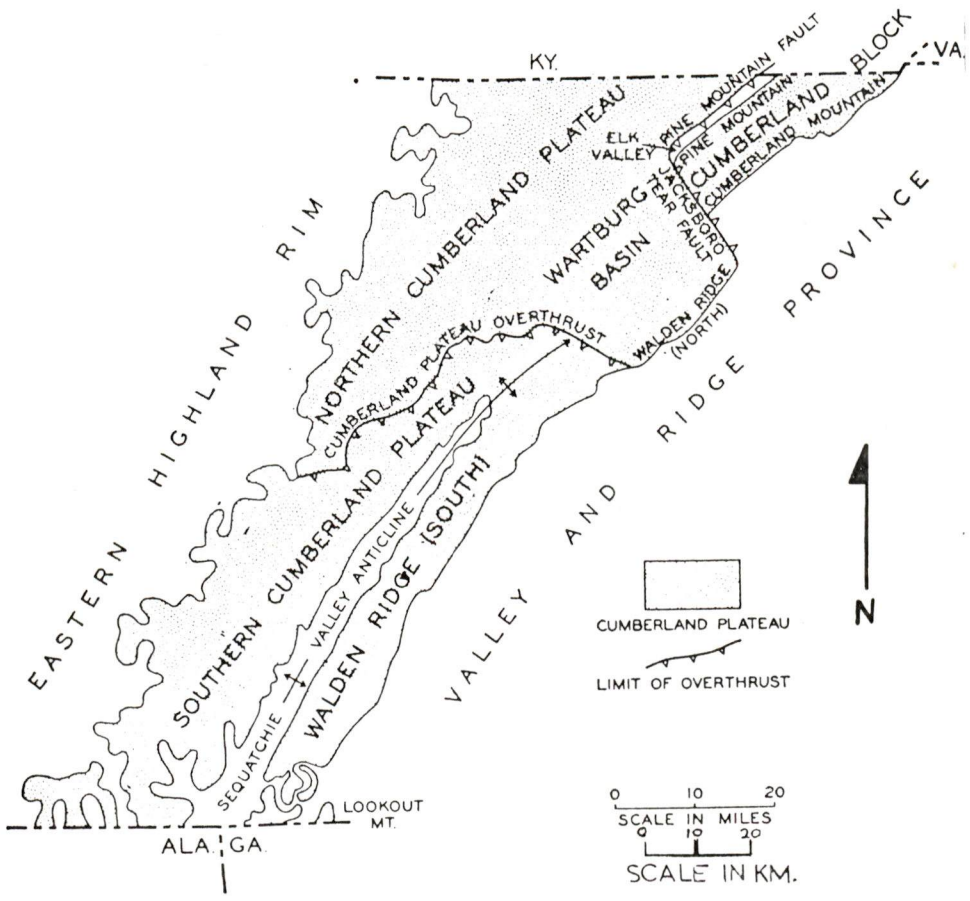

Figure 2. Structural features of the Cumberland Plateau (from Luther, 1959).

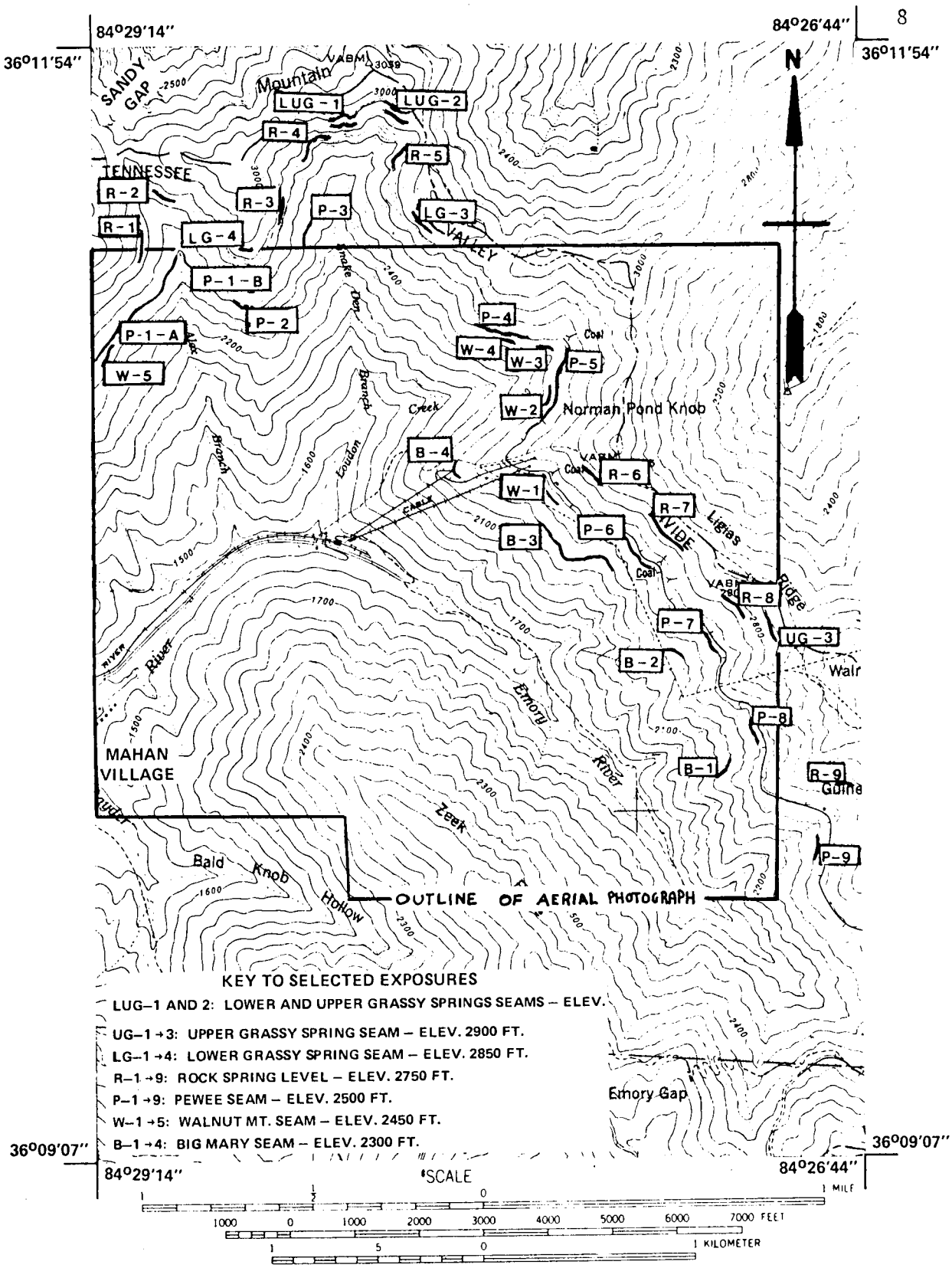

Figure 3. Distribution of selected outcrops in the study area.

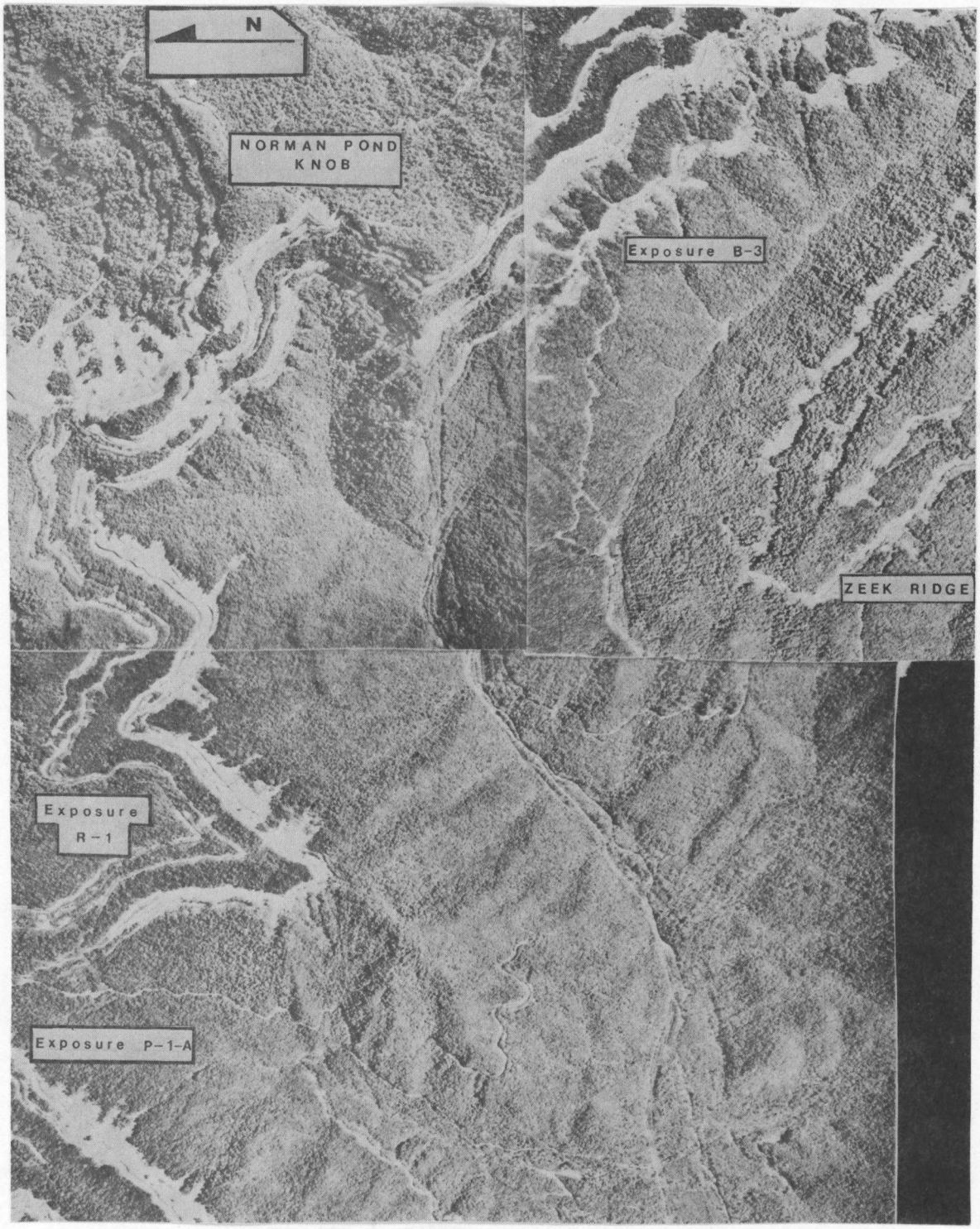

Figure 4. Aerial photograph of the study area.

IV. PREVIOUS AND RELATED WORKS

Glenn (1925) compiled a detailed stratigraphic section for each county in the plateau of northern Tennessee based on exploratory drill cores. He also proposed a regional correlation of major units, but the correlations were limited to the stratigraphically lower coal seams at that time.

Wanless (1946) presented similar lithologic descriptions and regional correlations based primarily on core and well log data. In addition, Wanless suggested several paleoenvironments such as delta, marsh, piedmont, lake, and shallow sea. His interpretations of these depositional environments are overgeneralized and perhaps inaccurate.

A workable stratigraphic section for the Northern Plateau was presented by Wilson, Jewell, and Luther (1956). Detailed lithologic descriptions was restricted, however, to the Southern Plateau where the major focus of Carboniferous stratigraphy has been centered.

Luther's The Coal Reserves of Tennessee (1959) is an expanded study of the 1956 folio. Although the purpose of this publication was the presentation of coal reserve data, Luther provides brief descriptions of the major lithologies of the Pennsylvanian section.

More recently, Johnson and Luther (1972) published an account of coal reserve estimates in the Northern Cumberland Plateau. Although the report contains no depositional environment interpretations, it is the most important reference available on the Northern Plateau, and includes a detailed topographic map which shows the stripped outcrop of the major

coal seams. While mapping of these coals provided a basis for correlating sedimentary facies, none of these coal reserve references describe the manner of deposition of these units.

Wilson and Stearns (1960) suggest that the sediments of the Northern Cumberland Plateau were deposited in deltaic, swamp, lake, and marine environments, but these interpretations are general and lack substantiating data.

Correlations using fossil plants were made by McLaughlin and Avignon (1970) and Barlow (1970). Barlow's Ph.D. dissertation (1969) gives some insight into the paleoenvironment of the Northern Plateau. His environmental interpretations are of particular value to this study because of the proximity of his area to the headwaters of the Emory River (Ligias Ridge is approximately five miles west of Barlow's area).

Whereas little paleoenvironmental interpretation is available for the Northern Plateau, extensive and accurate work has been done on the Southern Plateau. Milici (1974) is an example of the fluviodeltaic/ barrier island models proposed for the Carboniferous in the eastern United States. Milici, Ferm and Eason (1972) is another stratigraphic and depositional facies study in the Southern Cumberland Plateau of Tennessee, Alabama, and Georgia. Similar studies of depositional paleoenvironments are now being applied to Carboniferous units in Pennsylvania, Kentucky, Illinois, and West Virginia.

V. STRATIGRAPHY AND DEPOSITIONAL MODEL

All of Morgan County Tennessee is underlain by Pennsylvanian rocks, the maximum thicknesses of which may reach 1,110 m (Luther, 1959, p. 202). The stratigraphic sequence of the study area (located in southeast Morgan County) includes members of the Redoak Mountain, Vowell Mountain, and Cross Mountain Formations (Figure 5).

The Big Mary coal (elev. 2300 feet, 690 m) is selected as the base of the study section (Figure 6) because it was the lowermost recent strip horizon in the study area. The vertical sequence includes 200 m of sediments up through the Upper Grassy Spring coal. The highwall of the latter seam rises to approximately 2900 feet (870 m) above sea level and typically caps the ridges in the study area. As shown in Figure 5, the Big Mary and Walnut Mountain coals are located within the Redoak Mountain Formation; the Pewee and Rock Spring coals, in the Vowell Mountain Formation; and the two Grassy Spring coals, in the Cross Mountain Formation as defined by Johnson and Luther (1972).

Several of the sandstone units in the study area are laterally persistent and can be traced for long distances. These include the massive sandstone above the Big Mary coal, the Pilot Mountain sandstone, and the Frozenhead sandstone. Although the massive sandstone in the Pewee highwalls was not described in the stratigraphic sequence of Pennsylvanian rocks in Tennessee (Luther, 1959), the Pewee sandstone is nonetheless a prominent lithology in the study area. This sandstone is discontinuous and crops out intermittently. Consequently, it is not

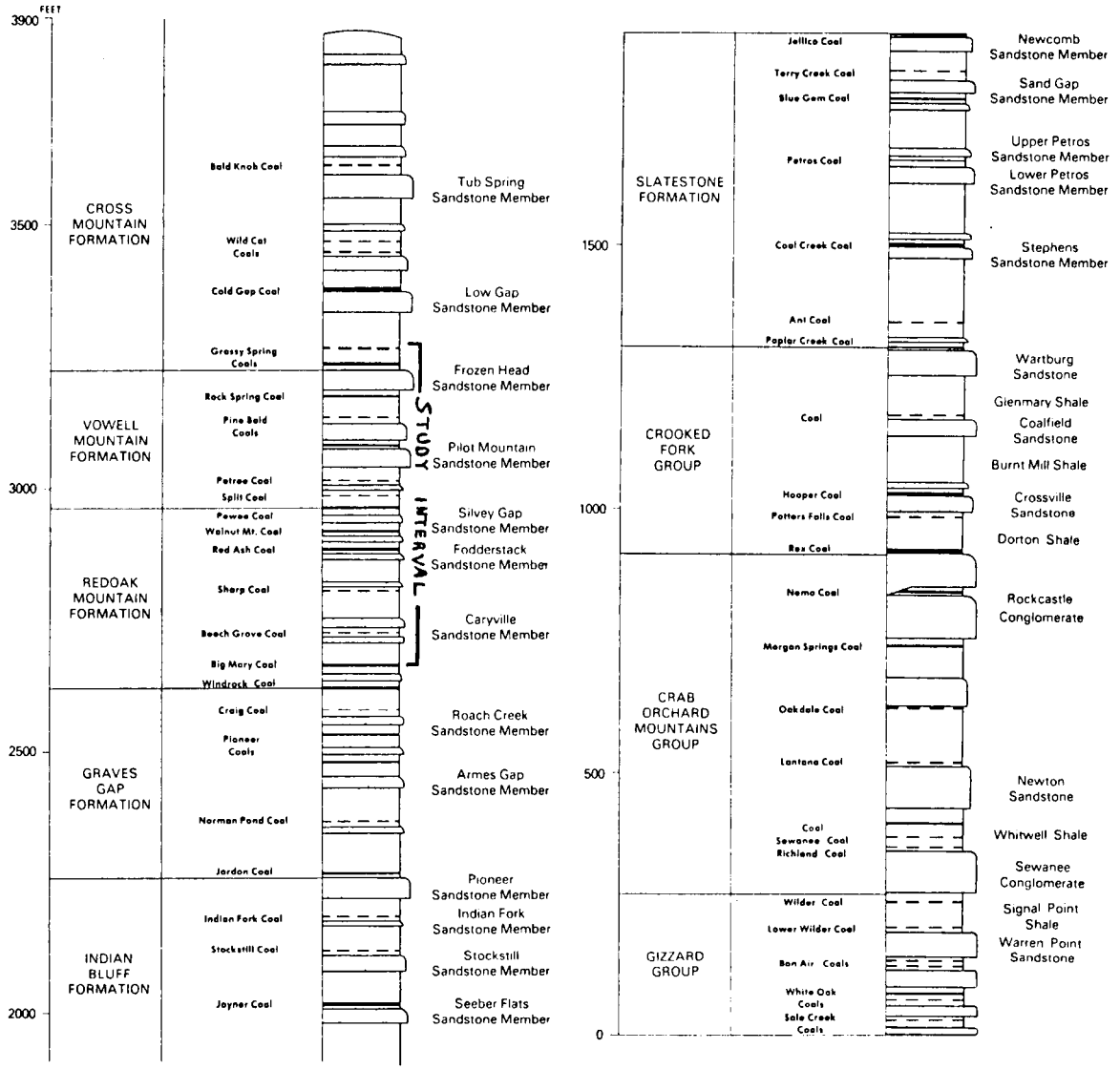

Figure 5. Generalized stratigraphic sequence of Pennsylvanian rocks in Tennessee (from Johnson and Luther, 1972).

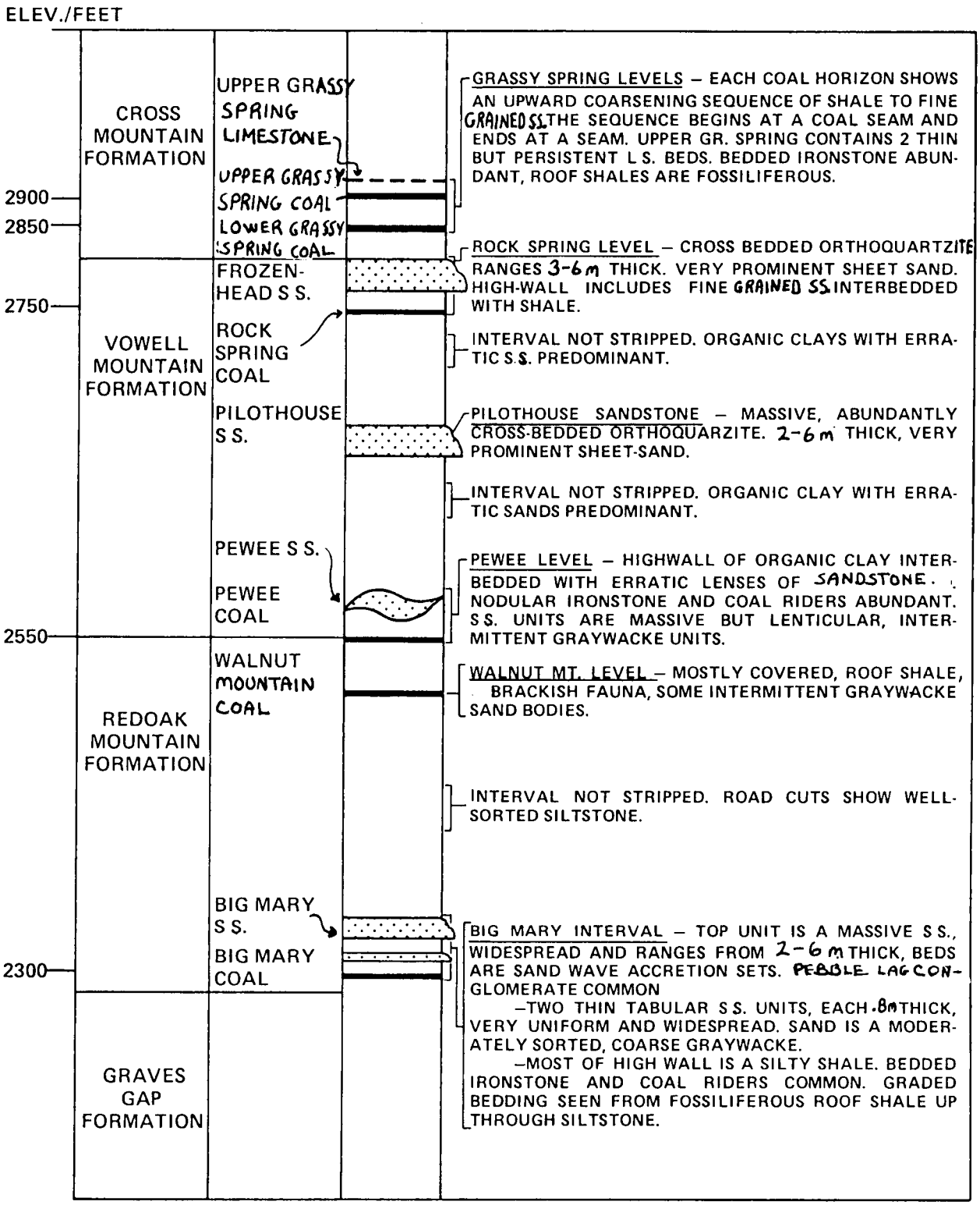

Figure 6. Stratigraphic section exposed at the headwaters of the Emory River.

regarded as a formal member of the Vowell Mountain Formation. Its lenticular nature, though, is an important element of the paleo-environmental interpretation and so is included in the stratigraphic column (Figure 6) for the study area. Several other highwall localities exhibit similar discontinuous sandstones (e.g., the sandstone associated with the Walnut Mountain coal), but these units are too thin (1 to 3 m thick) to be regarded as mappable members. However, these thin sands are important in the construction of the sedimentary facies diagrams and are illustrated on the plates included in Appendix C.

Fine-grained rocks constitute the bulk of the sediments present in the field area. The shale and most of the siltstone are believed to have accumulated in large, shallow marine basins or marshes by the relatively slow settling of suspended material. Therefore, these deposits will tend to be thicker and more widespread than the sandstone layers which represent a constantly migrating fluvial network. The covered intervals between the major coal seams indicate the presence of incompetent shale and siltstone. The major sandstone units which represent the most dynamic processes of alluvial sedimentation occur stratigraphically close to the major coal seams and are commonly present in the strip highwalls. Therefore, the depositional facies most important in interpretation are generally exposed by the mining operation.

The basic sedimentary model used in this study is the prograding delta system, which can be generally subdivided into three regions: the lower delta plain, upper delta plain and lower alluvial valley. Figure 7 illustrates the relative distribution of sedimentary facies in a prograding delta model with respect to the Big Mary, Walnut Mountain,

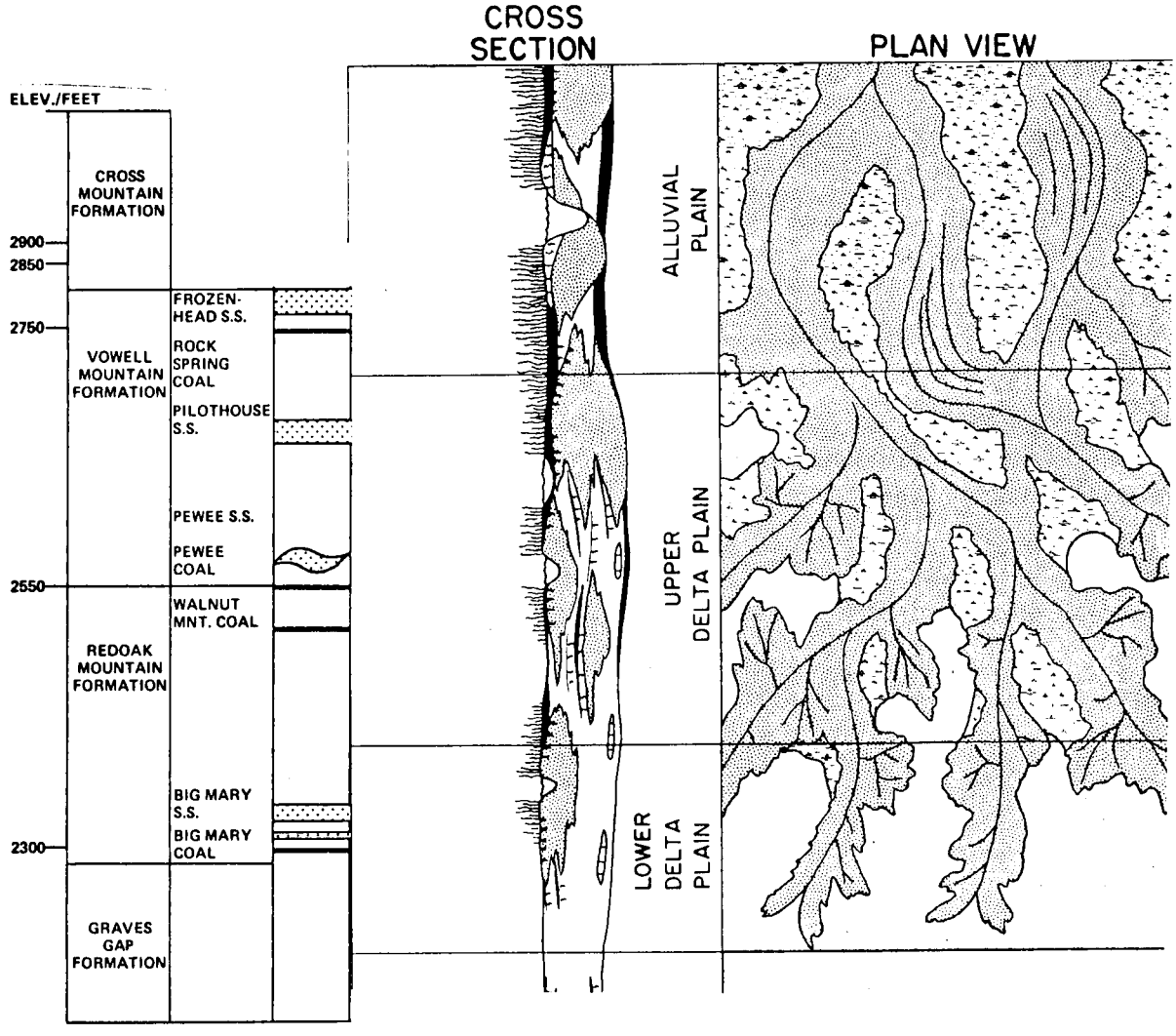

Figure 7. Depositional model of the study area (adapted from Ferm et al., 1971).

Pewee, and Rock Spring horizons (Figure 6). This interval between the Big Mary and Rock Spring levels represents delta construction, whereas the Grassy Spring horizons (Figure 6) characterize decay or the destructive phase of the delta cycle.

The lower delta plain is the most seaward extension of the prograding delta. It is bounded upstream by the upper delta plain where topographic relief and terrestrial vegetation begin to appear. The lower delta area is a flat, widespread platform of predominantly fine-grained sediments which is dissected by large straight distributaries. The Big Mary and Walnut Mountain levels represent the lower delta plain (Figures 8 and 9). The depositional framework is dominated by marine processes, and a cessation of sediment supply to the delta results in a relatively quick marine inundation of the lower delta plain. The inundation is caused by a rapid subsidence of the marine trough and compaction of the fine-grained sediments. The factors which control deposition are: (1) current and wave activity, (2) tidal range and frequency, and (3) depth and stability of the marine basins. Vegetation, climate, and frequency of storms may also be considered important.

The basic subdivisions of the lower delta plain are the subaqueous delta front, subaerial delta platform, distributary network, interdistributary bay, marsh, brackish lake, fresh water lake, tidal flats, and beaches. Distributary mouth bars are dominant depositional facies; point-bars and natural levees may be present but are thin and usually insignificant. A rapidly shifting distributary network may cause the

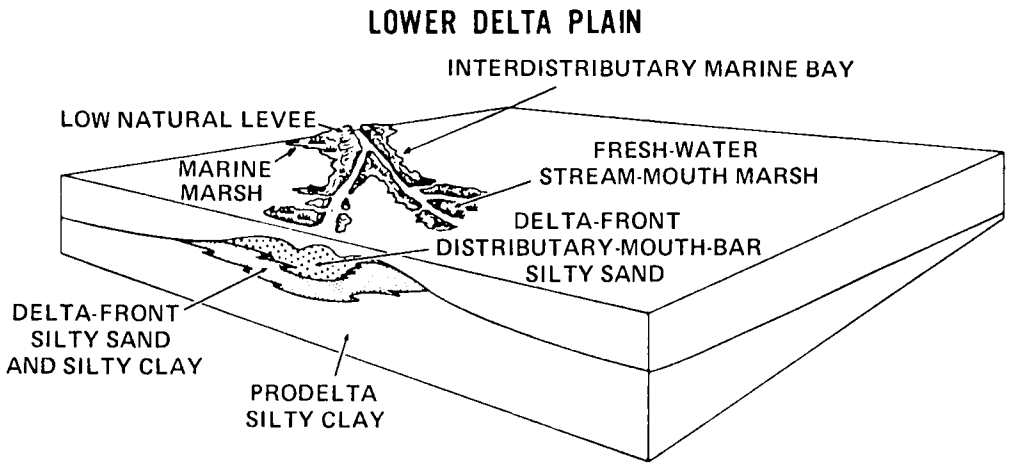

Figure 8. Block diagram of the Big Mary paleoenvironment illustrating initial progradation of a deltaic distributary into a marine bay or shelf (adapted from Frazier and Osanik, 1964).

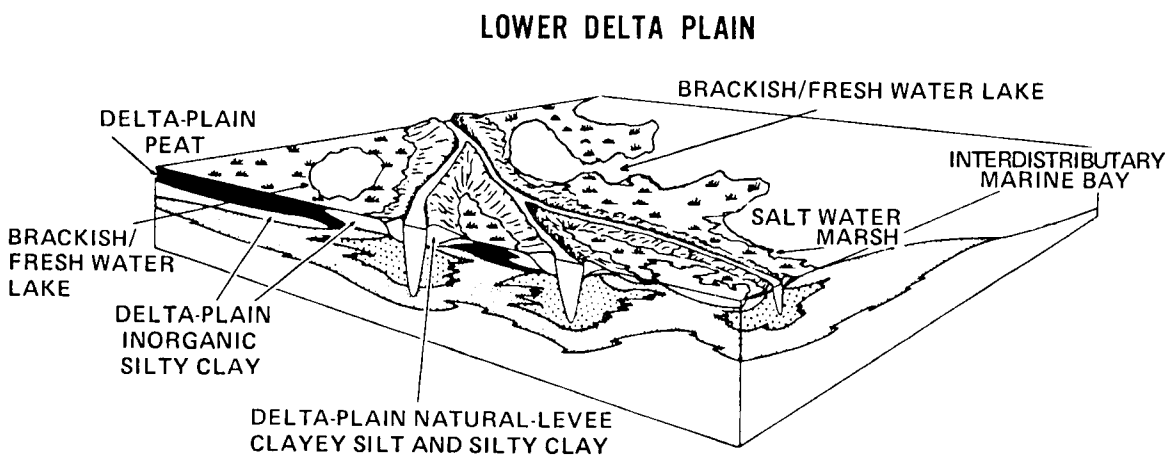

Figure 9. Block diagram of the Walnut Mountain paleoenvironment illustrating intermediate progradation of the deltaic distributary and the presence of brackish/fresh-water marsh (adapted from Frazier and Osanik, 1964).

coalescing of distributary mouth bars to form a delta front sheet sand. The distributary channel is straight, shallow, and free to wander laterally. Terrestrial vegetation is virtually absent but may be present on the thin subaerial levees. A marine fauna is present in the interdistributary bays, marshes, brackish lakes, and occasionally the distributary channel.

The upper delta plain is characterized by the first appearance of appreciable topography on the delta platform. Channel meanders and distinct natural levees mark the transition of the lower delta plain into the upper delta environment. The upper delta plain is bounded upstream by the lower alluvial valley where features of fluvial deposition dominate the sedimentary framework.

The definitive features of the upper delta area are meanders, point-bars, natural levees, dense terrestrial vegetation, well-developed floodplains and abandoned channel troughs. (The Pewee horizon, Figure 10, represents the upper delta plain.) The channel meander, point-bars and natural levees are distinct but not as thick or widespread as in the lower alluvial valley. Floodplains on the upper delta platform are more widespread and persistent than in the alluvial region where the interfluvial areas are confined by topographic relief.

Also characteristic of the upper delta plain are thick accumulations of overbank sediments, widespread backswamps and crevasse-splay deposits. Abandoned distributaries may be filled with fine suspension material or sand plugs. Channel abandonment is commonly produced by the rapid avulsion of the distributary into the adjacent

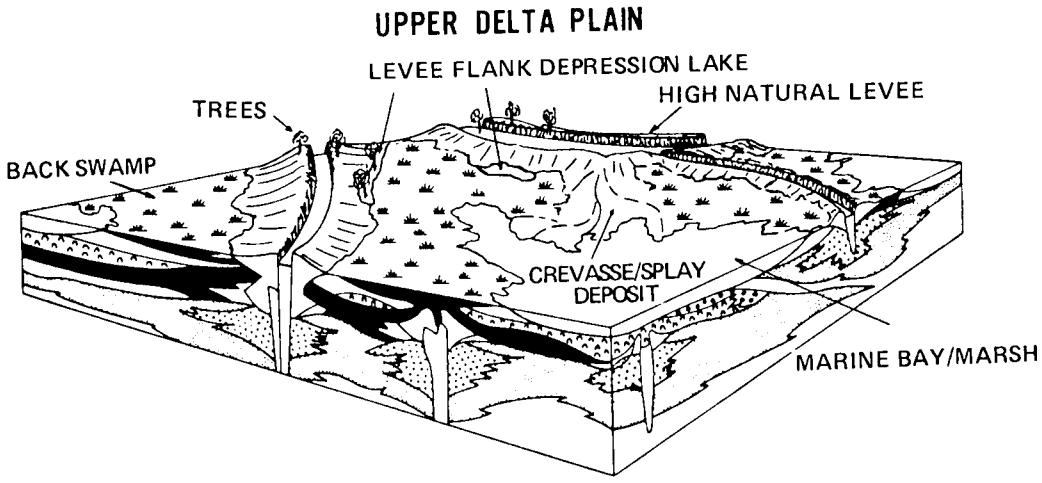

Figure 10. Block diagram of the Pewee paleoenvironment illustrating established terrestrial conditions (adapted from Frazier and Osanik, 1964).

floodplain. The lateral variability of sedimentary facies is high in the upper delta plain. Overbank deposits are usually thin and lenticular. Marine processes commonly do not affect the upper delta area.

The lower alluvial valley borders the landward margins of the upper delta plain. Fluvial processes of sedimentation create well-developed point-bars, meanders, natural levees and channel courses (characterized by the Rock Spring horizon, Figure 11). The most prominent sediment facies preserved are the bar sands, abandoned channel plug sands, and the backswamp silty clays. The natural levee is usually erased from the sedimentary record due to extensive channel meander. Abundant point-bars resulting from the extensive meandering will coalesce to form widespread belt sandstone units. The flood plains are relatively small compared to those of the upper delta plain. Terrestrial flora is common throughout this area.

The Grassy Spring horizons which overlay the Rock Spring interval are characterized by black marine shales, limestones, and bay fill siltstones and sandstones (Figure 12). This interval represents decay or the destructive phase of a prograding delta system. The destructive phase of the delta cycle is primarily the result of cessation in sediment supply from the alluvial source. The marine basin is usually an area of rapid subsidence, and with the cessation of sediment influx, the delta plain is quickly inundated by the sea. Compaction of the silts and muds of the interdistributary basins accelerates subsidence. The most characteristic result of delta abandonment is the enlargement of the bays and marshes. Lakes become more numerous, and extensive peat deposits occur in the subsiding lower delta plain.

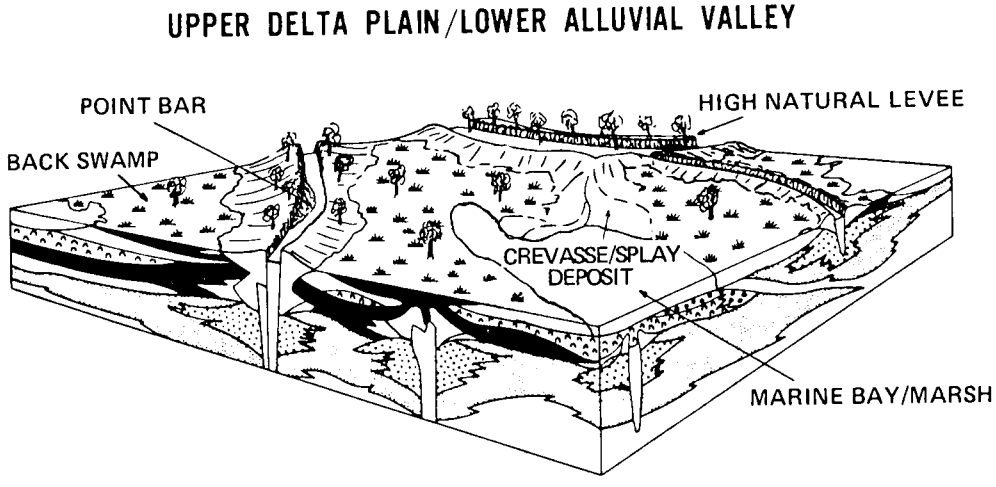

Figure 11. Block diagram of the Rock Spring paleoenvironment illustrating the terrestrial conditions in the alluvial valley (adapted from Frazier and Osanik, 1964).

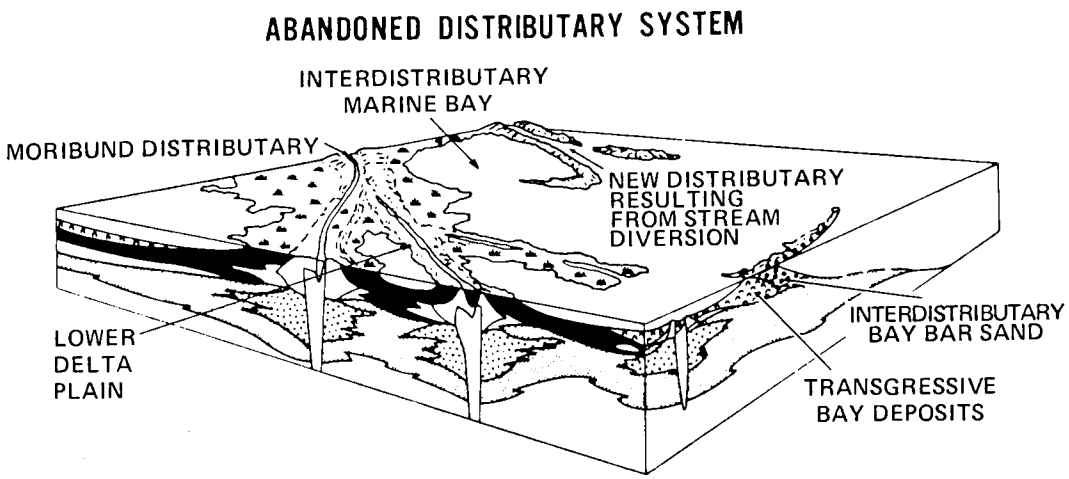

Figure 12. Block diagram of the Lower and Upper Grassy Spring paleoenvironment illustrating marine transgression after distributary abandonment (adapted from Frazier and Osanik, 1964).

The sand units of the lower delta platform are commonly reworked by current and wave activity. Delta front sheet sands and strandplain deposits may originate from the reworking of distributary mouth bars. The prodelta area reverts to a normal shelf facies.

VI. FIELD DESCRIPTION OF SEDIMENT TYPES

The term used in this paper to denote sediment grain size and texture are field descriptions. Table III (Appendix A), adopted from Spock's Rock Analysis Chart (Table IV, Appendix B), outlines the basic descriptions of each major lithology in the study area. Other guides for the lithologic descriptions were the Wentworth Scale (Spock, 1953), Table of Principal Sandstone Types (Spock, 1953), and Diagram of Terrigenous Sedimentary Rocks (Folk, 1954).

Table III was mainly designed to categorize the textural characteristics of each sediment type including mineralogy and primary sedimentary features. Bedding morphology was also emphasized to support the interpretations for the sedimentary facies. Table V (Appendix B) uses the textural and bedding properties of the sediments to describe the major lithogenic units (sedimentary facies) of the study area.

VII. PRIMARY SEDIMENTARY FEATURES

Certain primary sedimentary features characterize the various bedding types in the study area. Bed morphology and bedding features were emphasized in the field study, as interpretation of sedimentary paleoenvironments is partially based on laterally interrelating facies. Plates 1 through 13 (Appendix C) refer to these primary sedimentary features throughout the discussion.

Cross-Bedding

Four general types of cross-beds are observed: foreset accretion beds, trough festoon crossbeds, planar cross-beds, and ripple cross-laminations.

Foreset accretion stratification (McGowen and Garner, 1970, p. 97) is the most characteristic bedding type of point-bar features in the study area (Plate 7, Appendix C). These cross-beds originate by lateral accretion of sediment from unidirectional stream currents. The large foreset accretion beds of the lower point-bar (McGowen and Garner, 1970, p. 82) form much in the same manner as do the foreset stratifications of the lower delta distributary. The slope of the lower point-bar appears steeper than on any part of the subaqueous bar (Plate 7-B) as the foreset beds dip toward the channel bottom.

Foreset accretion beds are the characteristic stratification of the shallow but wide lower delta plain distributary channel. Figure 13 illustrates the large foreset accretion sets of the Big Mary

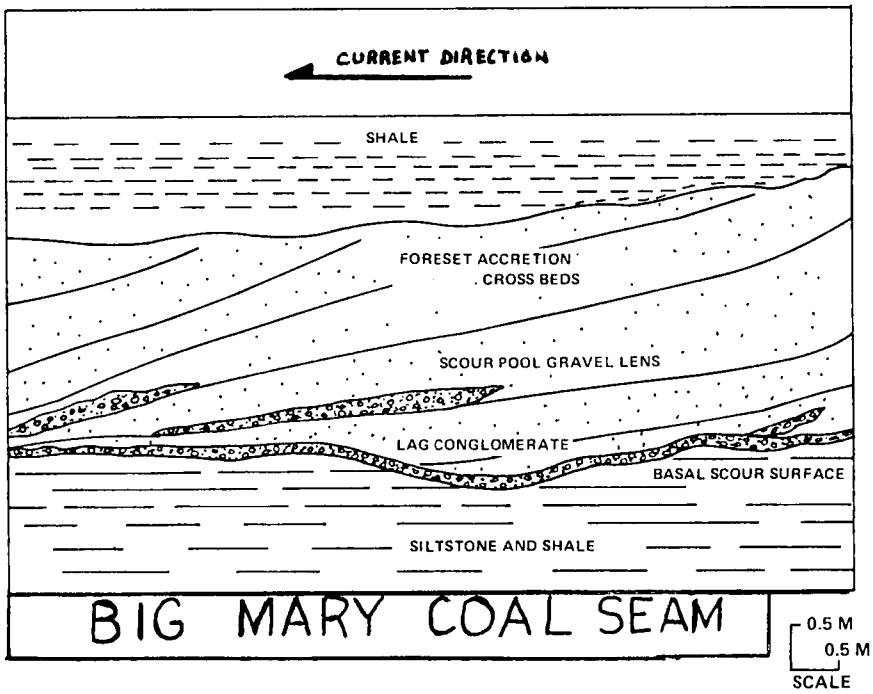

Figure 13. Big Mary exposure No. 3: foreset cross-beds and scour pools.

horizon (Plate 1-A, Appendix C) which were formed by channel bar migration.

Trough cross-beds (McGowen and Garner, 1970, p. 84) are also characteristic of the point-bar and form under similar flow conditions as do the foreset accretion beds. However, the trough cross-sets represent current scour and subsequent sediment filling of the scour depression. Trough cross-sets possess a steeper bedding angle than do the foreset accretion beds. Trough cross-stratification is the predominant bedding type of the alluvial point-bar illustrated in Plate 10 (Appendix C).

Planar cross-beds (McGowen and Garner, 1970, p. 84) are long, slightly inclined laminations which result from deposition on the point-bar during falling river stage. These are observed as the tabular beds in the complexly cross-bedded point-bar sequences (Plate 9, Appendix C) of the study area.

Ripple cross-laminations (McKee, 1965, p. 76) are indicative of sediment moved under conditions of the lower flow regime subsequent to strong current activity and sediment influx. For example, an abandoned channel may receive overflow material during flood season and the fine-grained sediments will form ripple laminations when the high water recedes (Plate 10-A). Similarly, the fine-grained sediment introduced into the marine bay forms ripples due to mild current activity in shallow water (Plate 13-A, Appendix C).

Scour Surface

A scour surface is the erosional contact a channel produces when migrating over preexisting sediments of the channel bed load or adjacent floodplain. Truncation of the underlying beds is the most diagnostic feature of the scour. Soft sediment deformation beneath a massive channel sandstone can be mistaken for a scour; however, these deformed beds are not truncated (refer to Plate 12-A, Appendix C). The greatest amount of scour occurs in the deep parts of the channel near the concave bank of a meander and in the floodplain during heavy overbank flow. A massive bed load channel fill may include multiple scour surfaces that truncate each other and indicate successive periods of high water flow (Allen and Friend, 1968, p. 36).

Lag Deposit, Scour Pool

Lag deposit, as used herein, is the coarsest material transported in a channel, usually pebble-sized detritus moved with the bed load during flooding. Ferm et al. (1972, p. 121) list several characteristic features of channel lag, namely, pebble conglomerate, scour surface, and current oriented plant fragments. A basal lag conglomerate and current oriented plant stems were observed in several channel fill facies of the study area. [Refer to Figure 13 and Plate 1-A (Appendix C)].

The scour pool is a depression in the deepest part of the channel bottom at any one time, usually close to the concave bank (McGowen and Garner, 1970, p. 82). Russell (1967, p. 23) explains that the scour pool

is where much of the bed load is deposited. Frazier and Osanik (1961, p. 136) describe the troughs between large ripples as pockets which trap the lag deposit. Scour pool lag deposits from both large ripple troughs and channel floor depressions are evident in several active channel fill features of the study area.

The channel fill features illustrated in Plates 1-A and 6-A (Appendix C) accumulated by the movement of bed load material during a flood. This occurred along the deeper parts of the original channel bottom. The conglomerate observed along the basal surface of the channel sand in exposure B-3 (Plate 1-A) is an example of a scour pool filled with a pebble lag deposit. The lag conglomerates in the channel fill of exposure P-8 (not illustrated on Plate 6-A) are also scour pool deposits.

Slump and Soft Sediment Deformation

Rapid deposition on the deltaic platform causes slumping. Horne et al. (1974, p. 106) note abundant channel bank slumping in the Allegheny Group in Kentucky where sandstone bodies intertongue with dark shales. The slumps are described as rotated blocks of sandstone and siltstone in badly deformed shales.

Three distinct processes of slumping were observed in the study area. A channel bank slump is present in exposure B-3 (not illustrated in Plate 1-A). In this outcrop, a coal bed dips at 45° to the horizontal. Evidently, the unconsolidated silt was mobile, and the whole slump block slid and was thrust upwards in an arc-like path (R. C. Milici, personal communication, 1974). The levee illustrated in Plate 4-C

(Appendix C) is an example of a channel bank slump occurring on a natural levee, probably adjacent to the concave bank of a meander. Slumping along the natural levee is evidently a common process due to undercutting of the concave bank, where the levee is best developed (Kesel et al., 1974, p. 461; Fisk, 1951, p. 2011).

Plate 11 (Appendix C) illustrates a flood feature in exposure R-7. The steeply inclined bedding plates are the result of slump deformation (R. C. Milici, personal communication, 1974). Apparently large blocks of sediment rotated after a massive influx of sediments emptied into the flood basin. Although the flooding was very rapid, it occurred in several stages. This is suggested by the regularly bedded shale labeled in the photograph of Plate 11. It appears that the sediments of exposure R-7 were deformed as one huge slump block.

Soft sediment deformation is a slump feature common throughout the study area. Wanless (1946, p. 120) illustrates a pillow structure, considered common in the northern Tennessee coalfield. This type slump is the result of massive sands bulging downward into the underlying softer silt and clays. It is also referred to as a load feature. This structure is most commonly observed along a channel scour surface that overlies a fine-grained organic deposit (refer to the channel fill sandstone of Plate 12-A, Appendix C).

VIII. PROMINENT FLUVIODELTAIC FACIES

The delta plain environment is commonly divided into three different regions: lower delta plain, upper delta plain, and alluvial valley. Sedimentation in each of these three areas is governed basically by one of two processes: fluvial deposition; or, suspension settling and organic accumulation in the floodplain. The channel-related deposits tend to be thin, lenticular, and exhibit features of rapid sediment transport. The floodplain deposits are generally thick, widespread, and display features suggesting a lack of rapid sediment movement. Each of the three basic areas of the delta is characterized by a distinct suite of fluvial facies and floodplain deposits.

The description of fluviodeltaic facies explains the types of fluvial and floodplain features inherent to the various regions of the delta plain observed in the study area. Reference is made to Plates 1 through 13 (Appendix C).

Natural Levee

The natural levee is the slightly elevated ridge which borders alluvial channels and deltaic distributaries. This ridge is formed by the buildup of sediments washed over the channel bank during flooding. A gradation of coarse to fine overbank sediments is observed from the crest of the levee, down its flanks toward the floodbasin. The levee thins out along its distal edge, and the silts and sands grade

laterally into the organic deposits of the swamp or marsh. The floodbasin of the alluvial valley may be composed entirely of point-bar sands, and the levee sediments would overlie or grade laterally into these sands.

A modern levee can be traced throughout the floodplain as a general rule by its relief and dense vegetation. The slight elevation and coarse sediments of the levee provide a firm, well-drained substrate for plants (notably Calamites in the study area). Oxidation and dessication of the natural levee deposits also add to the strength of the substrate.

In relation to the whole floodplain, the levee is a narrow, thin unit. The levee deposits generally consist of alternating beds of poorly sorted sand and silt beds resulting from repeated and intermittent flooding (Allen, 1965a, p. 147). Bedding is generally laminar; cross-beds are generally absent. The sediments are abundantly rooted. (Refer to Table V, Appendix B.)

The natural levee is thickest along the concave bank of the channel meander (Kesel et al., 1974, p. 461) in the alluvial environment. The levee becomes smaller and indistinct on the lower delta plain (Fisk et al., 1954, p. 83; Ferm et al., 1972, p. 31). Vegetation on these ridges becomes less concentrated on the lower delta plain due to the influx of marine water.

The natural levee is not adequately described from ancient delta studies. Ferm and Cavaroc (1968, p. 12) are indefinite as to levee shape and relation to levees of other sedimentary facies. Wanless et al. (1970, p. 221) are unable to identify the levee in their studies

of subsurface Illinois. There are good reasons for the lack of description for this feature. First, the levee constitutes a small areal part of the floodplain and core data are usually too widespread to encounter the thin dimensions of the levee (Coleman and Gagliano, 1964, p. 61). Second, the subaerial levee has little relief in the lower delta plain. Third, the levees in an alluvial valley are very prominent but are destroyed by subsequent meandering. The levee is most pronounced on the concave bank of a meander; however, this is also the site of maximum channel erosion as meandering progresses.

The upper delta plain environment of the study area (Pewee level) exhibits several levee units (e.g., Plate 6-B, Appendix C). Although the levee in this region was well developed, lateral channel erosion was not a dominant sedimentary process. Hence the levee was not quickly erased by channel meander. Channel diversion probably occurred by rapid avulsion into the floodplain. Figures 14 and 15 illustrate the upper delta plain levee and its relation to the channel.

Levee Flank Depression

The levee flank depression (Figure 15) is a distinct feature of the alluvial floodplain. The large amount of coarse sediment on the levee produces an overloading effect and downwarp in this part of the floodbasin (Morgan, 1967, p. 117). Hence, the levee flank depression forms as a small trough on the distal margins of the levee. Further subsidence of the levee flank depression results in the formation of lakes and ponds (Morgan, 1967, p. 118). Coleman et al. (1972, p. 54)

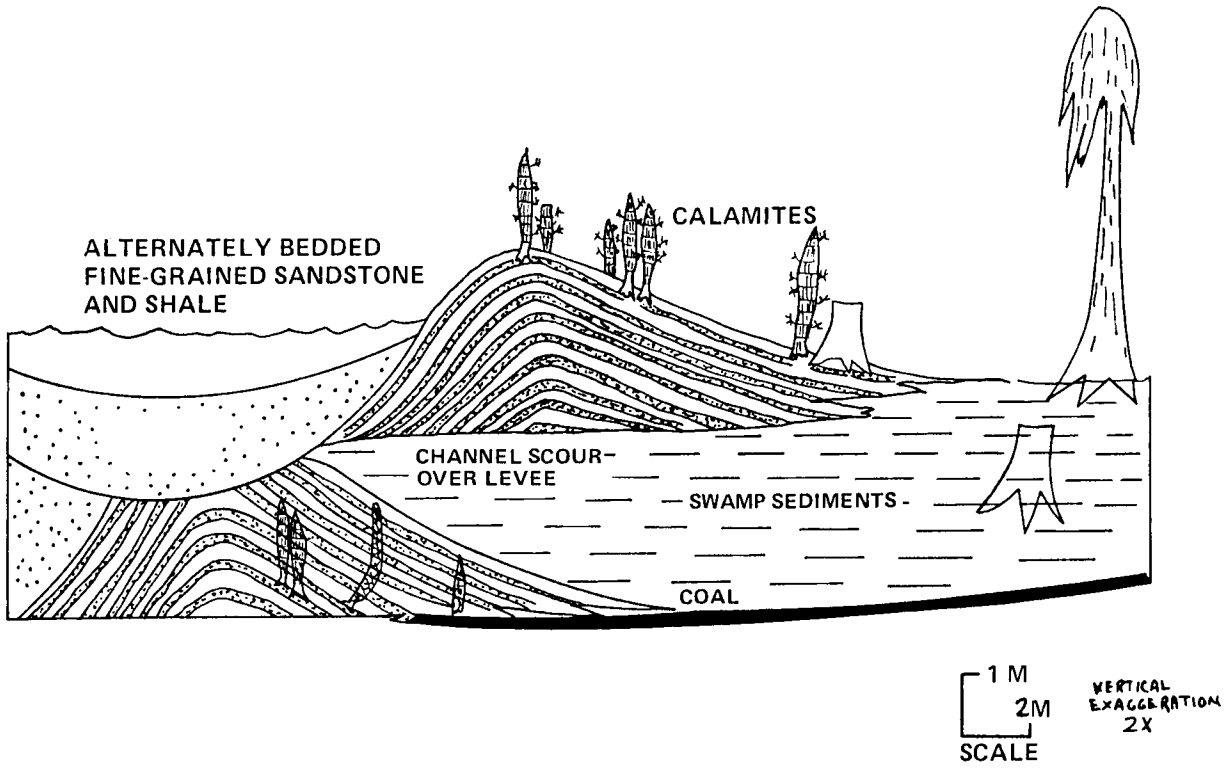

Figure 14. Natural levee form of the study area.

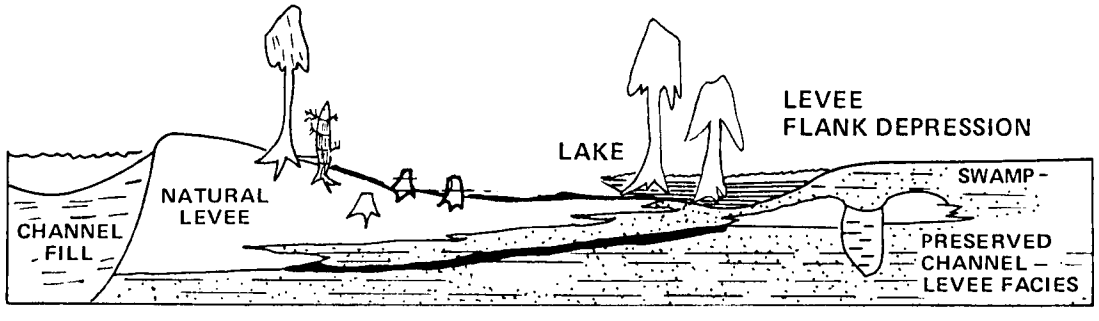

Figure 15. Natural levee, levee flank depression, lake (modified from Fisher et al., 1969).

report that lakes are commonly associated with the distal flanks of natural levees.

Exposure P-1-A (Plate 2-A, Appendix C) illustrates a levee flank depression facies. The smaller trees are rooted along an irregular horizon which appears to be a scour surface. Below this rooting surface is a well sorted, evenly bedded siltstone. This lithology is interpreted as an upper delta plain lake deposit. Ferm et al. (1972, p. 12) list several criteria of the delta plain lake: shallow water current and wave features, and well-developed parallel strata. The lake siltstone of exposure P-1-A is very evenly bedded. The silt is well sorted which indicates current winnowing. A lack of rooting in the siltstone shows that the lake bottom was never subaerial. Only when the trough filled with sediment were the trees able to take root in the semiaquatic substrate. The levee flank depression subsided just enough to keep pace with the overbank sediment influx. Thus, the lake was probably relatively shallow. Russell (1967, p. 46) describes lakes in the Mississippi River Delta as being 14 to 16 feet at the deepest point. In summary, the trees in Plate 2-A (Appendix C) grew in a levee flank depression of the upper delta plain.

The massive sand deposit above the siltstone in exposure P-1-A in Plate 2-A is a flood sequence which accumulated very rapidly in the levee flank depression. The source of the sands was probably a crevasse in a nearby levee. The rate of deposition was fast and probably took place within one flooding season. The most striking evidence of rapid sedimentation is the presence of large tree trunks buried in life

position. Although fossil stumps are common in ancient delta swamps, the burial of living trees to a depth of 15 feet or more requires an abnormally fast rate of sedimentation. The contact between the flood sand and the underlying silt marks the original slope surface of the levee flank depression into which the sand was fed. This depositional slope was probably exaggerated after burial due to compaction of the shale and siltstone. However, the relief was steep enough to initiate a mass movement of this large volume of liquified sands. The sediment crept downslope into the trough. Two results are evident of this process (Figure 15).

First, the bedding is contorted. Coleman and Gagliano (1965, p. 136) explain that such bedding is characteristic of slow mass movement. Second, the trees rooted along the same irregular scour horizon are all bent in the same direction (presumably downslope) and at the same horizon. It is suggested that these trees were bent over in the downslope direction by shear during liquifaction (Allen and Banks, 1972, p. 257).

One other indication of rapid deposition is the presence of randomly mixed plant debris in the flood sand. The material is abundant in all sizes, and is not confined to parting laminations.

The continuous nature of the Pewee outcrop serves well to further understand this levee flank depression and flood feature. Figure 16 illustrates the relationship between exposures P-1-A and P-1-B which are adjacent and perpendicular outcrops on the same strip mining level (Plate 2, Appendix C). Exposure P-1-A is a longitudinal section of the

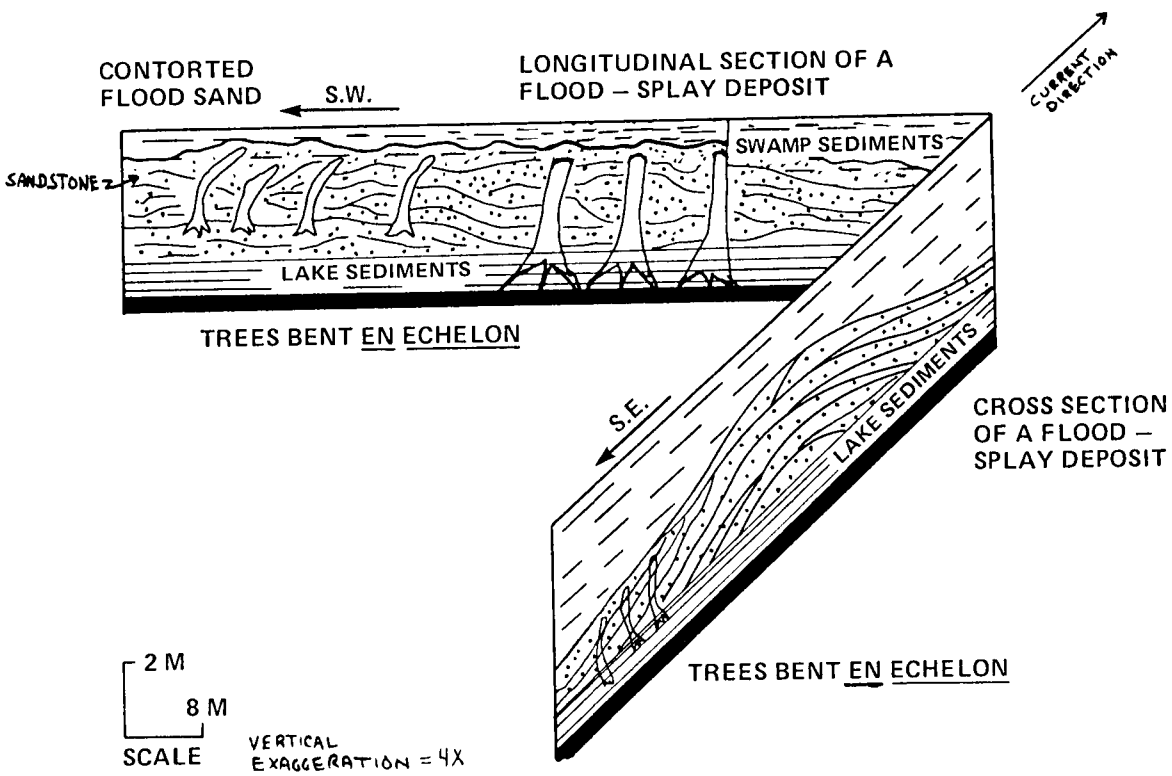

Figure 16. Relationship of exposure P-1-A to exposure P-1-B: a flood deposit in a levee flank depression.

flood splay. Exposure P-1-B is a cross section of the splay. As expected, the splay beds in this outcrop are overlapping, and truncate downward along the underlying lake sediment surface. This imbricated appearance of the flood sands is the result of successive and overlapping blankets of splay sediments being issued through the crevasse into the levee flank depression.

Lake

The lacustrine environment is common throughout the entire delta system. Lakes present in the lower delta plain result from the rapid subsidence of the interdistributary marsh which has ceased receiving sediment. The marsh cannot keep pace with subsidence, and the area becomes an open body of water (Frazier and Osanik, 1969, p. 68).

Lakes and ponds are also numerous in the upper delta plain and are commonly formed from levee flank depressions which become open bodies of water and enlarge with continued subsidence and wave activity (Morgan, 1967, p. 117).

The typical lacustrine deposit is a suite of well-developed beds of fine-grained sediments. Bedding is thin and may not be apparent in outcrop because of the slow rate of deposition (Ferm et al., 1972, p. 13). Seasonal variations may be seen in the fine silts which tend to be well sorted due to current/wave activity. Fresh-water arthropods and molluscs may be present in the lacustrine facies (Belt, 1968, p. 128).

Crevasse, Splay

A crevasse is a break in the natural levee through which a splay of alluvium fans out into the floodplain (Allen, 1965a, p. 123). The process usually occurs during a flood episode which creates a favorable diversion route for the distributary or channel.

The interdistributary bays and marshes of the lower delta plain are flat and widespread. The natural levee of this area has little relief, and the crevasse is not well developed. Therefore, a splay from the crevasse of the lower delta plain is a temporary episode. The splay occurs as a thin, tabular unit extending uniformly into the interdistributary bay for miles (exposure B-3, Plate 1-A, Appendix C). Due to the shallow depth of the lower delta plain distributary, the splay sediment may consist of the coarse bed load material of the channel (Ferm et al., 1972, p. 101). The splay of the lower delta area is widespread and persistent, has sharp top and bottom contacts and exhibits ripple laminations.

A crevasse through the upper delta plain levee provides a gap through which the channel can divert for a considerable length of time (Coleman and Gagliano, 1964, p. 67). New delta lobes and channels may build into the adjacent floodplain. The irregular topography of the upper delta floodplain constricts a widespread veneer of splay sediments. In contrast, localized troughs (i.e., abandoned channels, levee flank depressions, lakes) will accumulate thick volumes of splay sediments after successive episodes of flooding.

The splay units of the upper delta plain and the lower alluvial valley display lenticular distribution and commonly possess scour surfaces where successive splays accumulated in a trough (exposure R-7, Plate 11, Appendix C). Typical features of these splays are ripples, cross-beds, rooting, and a sharp basal contact.

Flood Deposit

A flood deposit is the sediment accumulated in the floodplain when the streamflow of a channel overtops or breaches the natural levee. This sediment is usually the suspended fraction in the stream water and forms the lenticular siltstone-fine-grained sandstone facies of the backswamp section.

Extreme or catastrophic flooding is the result of a crevasse in the levee through which the stream is partially diverted into the floodplain. Therefore, the sediments deposited from extreme flooding are massively bedded and coarse grained. Contorted bedding and slump features are common.

Exposure R-7 (Plate 11, Appendix C), along the Rock Spring level, possesses several features characteristic of extreme flooding in an alluvial valley paleoenvironment: scour surfaces truncating each other, slump blocks, load cast features, massive sandstone beds, and randomly oriented plant debris. Stumps rooted in the ancient peat (Plate 11) were quickly covered by sand, and the mobile sediment draped around their sides.

From observations of exposure R-7 (Plate 11, Appendix C) it appears that this sedimentation occurred over several flooding episodes, perhaps spanning several years. Evidence for this interpretation are the scour surfaces which erratically truncate underlying scours and the large slump block features. The 1 m thick shale bed of exposure R-7 dips at an angle of 30 degrees and lies between two massive flood sandstone beds. Therefore, a period of quiescence had to occur between deposition of these flood sediments. Subsequently, the whole sequence of interbedded sand and mud deformed as one huge slump block.

Point-Bar

The point-bar is an elongate body of cross-bedded sediments which accumulate on the convex bank of a channel meander. The cross-beds of the point-bar dip and build toward the deeper water near the scour pool which forms near the concave bank (McGowen and Garner, 1970, p. 83).

Maximum channel meander is developed in the lower alluvial valley and the point-bar becomes the most prominent depositional feature of this region. The channel system may migrate many times across the floodplain and a widespread belt of sandstone develops from the coalescing point-bar deposits. The entire floodplain may be composed of this broad belt of coalesced bar sands (Allen, 1965a, p. 122). The point-bar is also present in the upper delta plain but to a lesser degree. The straight distributaries on the lower delta plain are not favorable for the formation of point-bars (Fisher et al., 1969, p. 15).

The basic morphology of the point-bar consists of two parts: the upper bar and the subaqueous lower bar (McGowen and Garner, 1970, p. 83). The sediments and bedding of these two sections are generally different. The upper bar is alternately subaerially exposed and submerged, depending on river stage. This periodic fluctuation in water level causes the sediments to be well washed and drained. The shoaling activity on the upper bar causes the sediments to be well sorted. The most typical sedimentary structures of the upper point-bar are the festoon cross-beds, aligned parallel to currect direction. Laminar beds are also common in the upper bar and represent suspension filling of the bar chute channel.

In the subaqueous lower section of the point-bar, the bedding is predominantly the foreset accretion type (McGowen and Garner, 1970, p. 84) and these beds build laterally into the deeper parts of the channel toward the concave bank. Festoon cross-beds are also common (McGowen and Garner, 1970, p. 83). The shape of the lower point-bar conforms to the shape of the underlying channel bottom along the basal scour surface (Ferm et al., 1972, p. 118). The foreset accretion beds at the distal end of the lower bar are inclined at relatively high angle (15-20°) and resemble long, linear tongues of coarse-grained sediment (Plate 7, Appendix C). The sediment grade of the lower bar is coarser than in the upper bar, although a pebble lag deposit is usually not present (McGowen and Garner, 1970, p. 107).

Large amounts of randomly oriented plant material may accumulate along certain beds in the point-bar. Subsequent decay of the plant

debris in the well-drained subaerial bar results in large cavities occurring throughout the upper point-bar. Numerous vugs in the bar sediments are characteristic of the Frozenhead Sandstone in the study area (exposure R-6, Plate 10-B, Appendix C).

The Frozenhead unit of the Rock Spring level is a massive sequence of orthoquartzitic cross-bedded sandstones. Trough and foreset accretion cross-beds are the characteristic bedding types. Current activity and constant sediment migration in the fluvial channel produced the orthoquartzitic sandstones, which are characteristic of the point-bar facies in the study area. Lag deposits were not described from the Frozenhead Sandstone, as this material probably accumulated on the channel bottom near the concave bank (Allen, 1965a, p. 129) opposite the point-bar.

The most diagnostic feature of the point-bar sandstones in the study area are their widespread lateral extent, thickness, and uniformity. The Frozenhead Sandstone was traced laterally for over 4 miles without interruption along Sandy Gap Mountain and Ligias Ridge (Figure 3, p. 8). Extensive sheets of cross-bedded sandstones are typical of the alluvial valley floodplain (Frazier and Osanik, 1961, p. 136). These belt sandstones result from the coalescing of point-bar structures where a fluvial channel migrates rapidly back and forth across its floodplain.

Channel Fill

The channel fill is an elongate, lenticular body of sediments that accumulated in a channel trough. This feature is typical of fluvial

sedimentation and occurs most abundantly in the alluvial valley where the former channels are preserved in an en echelon fashion across the floodplain (Kolb and Van Lopik, 1966, p. 33). The process of filling occurs at any time during the activity of the river. A channel may be filled with its own bed load (Morgan, 1970, p. 114) and gradually change its course, or the channel may rapidly divert into the adjacent floodplain (Allen, 1965a, p. 155), leaving the abandoned trough to act as a sediment trap. The channel may partially fill by the accumulation of point-bar sands on the shallow trailing edge of a meander bend (refer to exposure P-6, Plate 5, Appendix C). These stratification types are directly related to the channel form and the physiography of the fluviodeltaic plain.

The typical channel fill is a lenticular body of planar-bedded sediments. In cross section, the structure resembles the concave shape of the former channel (Horne et al., 1974, p. 1069); refer to exposure P-4, Plate 3-B, Appendix C. Although this particular type most closely resembles the shape of the actual channel, several other less distinct channel-fill features—bed load, inactive, and point-bar fill deposits—are equally important in the fluviodeltaic plain. One type of active channel fill follows rapid avulsion of a channel into an adjacent floodplain. The abandoned trough serves as a collecting trap for flood-borne sediments (Russell, 1967, p. 37). If the river shifts due to a chute cut-off, the channel fills rapidly with bed load sediments (Allen, 1965a, p. 127). Inactive channel fill follows a neck cut-off. The channel bend will plug at each end with coarse sediments, and the former

meander will become a lake. The neck cut-off fill is characterized by fine-grained suspension deposition in the oxbow lake and possesses sedimentary structures indicative of shallow water deposition (Kesel et al., 1974, p. 461; McKee, 1965, p. 73). Both the active fill from chute cut-off and inactive fill from neck cut-off are present in the upper delta plain and lower alluvial valley. The channel feature in exposure R-5 (Plate 10-A, Appendix C) was filled by the inactive process; ripple cross-laminations (climbing ripples) are the dominant sedimentary structures.

As a meandering channel migrates laterally, the point-bar fills the channel trough of the convex bank during the meander process (Frazier and Osanik, 1961, p. 124). The migrating bar can actually fill the entire depth of the meandering river trough (Allen, 1965a, p. 138). The basal contact of the point-bar and the underlying floodplain sediments is a scour surface which represents the bottom of the former channel over which the point-bar accumulated (refer to exposure R-4-B, Plate 9, Appendix C). The widespread bar belt sands of the alluvial valley possess the basal scour contact and represent a type of active channel fill.

The coarse bed load of a wide shallow distributary carpets the bottom of the channel. This material is transported mainly by flood waters (Lane and Borland, 1953, p. 305) and remains practically stationary during normal river stage. Accumulation of bed load sediments is a type of channel fill whose presence does not interfere with normal river processes. If the bed load begins to choke the channel, the river will gradually divert to another course. The bed load channel material takes the shape of sand waves (refer to Figure 13, p. 27). The downstream

migration of these structures produces large foreset accretion cross-beds (refer to exposure B-3, Plate 1-A, Appendix C). Gravel lenses are present in the troughs of these cross-beds. Numerous erosion planes are present throughout the bed load fill as the result of scour during periodic flooding. This type channel fill occurs in the straight and shallow distributaries of the lower delta plain.

Backswamp

The backswamp is the most widespread and areally predominant environment in the upper delta plain. The swamps are located between distributary courses and are best developed where the interdistributary troughs receive a minimal amount of sediment supply. The backswamp is also present in the alluvial valley but is not as widespread due to the large amount of coarse sediments accumulating in the floodplain. The relatively high relief present in the alluvial floodplain also prohibits widespread development of the swamp. Further seaward into the lower delta plain, the backswamp is of minor importance and grades into the saline marsh environment.

The swamp is characterized by abundant tree growth, as the area is normally not affected by marine processes. The stability of the upper delta plain together with the firm sediment substrate provide a favorable support for dense aboreal vegetation. Fossil stumps and roots are the most prominent indicators of the backswamp environment of Carboniferous delta complexes.

Overwash sediments carried over the tops of the natural levees by periodic flooding (Ferm et al., 1972, p. 122) settle in the interdistributary trough as discontinuous lenses of sand and silt interbedded with organic muds of the swamp. A continuous gradation of coarse to fine sediments occurs from the edge of the levee extending into the swamp (Morgan, 1970b, p. 35; Kesel et al., 1974, p. 463). Peat accumulation is thickest in the center of the swamp where detrital influx is minimal (Frazier and Osanik, 1969, p. 67). The sands, silts, and muds of the backswamp remain poorly sorted due to the absence of standing water in this environment. The stagnant, reducing conditions of the swamp are favorable for the formation of abundant iron carbonate concretions.

The swamp floodplain is partially inundated during the flood season. This area may exhibit overbank gullies which radiate down the flank of the natural levees (Russell, 1967, p. 40; refer to the levee of exposure P-6, Plate 5, Appendix C). The flood basins contain a network of small overwash channels (Allen, 1965a, p. 124). Fluvial features such as trough cross-beds, ripples, and suspension settled deposits are present in the discontinuous lenses of overbank sands and silts (Ferm et al., 1972, p. 122).

Small suspension-filled floodplain gullies are illustrated in exposure P-6 (Plate 5). The lenticular fine-grained sandstone bodies in the backswamp facies of exposures P-5 (Plate 4-A, Appendix C) and P-7 (Plate 4-B, Appendix C) are overbank gully-fill features. These small channels possess inactive fill features such as ripple cross-laminations and small-scale scours. These are developed in a similar fashion as the

larger inactive channel-fill units (Plate 10-A, Appendix C). McGowen and Garner (1970, p. 108) include the floodplain scour gully in their vertical section of the alluvial valley sequence.

Interdistributary Bay

The interdistributary bay is a shallow subsiding trough which acts as a collecting basin for overbank distributary sediments in the lower delta plain. It is by definition connected with the open sea but may reach high into the delta plain in the case of the elongate delta. The most striking feature of the bay is its widespread areal extent (Figures 9, 10, and 13, pages 18, 20, and 27, respectively). This area comprises most of the deltain platform (Fisk, 1961, p. 30) and is the most widespread component of the lower delta plain (Ferm, 1974, p. 88). An ancient marine embayment totalling over 2000 square miles is described in the Allegheny Group (Pennsylvania) by Ferm and Williams (1965, p. 143). The interdistributary bay sequences of the study area (Big Mary, Lower and Upper Grassy Spring levels) typify this widespread paleoenvironment. Each of these bay sections is coarsening-upward sequence which remains laterally uniform for at least six miles.

The depositional history of the initiation and filling of the bay includes several processes. As soon as the deltaic lobe is abandoned, marine transgression begins (Kolb and Van Lopik, 1966, p. 27). This marine inundation results in the deposition of a thin veneer of tidal flat and offshore shelly clays and limy muds (Donaldson, 1974, p. 64). The fossiliferous roof shales above each coal seam reflect this process.

Delta abandonment and marine transgression together are termed the destructive phase of a deltaic lobe (Fisher et al., 1969, p. 13). Continued subsidence may allow the bay to reach a depth of 5 m. The subsiding interdistributary trough provides a suitable gradient for distributary diversion (Frazier and Osanik, 1969, p. 73) which initiates a new constructive phase of the deltaic lobe (Fisher et al., 1969, p. 13).

Distributary diversion into the subsiding bay can result in several lithologic changes. Although the distributary is a relatively small feature, flooding will cause overwash sediments to spread far into the bay. The interdistributary bay thus serves as a settling basin for overbank material (Shepard, 1956, p. 2550). As the channel approaches it scours directly into the bay-fill sediments. Exposure B-3 (Plate 1-A, Appendix C) illustrates both of these processes. The bay-fill siltstone indicates sediment influx from a nearby distributary system. The massive sandstone represents the distributary channel which apparently scoured into the bay-fill. As the delta lobe progrades (contructive phase), the shallowing interdistributary trough fills with coarser sediments. Finally, the bay shallows enough to support vegetation (presumably subaerial).

The typical interdistributary bay-fill is an upward-coarsening sequence: shale, silty shale, siltstone, sandy siltstone, and fine-grained sandstone (refer to Plate 13, Appendix C). The lowermost unit of the upward-coarsening bay sequence is a black fossiliferous roof shale overlying a coal seam. The shale occurs directly above the coal seam and

is up to 2 m thick. This lithology represents a cessation of detrital influx. Articulated brachiopod valves and 10 cm pelmatozoan stalks in the shale are evidence of deposition in a low energy marine environment. This shale grades upward into a well-sorted, thinly-bedded, rippled siltstone which is the thickest unit of the bay-fill sequence. The silt represents overbank material collecting in the subsiding trough. The fine particles are winnowed by current and wave activity, and coarse silt covers the floor of the bay (Fisk et al., 1954, p. 83). Other characteristic features of the siltstone are bedded ironstone, and mascerated plant debris washed in or eroded from the nearby land (Ferm et al., 1972, pp. 20, 111, and 112). The top of the bay-fill section grades into a fine-grained sandstone. This lithology, in close proximity to an encroaching deltaic lobe, represents the final filling of the bay (Fisher et al., 1969, p. 19). Ripple laminations and abundant burrows are characteristic features of this part of the section (Ferm et al., 1972, p. 111).

Interdistributary bay sequences in the study area are generally thick. The siltstone above the Big Mary coal exposed in a highwall averages 20 feet (7 m) in thickness (Plate 1-A, Appendix C). This bay-fill siltstone is the predominant lithology from the Big Mary coal up to the Walnut Mountain coal. Although the outcrop in this 200-foot (66 m) interval is poorly exposed, the lithology is easily identified as well-sorted siltstone (exposure along road cuts and streams). It is proposed that the section between these two coal seams represents a lower delta plain bay-fill facies interrupted at intervals by a distributary channel or splay sediments from a nearby channel crevasse.

The total thickness and sedimentation patterns are readily observed in the bay-fill facies of the two Grassy Spring levels (Plate 13, Appendix C). These interdistributary bay sections are about 40 feet (12 m) thick and show uniform sedimentary patterns throughout the study area.

Although the interdistributary bay sedimentary pattern remains remarkably consistent throughout the study area, lithologic variations are observed locally in each of the three lower delta plain paleo-environments. In the Big Mary sequence, a distributary complex cuts through the siltstone. A crevasse-splay sand is also observed in the Big Mary highwayy (refer to Plates 1-A, 1-B, Appendix C). A small isolated bay bar is presented in the Lower Grassy Spring level (refer to Plate 13-D, Appendix C). The Upper Grassy Spring horizon contains two thin tabular limestone beds which are laterally persistent throughout the study area.

Interdistributary Bay Bar

A large bar shaped sand body is located in a section of the Lower Grassy Spring horizon (Plate 13-D). It measures approximately six m thick in the middle and tapers out at the edges. Total length of this unit is around 60 m. The sediment is a well-sorted, ortho-quartzitic sandstone. Thin foreset accretion beds are predominant. The basal contact of the sand with the underlying bay silt is sharp but not scoured. The sand grades at its tapered edge. The presence of this relatively small lensoid unit is unusual in the Grassy Spring bay-fill

section. No other fluvial features are apparent along the Lower Grassy Spring level. However, sand bars are common features in the interdistributary bay.

Two explanations seem feasible: a distributary mouth bar or an interdistributary bay bar. Coleman et al. (1972, p. 53) describe small subdeltas forming from crevasses in the Mississippi River Delta. These small arcuate subdeltas possess typical features of deltaic progradation (e.g., channels, distributary mouth bars, delta front sheet sands). Due to the absence of these fluvial features in the Lower Grassy Spring sand, a distributary mouth bar interpretation is deemed unlikely. The interdistributary bay bar interpretation seems to be the appropriate explanation. Fisk (1954, pp. 82, 89) explains the possible origin of the bay bar:

> Wave and current action winnows fine particles from bay bottom sediments, leaving coarser particles to floor parts of the bays, or gathers some of the sands and silts to form splits and subaqueous bars . . . spits and subaqueous bars are made up of clean, well-sorted, fine sands which grade into marginal zones of silty sands.

The lenticular bar sand in exposure 1-G-4 (Plate 13-D, Appendix C) possesses these same sedimentary parameters. The sands are well sorted and clean. A gradation of sand to silt is seen at the tapered edges and top margin. Thin foreset cross-beds predominate.

Distorted laminations are observed on the tapered edge of the bar structure. Small scale slumping of the cross-beds at the bar edge caused this distortion. The feature is referred to as "pinch and swell" structure and the slumping was the result of wave activity (Allen and Friend, 1968, p. 41; Ferm et al., 1972, p. 129).

IX. DESCRIPTIONS OF SELECTED SEDIMENTARY FACIES ALONG EACH COAL HORIZON

The exposures illustrated in Plates 1 through 13 (Appendix C) represent the prominent sedimentary facies which define the deltaic model suggested for the study area. The sedimentary facies diagrams have corresponding photographic sections (except Plates 1-B, 13-C, 13-D) that illustrate the more important features in each selected exposure.

The best method of interpreting these plates is to locate the photographic section for each selected exposure. Each photo is placed directly beneath its respective diagram. Next, the drafted features labeled in each sketch should be compared to the actual features shown in the photographic section. To interrelate all lateral facies in a sedimentary facies diagram, it is necessary to refer to Table I which lists every large scale sedimentary feature in each selected exposure. The sedimentary facies diagrams, photographic sections, and Table I provide the basis for proposing the fluviodeltaic model. Detailed descriptions of individual sedimentary features and lithologic types are listed in Table III (Appendix A) and Table V (Appendix B).

There are fewer selected exposure for the Big Mary and Grassy Spring horizons than for the Pewee or Rock Spring levels. This is due to the relative lack of interrelating lateral facies along the Big Mary and Grassy Spring highwalls. It was necessary to concentrate the study for the Pewee and Rock Spring exposures where there was abundant lateral facies changes. The Walnut Mountain horizon was not included in the

TABLE I

DEPOSITIONAL FACIES ALONG THE STRIPPED EXPOSURE IN THE STUDY AREA

Big Mary Horizon (elev. 2300 feet) (690 m)	Stripped continuously for three miles. Four exposures were chosen. All four possess the same basic sedimentary facies:	
	B-1 through B-4	1. LOWER DELTA PLAIN DISTRIBUTARY 2. TWO LOWER DELTA PLAIN CREVASSE-SPLAYS 3. COARSENING-UPWARD INTERDISTRIBUTARY BAY FILL 4. FOSSILIFEROUS ROOF SHALE 5. CHANNEL BANK SLUMP
Walnut Mountain Horizon (elev. 2500 feet) (750 m)	This level is almost completely resloped. Several isolated exposures show small active channel fills, splays, and bay fill sequence. Major sedimentary facie:	
		1. BRACKISH WATER FAUNA FROM THE ROOF SHALE
Pewee Horizon (elev. 2550 feet) (765 m)	Stripped continuously for six miles. Many variable sedimentary features. The different facies are listed according to specific exposure.	
	P-1-A,B	1. LAKE DEPOSIT 2. LEVEE FLANK DEPRESSION 3. FLOOD DEPOSIT 4. BACKSWAMP SEQUENCE
	P-2	1. SMALL SCALE CHANNEL BANK SLUMP 2. BACKSWAMP SEQUENCE
	P-3	1. SMALL ACTIVE CHANNEL FILLS 2. BACKSWAMP SEQUENCE 3. OVERBANK FLOODPLAIN GULLY
	P-4	1. ACTIVE CHANNEL FILL 2. BACKSWAMP SEQUENCE 3. SEATROCK PAVEMENT SHOWING FOSSIL BARK AND STIGMARIA, IN-SITU
	P-5	1. SLUMPED NATURAL LEVEE 2. BACKSWAMP SEQUENCE
	P-6	1. UPPER POINT-BAR ACCRETION CHANNEL FILL 2. LEVEE SEDIMENTS 3. BACKSWAMP SEQUENCE

TABLE I (continued)

	P-7	1. BACKSWAMP SEQUENCE 2. FOSSIL STUMPS
	P-8	1. ACTIVE CHANNEL FILL 2. BACKSWAMP SEQUENCE 3. THREE NATURAL LEVEES
	P-9	1. ACTIVE CHANNEL FILL 2. BACKSWAMP SEQUENCE 3. TWO NATURAL LEVEES
Rock Spring Horizon (elev. 2750 feet) (825 m)	Stripped continuously except for a two-mile covered section in the middle of the valley. The different facies are listed according to specific exposure.	
	R-1	1. LOWER POINT-BAR BED LOAD CHANNEL FILL 2. ALLUVIAL BACKSWAMP SEQUENCE
	R-2	1. LOWER POINT-BAR BED LOAD CHANNEL FILL 2. UPPER POINT-BAR ACCRETION FILL 3. ALLUVIAL BACKSWAMP SEQUENCE
	R-3	1. LOWER POINT-BAR BED LOAD CHANNEL FILL 2. ALLUVIAL BACKSWAMP SEQUENCE
	R-4-A	1. LOWER POINT-BAR BED LOAD CHANNEL FILL 2. ALLUVIAL BACKSWAMP SEQUENCE
	R-4-B	1. UPPER POINT-BAR ACCRETION CHANNEL FILL 2. FINE GRAINED UPPER POINT-BAR SEDIMENTS 3. ALLUVIAL BACKSWAMP SEQUENCE
	R-5	1. ACTIVE CHANNEL FILL 2. INACTIVE CHANNEL FILL 3. NATURAL LEVEE 4. ALLUVIAL BACKSWAMP
	R-6	1. MASSIVE UPPER POINT-BAR FEATURE
	R-7	1. ALLUVIAL FLOOD DEPOSIT 2. LARGE FLOOD/SLUMP FEATURE 3. LOAD CAST FEATURES

TABLE I (continued)

	R-8	1. NATURAL LEVEE 2. ALLUVIAL FLOOD DEPOSIT 3. CHANNEL SCOUR 4. LOAD CAST FEATURES 5. ALLUVIAL BACKSWAMP
	R-9	1. TWO ACTIVE CHANNEL FILLS 2. ALLUVIAL BACKSWAMP
Lower Grassy Spring Horizon (elev. 2850 feet) (865 m)	Strip exposure is continuous for approximately 5 miles. The marine bay fill sequence is very uniform throughout the whole study area. Exposures LG-1 through LG-3 possess the same sedimentary facies.	
	LG-1 through LG-3	1. FOSSILIFEROUS MARINE ROOF SHALE 2. UPWARD-COARSENING BAY FILL SEQUENCE; SHALE THROUGH FINE GRAINED SANDSTONE 3. FRIABLE CALCAREOUS SANDSTONE
	LG-4	1. FOSSILIFEROUS MARINE ROOF SHALE 2. UPWARD-COARSENING BAY FILL SEQUENCE; SHALE THROUGH FINE GRAINED SANDSTONE 3. INTERDISTRIBUTARY BAY BAR
Upper Grassy Spring Horizon (elev. 2900 feet) (870 m)	Strip exposure is intermittently continuous. Total outcrop is approximately 3 miles. The three exposures studied possess the same lithologic sequences. One highwall shows two of the Upper Grassy Spring sections as a continium of the Lower Grassy Spring level. L U G -1 and L U G -2)	
	U G -1 through U G -3	1. FOSSILIFEROUS ROOF SHALE 2. TWO THIN, UNIFORM LIMESTONE BEDS 3. UPWARD-COARSENING BAY FILL SEQUENCE; SHALE THROUGH FINE GRAINED SANDSTONE

sedimentary facies diagrams because of its very limited highwall outcrop.

Plate 1-A
Big Mary Exposure No. 3: Channel, Interdistributary Bay Sequence

This exposure displays three major lower delta plain facies. These are the upward-coarsening bay-fill, distributary channel, and subaqueous splay.

This marine bay-fill begins with a basal seat-rock unit which is generally not exposed in the highwall. The overlying Big Mary coal seam is the lowermost observable unit in the stripped outcrop. The coal seam which represents peat accumulation is overlain by a fossiliferous marine shale. This shale is approximately 2 m thick and grades upwards into an interdistributary bay siltstone. The bay-fill unit is truncated at the top of the highwall by a massive channel sandstone. The shale-siltstone sequence is interbedded with ironstone beds and several thin coal rider seams.

The lower delta plain distributary is a wedge-shaped body of coarse-grained sediments possessing a basal scour surface which truncates the underlying siltstone laminae. The channel edge is the upward-thinning end of the clastic wedge, which truncates the bay-fill siltstone and also a tabular splay unit. A thin lag conglomerate overlies the basal scour surface of the entire channel. The channel also exhibits foreset accretion beds and scour pool gravel lenses (Figure 13, p. 27).

The subaqueous splay is the tabular coarse-grained sandstone unit beneath the distributary sands. There are two splays exposed along the

Big Mary highwalls. The splay in Plate 1-A extends uniformly along outcrop for at least three miles (4.5 km). Ripples and randomly oriented plant material were noted in the splay unit.

Plate 1-B
Big Mary Exposure No. 1:
Interdistributary Bay Sequence

Characteristic of this exposure are the upward-coarsening bay-fill and the two splay units. The bay-fill begins with the seat-rock and coal seam at the bottom of the highwall (not observable in Plate 1-B). The bay sequence continues from the fossilferous roof shale upwards into a sandy siltstone up to the top of the highwall. Bedded ironstone is abundant and coal riders are present. This bay-fill section is a lateral continuation of the section observed in exposure B-3 which is approximately two miles (3 km) to the northwest. The two subaqueous splays are also continuations of those present in exposure B-3. The channel sandstone at the top of the highwall is a part of the same distributary system illustrated in Plate 1-A.

Plate 2-A
Pewee Exposure No. 1-A:
Interdistributary Basin Flood Feature

An upper delta plain lake and a massive flood sand unit are the major sedimentary facies of exposure P-1-A. The seat-rock, coal seam, and fossil flora roof shale (in ascending order) are the lowermost units in the highwall outcrop. Overlying the shale is a sequence of tabular siltstone beds. These horizontal laminations are thinly bedded and lack features (i.e., cross-beds) that indicate active sediment transport. This unit is interpreted as being a fresh-water lake. The large vertical

fossil trees illustrated in the diagram of Plate 2-A are believed to have been rooted in the subaqueous substrate of the lacustrine environment. Suspension settling of fine-grained sediments buried these tree trunks under 1.8 m of silt. The top surface of this siltstone was also a substrate on which smaller trees grew after the lake had filled considerably with rapid siltation. Overlying the siltstone unit is a massive flood sandstone sequence. These sandstone beds are contorted and possess a basal scour surface. Several large trees were rapidly buried under 3 m of this sand. The smaller trees which were rooted at the top of the siltstone and covered by the flood deposit are seen bent all in the same direction. It is suggested that the rapidly deposited sands were mobile, and that the whole sequence of liquified sediments crept downslope into the small levee flank depression (the lake basin). The contorted beds support the mass movement of the flood sediment. This sandstone also possesses several small channel fill features.

Plate 2-B
Pewee Exposure No. 1-B:
Interdistributary Basin Flood Feature

Pewee exposures 1-A and 1-B are adjacent but perpendicular outcrops on the same strip mining level. Exposure P-1-B is a cross section of the flood splay sequence of exposure P-1-A (Figure 16, p. 38). In Plate 2-B, the splay beds are imbricated and truncate downwards. This illustrates the overlapping nature of flood splay units emptying through a crevasse into the floodbasin. The lake siltstone sequence and bent trees are also evident in exposure 1-B. The distal ends of the splay units resemble large foreset accretion cross-beds.

Plate 3-A
Exposure P-3: Channel,
Backswamp Association

The upper delta plain floodbasin and channel features are observed in Pewee exposure 3. The floodplain illustrated in the photographic section of Plate 3-A is predominantly a sequence of fine-grained sandstone and siltstone. Two vertically stacked channel features are present which were filled with planar cross-beds of subgraywacke sandstone. Several small gully scour and fill features are located in the sandstone/siltstone floodplain section. The sandstone/siltstone overbank sequence grades laterally into a backswamp sequence of sandstones and shales.

Plate 3-B
Exposure P-4: Channel,
Levee Association

This outcrop consists of two vertically stacked upper delta plain channel fill features and their associated floodplain facies. A section of the upper channel fill sequence has been deformed by slumping. The upper channel is a clastic wedge of coarse-grained sandstone which grades laterally into overbank and levee fine-grained sediments. In situ Calamites are present in the levee facies. The upper channel feature consists of a subgraywacke sandstone that originated as an active channel fill from accumulation of bed load material. These coarse-grained sediments were subsequently moved downstream by gentle bottom currents and took the form of large sand waves. The lower channel feature (partially covered) appears to have originated in the same manner. The upper channel basal scour surface overrides the lower channel and is truncated against Pewee coal seams. This channel grades laterally into shale and siltstone of the backswamp facies.

Plate 4-A
Pewee Exposure No. 5:
Interdistributary Backswamp Feature

Exposure P-5 illustrates a typical upper delta plain backswamp sequence. The major volume of sediments in this outcrop are the carbonaceous black shales and silty shales which represent the ancient swamp. These shales are interbedded with thin, discontinuous sandstone units that resulted from overbank flood deposition. The lenticular, fine-grained sandstone beds are abundantly rippled and trough cross-bedded.

The black shales are rooted with large Stigmaria roots preserved in outcrop. Randomly oriented plant leaves and debris are common throughout the shale beds. In situ Calamites are characteristic of the fine-grained overbank sandstones.

Features indicative of the fluvial system are observed in Plate 4-A. Several minor channels filled with medium to coarse-grained sandstone are present in the outcrop. A slumped section of a small natural levee was preserved with several large in situ Calamites. The levee beds are typically fine-grained sandstone laminae interbedded with shale. The lowermost sandstone unit of exposure P-4 and the levee feature are probably part of a large levee sequence.

Plate 4-B
Pewee Exposure No. 7:
Interdistributary Backswamp Sequence

This outcrop represents the backswamp of the upper delta plain. The swamp sediments are an accumulation of organic material and mud. These carbonaceous shales and siltstones contain the lenticular

fine-grained sandstone beds from overbank deposition. The black shales are abundantly rooted and rippled. In situ Calamites are present in the fine-grained sandstone. Another feature of these overbank units are large fossil stumps. It appears that these trees grew in the overbank sands for support in the subaqueous swamp. The roots extend from the sands into the underlying muds.

Plate 5
Pewee Exposure No. 6
Channel, Levee, Backswamp Association

An example of active channel fill is evident in exposure P-6. The channel is observed having a concave shape at one end and a tapered edge at the opposite end. The basal scour surface truncates underlying siltstone and fine-grained sandstone beds. The active fill of the channel consists of coarse orthoquartzitic sandstone beds which originated as foreset accretion cross-beds of a point-bar. Evidently, the point-bar filled the shallow channel bottom near the convex bank as the channel itself was migrating laterally in the direction of the concave (cut) bank. The tapered edge of the channel fill represents the leading edge of the point-bar descending toward the deeper parts of the channel.

The lateral interrelationship between the channel and its overbank sequence is illustrated in Plate 5. The overbank sediments are predominantly fine-grained sandstones that contain abundant in situ Calamites. It appears that this suite of overbank sediments is a natural levee sequence. Several small cut and fill channel features are evident in the levee stratification. These are probably overbank gullies which radiated down the flanks of the levee into the floodbasin.

The levee sediments grade laterally into shale and shaly siltstone that contain thin lenses of fine-grained sandstone. This facies is interpreted as a typical backswamp of the upper delta plain. A small fluvial channel is observed in this backswamp section.

The coal seam is approximately 0.8 m thick and the overlying black shale contains abundant terrestrial plant material. This is typical of the coal and its shale throughout the Pewee horizon.

Plate 6-A
Pewee Exposure No. 8:
Channel, Backswamp Association

This selected outcrop exhibits the fluvial channel, backswamp association of the upper delta plain. The channels were filled with bed load sediment deposited during successive periods of high river stage. The channel sandstone beds are planar cross-stratifications which generally parallel the concave shape of the channel. A basal scour surface and lag conglomerate are present in the larger of the two channels illustrated in Plate 6-A. Also located along the basal scour surface is a fossil stump which evidently snagged along the channel floor (not visible in photographic section). Fossil plant stems and branches are oriented along the bedding planes of the channel.

Plate 6-B
Pewee Exposire No. 9:
Channel, Levee Association

Several excellent examples of the upper delta plain levee are illustrated in exposure P-9. The levee consists of laminar fine-grained sandstone beds regularly interbedded with thin shale beds. A paleo-depositional slope, typical of the levee, is apparent in the photographic

section of Plate 6-B. *In situ Calamites* are present in the laminar bedding sequence.

The top of the levee (in section L-L') is truncated by an active channel fill feature. The channel is a concave wedge of coarse sediments which thins laterally into backswamp shales and siltstones. The levee grades laterally into the swamp shales and siltstones.

Plate 7-A
Rock Spring Exposure No. 1:
Point-Bar Feature

A coarse-grained point-bar sequence and its related floodbasin sediments are exhibited in exposure R-1. These two facies are the two most prevalent lithogenic units along the Rock Spring horizon which represents the lower alluvial valley paleoenvironment. The point-bar sequence is a section of a widespread and laterally persistent meanderbelt sandstone. The stratification type is the foreset accretion cross-bed. The point-bar sequence possesses a basal scour surface which suggests that the foreset cross-beds resulted from point bar migration over the channel scour near the convex bank of the stream.

The Rock Spring coal seam is approximately 1 m thick and is overlain by a roof shale containing abundant terrestrial plant material. The floodplain sediments are shale, siltstone and fine-grained sandstone.

Plate 7-B
Rock Spring Exposure No. 2:
Point-Bar Feature

Most prominent in this outcrop are point-bar foreset accretion cross-beds. The cross-beds are relatively steeply inclined, and a basal scour surface truncates underlying shales and siltstones. The sandstone

is interbedded with thin shale beds. It is proposed that these foreset accretion strata are subaqueous point-bar cross-beds that carpeted the channel floor near the convex bank. Evidence for this interpretation are the poorly sorted nature of the sandstone, basal scour surface, and steeply inclined beds.

The underlying and laterally interfingering shales and siltstones are indicative of the alluvial floodplain paleoenvironment. Roots, stumps, and *in situ* plants are characteristic features of this facies.

Plate 8-A
Rock Spring Exposure No. 3:
Point-Bar Feature

A subaqueous point bar sequence is illustrated in Plate 8-A. The bedding type is the foreset cross-stratification, and these beds are relatively steeply inclined. This sandstone unit is a section of meanderbelt point-bar sequence which is laterally persistent throughout the Rock Spring level. The point-bar possesses a basal scour surface and the sediment is poorly sorted. The fine-grained sediments of the alluvial valley floodplain occur as the thinly bedded shales and siltstones that underlie the point-bar unit.

Plate 8-B
Rock Spring Exposure No. 4-A:
Point-Bar Feature

This outcrop contains a subaqueous point-bar section and a fine-grained sediment sequence indicative of the alluvial floodplain. The point-bar consists of large foreset accretion cross-beds. This unit has a basal scour surface, poorly sorted sediments, and steeply inclined beds which suggest the lower (subaqueous) point-bar facies.

The alluvial floodplain is well represented in this selected exposure. The channel scour truncates thin laminar shale/siltstone beds of the backswamp. The point-bar also interfingers laterally with the fine-grained floodbasin sequence. The shales and siltstones are abundantly rooted and contain fossil stumps. Thin lenticular beds of overbank fine-grained sandstone are interbedded with the backswamp sediments.

Plate 9
Rock Spring Exposure No. 4-B: Point-Bar Accretion Beds, Active Channel Fill

Several depositional facies of the lower alluvial valley paleoenvironment are evident in exposure R-4-B. The predominant lithogenic unit in this outcrop is the subaerial point-bar sequence. These orthoquartzitic sandstones are bedded as foreset accretion and trough cross-stratifications. The wedge shaped channel fill illustrated in photographic section Q-Q' has a sequence of foreset cross-beds that built toward the opposite side of the stream. Presumably the point-bar migrated the entire width of the channel and filled the deeper parts near the concave bank. The channel fill point-bar beds truncate backswamp shales and siltstones.

Fine-grained sandstone and siltstone beds are regularly interbedded as a part of a levee/overbank sequence (photographic section R-R'). *In situ Calamites* and roots are present in the levee sediments. The levee is overlain by the coarse-grained point-bar beds. The basal surface of the bar sequence is apparently not scoured.

The Rock Spring coal seam is approximately 1.3 m thick and contains abundant sulfide mineralization. The roof shale is profused with plant debris. The overbank/floodplain sediment consists mainly of fine-grained sandstone and siltstone.

Plate 10-A
Rock Spring Exposure No. 5:
Channel, Levee Association

The interrelationships between an alluvial valley channel system, levee, and backswamp are demonstrated in Plate 10-A. The base of the highwall exposes the Rock Spring coal which is approximately 1 m thick. The seam is overlain by the typical Rock Spring black roof shale which grades upwards into a silty shale representative of the backswamp. These shale beds are rooted and thinly laminated.

The swamp sediments grade upwards into a levee sequence which is a parallel bedded fine-grained sandstone. The slight depositional slope of the levee beds and the abundant roots are characteristic features of this unit. The levee is truncated by a channel basal scour surface (photographic section S-S').

This channel is an example of inactive fill. The bedding type is predominantly climbing ripple lamination, and the particle size ranges from fine-grained sandstone to sandy siltstone. The alluvial valley sedimentary environment may contain these fine-grained channel plugs indicative of the neck cut-off process.

The inactive fill channel is overlain and truncated by an active fill channel feature. The sediment is a poorly sorted subgraywacke sandstone, and the beds roughly parallel the basal scour surface. This

active fill is representative of bed load deposition in the deeper section of the stream.

Evidently, these vertically stacked channels are the result of rapid alluvial migration in a narrow floodplain.

Plate 10-B
Rock Spring Exposure No. 6:
Upper Point-Bar Feature

This massive coarse-grained sandstone is a typical example of the meanderbelt facies of the Rock Spring horizon. It is known as the Frozenhead Sandstone, a characteristically orthoquartzitic and multicross-bedded unit. Average thickness is 8 m. Foreset accretion and trough (festoon) cross-beds are codominant. Intergranular cement is noticeably lacking. Large weathering vugs are common. There is present a basal scour surface which truncates underlying shale and siltstone beds.

This sandstone sequence is an upper point-bar which remained partially exposed above the water line of the alluvial channel. The sediments were apparently well washed and drained. Evidence for these observations are the lack of cement or matrix in the rock, the ortho-quartzitic texture of the sediment, and the festoon cross-beds. The large vugs reflect former plant stems and debris once trapped along the bedding planes and subsequently decayed from the draining of the bar sediments.

Plate 11
Rock Spring Exposure No. 7:
Interdistributary Basin Flood Feature

An alluvial valley flood deposit is illustrated in Plate 11. This section of the Frozenhead Sandstone is not typical of the

multicross-bedded meanderbelt sand of the Rock Spring horizon. It is an accumulation of slumped flood splay deposits. The massive sandstone of exposure R-7 does, however, grade laterally into a regular alluvial valley channel, and backswamp sequence.

The sandstone is a poorly sorted subgraywacke and is arranged in thick beds which are interbedded with shale lenses. Randomly oriented plant stems and debris are mixed throughout the sandstone beds. In situ Calamites are described from the shale units. A basal scour truncates the underlying swamp shale, and numerous scour surfaces are present throughout the massive unit.

Load casts and huge slump blocks are characteristic features of this flood deposit. The shale lenses are tilted approximately 30 degrees as are the bounding sandstone beds. Apparently, the lowermost sands splayed into the floodbasin and a period quiescence followed. After deposition of the muds, another flood episode occurred which resulted in successive splay sands. This sequence of events probably took place over several years. Evidence for this interpretation are the in situ plants and the thick shale beds interbedded between the flood sands.

Plate 12-A
Rock Spring Exposure No. 8:
Interdistributary Basin Flood Feature

Exposure P-8 is an alluvial channel, backswamp sequence which has been affected by a flood episode. The normal alluvial lithogenic features are present such as a concave shaped channel, natural levee, and overbank/floodplain sediments. However, heavy influx of bed load material into the channel caused deformation of preexisting bed load strata and the underlying beds of the floodplain sequence.

The basal scour surface of the channel truncates the crest of a natural levee. The same scour which truncates the overbank strata also possesses load cast features which bulge downward into the underlying shales, siltstones, and fine-grained sandstones.

The bed load stratification is essentially bedded parallel to the concave shape of the channel. Rapid deposition of the liquified sediments caused deformation of the sandstone beds. The sand grains are poorly sorted and are mixed with plant debris.

Plate 12-B
Rock Spring Exposure No. 9:
Channel, Backswamp Association

Plate 12-B illustrates a typical alluvial valley channel sequence which has been preserved subsequent to an abnormally heavy sediment influx. The channels filled quickly with bed load material and subsidence in the fluviodeltaic environment permitted preservation of these units. The normal sandstone facies of the alluvial valley are the point-bar meanderbelt sandstones; however, these facies reflect scour and fill deposition. Rapid sediment influx is reflected by the load casts present along the basal scour surface of the channel.

The overbank/floodplain sequence consists of fine-grained sandstone stratifications regularly interbedded with shale and siltstone beds. The alluvial valley floodbasin contains coarser overbank sediments than that of the upper delta plain. Roots and *in situ* plant fossils are common.

The coal (1 m thick) and its roof shale, typical of the Rock Spring horizon, are abundantly mixed with terrestrial plant debris.

Plate 13-A
Upper Grassy Spring Exposure No. 1:
Interdistributary Bay Sequence

This is an example of upward-coarsening sequence of the Upper Grassy Spring level. The coal seam is approximately 0.8 m thick and is overlain by a fossiliferous (marine fauna) roof shale (refer to Table II). The shale sequence is approximately 1 m thick and is capped by a well-indurated (biomicrite) limestone (.5 m) thick that possesses sharp top and bottom contacts. Above the limestone is another sequence of black marine shale (.7 m thick) which is in turn capped by another thin (.5 m) biomicrite. The black fossiliferous marine shale again overlies the limestone. This shale sequence is approximately 2.5 m thick and grades upwards into a (7 m thick) siltstone section. The siltstone also grades vertically into an overlying sequence of fine-grained sandstone beds.

The marine shale laminations are very thinly bedded and contain abundant marine fossils and randomly oriented plant material. The only distinction between the fossiliferous roof shale and the overlying marine shale units is the relatively thick concentration of marine fauna in the roof shale. The limestones are tabular units which remain laterally uniform throughout the entire study area. These biomicrite beds lack carbonaceous material.

The marine siltstone is a well sorted, rippled sequence of thinly bedded laminations. Marine fossils are present but scarce, and randomly oriented plant debris is common.

The fine-grained sandstone beds are also thin and rippled, but the grains appear to be moderately well sorted. There is relatively little carbonaceous plant debris. The section is approximately 4 m thick.

TABLE II

PALEONTOLOGY IN THE ROOF SHALE ABOVE EACH COAL SEAM

	Big Mary Roof Shale	Walnut Mt. Roof Shale	Lower Grassy Spring Roof Shale	Upper Grassy Spring Roof Shale
Brachiopods	Lingula Chonetes Mesolobus Spirifer Productus Derbyia		Lingula Chonetes Mesolobus Spirifer Productus	Lingula Chonetes Mesolobus Spirifer Productus
Pelecypods	unidentified bivalves	Naiadites	Pecten	Pecten
Gastropods	unidentified gastropods	small unidentified gastropods	unidentified gastropods	unidentified gastropods
Cephalopods	orthocone cephalopod			orthocone cephalopod
Ostracodes		small ostracodes		
Bryozoans	encrusting bryozoans			
Pelmatozoans	pelmatozoan stalks (up to 10 cm length		pelmatozoan stalks	pelmatozoan stalks

Vertical burrows are common throughout the siltstone and fine-grained sandstone sections. Bedded ironstone is present throughout the shale and siltstone sequences. Seat rock underlies the Upper Grassy Spring coal seam.

Plate 13-B
Lower Grassy Spring Sequence No. 1:
Interdistributary Bay Sequence

Exposure LG-1 is typical of the upward-coarsening sequence of the Lower Grassy Spring level. The section begins at the bottom of the highwall with 1 m thick coal seam which usually contains a 7 cm thick "clay parting" bed. This parting is bedded in the middle of the coal seam and remains laterally persistent.

Overlying the Lower Grassy Spring coal is a fossiliferous (marine faunal) roof shale (Table II) approximately 1 m thick. The black roof shale grades upwards into a shale that contains relatively few marine fossils.

This shale grades upwards into a well sorted, rippled, thinly bedded siltstone. The sequence is approximately 7 m thick and grades vertically into a fine-grained sandstone.

The sandstone is rippled, moderately well sorted and thinly laminated. The sequence is approximately 4 m thick.

A thin (0.8 m) and unusual unit is bedded between the siltstone and fine-grained sandstone. It is descriptively termed a "friable calcareous sandstone." The color is brown, grain size coarse, a cement lacking. Impressions of marine fossils are present but very scarce. It is suggested that this was once a calcareous sandstone which was subsequently leached of its carbonate content (matrix and cement).

Vertical burrows are common in the siltstone and fine-grained sandstone. Ironstone is abundantly interbedded throughout the shale. Seat rock underlies the Lower Grassy Spring coal seam.

Plate 13-C
Lower Grassy Spring and Upper Grassy Spring Exposure No. 1: Interdistributary Bay Sequence

This photographic section is an overall view of both Grassy Spring coal seam highwalls in vertical succession. The total height of highwall outcrop of the two levels (which are vertically continuous) is approximately 25 m.

Plate 13-D
Lower Grassy Spring Exposure No. 4: Interdistributary Bay Bar

This is an unusual outcrop of the upward-coarsening Lower Grassy Spring bay-fill paleoenvironment. Throughout the study area, this bay-fill (with the exception of LG-4) is devoid of coarse-grained sandstone bodies.

This atypical sandstone facies (4 m thick) is a bar unit bedded in the middle of the siltstone section of LG-4. Foreset accretion cross-beds are the dominant stratification, and the sediment is a well-sorted orthoquartzite lacking of carbonaceous material or fossils. The thinning edge of the bar unit possesses "pinch and swell structures" (not visible in Plate 13-D) which are indicative of wave attack on cross-beds. This orthoquartzite sequence is interpreted as a marine bay (interdistributary) bar.

X. PALEONTOLOGY

Fossil fauna and flora are characteristically abundant along the exposures of the study area. Table II, p. 73, lists the more common invertebrate faunas present in the roof shales above the Big Mary, Walnut Mountain, and Upper and Lower Grassy Spring coal seams. Paleofloras are particularly abundant and well preserved in several localities along the Pewee and Rock Spring horizons.

Analysis of the marine faunas was limited to observation in the field; therefore, no detailed descriptions of the fossil forms are given in this study. However, a general interpretation for the paleoenvironment of these black fossiliferous shales and limestones can be made by examining the sedimentary features of the lithologies in which the fossils are found.

Two marine paleoenvironments of the lower delta plain can be identified in the study sequence by the presence of invertebrate faunas. These sequences include shallow bay (Big Mary, Lower and Upper Grassy Spring levels) and brackish water lake (Walnut Mountain level) deposits.

The lower delta plain is commonly an area of widespread peat growth (Frazier and Osanik, 1969, p. 65). A cessation in sediment supply with continued subsidence will cause the lower delta plain to be inundated by the marine bay. Immediately following marine transgression, this area seems to have been a suitable environment for invertebrate faunal communities. The presence of articulated brachiopods and long

pelmatozoan stalks (Big Mary horizon) indicate that this paleoenvironment was devoid of much current activity. Wanless et al. (1970, p. 224) explain that Pennsylvanian deltas prograded into very shallow seas. Tidal range was small and current activity generally low. In fact, various studies refer to these embayments as "restricted marine environments" (Horne et al., 1974, p. 103; Ferm et al., 1972, p. 112). The fossiliferous roof shale of the Big Mary horizon is an example of the restricted marine embayment. Characteristic of this lithofacies is the dense black shale in which the occurrence of ironstone nodules and small amounts of pyrite suggest reducing stagnant conditions.

The fossiliferous roof shale interval of the Upper Grassy Spring level contains two tabular biomicrite beds. These units are about 0.5 m thick and appear as resistant and compact rocks. This fossil horizon indicates faunal habitation of a further offshore and less reducing part of the interdistributary bay. Current and wave activity would be more prevalent in this situation.

These marine zones (limestone and black shale) are relatively thin but very widespread. The thickest fossiliferous roof shale of the study area is a 2 m section of shale and limestone (Upper Grassy Spring). The fossiliferous shales and limestones are uniform and persistent for a distance of at least six miles in the Emory River Valley. This coincides with the general physiography of the lower delta plain. Wanless et al. (1970, p. 241) reports a thin, uniform limestone being traced for over 100 miles in a Pennsylvanian sequence of Illinois.

Abundant vertical burrows are present in the fine-grained sandstone unit which caps the upward-coarsening sequence of the Upper Grassy Spring interval. These burrows are in a sandstone that is rippled and current-sorted which suggests a marine environment of moderate current and wave activity.

The roof shale of the Walnut Mountain coal represents a brackish or fresh-water paleoenvironment. The pelecypod Naiadites, small gastropods and ostracodes, are identified from this horizon (Glenn, 1925, p. 331). The Naiadites fauna is very abundant, and the fossils are pyritized. The occurrence of pyrite and the carbonaceous shale suggest reducing conditions for the paleoenvironment of this unit.

There appears to be no definite agreement concerning the paleoenvironment of bivalves such as the Naiadites, though there does seem to be a consensus that this fauna did not exist in the normal open-water marine environment.

Glenn (1925, p. 330) described Naiadites from the Emory River Valley. He classified this pelecypod as a brackish-water organism. Belt (1968, pp. 128, 150) identified specimens of Naiadites from the Carboniferous of the Northern Appalachians, and assigns them a fresh-water lake habitat. Ferm and Williams (1965, p. 323) list two fresh-water pelecypods from the Allegheny Group: Carbonicola and Anthraconauta. These bivalves are very similar in appearance to the Naiadites. Belt (1968, p. 150) describes all three as once existing in the same paleoenvironment. This problem does not affect the interpretation of Walnut Mountain level. It is important that the Naiadites and ostracodes were not marine and does

represent the transitional paleoenvironment of the Walnut Mountain horizon. The interval between the Big Mary coal and the Pewee coal is a transitional from the lower to the upper delta plain. Marine facies dominate the former section, and the terrestrial environment dominates the latter. Whether the Walnut Mountain fauna represents a brackish bay or fresh-water lake is deemed to be of no great consequence.

Terrestrial flora is abundantly distributed throughout each coal horizon of the study area; however, only the Pewee and Rock Spring seams are characterized by these fossil plants in living position. The lower delta plain and marine facies produced only transported accumulations of terrestrial plant material.

The plants of the Pewee and Rock Spring levels have been preserved by in situ burial from overbank siltation, major flooding, and by entrapment in the channel bed lag deposits. Transported plant debris may also accumulate in the floodplain in thin tabular or lenticular beds.

Specific plant types were identified in several depositional facies of the terrestrial highwalls. Calamites is a characteristic feature of the thin but distinct natural levees of the Pewee level (levees were not commonly preserved in the Rock Spring paleoenvironment). Perhaps Calamites grew on the drier and more aerated substrate of the levee rather than the semiaquatic conditions of the backswamp. These plants were buried by suspension settling of fine-grained sand from periodic overbank flooding. It is also suggested that the Calamites could withstand partial burial from the relatively large amount of sediments deposited on the levee.

Upright tree stumps are common throughout the floodplain facies and levees of the terrestrial coal horizons. It appears that many of the stumps from the backswamp sections were rooted in lenticular sand deposits, usually about 1 m thick. Two possible explanations are suggested for this occurrence: that the large trees needed to root in sand for support or that a small perimeter around the tree was scoured during overbank flooding, and the sand filled the small depression. The *in situ* plant types identified from the backswamp paleoenvironment are *Lepidodendron*, *Sigillaria*, and *Calamites*. Major flooding in the Pewee floodbasin resulted in trees being buried to a depth of 5 m.

Transported plant debris is common in the backswamp deposits. Most of this material is unidentifiable, and randomly scattered along bedding planes. However, the roof shale of the Pewee coal is characterized by accumulations of nontransported *Pecopteris*-type leaves.

XI. DISCUSSION OF THE PALEOENVIRONMENTS ALONG EACH COAL HORIZON

Big Mary Paleoenvironment

The Big Mary horizon is a lower delta plain paleoenvironment (Figure 8, p. 18). The upward-coarsening sequence represents a marine interdistributary bay environment. The greatest concentration of marine fauna in the Big Mary highwall is in the roof shale of the coal seam. The fauna is diverse and very concentrated. The shells of the brachiopods and molluscs appear to be lacking calcareous material; this is probably the result of diagenetic alteration.

It is suggested that this marine assemblage occupied the very shallow (1 to 3 m deep) marine bay shortly after subsidence of the peat cover. With continued subsidence, the bay became deeper (up to 7-8 m) and the environment became unsuitable for the marine fauna.

Poor water circulation and reducing conditions due to the organic material were responsible for the formation of the ironstone concretions in the shallow bay. These concretions were probably formed diagenetically shortly after sedimentation.

The channel fill sequence at the top of the Big Mary highwall illustrates a large, wide distributary of the lower delta platform which migrated over the interdistributary bay fill. The channel was straight and the point-bars were not well developed. The topography of the interdistributary trough was flat and featureless. This allowed a crevasse splay to travel unimpeded for miles in the subaqueous floodbasin.

Walnut Mountain Paleoenvironment

The Walnut Mountain highwall caps a vertical section of sediments nearly 100 m thick deposited in a lower delta plain-marine bay environment similar to that described at the Big Mary horizon.

The Walnut Mountain highwall represents a brackish facies (Figure 9, p. 18) which was transitional from the Big Mary (marine influenced) lower delta region to the terrestrial paleoenvironment of the Pewee horizon. The supporting evidence for this interpretation is the fossil community of brackish-fresh-water pelecypods (Naiadites), gastropods and ostracodes present in the Walnut Mountain roof shale.

Pewee Paleoenvironment

The Pewee horizon represents a well-established terrestrial paleoenvironment. Land plants were abundant in nearly every subenvironment of this upper delta plain region (Figure 10, p. 20). Topographic relief of from 1 to 6 m was present in this area of the delta platform. The most prominent topographic features were the natural levees which flanked the meandering channel courses. The floodplain was probably marked by small rises and depressions which caused irregular distribution of overbank material.

The occurrence of the natural levees provide the key to understanding the physiography of the Pewee paleoenvironment. These levees were truncated and deeply scoured by channels which evidently jumped over their bounding levee ridges and were diverted into the adjacent

floodplains. This region was high enough above sea level so that distinct natural levees could form. The levees were not extensively eroded because of the lack of channel meander in the upper delta plain.

Another indication of significant relief in the Pewee paleoenvironment are the large in situ trees buried to a depth of 3 m. These plants were living in a levee flank depression lake which was apparently 3 m below the elevation of the channel levee. The bent trees also support the idea of significant slope near the levee flank.

Other features that suggest significant relief in the Pewee upper delta plain are the channel bank slumps, point-bar channel fill, and vertically stacked channels.

It appears that the Calamites preferred the drier and firmer substrate of the levee rather than the semiinundated sediments of the swamp. The marine environment did not affect the depositional processes of the Pewee region.

Rock Spring Paleoenvironment

The Rock Spring level represents a lower alluvial valley paleoenvironment (Figure 11, p. 22). Most characteristic of this region is the meanderbelt sheet sandstone. This unit results from the coalescing of point-bars after the channel has migrated many times across its floodplain. Topography in this area was very prominent and the streams were confined to a narrow valley floodplain.

The point-bar migrated laterally across the channel scour surface in the direction of the actively eroded concave bank of the stream.

Therefore, the foreset accretion cross-beds are observed truncating downward along the basal scour surface of the bar.

Although active point-bar fill is the dominant channel feature, inactive clay plug fills are present in the Rock Spring horizon. The lower alluvial valley is characterized by both chute (active fill) and meander cut-off processes (both active and inactive fill).

The floodplain of the Rock Spring level is composed of fine-grained sandstone, siltstone and shale with the coarser sediments most abundant. Both the levee and backswamp sequences consist of interbedded fine-grained sandstone and shale beds. Plants were abundant in these habitats.

A major flood episode affected the Rock Spring depositional environment. The actual flood sequence is illustrated in Plate 11 (Appendix C). Exposure R-4 displays a fluvial sequence—a point-bar migrated across the entire length of the channel. Exposures R-8 and R-9 exhibit load cast features and soft sediment deformation in several rapidly buried channels. Active fill of a stream by the heavy influx of bed load material is not the normal channel fill process in the alluvial valley.

Grassy Spring Paleoenvironment

Both the Upper and Lower Grassy Spring paleoenvironments represented the lower delta plain region (refer to Figure 12, p. 23), which was dominated by the interdistributary bay network. The bays were shallow enough to allow rapid distributary progradation toward the marine shelf.

The shallower and more restricted areas of the bay were suitable for a rapid habitation of diverse marine fauna.

Creation or enlargement of the bay begins with the destructive phase of the delta cycle or cessation of sediment influx. Differential compaction of the shales (versus the alluvial sands) initiates marine inundation of the distributary floodplain. This event is recorded by the roof shale which overlies the Grassy Spring coal seams (representative of peat accumulation in the ancient floodplain). Continued subsidence and compaction deepens the bay probably to a depth of around 7-8 m. While subsidence in the abandoned delta lobe continues, another deltaic distributary approaches this area due to lateral channel migration. This results in fine-grained overbank detritus (silt) being emptied in a relatively deepend bay (4 m). The silts become well sorted and rippled due to wave and current activity. The upward-coarsening of the sediments reflects the approaching distributary.

The two upward-coarsening cycles of the Grassy Spring horizons represent a bay filling with overbank detritus to a point where peat accumulation is possible (Upper Grassy Spring coal). The sediment influx then ceases and the area once again is inundated by the bay. The upward-coarsening sequence of the Upper Grassy Spring horizon represents a repetition of this cycle.

The friable calcareous sandstone at the top of the sequence indicates a temporary end to the sediment supply so that marine faunas could inhabit the rapidly filling bay. Likewise the two biomicrite

units signify a total lack of detrital material emptying into the shallow marine environment.

The bar facies is the result of redeposition of distributary mouth bar sands due to current and wave activity.

XII. DEPOSITIONAL MODEL FOR THE STUDY AREA

The depositional model for the sediments of the study area resembles the general Pennsylvanian delta models proposed by other Carboniferous stratigraphers. These ancient deltas prograded into shallow inland seas which were subjected to small tidal range and moderate wave activity (Wanless et al., 1970, p. 224). The thick volumes of coal, black shale, and widespread limestones suggest that the delta platform was completely free of detrital influx for significant periods of time (Ferm, 1970, p. 249-250). This delta system was smaller in areal extent, and had a coarser sediment fraction than that of the present Mississippi River Delta (Ferm et al., 1972, p. 101) which suggests proximity to a highland source area.

The Mississippi River Delta is the most studied delta system in the world. Many sedimentologists caution against using the Mississippi Delta as a standard model of deposition (Morgan, 1970a, p. 90). However, several prominent publications on deltaic sedimentation draw a striking similarity between deposits of the Mississippi and late Paleozoic deltaic complexes (Ferm and Cavaroc, 1968, p. 2). The elongate nature of the present Mississippi River Delta resembles the model proposed for the study area.

The specific model for the study area is categorized as a highly constructive elongate delta. Several processes of this delta system are explained by Fisher:

> Owing to progradation over thick mud sequences, differential subsidence of sand facies of elongate high-constructive deltas into underlying muds is marked. This promotes permanent storage of most of the prograded sand facies, leaving little sand available for marine reworking and redistribution. The result is an extensive but narrow progradation of delta front and delta plain facies. . . . Progradational sequences are overlaid by aggradational delta plain facies (levee, channel fill, crevasse, marsh, swamp, interdistributary bay and floodbasin deposits). The vertical variety of facies in the elongate delta sequence contrasts with the prominent vertical persistence of specific facies in the lobate high constructive deltas. (Fisher et al., 1969, p. 33)

The elongate model includes several features characteristic of the general Pennsylvanian delta. The highly constructive progradation resembles the late Paleozoic deltas building out over a stable, narrow basin where current and wave activity is minimal. Wanless suggested that in these Pennsylvanian deltas most of the coarse sediment was deposited in the upper delta area, and the lower delta plain is not well developed. Fisher's model illustrates this same distribution of sediments.

The sediments exposed in the Emory River valley represent several successive phases of a prograding delta lobe. The size of any one delta progradation was relatively small as indicated by the high variability in lateral/vertical facies over a short distance. Also the major fluvio-deltaic units are small scale compared to those of the Mississippi River Deltas (e.g., channels, levees, floodbasins).

A complete cycle of delta progradation and subsequent marine inundation is documented in the vertical section selected for the study area. This cycle represents the construction of one small deltaic lobe into a marine bay. Initial progradation is observed along the Big Mary

horizon, which represents the lower delta plain with further progradation continuing up through the terrestrially dominated Rock Spring horizon. A cessation of sediment supply and delta decay is recorded by the marine bay facies of overlying Grassy Spring horizons.

XIII. CONCLUSIONS

The sedimentary sequence of the study area represents a complete cycle of delta construction/destruction into a shallow epicontinental sea. This delta system was one small lobe of a large Pennsylvanian delta complex covering a major section of the eastern North America. The sedimentary model for the small delta lobe resembles the elongate high-constructive elongate delta where the upper delta plain and alluvial environments were characterized by well-developed fluvial features. In contrast, the lower delta plain region had poorly constructed fluvial features due to storage of coarse sediments in the alluvial environment.

The lower delta plain distributaries of the Big Mary horizon signify initial progradation of the delta lobe into the epeiric seas. Deltaic progradation continued in the Pewee and Rock Spring paleoenvironments where sedimentation was governed by fluvial processes and the thick Pennsylvanian vegetation. Following deposition of the Rock Spring interval, sediment supply into the delta system ceased. Rapid subsidence and compaction of fine-grained sediments allowed the marine bays to inundate the delta lobe. The destructive phase of the delta cycle, represented by the widespread bay fill sections of the Grassy Spring intervals, terminated construction of the delta lobe. The abandoned lobe became a site for peat accumulation prior to inundation by the sea.

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APPENDIXES

APPENDIX A

FIELD DESCRIPTION OF SEDIMENT TYPES

TABLE III

FIELD DESCRIPTION OF SEDIMENT TYPES

ROCK NAME: Coal

Texture: Not applicable.

Color: Black to gray black; lighter colors due to iron sulphide precipitate and clay partings.

Induration: Compact and well indurated.

Tenacity: Brittle

Density: Light

Porosity: Nonporous

Mineralogy: Carbonaceous; pyrite nodules present.

Major Grain Constituent/Percent Major Grain Fraction/Diameter Major Grain Size: Not applicable.

Bedding Characteristics: Bedding not applicable to coal; individual seams are uniform in thickness and laterally persistent; shale partings within coal seams are very thinly bedded.

Range of Thickness: Major seams range from 0.3 to 2 m thick; thin coal riders range from less than 1 cm to 7.5 cm thick.

Primary Sedimentary Features: Fossil plant materials; in situ roots on basal contact of coal seam; clay partings.

Fossil Content: Plant debris, usually nonidentifiable.

Appearance in Outcrop: Located at the base of highwalls; rider seam scattered throughout shale/siltstone section.

ROCK NAME: Limestone

Varieties: Micrite (lime mud) and limy carbonaceous shale

Texture: Lime mud is a biochemical deposit and individual particles not visible by the unaided eye; abundant macrofossils may be present.

Color: Ranges from black gray in the limy carbonaceous shale to a light brown gray of the micrite.

TABLE III (continued)

Limestone (continued)

Induration: Micrite is well indurated; limy carbonaceous shale can be either moderately or poorly indurated.

Tenacity: Micrite has subconchoidal fracture; limy carbonaceous shale easily splits along bedding planes and when weathered is friable.

Density: Micrite is dense; limy carbonaceous shale is compact and moderately dense.

Porosity: Micrite is moderately nonporous; limy is nonporous.

Mineralogy: Micrite is $CaCO_3$: limy carbonaceous shale is a combination of $CaCO_3$, clay minerals and macerated plant material.

Major Grain Constituent: Microscopic $CaCO_3$ grains in the micrite; clay minerals grains in the limy carbonaceous shale.

Percent Major Grain Fraction: Micrite is predominantly fine grained $CaCO_3$ particles; limy shale is over 50 percent clay mineral fraction.

Diameter Major Grain Size: Both micrite and limy carbonaceous shale grains not visible by unaided eye.

Bedding Characteristics: Bedding not apparent for the micrite in outcrop; individual micrite units are approximately 1 m thick and are laterally persistent; limy carbonaceous shale beds are very thin (less than 1 cm) and not laterally persistent.

Range of Thickness: Micrite ranges from 0.2 m to 0.8 m, individual units are remarkably persistent in thickness; limy carbonaceous shale ranges from 0.1 to 2.5 m.

Primary Sedimentary Features/Fossil Content: Marine fossils in both micrite and limy carbonaceous shale (Table II, page 73); limy carbonaceous shale contains terrestrial plant material and thin beds.

Appearance in Outcrop: Micrite is very resistant and prominant in the highwall exposures, the beds are tabular and laterally persistent, the color appears as a light brown gray bed in a highwall of dark gray shale/siltstone; the limy carbonaceous shale occurs as a roof shale of a coal seam and grades upwards into a silty shale, the color also grades upwards from a black gray to a medium brown gray.

TABLE III (continued)

ROCK NAME: Ironstone

Texture: Not applicable.

Color: Light orange red to medium red brown.

Induration: Well indurated and resistant to weathering.

Tenacity: Compact and brittle; possesses subconchoidal fracture.

Density: Heavy

Porosity: Nonporous

Mineralogy: Iron carbonate; carbonaceous plant fragments or roots often form the core of ironstone nodules.

Major Grain Constituent/Percent Major Grain Fraction/Diameter Major Grain Size: Not applicable.

Bedding Characteristics: Occurs either in thin laminar beds or a thin horizon of nodules; it is suggested that the laminar ironstone beds indicate freshwater deposition and the nodules indicate marine deposition (Donahue and Rollins, 1974, p. 159); laminar ironstone beds range from 1 cm to 7.5 cm thick; diameter of the nodules range from 1 cm to 1 m thick; ironstone beds regularly alternate with the shale/siltstone facies and comprise a large percentage of the fine-grained sediment section; some coal rider seams grade upward directly into a tabular ironstone deposit; ironstone nodules occur as pebbles of cobbles in lag conglomerate facies.

Range of Thickness: Laminar ironstone beds range from the thickness of a thin bed (1 cm) to a 2 m thick multibedded section; nodular ironstone beds usually range from 1 cm to 15 cm thick.

Primary Sedimentary Features: Laminar bedding in the bedded ironstone; root and plant cores for ironstone nodules.

Fossil Content: Roots and plant material.

Appearance in Outcrop: Laminar ironstone beds are regularly interbedded with shale or siltstone and appear conspicuous due to their red color and resistance to weathering; ironstone nodules are also conspicuous in the fine-grained sediments.

TABLE III (continued)

Ironstone (continued)

Miscellaneous: The depositional facies that include the ironstone is considered to be that of a reducing environment where the Eh-pH setting is low, water circulation is poor and having an abundance of organic material (Horne and others, 1974, p. 107).

ROCK NAME: Shale

Texture: Homogeneous accumulation of clay particles; individual grains not visible by unaided eye; carbonaceous material may be present.

Color: Ranges from dark black gray to dark gray brown.

Induration: Poorly indurated and friable when weathered.

Tenacity: Fresh shale is brittle; shale exposed to weathering is punky and friable.

Density: Moderately heavy.

Porosity: Nonporous

Mineralogy: Clay mineral composition, carbonaceous plant material.

Major Grain Constituent: Clay mineral grain.

Diameter Major Grain Size: 1/256 mm.

Percent Major Grain Fraction: Clay mineral approximately 90 percent; carbonaceous material 10 percent.

Bedding Characteristics: Thin laminar beds; individual beds are 1 cm thick; usually shale is stratigraphically close to coal seams; the shale directly overlying a coal seam is a "roof shale"; the shale beneath the seam is "seatrock."

Range of Thickness: Less than 1 cm to approximately 8 m.

Primary Sedimentary Features: Abundant marine and terrestrial fossils; slump features and soft sediment deformation; thin laminar beds.

Fossil Content: Plant roots, terrestrial plants, fresh water and marine fossils; the fossils identified for selected shale units are listed in Table II, page 73.

TABLE III (continued)

Shale (continued)

Appearance in Outcrop: Usually exposed as a weathered clay on a sloping cut in a highwall; color ranges from dark brown to gray; the freshly exposed shale is considerably darker; shale exposed as a vertical cut remains less weathered and has a dark gray color

ROCK NAME: Siltstone

Texture: Predominantly micaceous grains and very fine-grained sand with clay mineral matrix; well sorted; carbonaceous material commonly present.

Color: Light brown gray to dark gray brown.

Induration: Moderately indurated.

Tenacity: Compact; splits easily along bedding planes.

Density: Moderately heavy.

Porosity: Moderately nonporous.

Mineralogy: Very fine-grained quartz clay mineral content; biotite and muscorite content; carbonaceous plant material.

Major Grain Constituent: Very fine-grained sand.

Diameter Major Grain Size: 1/256 to 1/16 mm.

Percent Major Grain Fraction: Approximately 70 percent.

Bedding Characteristics: Thinly bedded and usually laminar; individual beds range from less than 1 cm to 3 cm thick; ripples and cross-laminations abundant; generally occurs in thick sequences of homogenous siltstone, but commonly interbedded with shale and fine-grained sandstone.

Range of Thickness: From 1 cm to 25 m.

Primary Sedimentary Features: Ripples, cross-lamination, laminar beds.

Fossil Content: Terrestrial plants, marine fossils.

TABLE III (continued)

Siltstone (continued)

Appearance in Outcrop: Appears as a vertical wall of gray fine-grained sediments; massive siltstone sequences grade upwards from a shale into a fine-grained sandstone, vertical siltstone wall may reach a 25 m height.

ROCK NAME: Fine-Grained Subgraywacke Sandstone

Texture: Polymodal combination of quartz, feldspar, heavy mineral and micaceous grains; particles are subrounded and moderately well sorted; matrix may contain clay mineral fraction.

Color: Light gray brown to medium brown.

Induration: Well indurated.

Tenacity: Compact

Density: Moderately heavy.

Porosity: Moderately porous.

Mineralogy: Quartz, feldspar, pyroxene/amphibole, micaceous and clay mineral fraction.

Major Grain Constituent: Quartz

Diameter Major Grain Size: Ranges from 1/16 mm to 1/4 m.

Percent Major Grain Fraction: Ranges from 75% to 95% quartz.

Bedding Characteristics: Occurs mainly in three type deposits: laminar beds in a coarsening upwards sequence, discontinuous lenses in a shale/siltstone sequence and thin laminar beds regularly interbedded with shale.

Range of Thickness: 5 cm to 6 m.

Primary Sedimentary Features: In the coarsening-upward sequence, burrows, ripples and small scale foreset accretion beds are common; the discontinuous fine-grained sandstone lenses possess small scale trough and foreset accretion cross-beds, basal scour surface, abundant roots, and ripples; the regularly interbedded fine-grained subgraywacke sandstone and shale contain few cross-beds but abundant terrestrial plant fossils.

TABLE III (continued)

Fine-Grained Subgraywacke Sandstone (continued)

Fossil Content: Laminar beds of upwards coarsening sequence are commonly burrowed; the discontinuous lenses may possess in situ terrestrial plant fossils and abundant plant debris; the fine-grained subgraywacke sandstone interbedded with shale contain abundant in situ terrestrial plant fossils.

Appearance in Outcrop: Exposed as a resistant light brown sandstone in a highwall of poorly indurated dark gray shale or siltstone.

ROCK NAME: Subgraywacke Sandstone

Texture: Polymodal combination of quartz, feldspar, heavy mineral and micaceous grains; particles are subrounded and moderately sorted; matrix may contain a small clay mineral fraction; cement is quartz or calicm carbonate.

Color: Light tan to medium gray brown.

Induration: Well indurated.

Tenacity: Compact

Density: Moderately heavy.

Porosity: Moderately porous.

Mineralogy: Quartz, feldspar, pyroxene/amphibole, mica.

Major Grain Constituent: Quartz

Diameter Major Grain Size: Ranges from 1/4 mm to 2 mm.

Percent Major Grain Fraction: Ranges from 75% to 95% quartz.

Bedding Characteristics: Trough and foreset accretion crossbeds abundant, alluvial sequences are massive and commonly elliptical, splay sequences are tabular and laterally persistent; basal contact is sharp and usually a scour surface.

Range of Thickness: 5 cm to 8 m.

TABLE III (continued)

Subgraywacke Sandstone (continued)

Primary Sedimentary Features: Trough cross-beds, foreset accretion beds, ripple cross-laminations, laminar beds, sand waves, scour surface, graded bedding channel deposits, scour marks, ripples, load cast features, plant casts/molds, roots, slump features, liquification features.

Fossil Content: In situ plants, current oriented plant material, roots.

Appearance in Outcrop: Alluvial channel subgraywacke sandstone occurs as a clastic wedge; the splay subgraywacke is a thin tabular tongue of sediment in a shale/siltstone sequence; overbank subgraywacke appears as thin discontinuous with shale and siltstone.

ROCK NAME: Orthoquartzite

Texture: Grains are coarse, well sorted, rounded; sediment is unimodal; minor matrix and cement fraction, quartz constitutes 95% of sediment.

Color: Light brown gray to white.

Induration: Moderately indurated.

Tenacity: Compact to friable.

Density: Moderately heavy.

Porosity: Porous

Mineralogy: Quartz, feldspar, pyroxene/amphibole.

Major Grain Constituent: Quartz

Diameter Major Grain Size: 1/2 mm to 2 mm.

Percent Major Grain Fraction: Quartz is greater 95%.

Bedding Characteristics: Primarily occurs as a multicrossbedded alluvial belt sandstone; the bedding sequences possess a basal scour surface and are widespread and persistent.

Range of Thickness: 1 m to 13 m.

TABLE III (continued)

Orthoquartzite (continued)

Primary Sedimentary Features: Trough cross-beds and laminar beds are present but subordinate; basal scour surface, beds fine upwards and truncate downwards.

Fossil Content: Current oriented plant material; can be rooted at top of fining-upward sequence.

Appearance in Outcrop: Orthoquartizite occurs as a massive, cross-bedded bar sandstone; thickness and lateral extent are persistent; color is generally light brown gray in weathered outcrop and light tan when freshly exposed; weathered orthoquartzite may be characterized by abundant vugs which were the result of the decay of bedded plant fragments.

ROCK NAME: Conglomerate

Texture: Polymodal combination of coarse sand grains, pebbles, granules and cobbles; grains range from rounded to angular; sorting is poor, abundant of shale and ironstone clasts; matrix is sub-graywacke sandstone.

Color: Ranges from medium red brown to light gray brown.

Induration: Well indurated.

Tenacity: Compact

Density: Moderately heavy to heavy.

Porosity: Moderately nonporous.

Mineralogy: Quartz, feldspar, pyroxene/amphiboles, mica, clay mineral fraction, ironstone, carbonaceous material.

Major Grain Constituent: Quartz

Diameter Major Grain Size: Ranges from 1/2 to 125 mm.

Percent Major Grain Fraction: Not applicable.

Bedding Characteristics: Occurs as the lag deposit of alluvial channel deposits, or lenses of coarse alluvium in the troughs of sand wave beds.

TABLE III (continued)

Conglomerate (continued)

Range of Thickness: 5 cm to 1 m.

Primary Sedimentary Features: Basal scour surface.

Fossil Content: Current oriented plant material.

Appearance in Outcrop: Appears as a red brown lens of gravel or as a lag deposit in an alluvial subgraywacke.

APPENDIX B

GUIDE TO SEDIMENTARY ROCK DESCRIPTIONS

TABLE IV

SEDIMENTARY ROCK ANALYSIS CHART
(From Spock, 1953)

No.: Location:

Bulk Properties. Texture:
Color: Density:
Induration: Porosity:

Clastic Constituents

Minerals, rock fragments	Sizes (mm)	Shapes	Percent	Miscellaneous
Grains				
Matrix				

Sorting:

Precipitated Material (including chemical cement)

Composition: Texture:
Color: Distribution: Percent:

Bedding (include dimensions):
Other Structures (fossils, concretions, nodules, markings, lineation, etc.):

Diagenesis:
Deformation, weathering, mineralization, other modifications:

Rock name: Classification:
Inferred Depositional Environment:
Inferred Source:

Date: Petrographer:

TABLE V

CHARACTERISTICS OF LITHOGENIC UNITS IN THE STUDY AREA

UNIT	CHARACTERISTICS											
	CROSS SECTIONAL SHAPE	LATERAL EXTENT	VERTICAL THICKNESS	BED THICKNESS	CHARACTERISTIC BEDDING TYPES	BASAL CONTACT	DOMINANT LITHOLOGIC TYPE	DOMINANT GRAIN SIZE DIAMETER	CHARACTERISTIC SEDIMENTARY FEATURES	FOSSIL CONTENT	ASSOCIATED LATERAL FACIES	LOCATION IN THE DELTA MODEL
CHANNEL	BICONVEX, LENTICULAR	10 M. TO 25 M.	2 M. TO 8 M.	5 CM. TO 1 M.	PLANAR CROSS-BEDS, TROUGH CROSS-BEDS, FORESET ACCRETION BEDS, RIPPLE LAMINATIONS	SHARP, SCOURED	SUBGRAYWACKE SANDSTONE	1/8 MM. TO 1 MM.	SAND WAVES, SCOUR SURFACE, PLANAR CROSS-BEDS, FORESET ACCRETION BEDS, TROUGH CROSS-BEDS, LOAD CASTS, RIPPLES	PLANT FRAGMENTS ALONG BEDDING PLANES	ALLUVIAL CHANNEL: OVERBANK, NATURAL LEVEE, LAKE, SWAMP. DISTRIBUTARY: SPLAY, INTERDISTRIBUTARY BAY	LOWER DELTA PLAIN, UPPER DELTA PLAIN, LOWER ALLUVIAL VALLEY
POINT BAR	WEDGE, LENTICULAR	60 M. TO 200 M.	3 M. TO 12 M.	2 CM. TO 1 M.	FORESET ACCRETION BEDS, TROUGH CROSS BEDS	SHARP, SCOURED	ORTHOQUARTZITIC SANDSTONE	1/2 MM. TO 1 MM.	FORESET ACCRETION BEDS, TROUGH CROSS-BEDS, WEATHERED VUGS FROM PLANT MOLDS	PLANT FRAGMENTS ALONG BEDDING PLANES	NATURAL LEVEE, ALLUVIAL CHANNEL, BACKSWAMP, OVERBANK	UPPER DELTA PLAIN, LOWER ALLUVIAL VALLEY
NATURAL LEVEE	WEDGE, LENTICULAR	10 M. TO 50 M.	2 M. TO 6 M.	1 CM. TO 10 CM.	PARALLEL ALTERNATIONS OF FINE AND MEDIUM GRAINED LAMINAR BEDS	GRADATIONAL	FINE-GRAINED SUBGRAYWACKE SANDSTONE	1/16 MM. TO 1/2 MM.	ORIGINAL DEPOSITIGNAL SLOPE, DENSE PLANT GROWTH, ALTERNATING SILTSTONE AND SANDSTONE BEDS	IN SITO PLANTS (PREDOMINANTLY CALAMITES)	BACKSWAMP, OVERBANK, ALLUVIAL CHANNEL	UPPER DELTA PLAIN, LOWER ALLUVIAL VALLEY
SPLAY	TABULAR	UP TO 2 KM.	0.3 M. TO 2 M.	10 CM. TO 2 M.	LAMINAR BEDS, RIPPLE LAMINATIONS	SHARP	SUBGRAYWACKE SANDSTONE	1/4 MM. TO 1 MM.	BASAL SCOUR SURFACE, SCATTERED PLANT FRAGMENTS, RIPPLES	MACERATED PLANT FRAGMENTS ALONG BEDDING PLANES	DISTRIBUTARY CHANNEL, INTERDISTRIBUTARY BAY	LOWER DELTA PLAIN, UPPER DELTA PLAIN
OVERBANK SANDS	LENTICULAR	0.5 M. TO 100 M.	UP TO 10 M.	1 CM. TO 10 CM.	LAMINAR BEDS, RIPPLE LAMINATIONS, SMALL SCALE TROUGH CROSS-BEDS	SHARP OR GRADATIONAL	FINE-GRAINED SUBGRAYWACKE SANDSTONE	1/16 MM. TO 1/2 MM.	SMALL SCALE SCOUR SURFACES AND TROUGH CROSS-BEDS, RIPPLES, ROOTS	ROOTS, TREE STUMPS, RANDOMLY ORIENTED PLANT FRAGMENTS	POINT BAR, BACK SWAMP, CHANNEL, NATURAL LEVEE	UPPER DELTA PLAIN, LOWER ALLUVIAL VALLEY
BACKSWAMP	TABULAR	UP TO 1 KM.	UP TO 20 M.	1 CM. TO 10 CM.	LAMINAR BEDS	GRADATIONAL	SHALE	1/256 MM. TO 1/16 MM.	TREE STUMPS, ROOTS	ROOTS, TREE STUMPS, LEAVES, RANDOMLY ORIENTED PLANT FRAGMENTS	OVERBANK, CHANNEL, NATURAL LEVEE, POINT BAR	UPPER DELTA PLAIN, LOWER ALLUVIAL VALLEY
LAKE	TABULAR	UP TO 0.5 KM.	1 M. TO 6 M.	1 CM. TO 3 CM.	LAMINAR BEDS	GRADATIONAL	SHALE	1/256 MM. TO 1/16 MM.	THIN LAMINAR BEDS, RIPPLES	PLANT FRAGMENTS ALONG BEDDING PLANES	NATURAL LEVEE, CHANNEL, BACKSWAMP, OVERBANK, SPLAY	LOWER DELTA PLAIN, UPPER DELTA PLAIN, LOWER ALLUVIAL VALLEY
INTERDISTRIBUTARY BAY	TABULAR	SEVERAL MILES IN EXTENT	UP TO 25 M.	1 CM. TO 3 CM.	LAMINAR BEDS	GRADATIONAL	SILTSTONE	1/256 MM. TO 1/16 MM.	BURROWS, THIN LAMINAR BEDS, RIPPLES	PLANT FRAGMENTS ALONG BEDDING PLANES, BURROWS, MARINE FOSSILS (SEE TABLE NO. 3)	CHANNEL, SPLAY	LOWER DELTA PLAIN
INTERDISTRIBUTARY BAY BAR	WEDGE, LENTICULAR	UP TO 35 M.	1 M. TO 6 M.	2 CM. TO 0.3 M.	FORESET ACCRETION BEDS	GRADATIONAL OR SHARP	ORTHOQUARTZITIC SANDSTONE	1/2 MM. TO 2 MM.	FORESET ACCRETION BEDS, TROUGH CROSS-BEDS, PINCH AND SWELL STRUCTURES	PLANT FRAGMENTS ALONG BEDDING PLANES	INTERDISTRIBUTARY BAY, SPLAY	LOWER DELTA PLAIN

APPENDIX C

DEPOSITIONAL FACIES DIAGRAMS;

PLATES 1 THROUGH 13

KEY:


Conglomeratic Sandstone


Coarse Sandstone


Fine Grained Sandstone


Siltstone


Silty Shale


Roof Shale

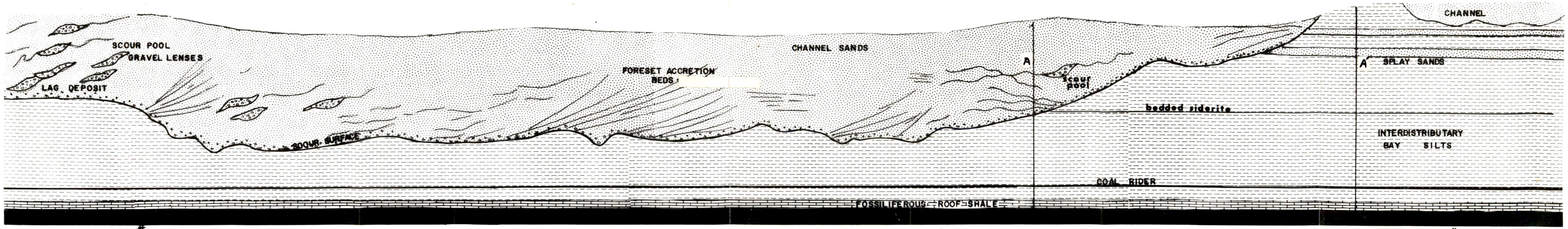

Limestone


Coal

PLATE 1

A. Diagram (Vertical Exaggeration = 4x) and Photographic Sequence of Exposure B-3: Big Mary Channel, Interdistributary Bay Association.

B. Photographic Sequence of Exposure B-1: Big Mary Lower Delta Plain, Channel, Bay Association.



BIG MARY EXPOSURE #3
CHANNEL— INTERDISTRIBUTARY BAY ASSOCIATION

10 SCALE/FT.
40

PLATE 1-A: EXPOSURE B-3



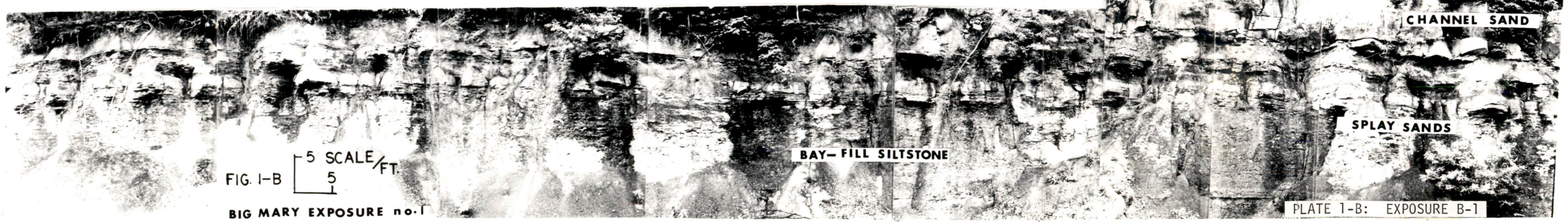


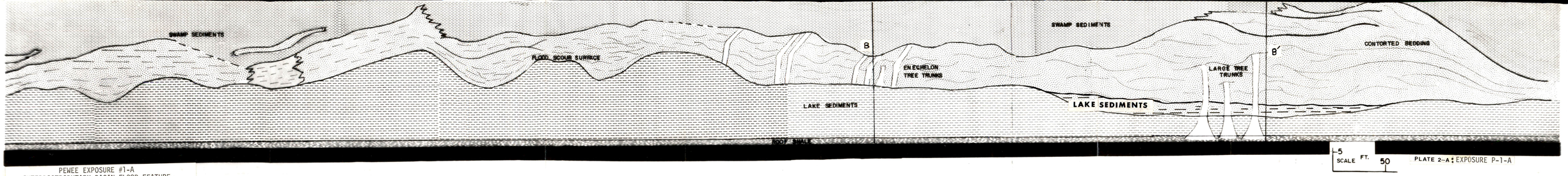
PLATE 1-B: EXPOSURE B-1

PLATE 1

PLATE 2

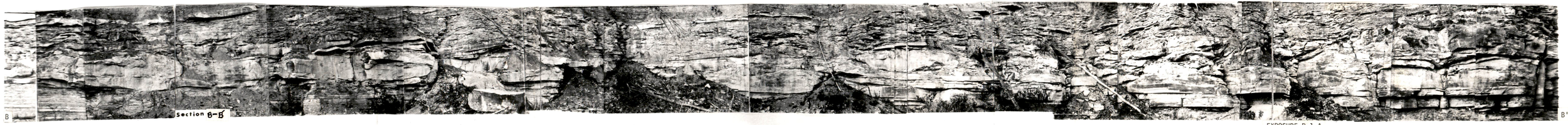
A. Diagram (Vertical Exaggeration = 4x) and Photographic Sequence of Exposure P-1-A: Pewee Interdistributary Basin, Levee Flank Depression Flood Feature.

B. Diagram (Vertical Exaggeration = 6x) and Photographic Sequence of Exposure P-1-B: Pewee Interdistributary Basin, Levee Flank Depression Flood Feature. (This Outcrop is a Perpendicular Continuation of the Outcrop Illustrated in Plate 2-A.)



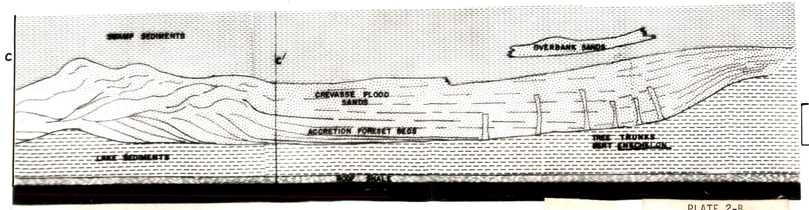
PEWEE EXPOSURE #1-A
INTERDISTRIBUTARY BASIN FLOOD FEATURE

PLATE 2-A ‡ EXPOSURE P-1-A



EXPOSURE P-1-A

5 scale/ft.



PEWEE EXPOSURE #1-B
INTERDISTRIBUTARY BASIN FLOOD FEATURE

PLATE 2-B
EXPOSURE P-1-B



EXPOSURE P-1-B

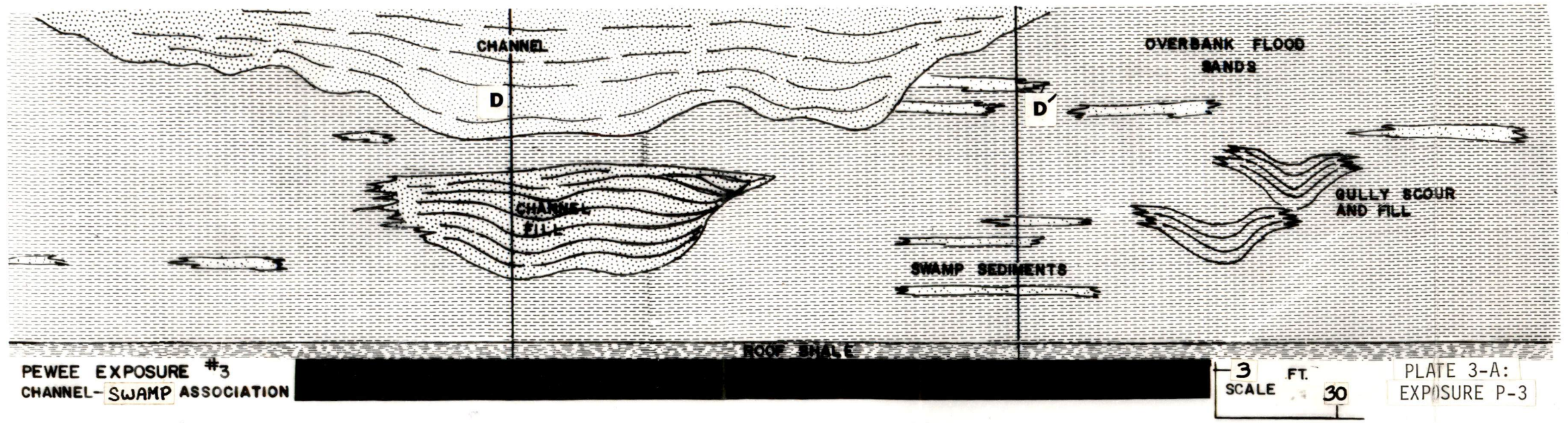
6 SCALE/FT. 6

PLATE 2

PLATE 3

A. Diagram (Vertical Exaggeration = 4x) and Photographic Sequence of Exposure P-3: Pewee Channel Backswamp Feature.

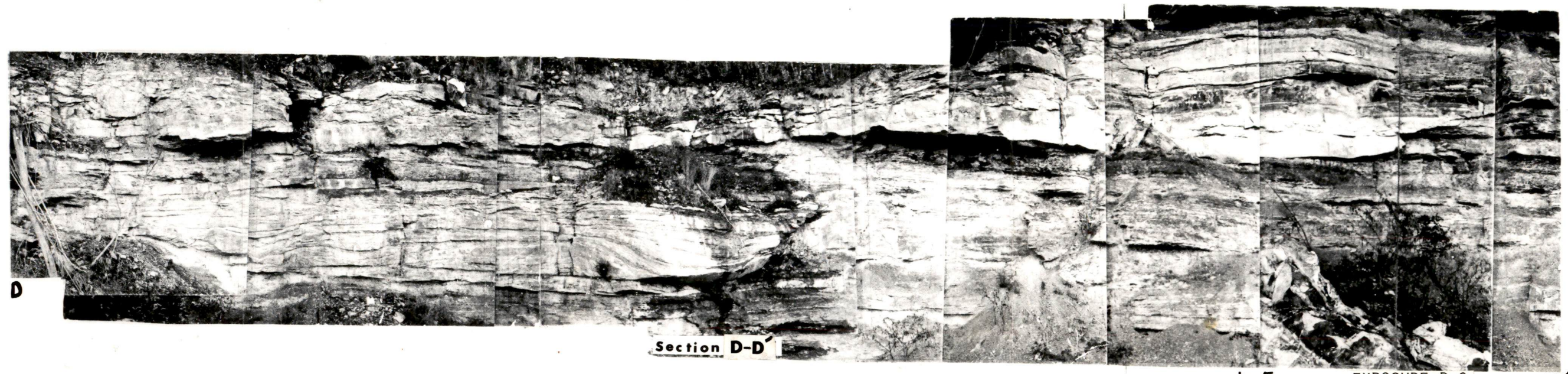
B. Diagram (Vertical Exaggeration = 4x) and Photographic Sequence of Exposure P-4: Pewee Channel, Levee Association.



PEWEE EXPOSURE #3
CHANNEL-SWAMP ASSOCIATION

3 FT.
SCALE 30

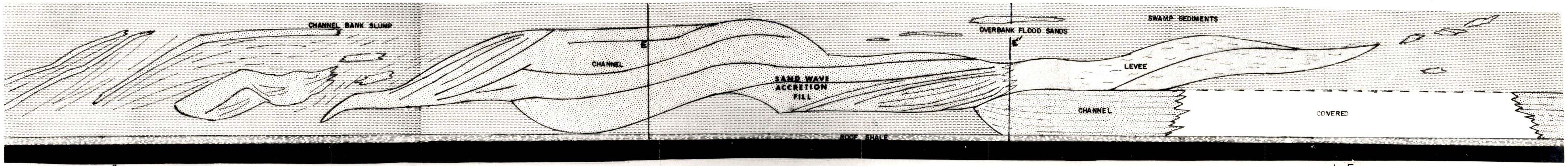
PLATE 3-A: EXPOSURE P-3



5 Scale/ft.
5

EXPOSURE P-3

120



PEWEE EXPOSURE #4
CHANNEL - LEVEE ASSOCIATION

5
SCALE/FT.
20

PLATE 3-B: EXPOSURE P-4

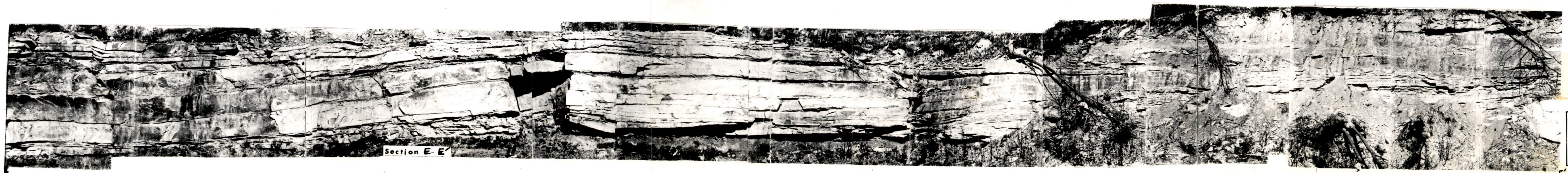


PLATE 3

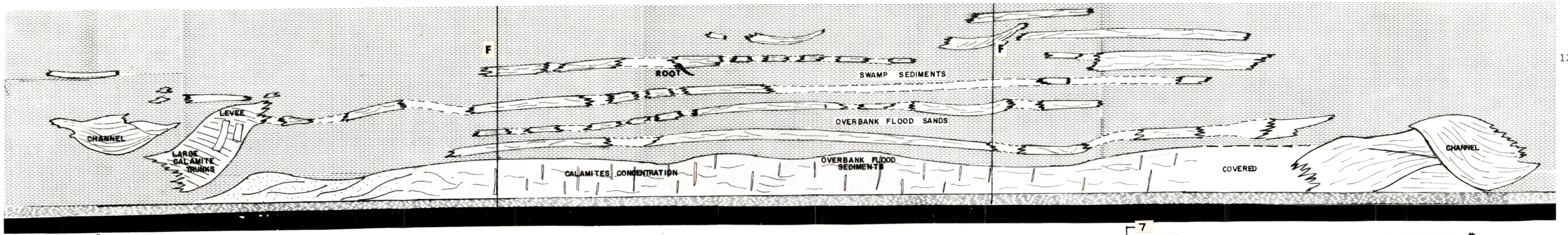
8
SCALE/ft.
7

EXPOSURE P-4

PLATE 4

A. Diagram (Vertical Exaggeration = 4x) and Photographic Sequence of Exposure P-5: Pewee Interdistributary Backswamp Feature.

B. Diagram (Vertical Exaggeration = 4x) and Photographic Sequence of Exposure P-7: Pewee Interdistributary Backswamp Feature.



PEWEE EXPOSURE #5
INTERDISTRIBUTARY BACKSWAMP FEATURE

7
SCALE / FT.
28

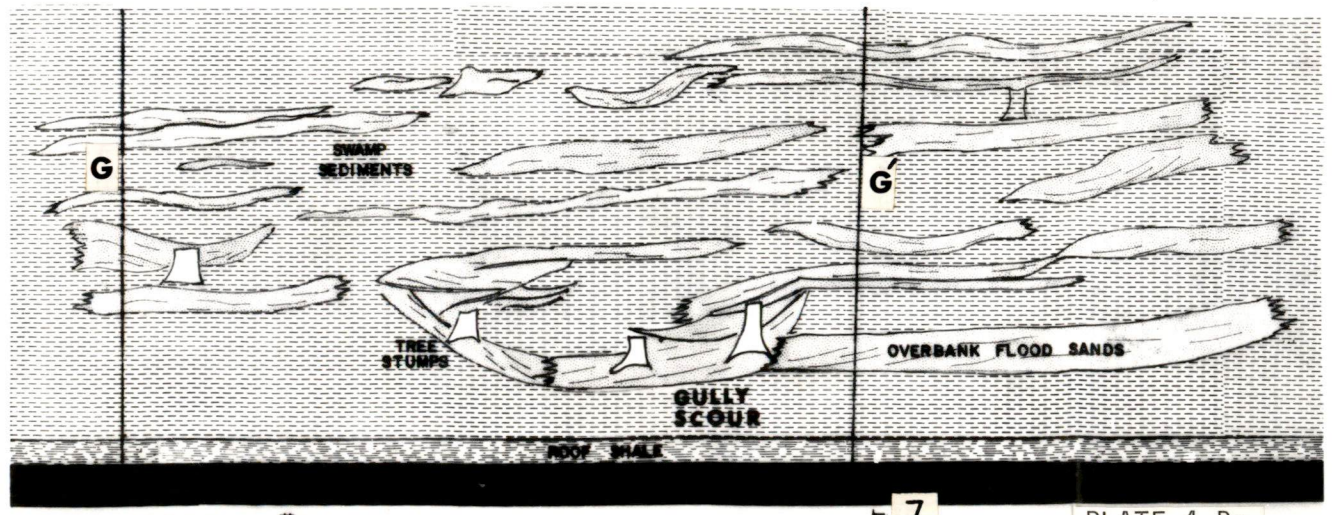
PLATE 4-A: EXPOSURE P-5



Section F-F'

EXPOSURE P-5

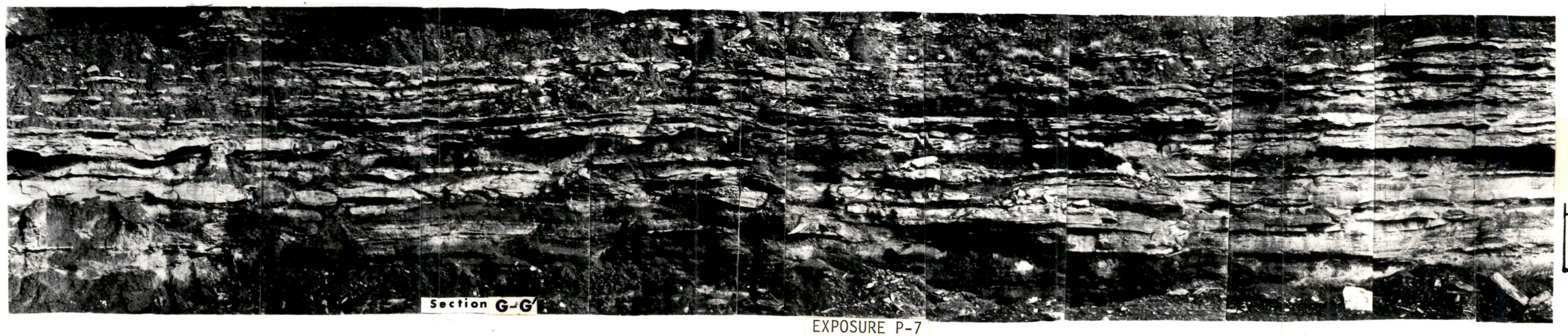
7
SCALE/FT.
7



PEWEE EXPOSURE #7
INTERDISTRIBUTARY BACKSWAMP SEQUENCE

7
SCALE / FT.
28

PLATE 4-B: EXPOSURE P-7



Section G-G'

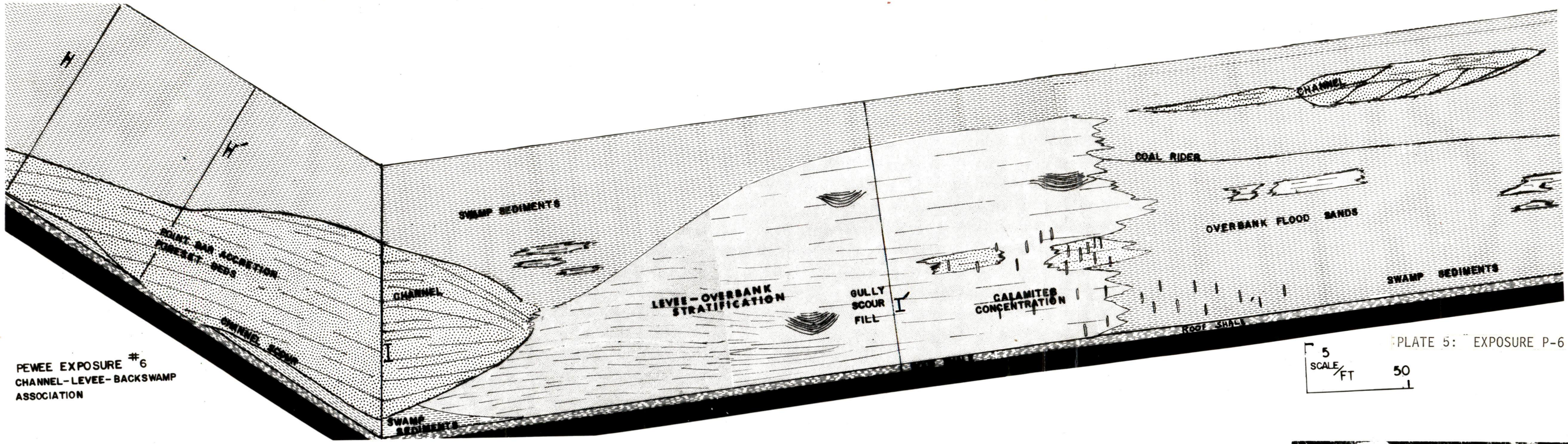
EXPOSURE P-7

PLATE 4

7
SCALE/FT.
7

PLATE 5

Diagram (Vertical Exaggeration = 4x) and Photographic Sequence of Exposure P-6: Pewee Channel, Levee, Backswamp Association.



PEWEE EXPOSURE #6
CHANNEL-LEVEE-BACKSWAMP ASSOCIATION

PLATE 5: EXPOSURE P-6



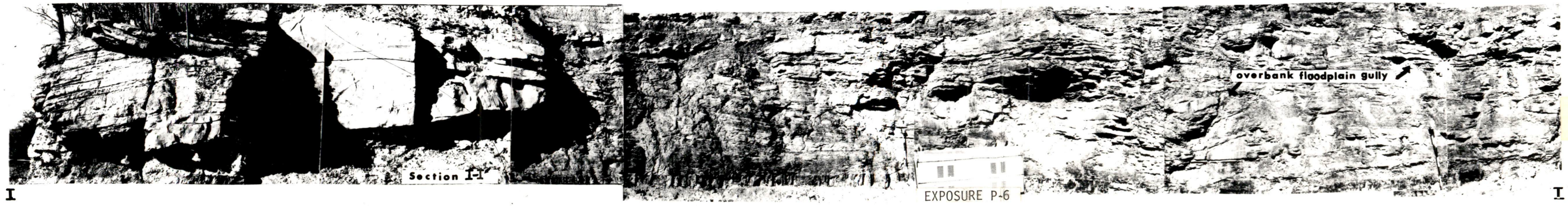
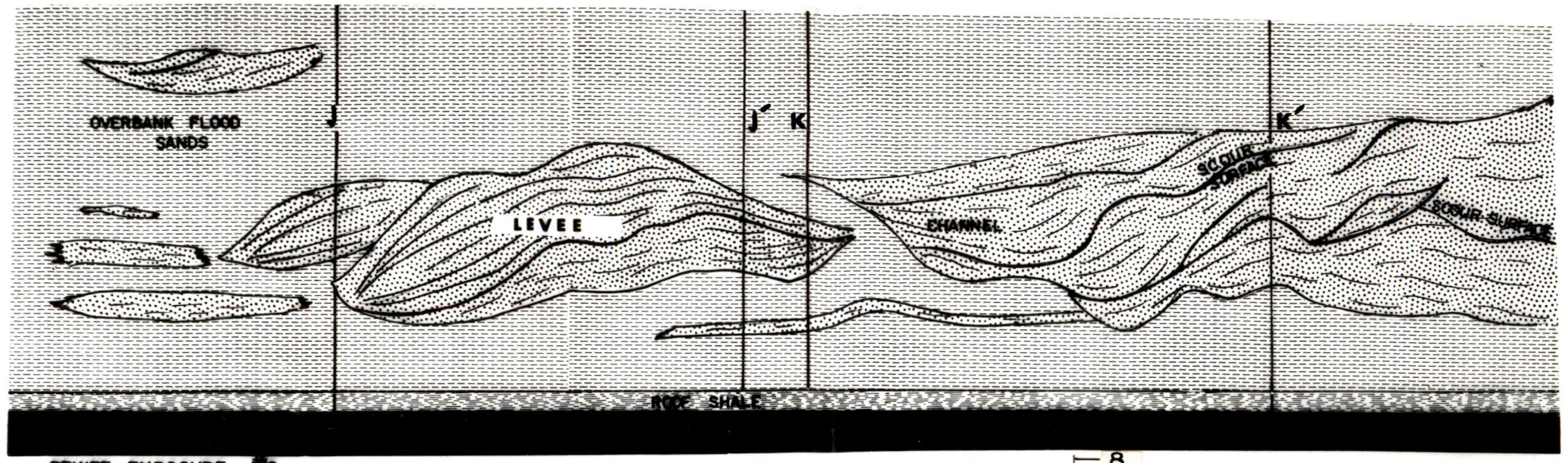


PLATE 5

PLATE 6

A. Diagram (Vertical Exaggeration = 4x) and Photographic Sequences of Exposure P-8: Pewee Channel, Levee Association.

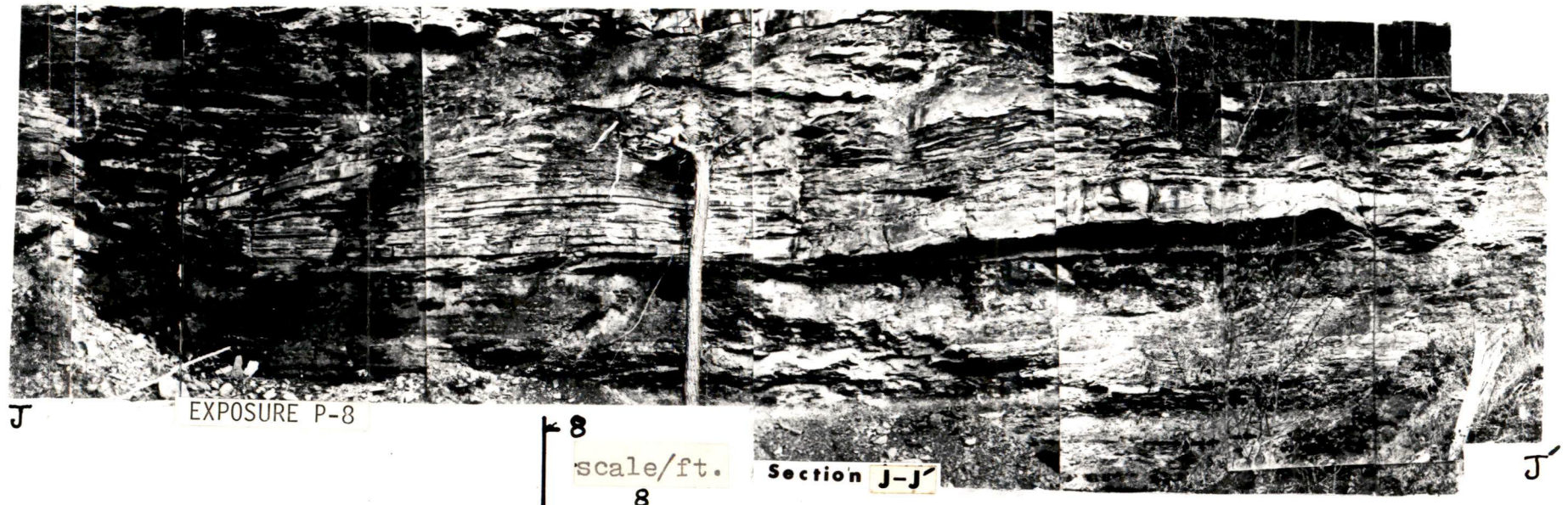
B. Diagram (Vertical Exaggeration = 5x) and Photographic Sequence of Exposure P-9: Pewee Channel, Levee Association.



PEWEE EXPOSURE #8
CHANNEL BACKSWAMP ASSOCIATION

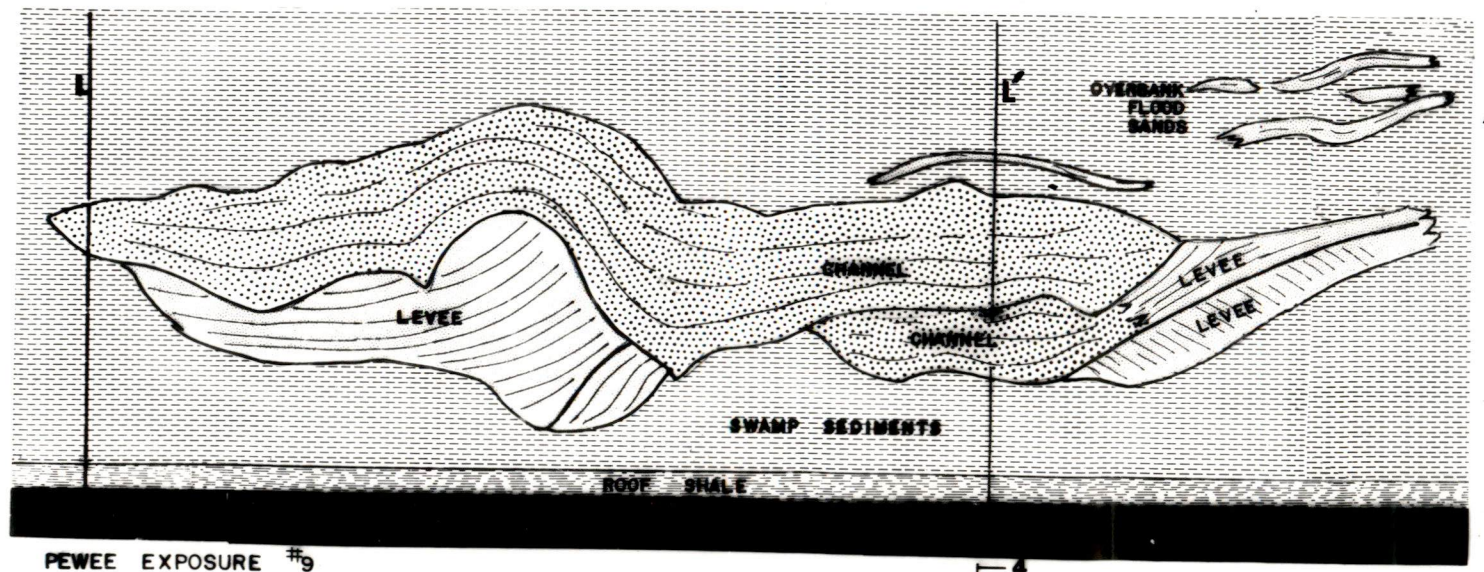
8
SCALE / FT.
40

PLATE 6-A: EXPOSURE P-8



8
scale/ft.
8

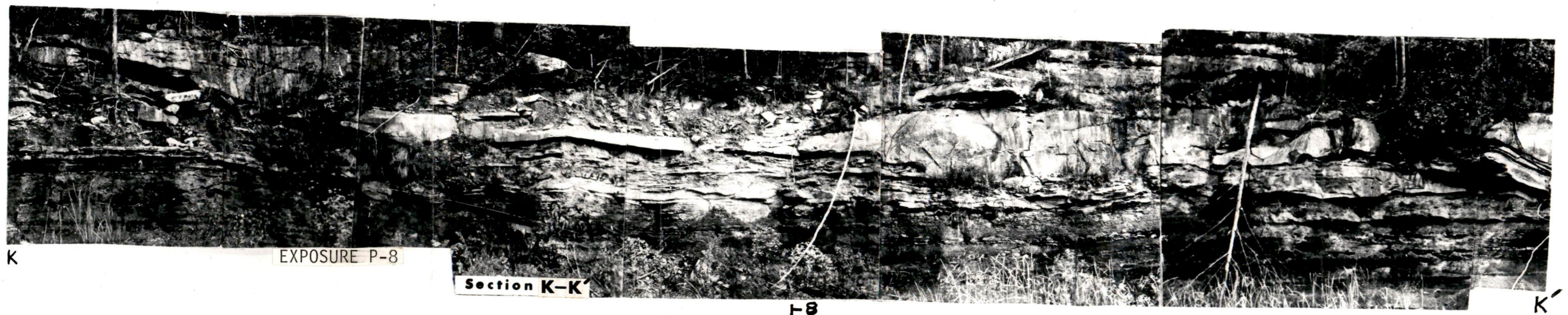
Section J-J'



PEWEE EXPOSURE #9
CHANNEL — LEVEE ASSOCIATION

4
SCALE / FT.
20

PLATE 6-B: EXPOSURE P-9



Section K-K'

8
scale/ft.
8

4
scale/ft.
4

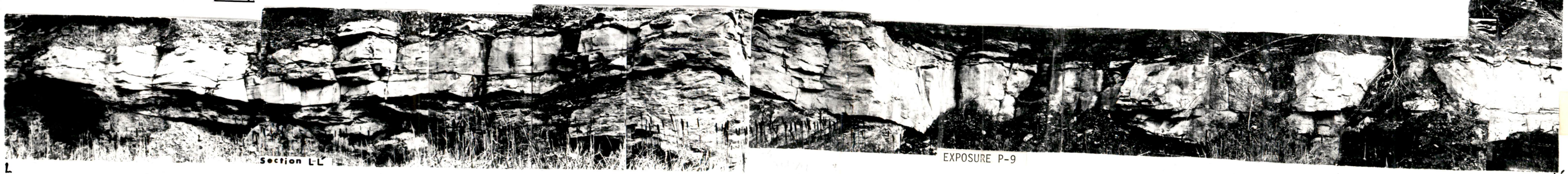
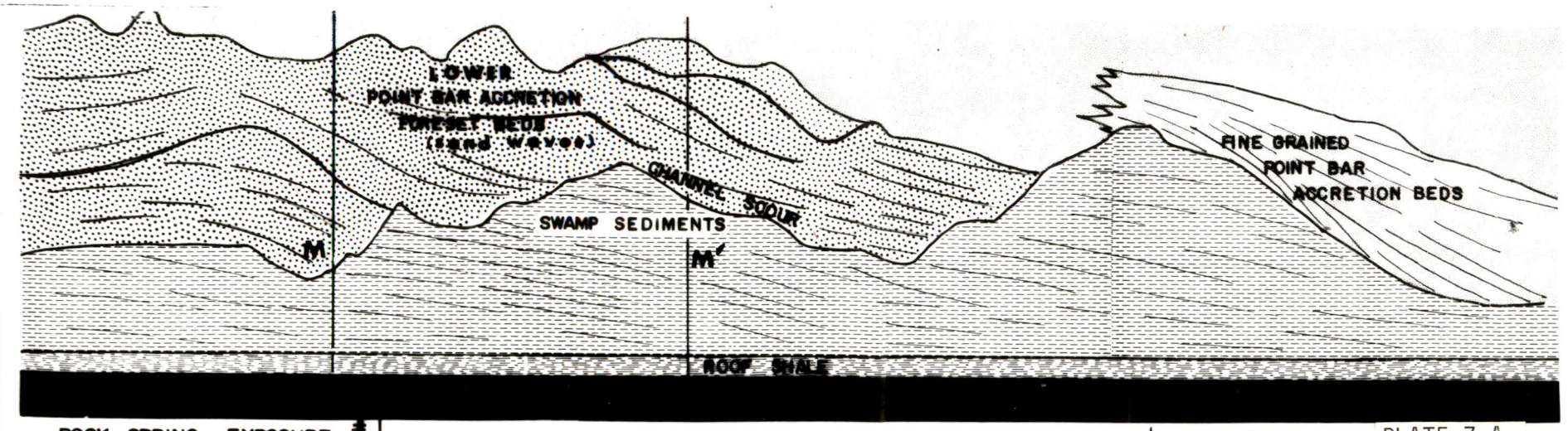


PLATE 6

PLATE 7

A. Diagram (Vertical Exaggeration = 4x) and Photographic Sequence of Exposure R-1: Rock Spring Point-Bar Feature.

B. Diagram (Vertical Exaggeration = 4x) and Photographic Sequence of Exposure R-2: Rock Spring Point-Bar Feature.



ROCK SPRING EXPOSURE #1
POINT BAR FEATURE

5
SCALE/FT.
50

PLATE 7-A:
EXPOSURE R-1

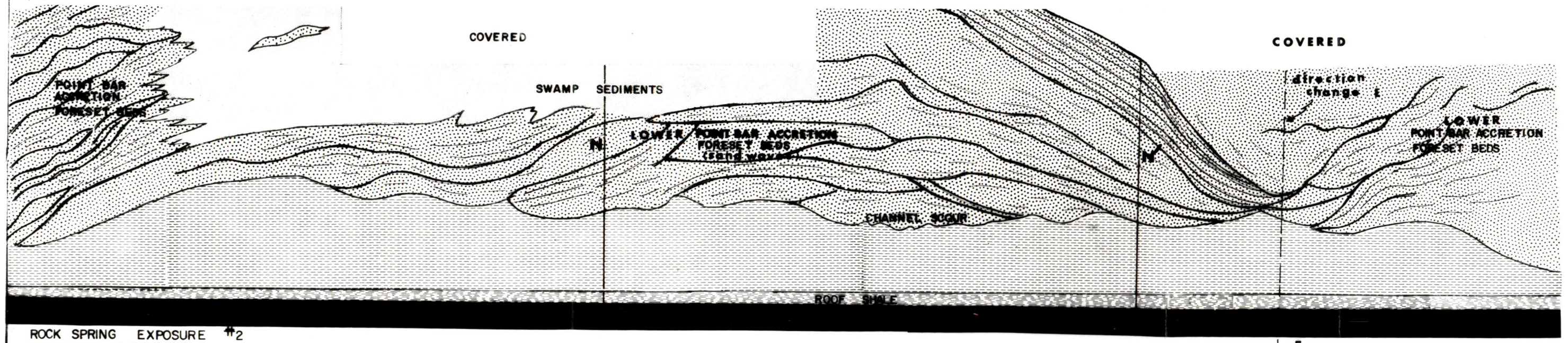


M

Section M-M'
EXPOSURE R-1

5 scale/ft.
5

M'

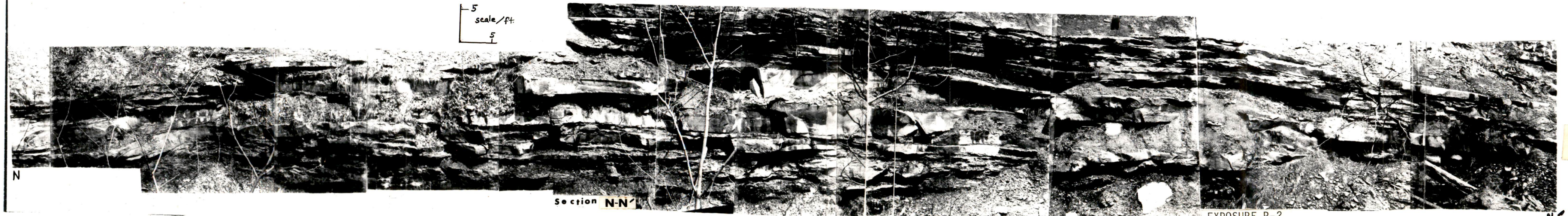


ROCK SPRING EXPOSURE #2
POINT BAR FEATURE

5
SCALE/FT.
50

PLATE 7-B: EXPOSURE R-2

5
scale/ft.
5



N

Section N-N'
EXPOSURE R-2

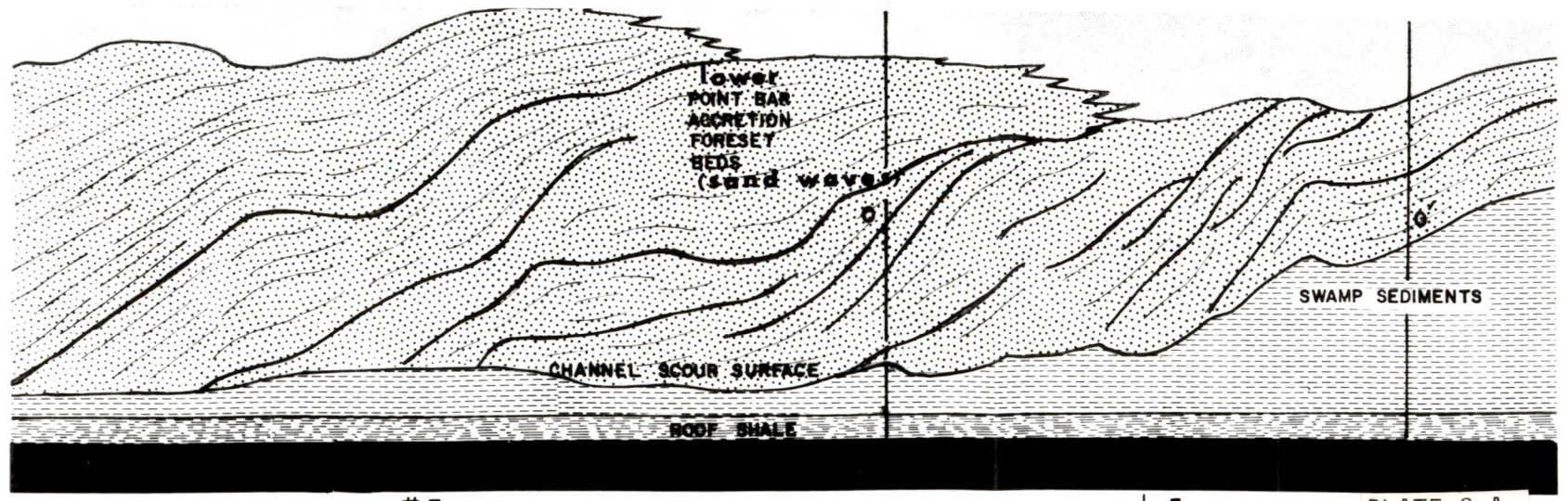
N'

PLATE 7

PLATE 8

A. Diagram (Vertical Exaggeration = 4x) and Photographic Sequence of Exposure R-3: Rock Spring Point-Bar Feature.

B. Diagram (Vertical Exaggeration = 4x) and Photographic Sequence of Exposure R-4-A: Rock Spring Point-Bar Feature.



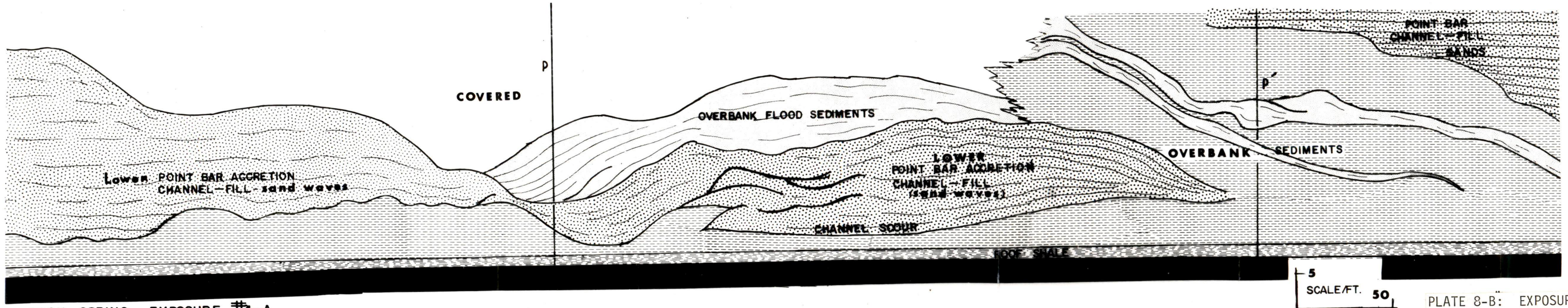
ROCK SPRING EXPOSURE #3
POINT BAR FEATURE

PLATE 8-A: EXPOSURE R-3



EXPOSURE R-3

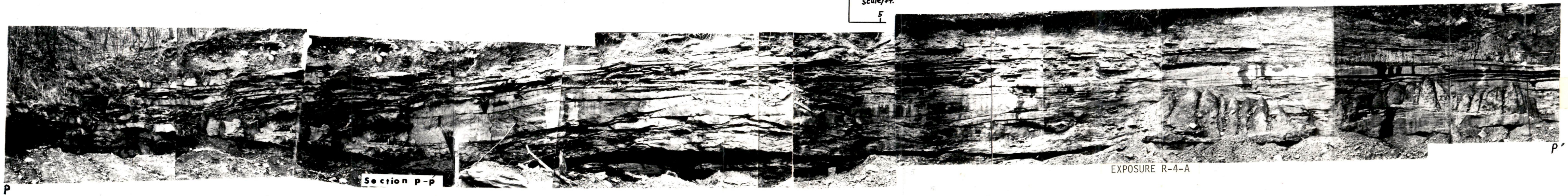
5 scale/ft. 5



ROCK SPRING EXPOSURE #4-A
POINT BAR FEATURE

PLATE 8-B: EXPOSURE R-4-A

5 scale/ft. 5

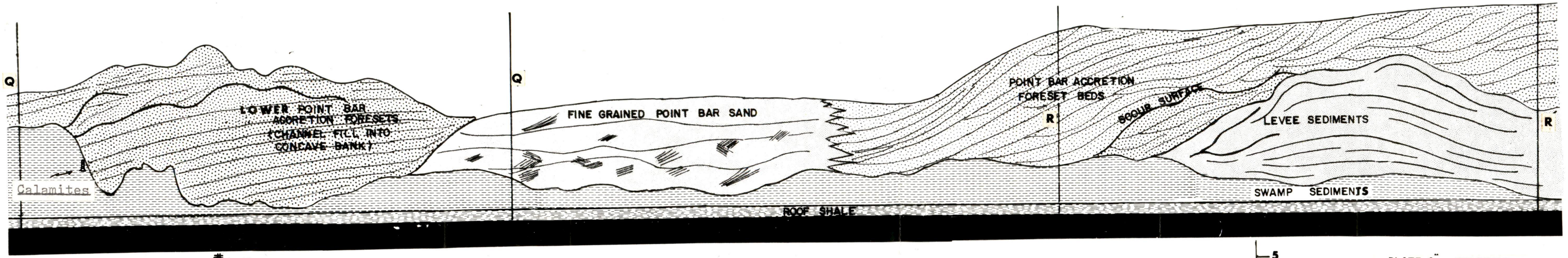


EXPOSURE R-4-A

PLATE 8

PLATE 9

Diagram (Vertical Exaggeration = 4x) and Photographic Sequence of Exposure R-4-B: Rock Spring Point-Bar, Active Channel Fill Association. (This Outcrop is a Perpendicular Continuation of the Outcrop Illustrated in Plate 8-B.)



ROCK SPRING EXPOSURE #4-B
POINT BAR ACCRETION AS ACTIVE CHANNEL FILL

PLATE 9: EXPOSURE R-4-B



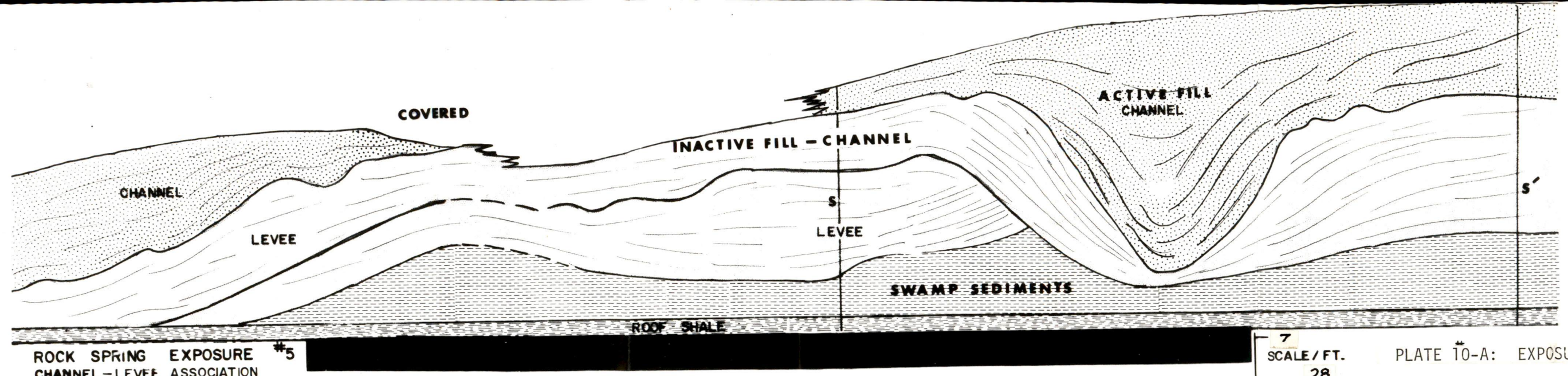


PLATE 9

PLATE 10

A. Diagram (Vertical Exaggeration = 4x) and Photographic Sequence of Exposure R-5: Rock Spring Channel, Levee Association.

B. Diagram (Vertical Exaggeration = 3x) and Photographic Sequence of Exposure R-6: Rock Spring Upper Point-Bar Feature.



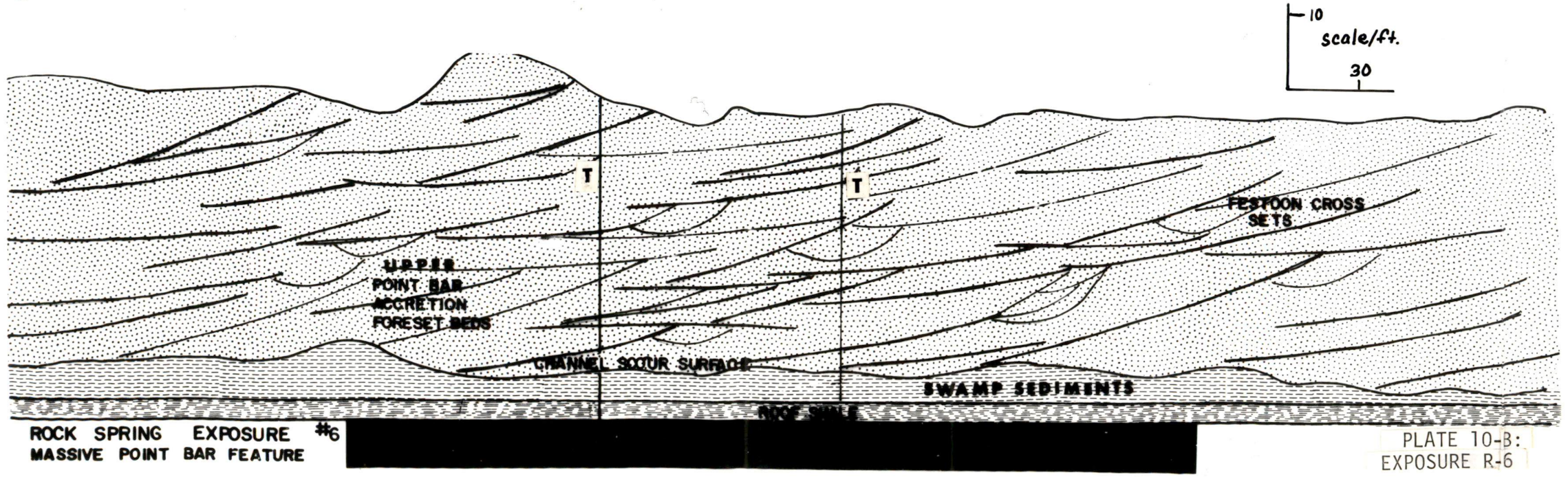
ROCK SPRING EXPOSURE #5
CHANNEL – LEVEE ASSOCIATION

7
SCALE / FT.
28

PLATE 10-A: EXPOSURE R-5

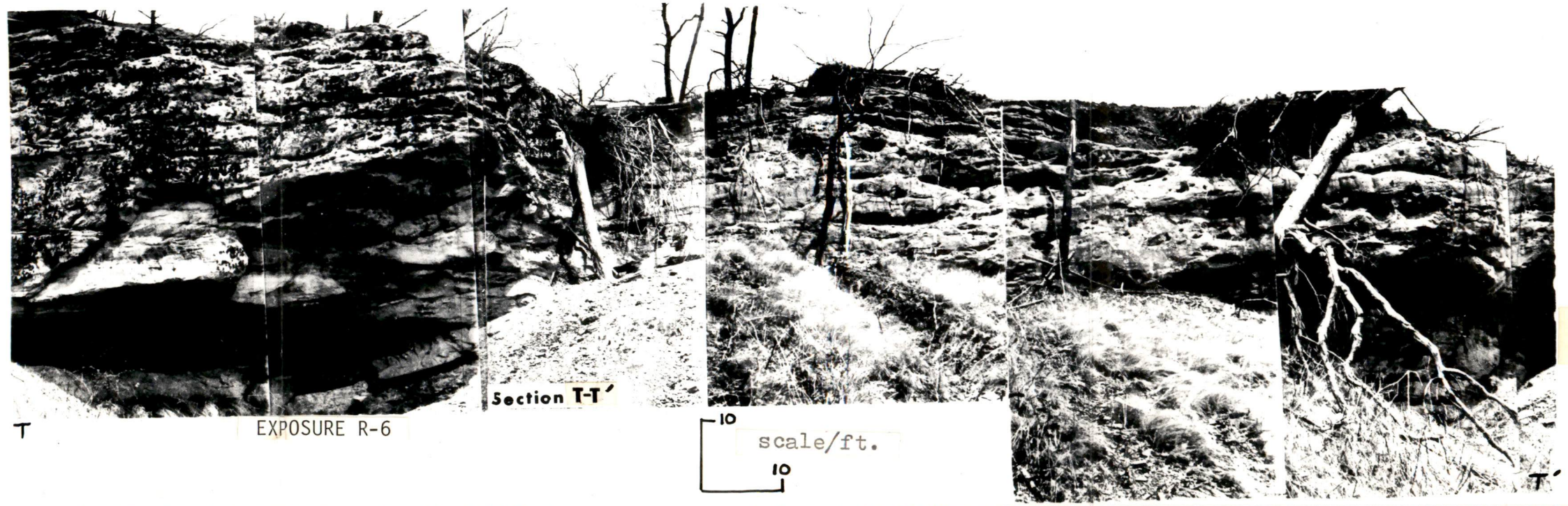


EXPOSURE R-5



ROCK SPRING EXPOSURE #6
MASSIVE POINT BAR FEATURE

PLATE 10-B: EXPOSURE R-6



EXPOSURE R-6

PLATE 10

PLATE 11

Diagram (Vertical Exaggeration = 4x) and Photographic Sequence of Exposure R-7: Rock Spring Interdistributary Basin Flood Feature.

PLATE 11: EXPOSURE R-7

PLATE 12

A. Diagram (Vertical Exaggeration = 4x) and Photographic Sequences of Exposure R-8: Rock Spring Interdistributary Basin Flood Feature.

B. Diagram (Vertical Exaggeration = 3x) and Photographic Sequence of Exposure R-9: Rock Spring Channel, Backswamp Association.

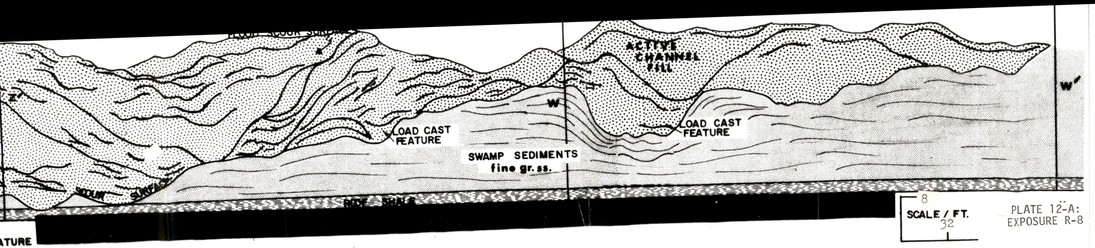
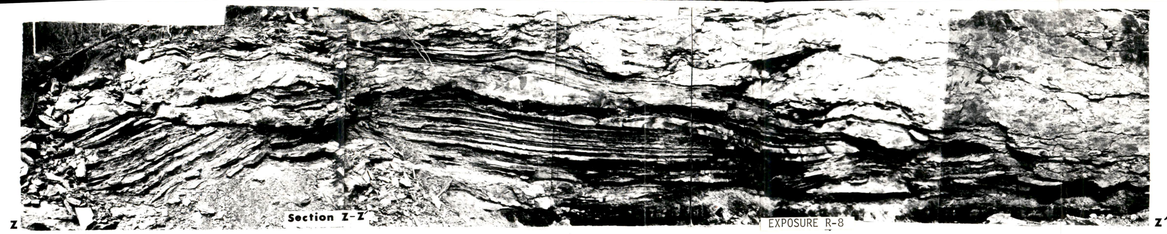
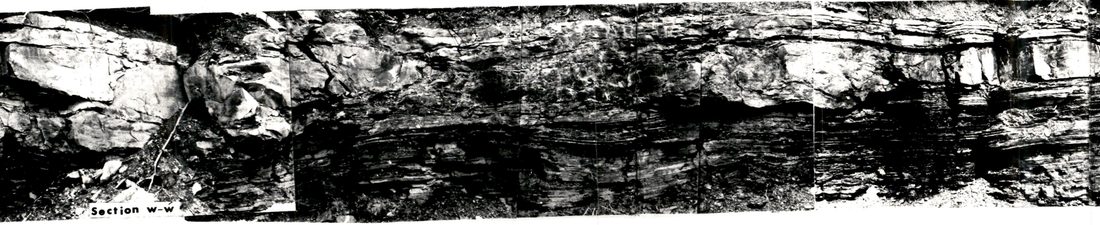


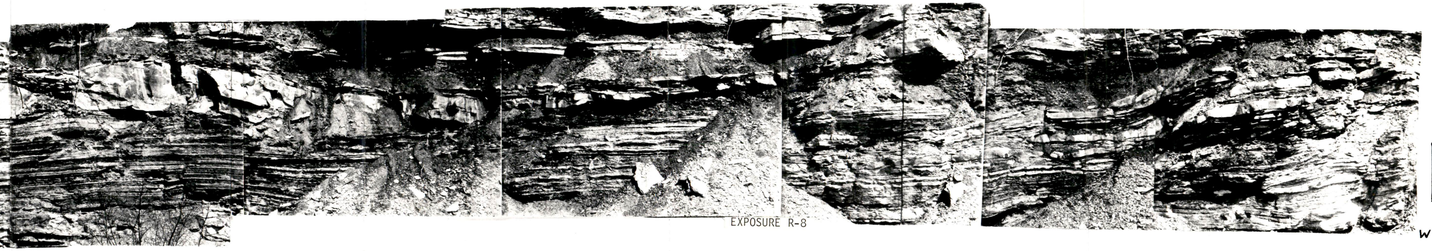
PLATE 12-A:
EXPOSURE R-8



EXPOSURE R-8

8
scale/ft.
8

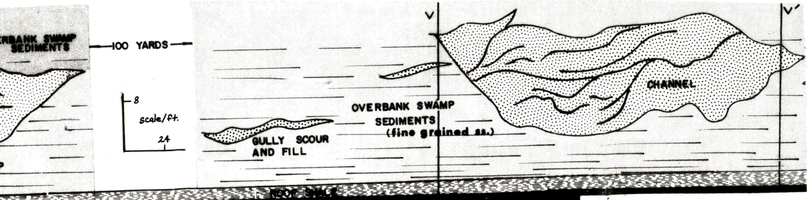


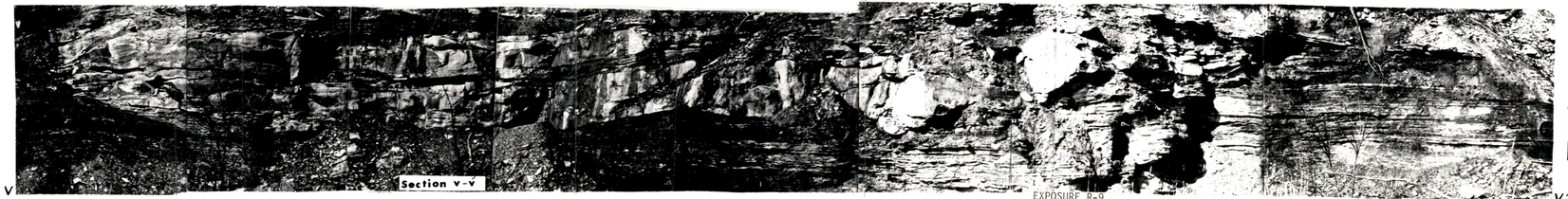


EXPOSURE R-8

W'

8
scale/ft
8





EXPOSURE R-9

8
scale/ft.
8

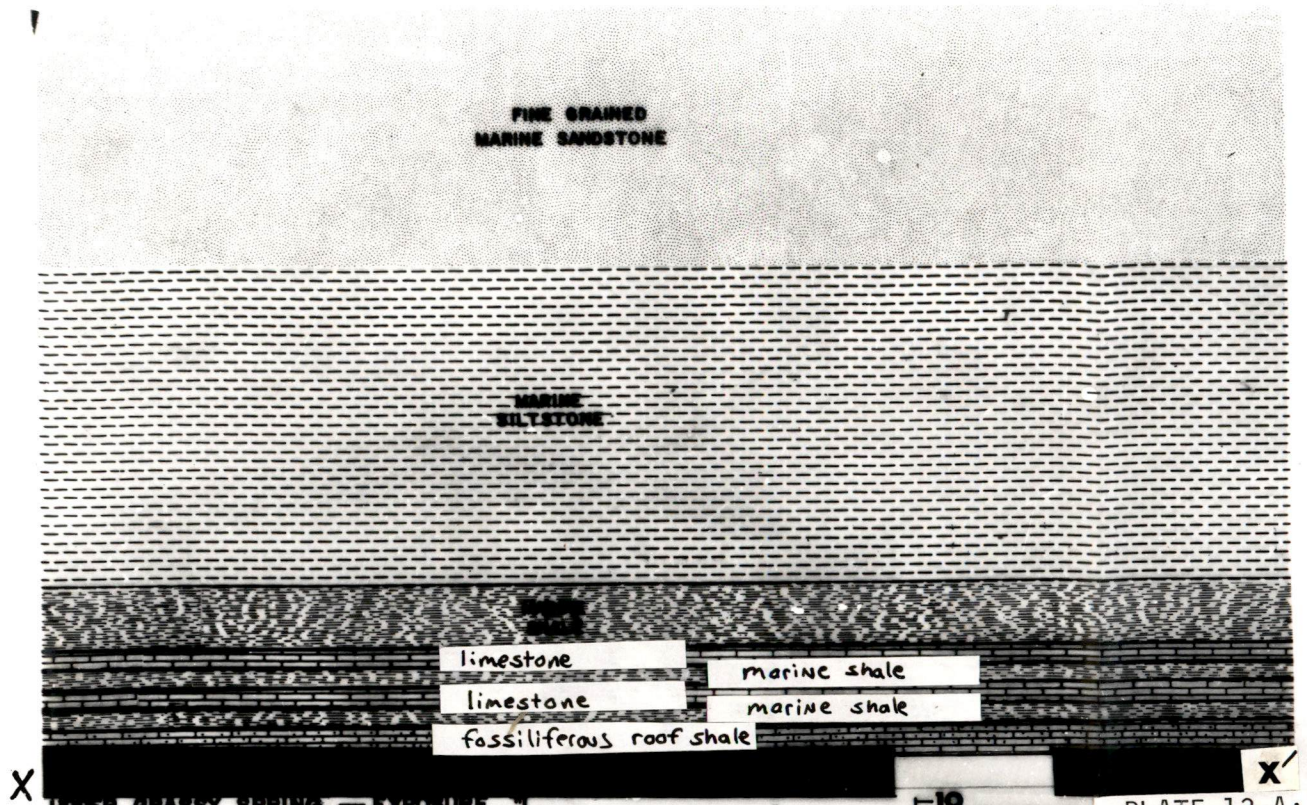
PLATE 13

A. Diagram (Vertical Exaggeration = 2x) and Photographic Sequence of Exposure UG-1: Lower Grassy Spring Interdistributary Bay Section.

B. Diagram (Vertical Exaggeration = 2x) and Photographic Sequence of Exposure LG-1: Upper Grassy Spring Interdistributary Bay Section.

C. Photographic Sequence of Exposure LG-2/UG-2: Complete Vertical Section of Lower and Upper Grassy Spring Interdistributary Bay Feature.

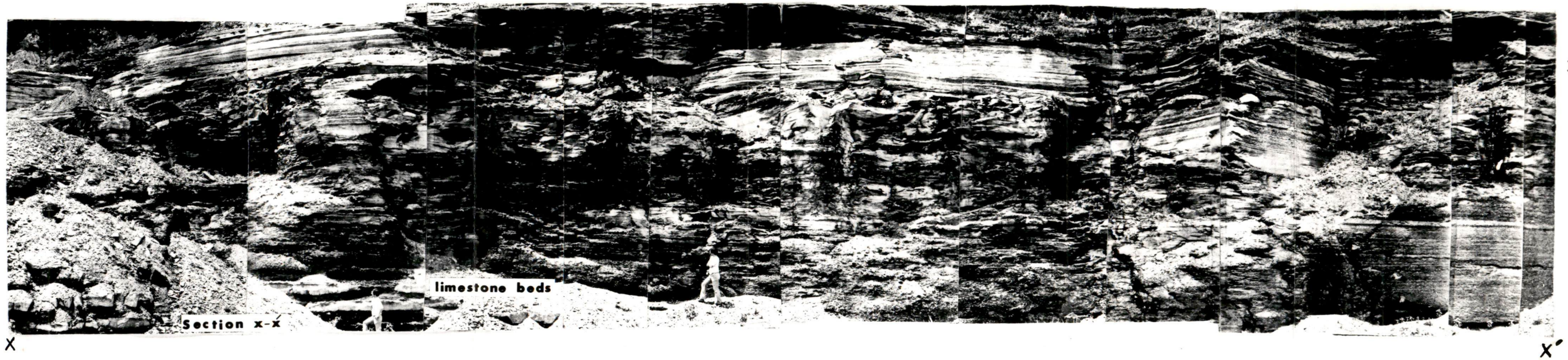
D. Photographic Sequence of Exposure LG-4: Lower Grassy Spring Interdistributary Bay Bar Feature.

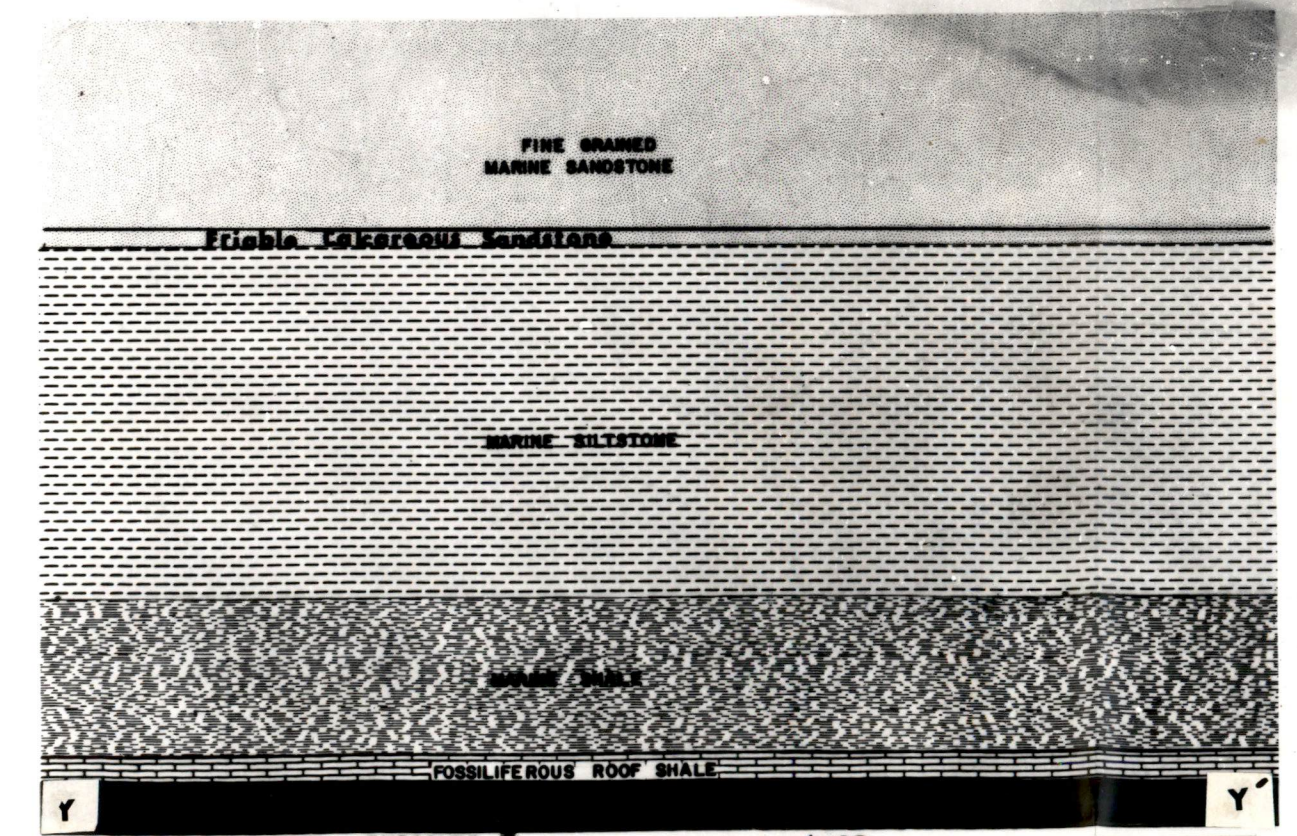


UPPER GRASSY SPRING — EXPOSURE "1"
INTERDISTRIBUTARY BAY SEQUENCE
section x-x'

10 SCALE/FT. 20

PLATE 13-A: EXPOSURE UG-1

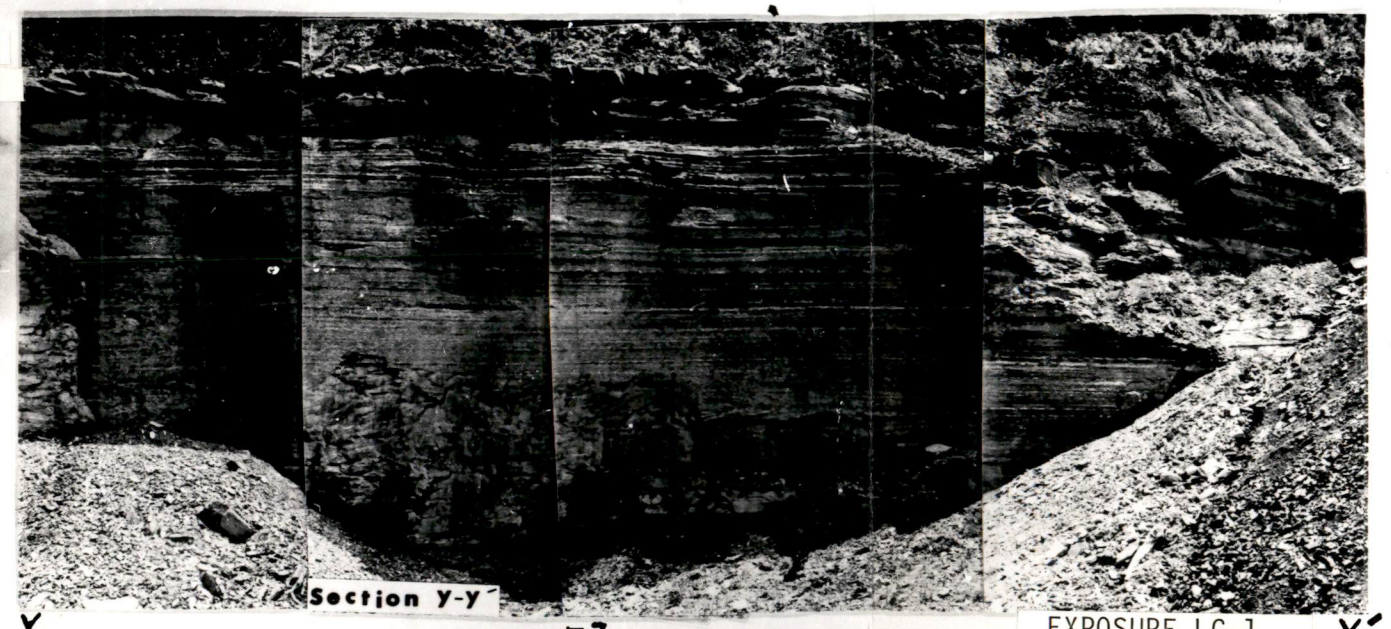




LOWER GRASSY SPRING — EXPOSURE "1"
INTERDISTRIBUTARY BAY SEQUENCE
SECTION Y-Y'

10 SCALE/FT. 20

PLATE 13-B: EXPOSURE LG-1



7 scale/ft. 7

EXPOSURE LG-1

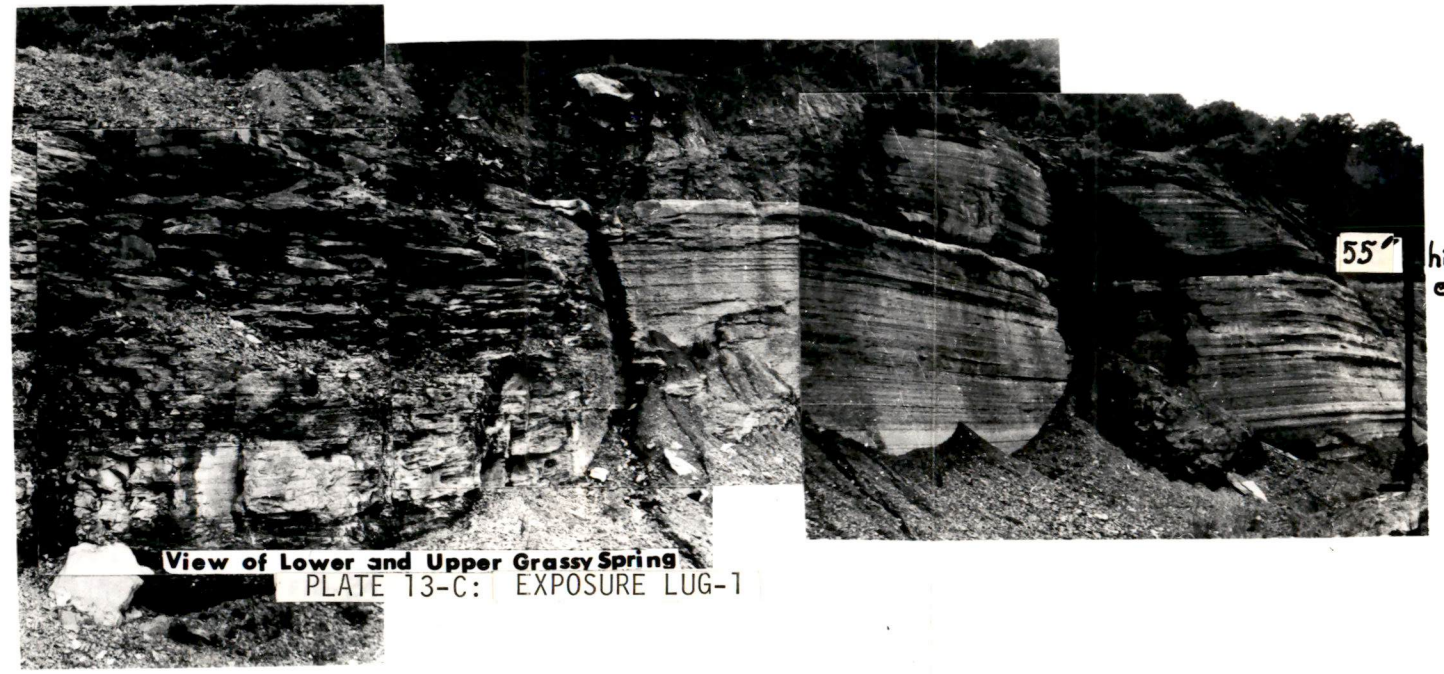


PLATE 13-C: EXPOSURE LUG-1



LOWER GRASSY SPRING — INTERDISTRIBUTARY BAY BAR

EXPOSURE L.G.S. no. 4

PLATE 13-D: EXPOSURE LG-4

PLATE 13

VITA

Steven Clinton Minkin was born in Lausanne, Switzerland, on April 28, 1947. He graduated from high school at Memphis University School in 1965 and the following September enrolled at The University of Tennessee in Knoxville. In June, 1970, he received a Bachelor of Science degree in Zoology.

In the fall of 1970 he began work towards a Master's degree at The University of Tennessee and received a graduate assistantship. He received this degree in March, 1977, and is currently employed with Union Carbide's Nuclear Division in Oak Ridge. He is a member of the Geological Society of America, Society of Economic Paleontologists and Mineralogists, and American Association of Petroleum Geologists.

He is married to the former Melissa Jane Coulter of Nashville, Tennessee.