

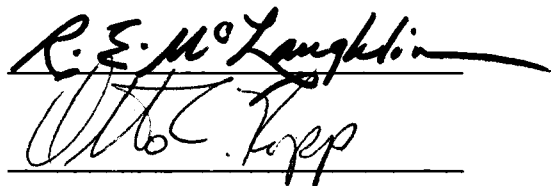
To the Graduate Council:

I am submitting herewith a thesis written by Douglas James Schnoebelen entitled "Depositional Environments of the Lower Crooked Fork Group Near Wartburg, Morgan County, Tennessee." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Geology.

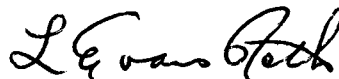


Kenneth R. Walker, Major Professor

We have read this thesis and
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Accepted for the Council



Vice Chancellor

Graduate Studies and Research

DEPOSITIONAL ENVIRONMENTS OF THE LOWER
CROOKED FORK GROUP NEAR WARTBURG,
MORGAN COUNTY, TENNESSEE

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Douglas James Schnoebelen

June 1983

1783913

This volume is dedicated with love
to my wife, Nancy, whose constant
support and help made this thesis possible.

ACKNOWLEDGMENTS

I would like to thank Dr. Kenneth R. Walker, my committee chairman, for his guidance and help. He read numerous drafts of this thesis and made many useful suggestions. My other committee members, Drs. Robert E. McLaughlin and Otto C. Kopp also read drafts of this thesis, often when I was pressed for time. Their ideas and amendments were greatly appreciated. I am also grateful to Dr. Steve Driese for his assistance and advice.

I would like to thank all my friends and colleagues for their support. Special thanks go to Bryn Howze who assisted with all the plane-table and alidade work. Also, Wally Borowski and Craig Clement who provided valuable help with most of the photographic work in this thesis. Allan Jenkins graciously provided numerous references and contributed several helpful ideas.

My family has always been a constant source of support and guidance. My parents, James and Martha, and my grandparents, John and Grace Yeggy, have helped me throughout my career. Without them, none of my successes would have been possible. I would also like to thank my brothers and sisters: Janice and her husband Doug Bean, Randy, Greg, Anne, Tom, and Marcy. Also my wife's family, Bill and Ardee Cushing, and Barb and Dick Farnsworth. All of these people provided constant encouragement.

Last, but not least, I would like to thank my wife, Nancy, to whom this thesis is dedicated. She assisted in every stage of its preparation, from field work to typing. I feel it is as much her thesis as mine.

This work was supported by a grant from the U.T. Department of Geological Sciences Discretionary Fund. SOHIO Petroleum provided valuable help by making fifty thin sections used in this study. James and Martha Schnoebelen provided financial assistance for all of the photographic work which appears in this thesis.

ABSTRACT

The relatively unstudied lower Crooked Fork Group is described and discussed in terms of petrology and depositional environments from 14 exposures near Wartburg, Morgan County, Tennessee. These formations are Early Pennsylvanian in age and include (oldest to youngest), the Dorton Shale, Crossville Sandstone, Burnt Mill Shale, and the Coalfield Sandstone. The Crooked Fork Group is only exposed in the northern Cumberland Plateau of Tennessee.

The Dorton Shale contains seven distinct subfacies; five were traceable across the study area. In general, the Dorton represents an embayment at least partially open to the sea. Initial conditions leading to peat-formation (represented by the Rex Coal) were terminated by a local transgression. The lower one-third of the Dorton (subfacies 1 to 4) records anoxic conditions, slow sedimentation rates, and little current or wave/tidal activity. These conditions are interrupted by a period of oxygenation and intense bioturbation (subfacies 2) and a storm event (subfacies 3). The upper two-thirds of the Dorton (subfacies 5, 6 and 7) reflect increased current or tidal/wave activity and greater sedimentation rates; the latter evidenced by dewatering structures and discrete slump zones.

The Crossville is a complex sand body which represents delta front sands that prograded across the bay sediments of the Dorton. The Crossville in the study area displays characteristics of both marine and fluvial processes. Seven facies recognized within the Crossville are:

(1) reworked distributary bar sands, (2) interbedded flaser sublitharenites and quartzarenites, (3) washovers, (4) thick-bedded channels, (5) multistory channels, (6) abandoned channel fill, and (7) interbedded sublitharenites and quartzarenites.

The Burnt Mill Shale overlies and in one place interfingers with the top of the Crossville. The Burnt Mill is dominated by a stagnant bay facies, although splay, minor mouth bar, and splay abandonment facies were also recognized.

The Coalfield Sandstone unconformably overlies the Burnt Mill and appears more fluviially dominated than the Crossville. The Coalfield contains "dirty sands," abundant fossil twig debris, and numerous channel forms, some of which are abandoned. The Coalfield displays 3 facies: small channels, abandoned channel fill, and large, low-sinuosity channels or chenier-like deposition.

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CHAPTER I

INTRODUCTION

General Background

Pennsylvanian coal-bearing strata in Tennessee lie within the physiographic province known as the Cumberland Plateau. This belt of relatively undeformed sediment trends northeast-southwest across east-central Tennessee (Fig. 1.1).

Throughout the Cumberland Plateau as more coals are mined, it is becoming increasingly important to understand in greater detail the depositional environments of these Carboniferous strata. Horne et al. (1978) demonstrated that the recognition of these environments are important in predicting variations in the geometry, thickness, and quality of coal seams. Thus, constructing and refining paleoenvironmental models for rocks of the Cumberland Plateau may be economically useful.

This study contributes to the knowledge of Early Pennsylvanian depositional environments by investigating the relatively unstudied lower Crooked Fork Group (Fig. 1.2) from new exposures found near Wartburg, Tennessee (Fig. 1.3).

Purpose

The objectives of this study are threefold:

1. To describe the petrology and small scale sedimentary features of the lower Crooked Fork Group, particularly concentrating on recognizing environmental subfacies in the Dorton Formation.

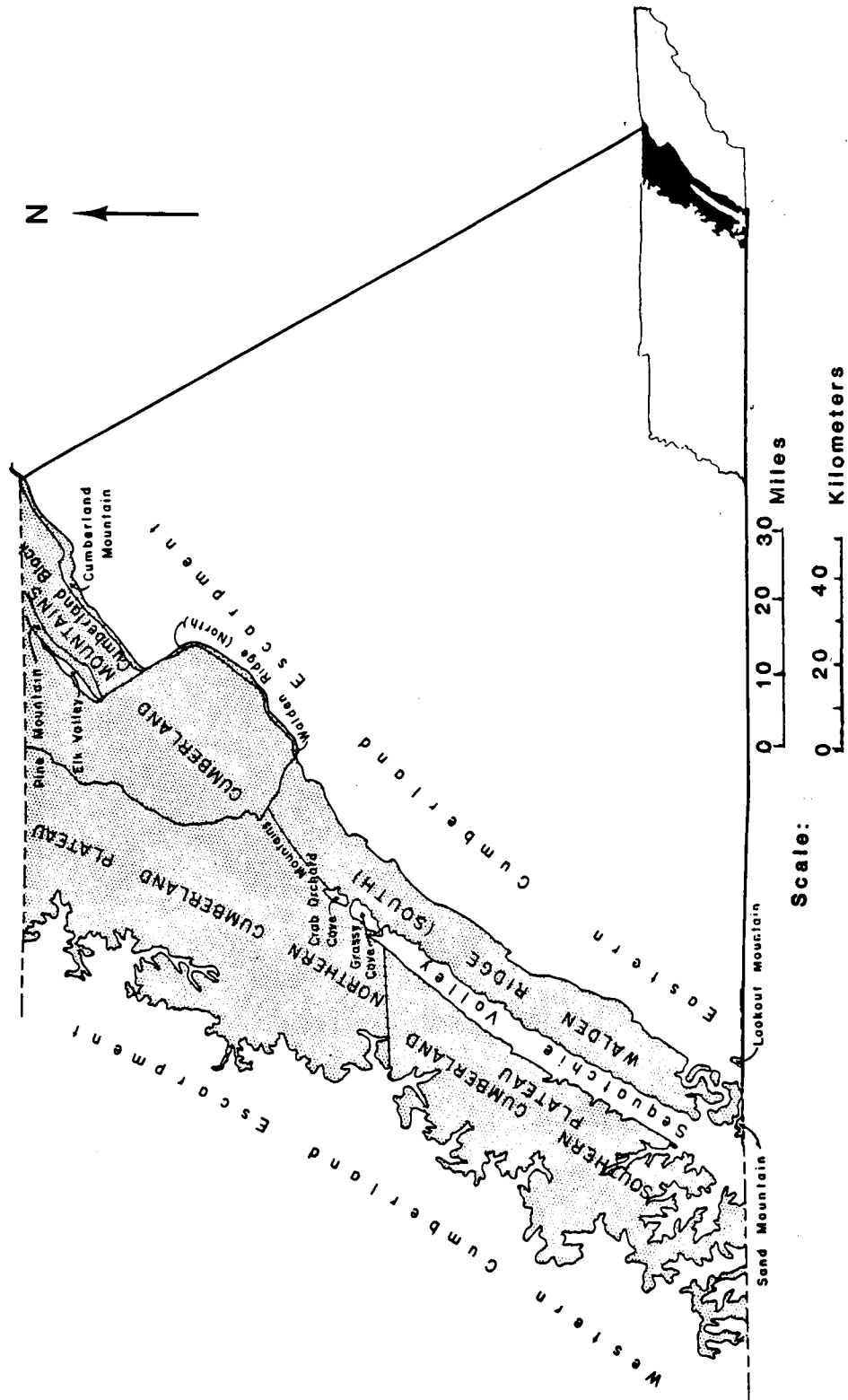


Fig. 1.1. Physiographic features of the Cumberland Plateau (from Luther, 1959).

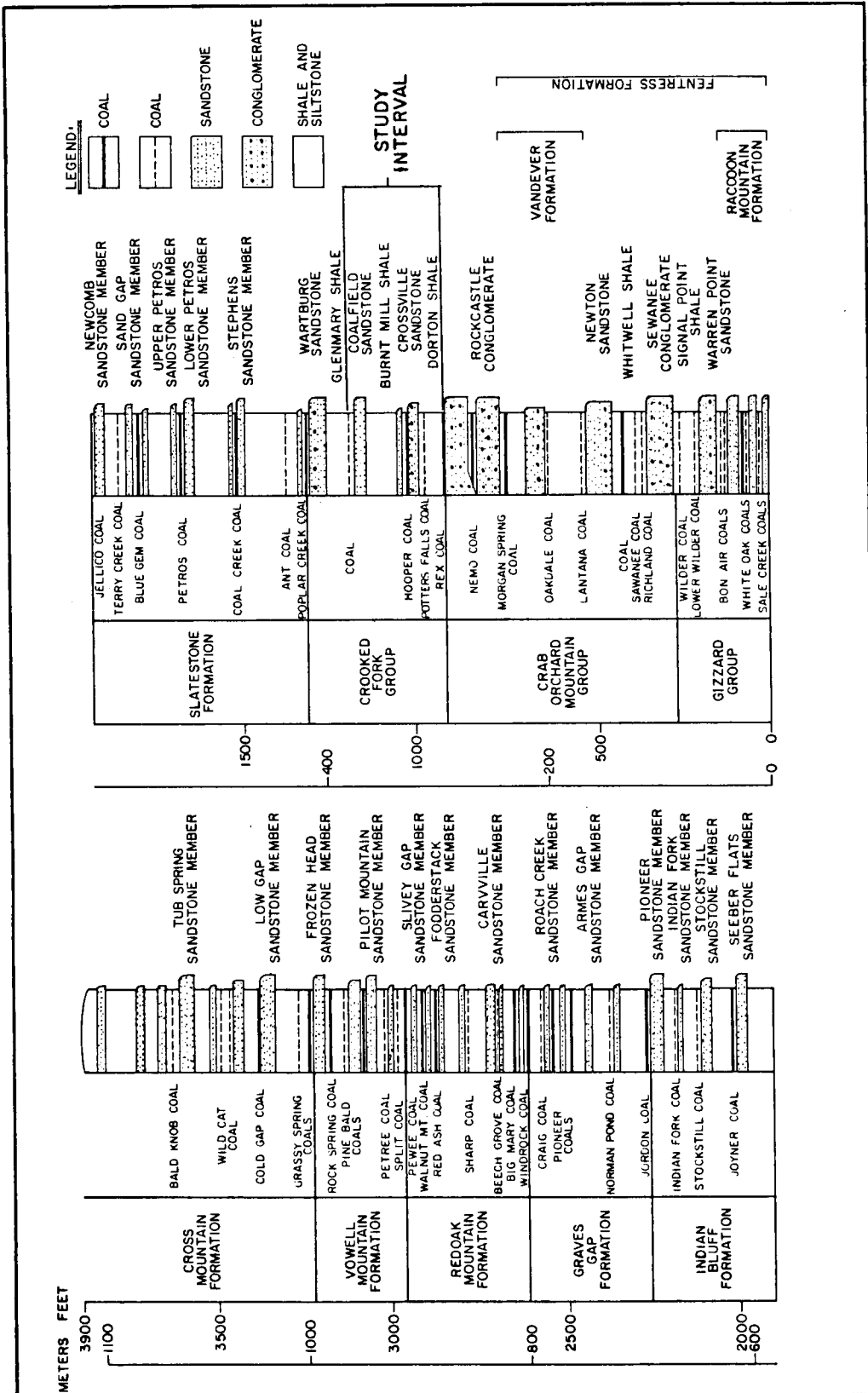


Fig. 1.2. Stratigraphic column for Pennsylvanian rocks of the northern Cumberland Plateau, showing the interval of study (modified from Luther, 1959).

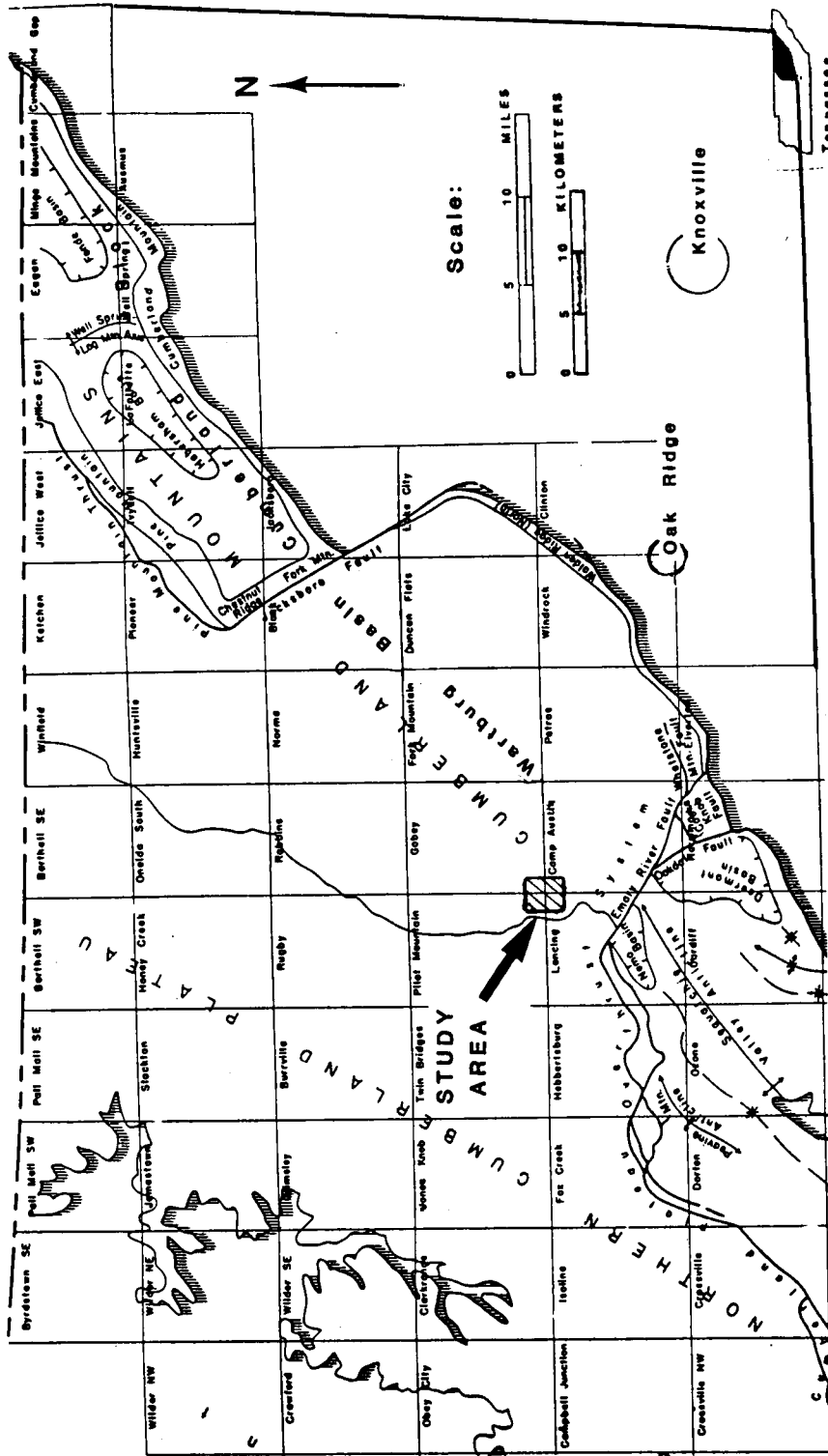


Fig. 1.3.3. The Wartburg basin, showing the location of the study area
(from Wilson et al., 1956).

2. To contribute a detailed depositional history of the lower Crooked Fork Group in the study area, and to construct a fence diagram connecting the facies interpretations of outcrop exposures within the study area (see Chapter III, p. 64).

3. To determine whether the inferred environments of the study area agree with paleoenvironmental interpretations on a regional scale advanced by workers such as Ferm et al., (1972), Ferm (1974), and Milici et al. (1979).

Study Area

The Cumberland Plateau was divided by Nelson (1925) and Glenn (1925) into the northern and southern divisions along the Tennessee Central Railroad. Located within the northern Cumberland Plateau is the Wartburg basin (Fig. 1.3). The term "basin" is used here in agreement with previous authors' terminology although a more correct term would be depocenter. This basin is bounded on the northeast by the Jacksboro fault, on the southeast by Walden Ridge, and on the southwest by the Emory River and Whetstone Mountain faults. To the west and northwest the Wartburg basin merges with the rest of the northern Cumberland Plateau.

The study area is situated near the southwest edge of the Wartburg basin in the vicinity of Wartburg, Morgan County, Tennessee. More specifically, the study area is located in the eastern part of the Pilot Mountain Quadrangle, the southwestern corner of the Gobey Quadrangle, and the northwestern corner of the Lancing Quadrangle (Fig. 1.3).

Ten road outcrops and four railroad outcrops were measured and described in detail. Outcrop locations are shown in Fig. 1.4 with each outcrop designated by a letter.

Methods

In order to accomplish the goals outlined, several levels of investigation were used.

Reconnaissance of roadcuts, railroad cuts, and natural outcrops determined the lithologic components present and their lateral variability. Facies relationships were then examined by detailed mapping of the outcrops using drawings made from photo-mosaics (Appendix E), measured sections, (Appendix B), as well as recording sedimentary structures, fossils, and trace fossils. Two hundred paleocurrent readings were obtained to delineate paleocurrent directions, (see Appendix C for the procedures used and types of measurements obtained). Eighty samples were collected for later thin section analysis and 200 samples were collected for acetate peels. Exact sample locations are shown on the drawings made from the photo-mosaics in Appendix E. Appendix F relates the facies described in the text to the field "units" described in Appendix B for each outcrop.

Thin sections (5 × 7.5 cm) were used as an aid in recognizing small scale sedimentary structures (grading, loading, lamination, burrows, etc.) and petrology of the lower Crooked Fork Group. Selected thin sections were point counted (300 points per slide) in order to better estimate the different constituents of each lithology. Appendix D

Fig. 1.4. Simplified topographic map of the study area showing the location of outcrops used in this study.

describes the point counting procedure, lists the data, and the cautions to be followed when using this data.

The classification and terminology as used in this thesis for the description of the different lithologies can be found in Appendix A. All field thicknesses were measured to the nearest centimeter. However, this is not meant to imply that these measurements are that precise. These thickness measurements should be viewed as approximate thicknesses only.

Since the Dorton Formation was to be examined in detail, 160 serial samples were collected in vertical section from the top of the Rex coal to the base of the Crossville Formation at outcrop A, as this was the most complete exposure in the study area. Field relationships determined sampling of the Dorton Formation at the other outcrops in the study area. Exact sample locations for each outcrop of the Dorton Formation can be found on the drawings made from the photo-mosaics in Appendix E.

All mudrock samples were collected by using a Target portable rock saw, which often required impregnating the outcrops with boat resin. Most samples were subsequently coated again with this resin in the lab. These were slabbed and polished, so acetate peels could be made from each slab. The acetate peels were examined in detail using binocular and petrographic microscopes.

Highway outcrops (A, A1, A2, B, C, D1, D, E, F, and G) and railroad outcrops (AA, BB, CC, and DD) formed two "panels" of the fence diagram (Chapter III, p. 64). The correlation of these outcrops is discussed below. The reader is asked to refer back to the measured section

descriptions in Appendix B or the photo-mosaic sketches (Appendix E) if necessary in the following discussion.

The Crossville Formation is the only traceable unit in outcrops A, A1, A2, B, and C; thus it was chosen as a datum for these outcrops. The very top of the Crossville is only partially exposed at outcrop A which necessitates using the center of this sandstone in correlating outcrops A to C.

Outcrops E, F, and G were correlated by using the first carbonaceous black clayshale (marker bed 1) occurring in each of these outcrops. This correlation was based on the same stratigraphic position of marker bed 1 in each of these outcrops. Outcrops E, F, and G were only 30-70 meters apart and the elevation of marker bed 1 was found to be nearly the same (within 2 meters).

Outcrops D and E were correlated by using the second black carbonaceous-coaly clayshale (marker bed 2) which lies above the Coalfield Formation. This correlation was based on the similar stratigraphic position of that unit in these two outcrops.

Outcrops C and D1-D were approximately 550 meters apart. A plane-table and alidade were used to sight a bearing from the top of the Crossville Formation at outcrop C to the top of the Crossville Formation at outcrops D1 and D. These outcrops (C, D1, and D) were hung on this datum as only 1.5 meters of difference in elevation was recorded between the top of the Crossville at these outcrops.

The railroad outcrops (AA, BB, CC, and DD) were correlated using the middle of the only common unit, the Crossville Formation. The

elevation of the Crossville along the railroad tracks was determined through use of a plane-table and alidade. The elevation differences along the railroad exposures varied from 1 to 4 meters.

In correlating outcrops along the railroad (AA, BB, CC, and DD) with those of the highway (A, A1, A2, B, C, D1, D, E, F, and G) it was determined that the coal in outcrop DD was the same as the coaly-clayshale (marker bed 2) of outcrops D and E. This was evidenced by the same position of the two units in the stratigraphic sequence and similar elevations (after regional dip was accounted for). The apparent difference in elevation between the highway and railroad exposures (43 meters) was accounted for by the gentle regional structure of the area, which causes a one to three degree dip to the southeast (Fig. 1.5).

Stratigraphy

Much of the present stratigraphic nomenclature of the Cumberland Plateau is based on revisions organized by Wilson et al. (1956). A summary of the development of this nomenclature is shown in Fig. 1.6.

The stratigraphic sequence in the study area is from the top of the Rockcastle Formation to the unnamed coal directly above the Coalfield Formation (Fig. 1.2, p. 3). This interval was chosen for study because of its excellent exposure and the lack of previous detailed paleoenvironmental work on the Crooked Fork Group.

The Crooked Fork Group includes all of the strata between the top of the Rockcastle Formation to the Popular Creek coal which overlies the Wartburg Formation. The Crooked Fork Group is named from the composite

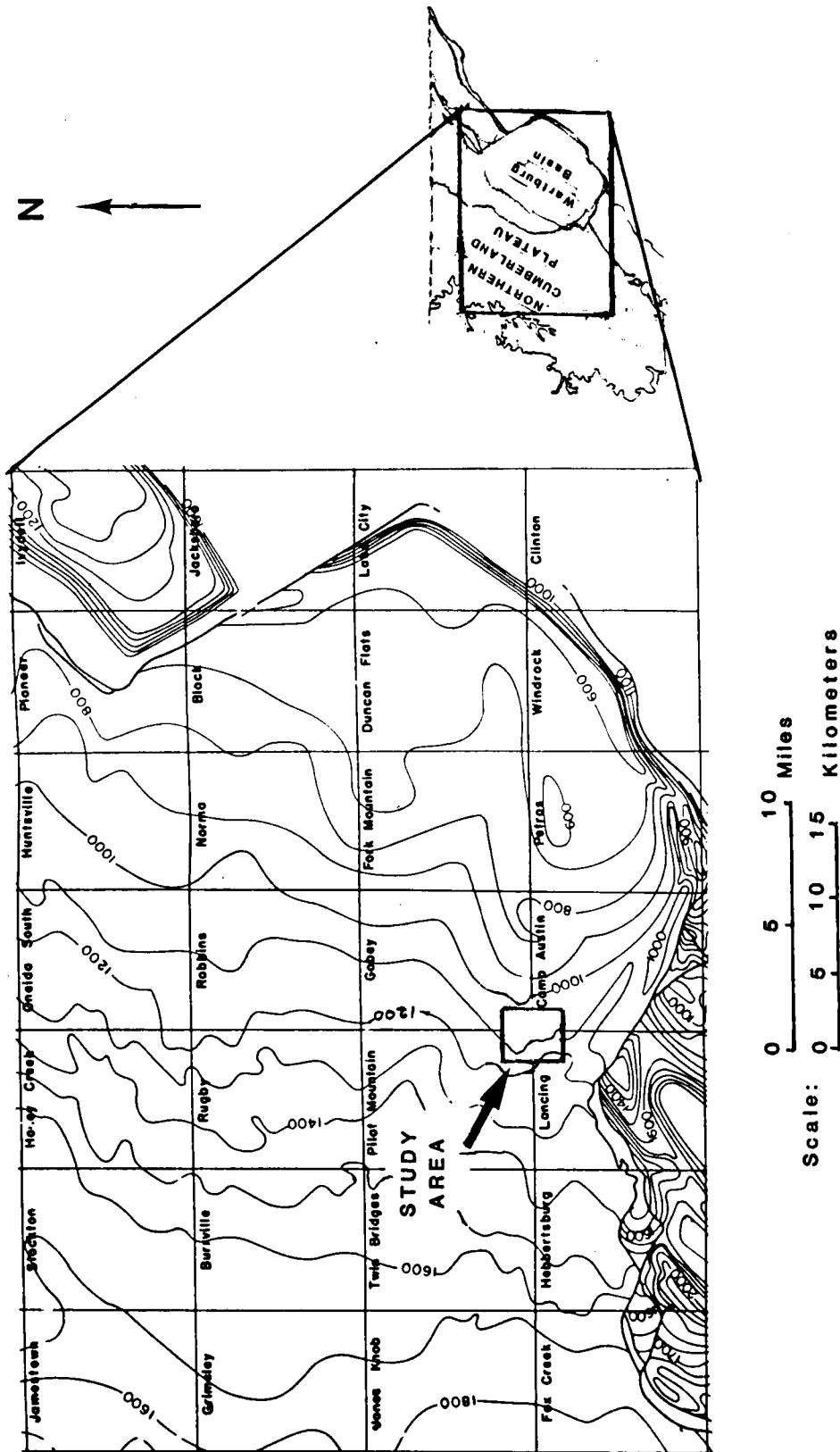


Fig. 1.5. Structure contour map on the top of the Rockcastle Formation showing the gentle southeastern dip in the study area (from Wilson et al., 1956).

section exposed southeastward from Wartburg and along Crooked Fork Creek in Morgan County, Tennessee (Wilson et al., 1956). The area of preservation for the Crooked Fork Group is limited to the northern Cumberland Plateau.

Rockcastle Formation

Wanless (1946) named the Rockcastle Formation from exposures near Rockcastle Cove at Jamestown, Fentress County, Tennessee. The Rockcastle underlies the Crooked Fork Group and because of its comparatively uniform character, the Rockcastle is a readily traceable unit across much of the northern Plateau.

Distribution. Exposures of the Rockcastle in the study area can be found in Rock Creek near section A and along the Emory River gorge at section AA.

Thickness. Only the top part (3-20 m) of the Rockcastle is exposed in the study area. The total thickness of the Rockcastle is from 33 to over 95 m across the northern Plateau (Luther, 1959). In the study area the Rockcastle is a coarse-grained quartzarenite, often thick-bedded, with large (1-2 m long) festoon crossbeds. Luther (1959) reports that the Rockcastle across much of the Cumberland Plateau has a widespread 5 m shaley unit which contains the Nemo coal. In the study area the Rockcastle grades upward into the Dorton Formation.

Dorton Formation

The Dorton Formation is named from exposures near Dorton, Cumberland County, Tennessee (Wilson et al., 1956). The Dorton Formation is the youngest formation of the Crooked Fork Group, and lies between the top of the Rockcastle Formation and the base of the Crossville Formation.

Distribution. In the study area the Dorton Formation is completely exposed at sections A, AA and partially exposed (20-60%) in sections A1, A2, B, C, D1, D, E, BB, CC, and DD. The Rex coal (also known as the Christmas coal) occurs near the base of the Dorton and is only exposed at outcrop A.

The Potter Falls coal described by Wilson et al. (1956), near the top of the Dorton Shale was not found in the study area.

Thickness and Lithology. The Dorton Shale ranges from 17-27 m across the Cumberland Plateau (Wilson et al., 1956) but in the study area it is 26 m thick (section AA). Across the northern Cumberland Plateau the Dorton Shale thins gradually to the west and northwest (Luther, 1959).

The Dorton Shale across the study area is dark-gray, medium- to thick-laminated siltstone to mudshale. The laminations are usually lenticular coarse quartz silt and rhythmically layered (1 mm - 5 cm spacing). Marine fossils in the study area (straight cephalopod, trilobite, horn coral, and gastropods) have been found by this author at outcrops A and AA. Wilson and Stearns (1960) mention marine fossils collected from the Dorton Shale in the northern Plateau.

Crossville Formation

The Crossville Formation was named by Wanless (1946) for the stone quarried near Crossville, Cumberland County, Tennessee. The Crossville Formation overlies the Dorton Formation and underlies the Burnt Mill Formation.

In the study area, the Crossville Formation unconformably overlies the Dorton Formation. Along the highway outcrops in the study area, the contact is flat with little scour (20-50 cm) into the underlying Dorton; but at outcrop CC along the railroad approximately 1.0 to 2.0 meters of scour into the Dorton is present.

Distribution. The Crossville Formation is present in all of the measured exposures in the study area.

Thickness and Lithology. East of a north-south line through Harriman, Wartburg, Sunbright, and Oneida, the Crossville Formation thins or may be absent. West of this line the Crossville Formation thickens (16-144 m), (Wilson et al., 1956). The formation in the study area is a buff, fine-grained, well-sorted quartzarenite, containing numerous planar and trough crossbeds as well as ripple cross-laminations.

Burnt Mill Formation

The Burnt Mill Formation is named from exposures near Burnt Mill, Scott County, Tennessee (Wilson et al., 1956). The Burnt Mill Formation in the study area overlies and interfingers with the top of the Crossville Sandstone at outcrops D1 and D. The Coalfield Formation overlies the Burnt Mill Formation.

Distribution. A complete section of the Burnt Mill Formation is seen in the study area at outcrops D and DD. Outcrops D1, E, F, G, BB, and CC in the study area contain partial exposures of the formation (20-75%).

In other areas across the northern Plateau where the overlying Coalfield Formation is missing, the Burnt Mill is not separable from the Glenmary Formation above (Luther, 1959). Also, in some localities the Burnt Mill Formation may be truncated by higher sandstones which overlap it to the west (Luther, 1959).

Thickness and Lithology. Where neither of the above conditions prevail, the Burnt Mill Formation ranges in thickness across the northern Plateau from 12-44 m (Wilson et al., 1956). In the study area it is 14 m thick. In some places, the Hooper coal occurs near the base of the Burnt Mill Formation and has been mined near Oakdale and Oliver Springs (Luther, 1959). The Hooper coal is not present in the study area.

The Burnt Mill Formation in the study area is a black, medium-laminated, organic-rich mudshale to clayshale. Marine fossils have been collected from the Burnt Mill Shale, 3.2 kilometers south of Wartburg, Tennessee (Wilson and Stearns, 1960). Siderite replaced, in-situ plant roots have been found at outcrop D in the study area by the present author.

Coalfield Formation

The Coalfield Formation is named for the sandstone underlying Coalfield, Morgan County, Tennessee (Wilson et al., 1956). The Coalfield

Formation has a sharp, scoured, contact with the underlying Burnt Mill. Overlying the Coalfield Formation is the Glenmary Formation.

Distribution. In the study area the Coalfield is present at outcrops D, E, and DD.

Thickness and Lithology. When present, the Coalfield Formation ranges from 3 to 15 meters thick in the northern Cumberland Plateau. The unit is thicker (greater than 7 m) in southeastern Morgan County and thinner (less than 7 m) near the western edge of Scott County (Wilson et al., 1956).

In Morgan County, the Coalfield Formation may be locally split into several benches separated by thin shales (Luther, 1959). In the study area the formation is 4-5 meters thick. Usually in the study area, the Coalfield is a very fine-grained, medium-bedded sublitharenite to quartzarenite. At outcrop E, the lower part of the Coalfield Formation (1.7 m) is a shale arenite.

Glenmary Formation

The Glenmary Formation is named from exposures near Glenmary, Scott County, Tennessee. The Glenmary Formation rests on the Coalfield Formation and is overlain by the Wartburg Formation. The Burnt Mill Formation and the Glenmary Formation are not separable when the Coalfield Formation is absent. To the northwest in the northern Plateau, the Glenmary is truncated by the Wartburg Formation and may be missing altogether (Luther, 1959).

Distribution. In the study area, the Glenmary Formation outcrops at D, E, and DD. It is also exposed along Highway 27 at Wartburg, Tennessee.

Thickness and Lithology. The Glenmary ranges from 14-26 m thick over most of its outcrop belt, but thins in northern Scott County to 7 m (Wilson, et al., 1956). In the study area, this unit was not examined in detail, although 12 meters of Glenmary Formation is exposed on Highway 27 at Wartburg, Tennessee, as well as at outcrop E.

A thin (17 cm), unnamed coal occurs near the base of the Glenmary Formation at outcrop DD in the study area. At outcrops D and E in the study area, this coal is more of a coaly-clayshale, and is thought to represent the same coal described by Wilson et al. (1956), and Luther (1959) elsewhere on the Plateau.

The Glenmary Formation in the study area is a dark-gray, very thin-bedded siltstone, which contains marine fossils east of Coalfield, Tennessee (Wilson and Stearns, 1960).

Wartburg Formation

The Wartburg Formation was named by Keith (1897) from exposures at Wartburg, Morgan County, Tennessee. The Wartburg Formation and Popular Creek coal overlying it, mark the top of the Crooked Fork Group. The Wartburg Formation has a sharp, flat contact with the underlying Glenmary Formation.

Distribution. The Wartburg is a fairly persistent and traceable unit throughout much of the Cumberland Plateau. In the study area it is present along Highway 27 at Wartburg, Tennessee.

Thickness and Lithology. The Wartburg Formation ranges from 15-20 m thick west of a north-south line from Petros to Oneida, while east of this line it is thin, and shaly (Luther, 1959). In the study area, the Wartburg Formation was not studied in detail though 17 m of this sandstone is exposed along Highway 27 at Wartburg, Tennessee.

The Wartburg Formation in the study area is a thick-bedded, medium- to fine-grained, quartzarenite to sublitharenite. Large (20° dip, 80 cm long) festoon crossbeds are often present.

The Popular Creek coal occurs 2-3 meters above the Wartburg Formation and has been mined across much of the northern Cumberland Plateau. This coal is exposed in outcrop along Highway 27 at Wartburg, Tennessee.

Previous Investigations

The earliest workers of the northern Cumberland Plateau, such as Safford (1869), Keith (1897), and Campbell (1898) were primarily concerned with the distribution and thickness of coal beds.

Glenn (1925) was one of the first workers in the northern Cumberland Plateau to establish the groundwork for stratigraphic nomenclature in Scott, Pickett, Fentress, and Morgan counties. Glenn's work was mainly descriptive and designed as a coal prospecting guide.

Wanless (1946) working in the southern Cumberland Plateau tried to establish a regional correlation of Pennsylvanian age rocks over parts

of Tennessee, Georgia, Kentucky, and Virginia. No attempt was made to assign specific paleoenvironments to specific rock units and the paleoenvironments are overgeneralized.

The dissertation of Mitchum (1954) was important for establishing a more detailed sedimentary history for the Cumberland Plateau in Tennessee. He proposed the existence of marine environments during deposition of lower Pennsylvanian sandstone and conglomerates (Gizzard, Crab Orchard Mountain and Crooked Fork Groups).

Wilson et al. (1956) mapped the Cumberland Plateau in Tennessee and compiled the first composite stratigraphic section for Pennsylvanian sedimentary rocks in Tennessee.

Wilson and Stearns (1960) attempted to explain the Pennsylvanian sediments of the Plateau in Tennessee in terms of cyclothems. They visualized alternating peat swamps and marine conditions as resulting from eustatic sea level fluctuations. They present a good summary of marine fossils collected from Pennsylvanian strata. However, their environmental interpretations are somewhat overgeneralized and lack substantiating data.

Ferm (1970), Ferm et al. (1971), Horne and Ferm et al. (1974), and Horne and Ferm (1977), have interpreted the coal-bearing, middle Pennsylvanian sediments in eastern Kentucky and West Virginia as prograding deltaic complexes. They have shown that studies of Holocene deltas and coastal plain environments are an aid in interpreting rock sequences. Using these analogs, they developed a general deltaic model to describe the coal measures of the southern Appalachian coal fields.

Briggs (1978) and his students, Tisdale (1974), White (1975), Minkin (1977), and Roberts (1978) applied Ferm's generalized model to the Pennsylvanian rocks of the Wartburg basin. They attributed the stratigraphy (Redoak Mountain through Cross Mountain Groups) to delta progradation and periodic reworking by shorezone processes

Work in the lower Pennsylvanian groups of Tennessee (Gizzard, Crab Orchard Mountain and possibly part of the Crooked Fork) by Ferm et al. (1972), Eason (1973), Milici (1974), and Carlson (1978) show that these quartzarenites, shales, and conglomerates were of littoral origin. Milici et al. (1979) suggested that the Crooked Fork Group was transitional between the littoral groups below (Gizzard, Crab Orchard Mountain) and the more deltaic groups above (Slatestone through the Cross Mountain Groups). However, Milici et al. (1979) pointed out that the depositional environments of the Crooked Fork Group had not been studied in any detail.

Regional Model

In this section, the evolution of a regional model depicting the rocks of the Cumberland Plateau as proposed by previous workers is discussed. The discussion also serves to illustrate the role previous workers have assigned to the Crooked Fork Group in constructing the model. The reader should keep in mind that the regional ideas concerning rocks of the Cumberland Plateau are not fully tested, but simply the best working model at this time.

In general, the Carboniferous sequence in Tennessee can be divided into a lower and upper part. Milici et al. (1979) briefly discuss this division:

The Lower part of the Carboniferous sequence in Tennessee is composed of carbonate rocks which were deposited on a relatively stable, shallow, platform to the west; to the east terrigenous clastic and carbonate rocks were deposited in a subsiding geosyncline. The upper part of the sequence is dominated by coal-bearing terrigenous clastic rocks, representing either coastal barrier island-lagoonal deposits or deltaic environments. The carbonate sequence is separated from the coal-bearing beds by a transitional unit, the Pennington Formation. In general, the lower carbonate rocks and Pennington Formation are Mississippian whereas the overlying terrigenous clastic rocks are Pennsylvanian.

The upper sequence mentioned above (lower and middle Pennsylvanian) can be subdivided in Tennessee into two broad groups:

1. A lower sequence of thick quartzarenites interbedded with shale and a few coals (Gizzard, Crab Orchard Mountain, and Crooked Fork Groups).
2. An upper sequence dominated by shale, but containing fair amounts of sandstone and numerous coals (Slatestone through Cross Mountain Groups). This division of the Pennsylvanian in Tennessee is illustrated by a cross-section from Milici et al. (1979) (Fig. 1.7).

Ferm (1974) recognized these divisions (Mississippian and Pennsylvanian, as well as the lower and middle Pennsylvanian) on a regional basis across Tennessee. Ferm (1974) showed a progradational sequence from the limestones, shales, and argillaceous sandstones of the Pennington, through the quartzarenites, to upper strata dominated by shale and coal as a transition from marine deposits, to littoral deposits, to delta plain facies.

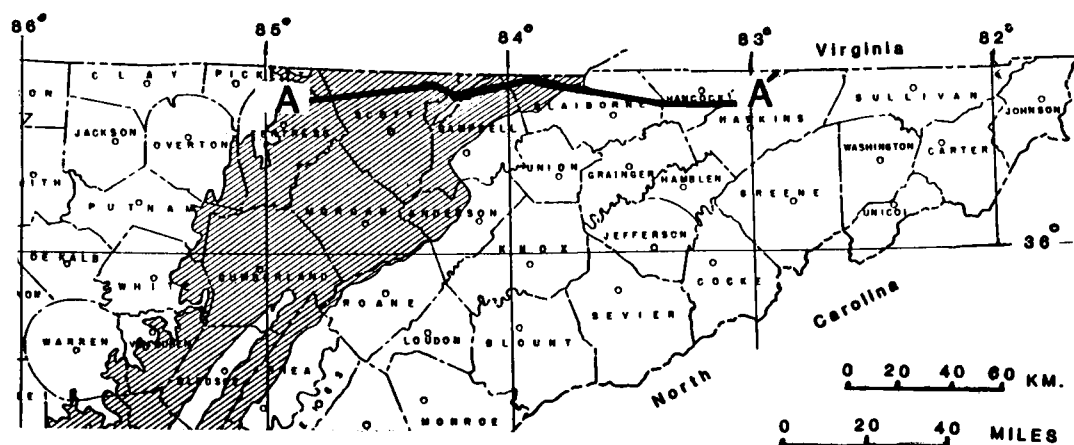
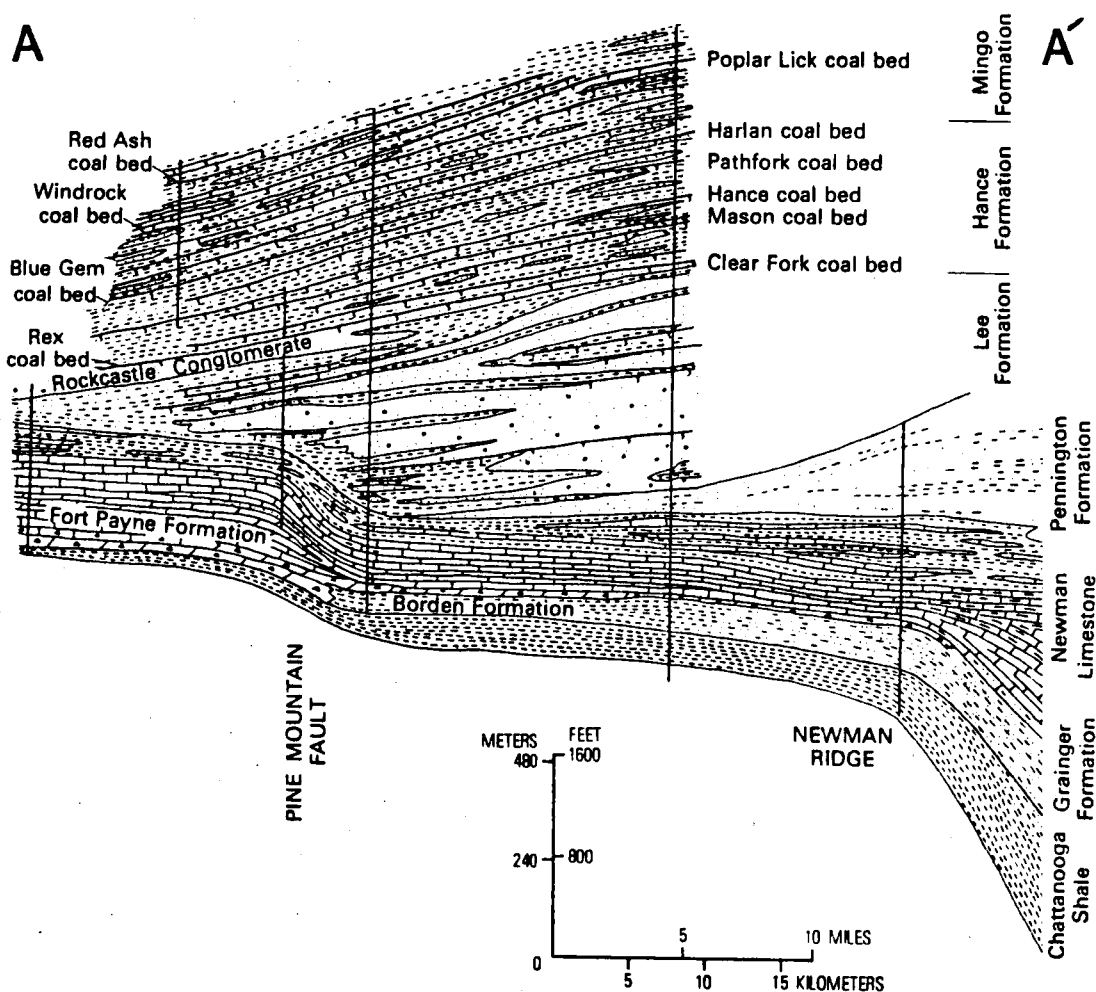


Fig. 1.7. Location map and cross-section across the northern Cumberland Plateau (modified from Milici et al., 1979).

The lower sequence of thick Pennsylvanian age quartzarenites and dark-gray shales contain much evidence of their origin in barrier environments. Deposits representing beaches, tidal flats, tidal deltas, tidal channels, washovers, bars, and lagoons are abundant in the Gizzard and Crab Orchard Mountain Groups (Milici et al., 1979). Milici et al. (1979) states that the Crooked Fork Group may contain many of these same features. A marine fauna consisting of trilobites, crinoids, brachiopods, pelecypods, and gastropods has been found in the lower Pennsylvanian sequences (Gizzard, Crab Orchard Mountain, and Crooked Fork Groups) by numerous workers (Wanless, 1946; Mitchum, 1954; Wilson and Stearns, 1960; and the present writer). Horne (1979) shows that a Carboniferous coastal embayment probably existed in east Tennessee during the deposition of the Crab Orchard Mountain and Gizzard Groups, perhaps extending into the Crooked Fork Group (Fig. 1.8).

Horne (1979) thought tidal range increased toward the center of this embayment based on sediment distribution and regional paleocurrent trends. Horne (1979) based much of his work on the following authors: Hobday (1974) and Horne et al. (1976) in Alabama; Ferm et al. (1972), Eason (1973), Milici (1974), and Carlson (1978) in Tennessee; Horne and Ferm (1970), Ferm et al. (1971), Horne et al. (1974), and Horne and Ferm (1978) in Kentucky; and Hobday and Horne (1977) in West Virginia. Horne (1979) also used paleocurrent data from several studies: Potter and Sevier (1956), Englund and Windolph (1971), and Barwis and Horne (1979) in Kentucky; Schlee (1963), Ferm et al. (1972), Jones (1972), Eason (1973), and Milici (1974) in Tennessee; Schlee (1963), Hobday (1969), and Horne et al. (1976) in northern Alabama.

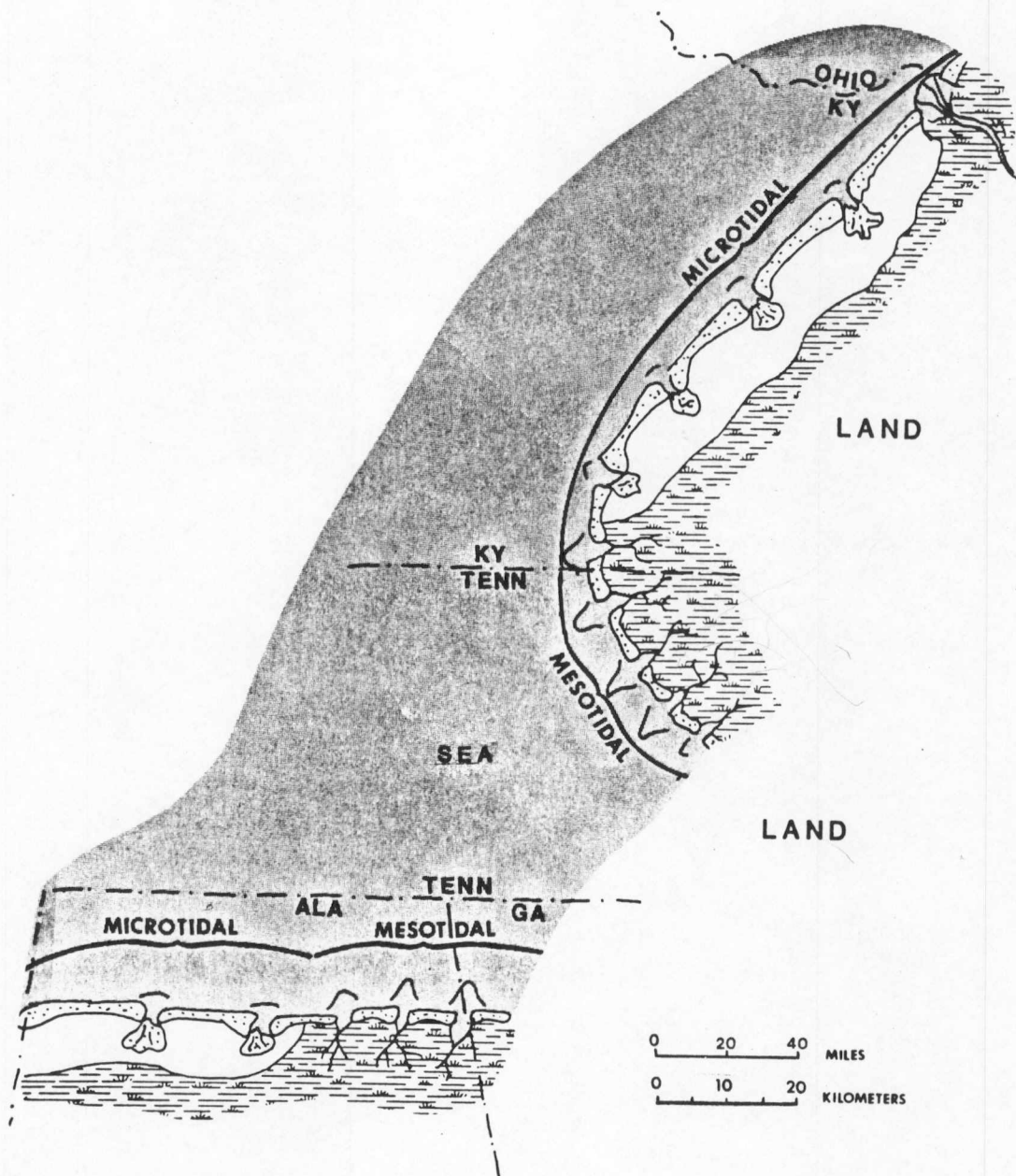


Fig. 1.8. Carboniferous coastal embayment postulated for Kentucky, Alabama, and Tennessee (from Horne, 1979).

The upper division of middle Pennsylvanian age strata in Tennessee (Slatestone through Cross Mountain Groups), is discussed by Milici et al. (1979) as a result of delta progradation from the east.

Briggs (1978) and his students Tisdale (1974), White (1975), Minkin (1977) and Roberts (1978) have shown that middle Pennsylvanian groups in the Wartburg basin (Redoak Mountain through Cross Mountain) have resulted from deltaic progradation from the east, with periodic abandonment and reworking by shorezone processes. Evidence cited for lower delta plain processes are thin areally restricted levees, splays, and bar deposits devoid of plants preserved in life position. Upward in the section, larger and coarser levee, splay and point bar deposits are common. Thick channel deposits and large preserved trees are abundant. These features are all characteristic of upper delta plain facies.

In summary, a Carboniferous coastal embayment existed in east Tennessee. During early Pennsylvanian sedimentation (Gizzard, Crab Orchard Mountain, and possibly part of the Crooked Fork Group), barriers migrated northwest-southeast. The sea was to the south and west of the barriers, with back barrier and more continental environments to the northeast and east in the Wartburg basin. Delta progradation occurred from the east as evidenced by the middle Pennsylvanian strata, with the Crooked Fork Group representing transitional nearshore environments.

CHAPTER II

THE DORTON FORMATION, A CASE STUDY OF ENVIRONMENTS OF DEPOSITION IN FINE-GRAINED, TERRIGENOUS CLASTICS

Introduction

The petrology, small-scale sedimentologic features, and paleoenvironments for seven subfacies within the Dorton Formation are discussed in this chapter. A general outline of paleoenvironments represented by the Dorton Formation is presented below. Each subfacies is then described in detail and interpreted in terms of its depositional environment.

Initially, the Dorton Formation appears to be an essentially monotonous mudrock. This is often true of shales with the superficial level of observation usually applied to them. Detailed examination of the Dorton reveals seven distinct subfacies, five of which are recognizable across the study area. The recognition of these subfacies was based on detailed field work, examination of 200 acetate peels, and 50 thin sections (sample locations are shown in the sketches drawn from photo-mosaics in Appendix E). Terminology used in the description of the mudrocks is in Appendix A. Since outcrop A afforded the only complete exposure of the Dorton Formation in the study area, subfacies 1 and 2 described from outcrop A were unexposed at the other outcrop locations. Subfacies 3, 4, 5, 6, and 7 described within the Dorton Formation were exposed and recognizable across the study area.

General

The Dorton Formation across the study area represents an embayment near the distal margin of a delta, at least partially open to the sea. Initially, this embayment was very shallow and dominated by marsh deposits which were probably protected from the sea by barrier islands (Rockcastle Formation, Milici et al., 1979). These marsh deposits are represented by the Rex coal at the base of the Dorton Formation. Inundation of the marsh and deepening of the embayment resulted from a local transgression, perhaps by the breaching of barrier island protection or a decreased sediment supply with subsidence.

The lower one-third of the Dorton Formation (subfacies 1 to 4), in general, records fairly restricted anoxic conditions, slow sedimentation rates, and slight current, or wave/tidal activity. Subfacies 2 in this lower sequence indicates a break in anoxic conditions with intense bioturbation. Subfacies 3 also records a break in the lower sequence, as this subfacies records a storm event that swept into the embayment.

The upper two-thirds of the Dorton Formation (subfacies 5, 6, and 7), shows an increased sediment supply, more current influence with some wave/tidal activity, and soft-sediment deformation. These subfacies reflect the increased sedimentation rates as the delta front prograded into the embayment. Subfacies 7 lithologies occur within subfacies 6 and are distinct soft-sediment deformation zones, interpreted as slumps.

Table 2.1 summarizes some of the characteristics distinguishing the different subfacies within the Dorton Formation.

Table 2.1. Characteristics of the different subfacies within the Dorton Formation

		CONSTITUENTS				LAMINATION										SIDERITE			BIOTURBATION			SOFT SEDIMENT DEFORMATIONAL FEATURES					
SUBFACIES	THK. RANGE (cm)	QUARTZ SILT	CLAY	MACERATED ORGANICS	MICA AND FOSSIL DEBRIS	THICKNESS	SPACING	UPPER BOUNDARY	LOWER BOUNDARY	PARALLEL	EVEN	DISCONTINUOUS	CONTINUOUS	LENTICULAR	NODULAR	BEDDED	RARE (0 TO 5%)	COMMON (5 TO 50%)	ABUNDANT (50 TO 100%)	PSEUDO-NODULES < 2 mm	PSEUDO-NODULES > 2 mm	DEWATERING	SOFT SED FOLDING	LOADCASTS	SMALL SLUMPS (mm TO cm)		
7	7-20	68%	20%	10%	2% MICA	● 2 mm TO 1 cm	● 2 mm	D I F F U S E	●	●		●					×					×	×		×		
6	800-980	70%	18%	10%	2% MICA	2 mm TO 1 cm	2 mm TO 4 mm	D I F F U S E	S H A R P	×	×	×	×	×			×			×	×			×	×		
5	620-700	55%	20%	12%	5% MICA	1 mm TO 2 mm	1-2 mm	S H A R P	S H A R P	×	×	×	×	×				×		×	×			×	×		
4	300-560	10%	70%	20%	0%					UNLAMINATED						×		×									
3	40-80	75%	10%	5%	10% FOSSIL FRAG.					UNLAMINATED									×				×				
2	170-180	40% TO 45%	32% TO 36%	15% TO 25%	2% MICA	● 1 mm	● 1 mm	D I F F U S E	●	●		●			×				×								
1	340-350	40%	35%	20%	5% MICA	0.5 mm OR LESS	0.5 mm TO 1 mm	D I F F U S E	D I F F U S E	×	×		×			×	×										

LEGEND:

×

= PRESENT

●

= WHEN PRESENT

X = PRESENT

LEGEND:

● = WHEN PRESENT

Subfacies 1Description

Subfacies 1 lithologies occur above the Rex coal and below subfacies 2. Subfacies 1 lithologies in the study area were only exposed at outcrop A.

Subfacies 1 is a gray, laminated mudshale, which is approximately 340 to 350 centimeters thick. Subfacies 1 lithologies are composed of 40% quartz silt, 35% clay, 20% macerated carbonaceous material, and 5% muscovite. Very thin (0.5 mm or less), even, parallel, discontinuous to continuous, quartz-rich silt laminae alternate with more clay-rich layers. The laminae boundaries (lower and upper) are usually diffuse and laminae exhibit fairly regular spacing (0.5 to 1 mm). The macerated carbonaceous material and muscovite occur throughout, though they are dominant in the more clay-rich layers. The macerated, carbonaceous material and muscovite both have their long axes aligned parallel to bedding. Some slight bioturbation in the form of small (2 mm diameter) burrows are present, though rare. The boundaries of the burrow walls are sharp.

Very thin bedded siderite (1 cm) occurs at fairly regularly spaced intervals (5 to 6 cm) throughout this subfacies. The contacts of the siderite beds (upper and lower) appear diffuse, and the beds have the same internal structure as the surrounding sediments. Figures 2.1A and 2.1B illustrate a typical subfacies 1 lithology.

At the south end of outcrop A, a thin, (5 cm) poorly developed coal and underlying 15 cm thick seatearth cuts diagonally across subfacies 1 lithologies (Fig. 2.1C). This coal and seatearth curve downward to the

Fig. 2.1. Photographs pertaining to subfacies 1 of the Dorton Formation. The small arrows indicate stratigraphic up.

- A. Photograph of a polished slab (sample A-2) from subfacies 1. The light-colored thick band in the center is siderite. Bar equals 1 centimeter.
- B. Photomicrograph of subfacies 1 (sample A-3) illustrating the very thin (0.5 mm) quartz silt laminae. Bar equals 0.4 millimeters.
- C. Field photograph illustrating the thin coal and seatearth (see arrow) which cut diagonally across subfacies 1 lithologies. Scale is 1.25 meter stick.

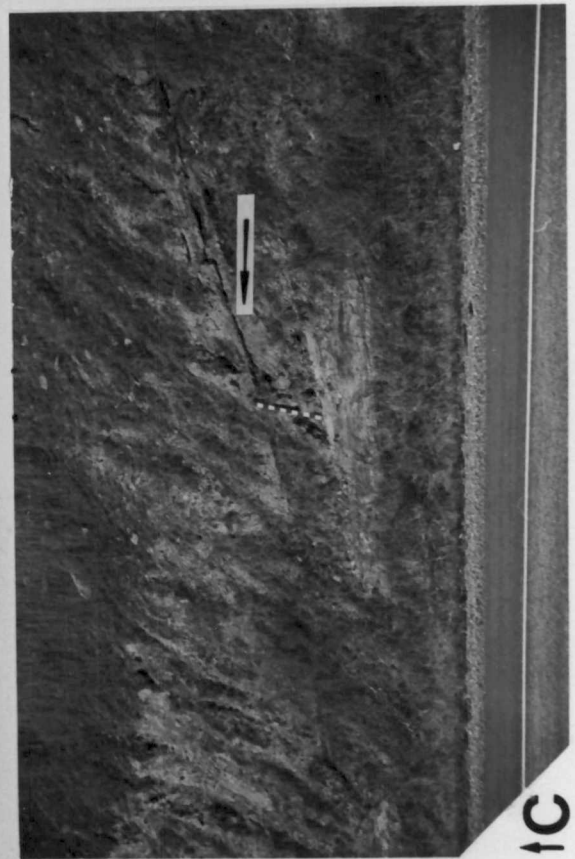
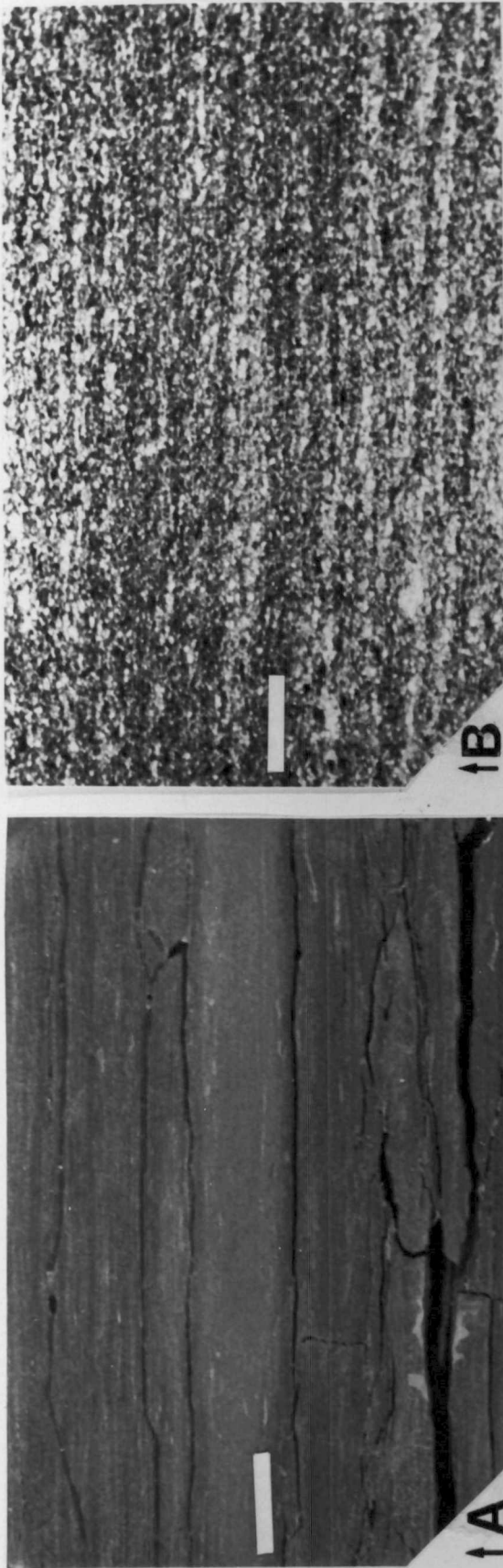


Fig. 2.1

north, and pinch out into subfacies 1; to the south they curve upward and pass into a covered interval. The beds on either side of this coal and seatearth are nearly horizontal and terminate against the coal and seatearth. It was found that on the south side of this coal, the lithologies were coarser (sandy siltstones) and contained no siderite.

Environmental Interpretation

Subfacies 1 lithologies represent drowning of the peat-forming environment (Rex coal below). This marks the beginning of a shallow embayment that was at least partially open to the sea. Initially, very quiet, restricted conditions prevailed.

The alternating quartz-rich and clay-rich laminae described earlier could only accumulate under quiet water conditions. This is evidenced by the very thin (0.5 mm), dominantly continuous, parallel, and even nature of the laminae. The diffuse upper and lower boundaries of the quartz-rich silt laminae indicate little reworking by waves. Coleman and Gagliano (1965) report parallel laminations in bay areas as the result of gentle wave or tidal currents. Reineck and Singh (1980, p. 248) suggest that suspension clouds, produced by wave action could form such thin laminations because the silt would settle quickly, while the clay settled more continuously and slowly. The lack of dewatering structures in these clay- and silt-rich sediments also argues for slow deposition which would allow for gradual dewatering. The fact that the burrow walls have sharp boundaries indicates the sediment was rather firm (low water content). A low water content for these sediments would also argue for slow depositional rates. The parallel alignment of the

macerated carbonaceous material and mica flakes to bedding was probably produced as these constituents settled out of suspension. Compaction would further enhance the alignment of these platy grains. The general lack of bioturbation implies fairly stagnant and anoxic conditions. Sedimentation rates would not have been too high to exclude burrowing organisms; and the abundant, fine organic material would have constituted an adequate sedimented food resource in the absence of otherwise deleterious conditions.

The very thin, regularly spaced siderite beds may have formed either early while the sediment was still unconsolidated or late after consolidation conditions had occurred. Unfortunately, studies investigating the timing of siderite precipitation and growth (Raiswell, 1971; Pantin, 1958; Woodland, 1964; Crimes, 1966; and Gautier, 1982) have been concerned with the concertionary form of siderite. Early siderite growth is favored by anoxic conditions (Garrels and Christ, 1965). Since seawater contains 2700 mg/l SO_4^{2-} (Goldberg, 1963) abundant siderite is evidence for the reduction of pore water sulfate and reaction of the resulting aqueous sulfide during early diagenesis (Gautier, 1982). In recent marine sediments this sulfate reduction is accomplished by sulfate-reducing bacteria, often after very shallow burial (Kaplan et al., 1963). Siderite can also be formed after consolidation of the sediment. Crimes (1966) observed concretions over-growing certain depositional structures (e.g., lamination planes, current bedding, and convolute laminations). Raiswell (1971) points out that siderite concretions which form late may be concentrated along zones of greater permeability (e.g., bedding planes).

The timing of the formation of the siderite beds in subfacies 1 is unresolved. It is possible that the siderite beds formed late as they have the same internal structure as the surrounding sediments. If the siderite did form late, no explanation is available for the regular spacing of the siderite beds. Increased permeability in these zones does not seem to have been a factor as they are similar to the surrounding sediment.

It may be possible that favorable conditions for the formation of early siderite occurred at a specific depth (only a few centimeters) below the sediment water interface. Widespread anoxic conditions would be needed and the lack of bioturbation suggests as much. Continued growth of the siderite, once initiated, may explain the diffuse boundaries (upper and lower) and similar internal structure of the siderite beds with the surrounding sediments. Perhaps consistent sedimentation rates and chemical conditions would then produce the regularly spaced siderite beds. However, no conclusions regarding these siderite beds can be made at this time.

One explanation of the thin (5 cm) coal that cuts across part of subfacies 1 would be vegetation which draped a mound-like "island" sitting in the bay. This would explain why the beds are horizontal on either side of the coal and terminate against the coal. This would also explain why the coal pinches out to the north. Unfortunately, the lack of exposure to the south precludes determining whether the coal indeed curves back down on that side. Another explanation for the derivation of this coal might be from vegetation growing on a small

splay projecting into the bay. The splay might have served as a "platform" more favorable for peat-forming conditions. This would also explain the sandier nature of subfacies 1 lithologies under the coal. However, lack of exposure makes one or the other of these explanations speculative at this time.

Subfacies 2

Description

Subfacies 2 lithologies are gradational with subfacies 1 lithologies below. Subfacies 2 lithologies in the study area were only completely exposed at outcrop A, and partially exposed at outcrop AA. Subfacies 2 is an olive-gray, bioturbated siltstone which is approximately 170-180 cm thick. Bioturbation has completely destroyed any laminations in the lower 100 cm of this subfacies (Fig. 2.2A). The upper 70 to 80 cm of subfacies 2 displays less bioturbation (Fig. 2.2B). Much of the bioturbation is from horizontal burrows, though some vertical burrows are present. Subfacies 2 lithologies are composed of 40-45% quartz silt, 32-36% clay, 15-25% macerated carbonaceous material, and 2% muscovite. The upper 70-80 cm of subfacies 1 contains the greatest percentage of macerated carbonaceous material (25%). The upper 70 to 80 cm of subfacies 2 (where nonbioturbated) contains thin (1 mm), even, discontinuous, subparallel, quartz-rich silt laminae which alternate with more clay-rich layers. The boundaries of the laminae (upper and lower) are sharp and laminae show regular (1 to 2 mm) spacing. A complete pygidium of trilobite was collected in the middle of

Fig. 2.2. Photographs pertaining to subfacies 2 of the Dorton Formation. The small arrows indicate stratigraphic up.

- A. Photograph of an acetate peel (sample A-25) showing the intense bioturbation in the lower part of subfacies 2. Bar equals 1 centimeter.
- B. Photograph of an acetate peel (sample A-29) showing the decrease in bioturbation near the top of subfacies 2. Bar equals 1 centimeter.

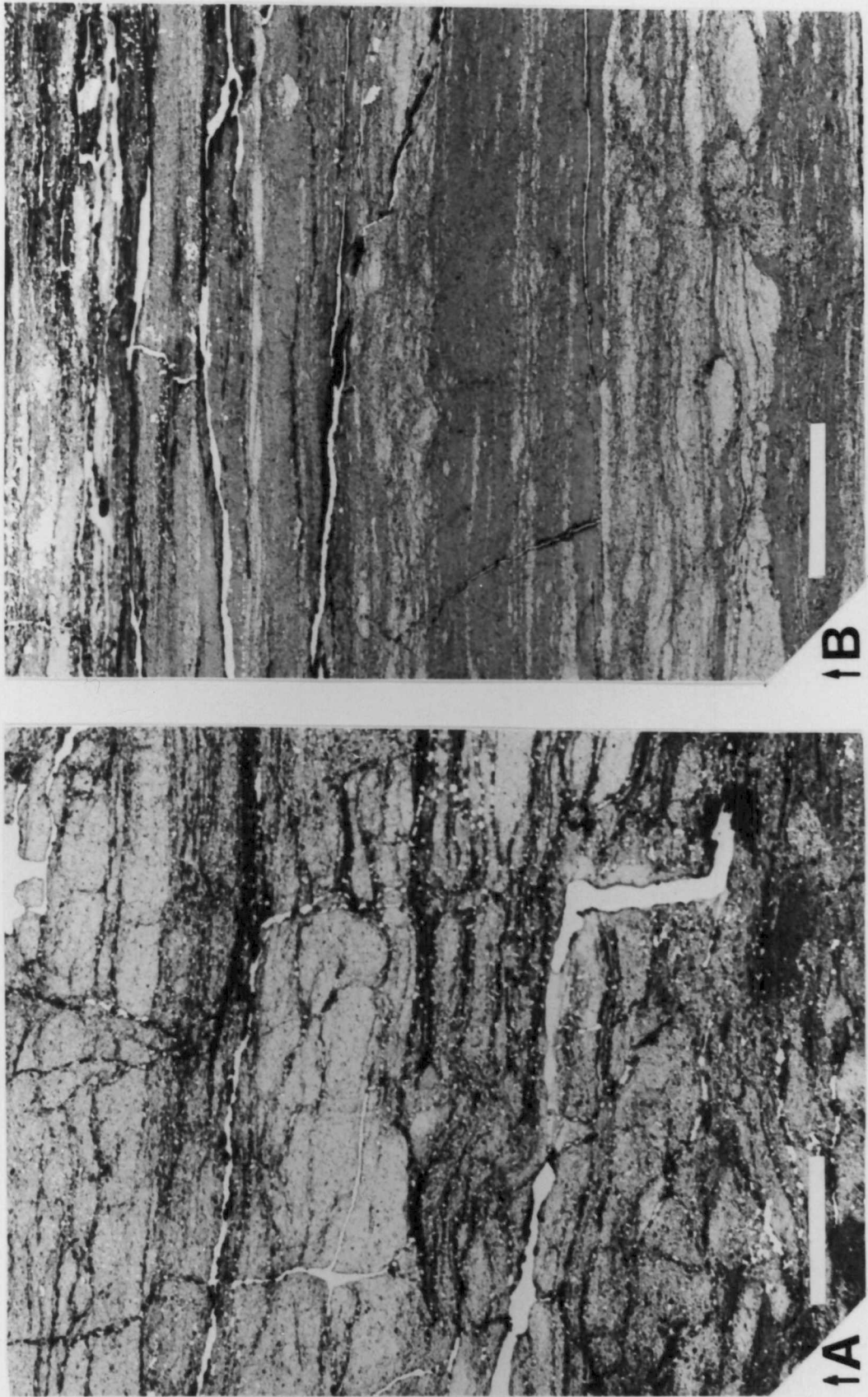


Fig. 2.2

subfacies 2. This has been identified as Ditomopyge (R. M. McLaughlin, per. comm., 1983).

Environmental Interpretation

Subfacies 2 lithologies accumulated in a similar environment to subfacies 1 below, only under less restricted conditions. Compositionally, these subfacies are similar except for the absence of siderite in subfacies 2.

The quartz-rich silt laminae of subfacies 2 (where undisturbed by bioturbation) are more discontinuous, less parallel, and have sharper boundaries (upper and lower) than those of subfacies 1 below. This indicates a slight increase in wave and/or tidal activity in subfacies 2 lithologies. Because the sedimentological conditions of subfacies 1 and 2 are similar, the intense bioturbation found in subfacies 2 probably represents a more oxygenated environment due to increased water circulation (Schmidt, 1958). The trilobite pygidium collected from subfacies 2 indicates that marine to brackish conditions prevailed. The lack of siderite in subfacies 2 is probably due to the better oxygenated conditions than those of the subfacies 1 environment (assuming the siderite of subfacies 1 was formed early).

Larson and Rhoads (in press) indicate that bioturbation extends in most cases only a few centimeters below the sediment-water interface. Thus, to get a fairly thick sequence of highly bioturbated sediments, slow deposition would have to prevail. This explanation for the 100 cm thickness of the intensely bioturbated sediment of subfacies 2 seems best. The decrease in bioturbation at the top of this subfacies

(upper 70 to 80 cm) may be a return to more reducing conditions as the percent of organic matter increases somewhat (25%). This increase may be due to less oxygenation of the organic material during stagnation, (Twenhofel, 1961). Alternatively, an increase in sedimentation in the top of subfacies 2 may have also lowered bioturbation, although the fairly regularly spaced thin laminae do not indicate very rapid deposition.

Subfacies 3

Description

Subfacies 3 lithologies occur in sharp contact with subfacies 2 below and grade into subfacies 4 above (Fig. 2.3A). Subfacies 3 lithologies in the study area are only exposed at outcrops A and AA. Subfacies 3 is a light- to dark-gray calcareous bedded siltstone which ranges from 40 to 80 centimeters thick. The lithologies of this subfacies contain 75% quartz silt, 10% clay, 10% fossil fragments, and 5% macerated carbonaceous material. In decreasing order of abundance the following fossil fragments have been identified in thin section and hand sample from this subfacies: pelecypod, trilobite, gastropod, echinoderm, straight cephalopod, and horn coral. Many of the fossil fragments are abraded.

The quartz silt grains in this subfacies average 0.25 to 0.30 mm in size and are usually larger than any quartz silt found in the rest of the Dorton Formation. This subfacies has a fairly flat, slightly scoured base (2-5 cm of relief). The lower 5 cm of subfacies 3 contains 0.5 to

Fig. 2.3. Photographs pertaining to subfacies 3 and 4 of the Dorton Formation. The small arrows indicate stratigraphic up.

- A. Field photograph illustrating the sharp contact of subfacies 3 with subfacies 2 below and the more gradational upper contact with subfacies 4 above. Scale is 20 centimeters.
- B. Photograph of a polished slab surface (sample A-31) illustrating the mudrock lag present in the lower 5 cm of subfacies 3. Scale is in centimeters.
- C. Negative print of an acetate peel (sample A-33) illustrating a fluid-escape structure from subfacies 3. Bar equals 1 centimeter.
- D. Negative print of an acetate peel (sample A-37) illustrating the nodular appearance of subfacies 4 when slabbed. Note the black and white "rinds" which impart the nodular appearance. Bar equals 1 centimeter.

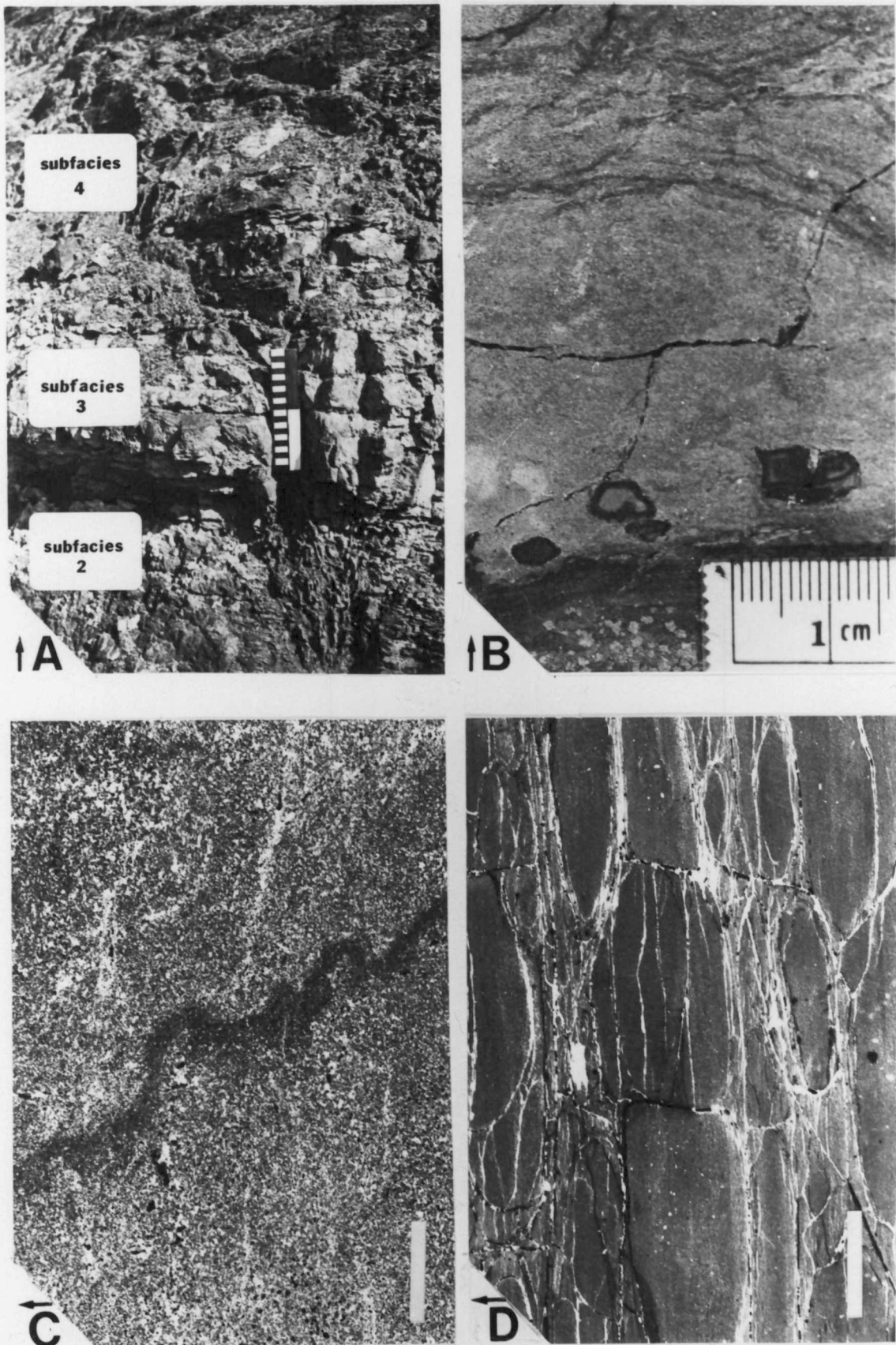


Fig. 2.3

1 cm clasts of subfacies 2 below (Fig. 2.3B). The grain size in subfacies 3 fines upward from 0.4 to 0.1 mm. The top 6 to 8 cm of this subfacies is bioturbated. A fluid-escape structure was found in sample A-31 (Fig. 2.3C).

Environmental Interpretation

Subfacies 3 lithologies are interpreted as resulting from a storm which swept coarser grained material into or across the embayment. Several authors have reported thin (0.10 m) to rare (100 cm) thick sand and coarse silt storm layers which occur in clay-dominated, shallow marine settings (Allen, 1965; Hayes, 1967; Brenner and Davies, 1973; Goldring and Bridges, 1973; Andrews and Laird, 1976; Kumar and Sanders, 1976; and others). In general, these authors show that storm layers in shallow marine environments are characterized by the following: sharp bases commonly with lag; fining upward texture; limited thickness (rarely over 1 m thick); wave-rippled or bioturbated tops; and abundant fossil debris may be present.

In the interpretation of subfacies 3 as a storm deposit, these and other lines of evidence listed below were used:

1. Subfacies 3 shows a fining upward sequence (grains from 0.4 to 0.1 mm) and is 40 to 80 cm thick, which is comparable to storm deposits.
2. Subfacies 3 has a flat, slightly scoured base (2-5 cm of relief). The lower 5 cm contains mudrock clasts (0.5-1 cm) derived from subfacies 2 below.
3. Subfacies 3 was caused by a widespread event as it is exposed and recognized at outcrops A and AA approximately 3 kilometers apart,

in the same stratigraphic position (after regional dip is accounted for).

4. Subfacies 3 is dominantly quartz silt (75%), which is coarser (0.25-0.30 mm average) than any other quartz silt in the Dorton Formation. This implies a different source for the quartz silt (perhaps from nearby offshore barriers).

5. The top 5-7 cm of subfacies is bioturbated, which is common in storm sand layers (Goldring and Bridges, 1973; and Brenchly et al., 1978).

6. The diverse and abundant fossil fragments in this subfacies suggest fauna swept from a wide area (Goldring and Bridges, 1973). The abraded nature of many of the fossils may or may not have occurred during storm transport.

7. The fluid escape structure (Fig. 2.3C) indicates rapid deposition from a dense sediment cloud.

Taken together these lines of evidence present a good case for a storm origin for subfacies 3.

Subfacies 4

Description

Subfacies 4 lithologies occur above subfacies 3 and below subfacies 5. Subfacies 4 lithologies in the study area were only exposed at outcrops A and AA. Subfacies 4 is a gray laminated clay-shale, ranging from 300 to 560 cm thick. Subfacies 4 lithologies are composed of 70% clay, 20% macerated carbonaceous material, and 10%

quartz silt. Subfacies 4 lithologies have a characteristic nodular appearance when slabbed (Fig. 2.3D). Enclosing these "nodules" is a black and/or white rind. the black rind appears to be composed of carbonaceous material, while the white rind is composed of quartz, dolomite, and some calcite grains. It is also possible that the dark rinds may be manganese oxides or iron sulfides. Macerated carbonaceous material also occurs as a poorly developed fabric lamination in subfacies 3 rocks. Fabric lamination as used in this thesis refers to an alignment of platy minerals, or organics parallel to bedding. No bioturbation was observed in this subfacies. Siderite nodules (1-4 cm in diameter) are common throughout subfacies 4. Some samples from subfacies 4 are slightly calcareous (will effervesce in 10% HCL).

Environmental Interpretation

Subfacies 4 lithologies are interpreted as forming in a very quiet, very stagnant environment. Apparently the introduction of silt into this environment was rare, and clay sedimentation dominated. This may have been due to blocked drainage in the bay area or a lack of flushing by incoming fluvial processes. The poorly developed fabric lamination caused by the macerated carbonaceous material and the lack of any other sedimentary structures suggests little wave or current action. The absence of bioturbation tends to support the existence of stagnant anoxic conditions. Siderite nodules found throughout subfacies 4 may also indicate reducing conditions, if they formed early (Gautier, 1982) (see p. 35).

Unfortunately, the most definitive evidence cited for early concretionary growth is the presence of laminations that have been deformed around the concretion (Hallam, 1969; and Raiswell, 1971). No silt laminations are present in subfacies 4 lithologies. However, the fabric lamination caused by the macerated carbonaceous material which can be seen to bend around the siderite nodules, may indicate early growth. Early growth of siderite concretions would be favored in an anoxic, reducing, environment (Garrels and Christ, 1965).

The dark and white "rinds" that give subfacies 4 lithologies a nodular appearance are somewhat of an enigma. These "nodules" are not the result of bioturbation or any sedimentologic process. Perhaps the best explanation of the origin of these "rinds" (which impart the nodular appearance) may come from work by Wanless (1979) on clay-rich limestones. Wanless (1979) reports that in limestone containing at least 10% clay, nonsutured seam solution can occur under pressure from overburden. Platy, insoluble material concentrates along small solution seams. These seams act as a solution path and as a site where soluble residues accumulate. The solution seams are thin because they become choked with insoluble residue before they can get very large. Dolomite may or may not be present in these solution seams. It is not known whether the nonsutured seams of Wanless (1979) could occur in a clayshale such as subfacies 4 which is low in calcium carbonate (most samples will effervesce in 10% HCL, but weakly). However, a nonsutured seam solution would explain the "rind" of insoluble inorganic material, quartz, dolomite, and some calcite which impart the distinct nodular appearance to subfacies 4 lithologies.

Subfacies 5

Description

Subfacies 5 lithologies are gradational with subfacies 4 below and subfacies 6 above. Subfacies 5 lithologies are exposed at outcrops A, AA, and BB in the study area. Subfacies 5 is a gray, laminated siltstone, which ranges from 620 to 700 cm thick. Subfacies 5 lithologies are composed of 65% quartz silt, 20% clay, 12% highly macerated carbonaceous material, and 3% muscovite. Thin (1 mm), even, parallel, discontinuous, quartz-rich silt laminae alternate with more clay-rich layers. Many of the quartz-rich silt laminae are lenticular and some are fairly symmetrical in shape (Fig. 2.4A). The laminae boundaries (lower and upper) are usually sharp and exhibit regular spacing (1-2 mm). The macerated carbonaceous material and muscovite occur throughout, although they are dominant in the more clay-rich layers. The quartz silt lenses often show load casting into the more clay-rich layer below (Fig. 2.4B). In places, the quartz silt lenses become partially or completely isolated in the underlying clay layer forming pseudo-nodules (Fig. 2.4C).

Bioturbation is commonly present in subfacies 5 lithologies, yielding small (1 to 2 mm in diameter) horizontal burrows. Small clay clasts (2-3 mm long) are typically present (10-15%), and are elongated parallel to bedding (Fig. 2.4D). No siderite is present in this subfacies.

Fig. 2.4. Photographs pertaining to subfacies 5 of the Dorton Formation. The small arrows indicate stratigraphic up.

- A. Photograph of an acetate peel (sample A-87) illustrating a symmetrical "starved" ripple, directly above the scale. Scale is in centimeters.
- B. Photomicrograph illustrating load casting of a quartz silt laminae into a clay-rich laminae beneath it (sample B-6). Bar equals 0.5 millimeters.
- C. Photomicrograph illustrating formation of a pseudo-nodule (sample A-105). Note that the pseudo-nodule has a "stringer" attached to the quartz silt laminae above it. Bar equals 2 millimeters.
- D. Photomicrograph of sample C-3 illustrating clay clasts aligned parallel to bedding. Bar equals 1.5 millimeters.

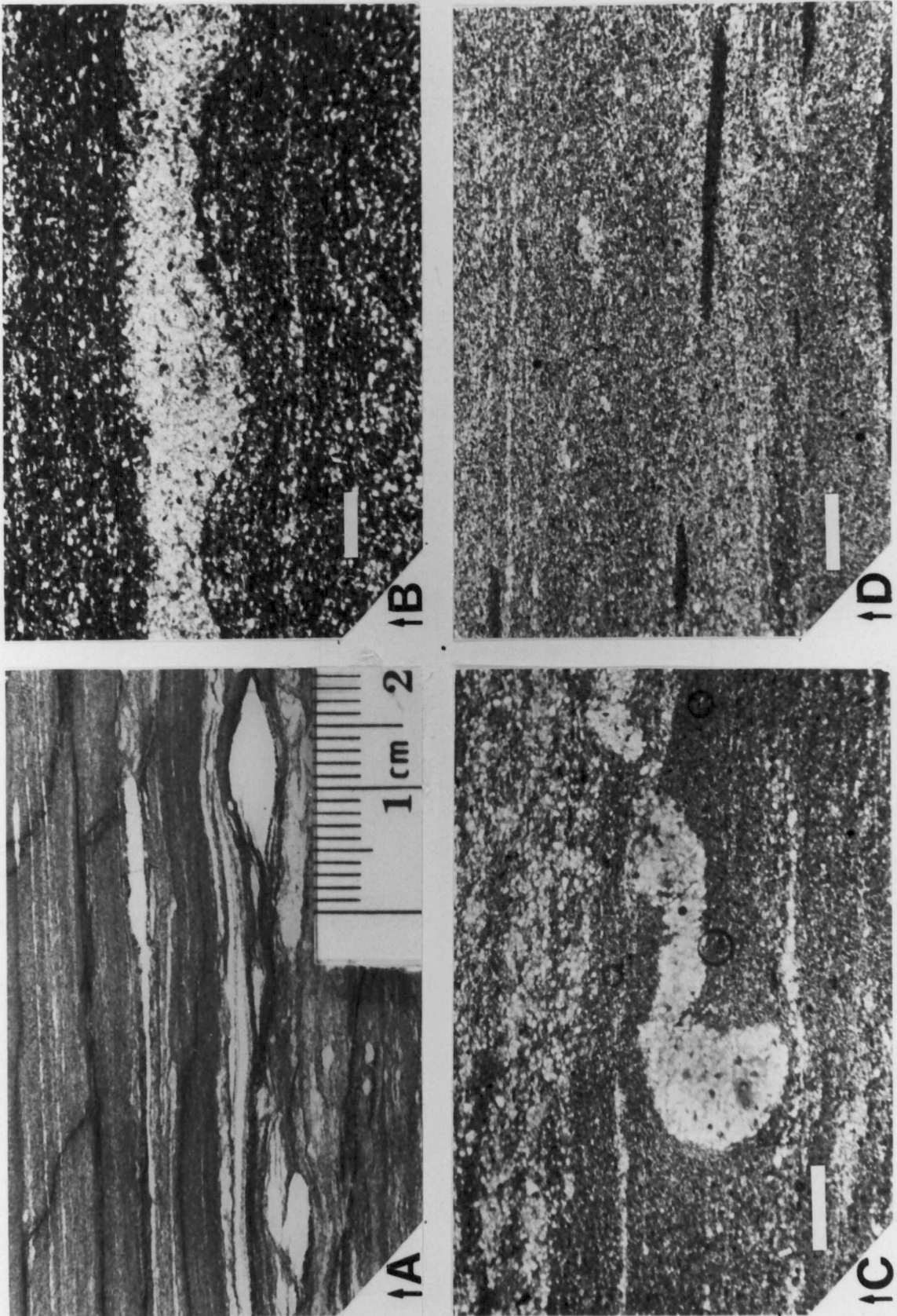


Fig. 2.4

Environmental Interpretation

Subfacies 5 lithologies reflect less restricted conditions and increased sedimentation rates as fluvial processes began to prograde into the embayment. The absence of siderite along with a decrease in macerated carbonaceous material (20% to 12%) upward from subfacies 4 into subfacies 5 indicate more oxidizing and less stagnant conditions (Coleman, 1966). Bioturbation also reflects the less stagnant conditions as burrows are fairly common in subfacies 5, while in subfacies 4 there is no evidence of burrowing. The more open and agitated conditions for subfacies 5 lithologies may have resulted from increased drainage out of the embayment, but most likely reflects increased sedimentation and flushing as the delta front approaches the embayment. The increase in sedimentation and current activity can be seen in the increase of quartz silt laminae that are slightly thicker, more sharply defined, commonly lenticular, and less continuous than those in the lower subfacies (1, 2, and 4), also compare the silt laminae of Fig. 2.4A and Fig. 2.1A (p. 31).

The lenticular laminations typically represent "starved" current ripples formed on a clay bottom, later covered by an influx of clay. Lenticular laminations are common in embayments as the delta front begins to extend in the bay areas (Coleman and Gagliano, 1965). Some of the lenticular laminae that appear symmetrical (Fig. 2.4A) are probably produced by oscillatory waves (Reineck and Wunderlich, 1968).

Load casting of quartz silt lenses and laminae are due to the density differences between the coarser silt layer above and the clay layer below. The pseudo-nodules are produced by the sinking of coarse

layers into the finer sediments below. Pseudo-nodules may look like horizontal burrows, but pseudo-nodules are usually aligned horizontally with regular spacing; are lensoid in shape, and are typically attached to the silt layer above. In contrast, horizontal burrows are more circular in shape, show manipulated grains, and have random spacing. Load casts and especially pseudo-nodules are evidence for increased sedimentation rates as these features indicate rapid deposition of clay, interrupted by coarser silt, resulting in differential loading and deformation, (Reineck and Singh, 1980, p. 86; Allen, 1982, p. 363-364). Thus, the initial high water content of the sediment resulted from rapid sedimentation. Features such as those described above are common in shallow marine bays where delta progradation occurs (Coleman, 1969; Lowe, 1975).

The presence of clay clasts in subfacies 5 lithologies also indicates strong currents which are necessary to rip up clay clasts; due to the strong cohesive forces between deposited clay particles.

Sedimentation rates were not too high to obstruct bioturbation, and may have been episodic giving organisms time to burrow between pulses of sedimentation (Reineck and Singh, 1980, p. 169). The increase of bioturbation from subfacies 4 below at least indicates more oxidizing, less restricted conditions.

Subfacies 6

Description

Subfacies 6 lithologies are gradational above subfacies 5 and continue upward to the base of the Crossville Formation. Subfacies 6

lithologies in the study area were completely exposed at outcrops A, AA, BB and partially exposed at outcrops B, C, D, CC, and DD. Subfacies 6 is a gray, laminated siltstone, 800 to 980 centimeters thick. Subfacies 6 rocks are composed of 70% quartz silt, 18% clay, 10% macerated carbonaceous material, and 2% muscovite.

Medium to thick (2 mm to 1 cm), even, parallel, discontinuous to continuous, quartz-rich silt laminae alternate regularly with more clay-rich layers. The macerated carbonaceous material and muscovite are distributed throughout, although this material is dominant in the clay-rich layers. Small (1 to 3 cm) clay clasts are present (10 to 20%) which are parallel to bedding and similar to those found in subfacies 5 below. The quartz-rich silt laminae tend to be the thickest in the upper 300 centimeters of subfacies 6. The silt laminae have distinct lower boundaries and slightly more diffuse upper boundaries; many of the laminae show normal grading (Figs. 2.5A and 2.5B). Lenticular quartz silt laminae are fairly common in subfacies 6 lithologies, and the silt lenses show load casting into the underlying clay layer. Some silt lenses are symmetrical, similar to those in subfacies 5 below. Commonly, the silt lenses become partially or completely isolated in the lower clay layer forming pseudo-nodules, similar to those in subfacies 5 below, only larger in size (subfacies 5, 1-2 mm; subfacies 6, 2-4 mm). Small-scale (1 mm to 1 cm) slumping (Fig. 2.5C) and dewatering (Fig. 2.5D) is common. Several outcrops (A, B, and C) have distinct zones within subfacies 6 lithologies which show extensive soft-sediment deformation. These zones are the subfacies 7 lithologies described later.

Fig. 2.5. Photographs pertaining to subfacies 6 of the Dorton Formation. The small arrow indicates stratigraphic up.

- A. Negative print of an acetate peel (sample A-139) showing grading from quartz-rich silt laminae to more clay-rich laminae. Bar equals 1 centimeter.
- B. Photomicrograph of an individual quartz silt lamina showing grading (sample A-140). Note the load cast at the base. Bar equals 1 millimeter.
- C. Negative print of an acetate peel (sample A-143) showing laminae disrupted by a small slump. Bar equals 1 centimeter.
- D. Photomicrograph illustrating dewatering which has disrupted a quartz silt lamina (sample C-8). Bar equals 1 millimeter.

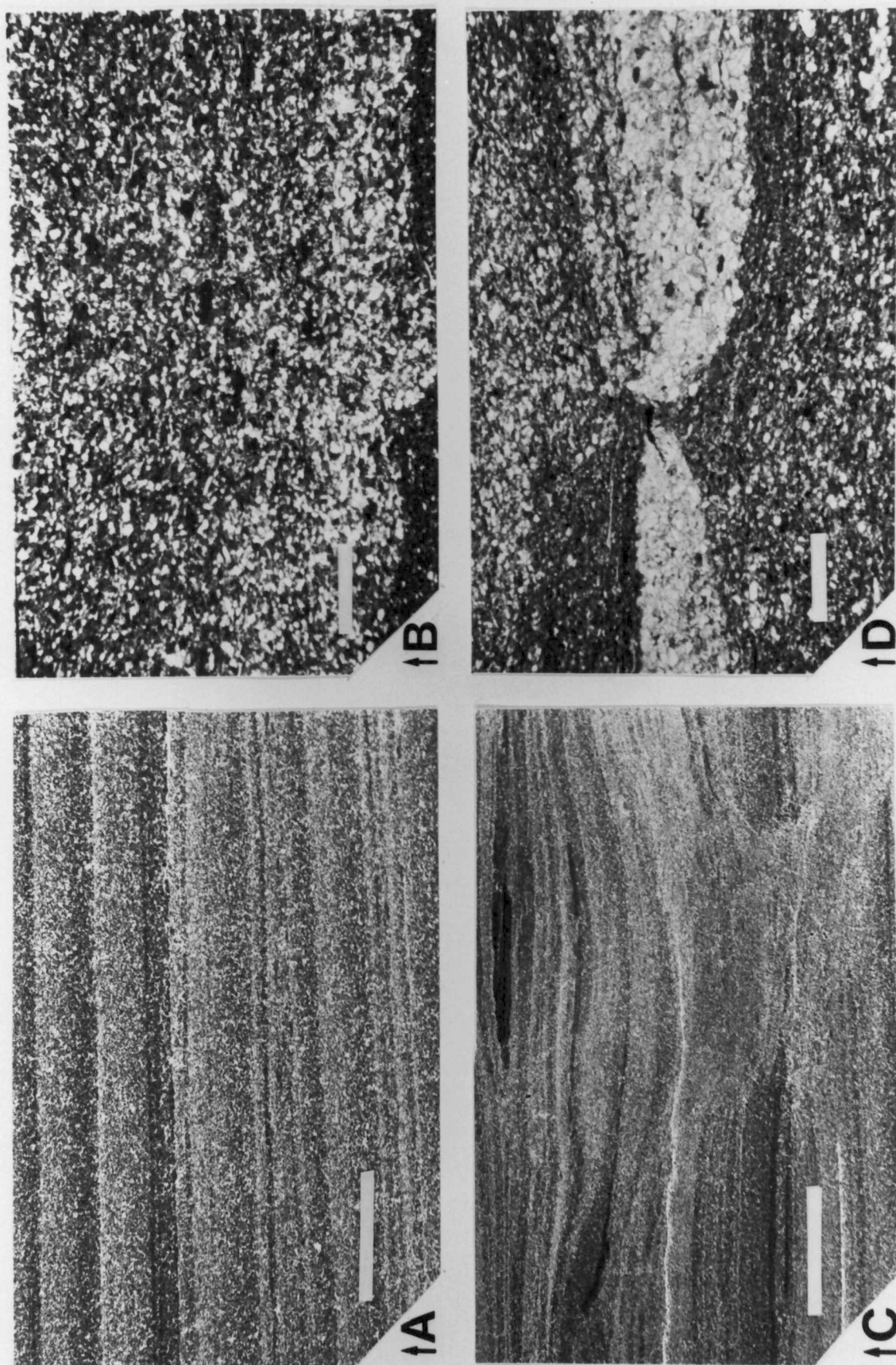


Fig. 2.5

Bioturbation in subfacies 6 is rare, one large (1 cm in diameter) horizontal burrow was found.

Environmental Interpretation

Subfacies 6 lithologies show the increased sedimentation rates and gradual coarsening upward trend as fluvial processes continued progradation into the embayment. This is illustrated by the increased size of the quartz silt laminae in subfacies 6 lithologies and the normal grading of these laminae. Horne and Ferm (1978, p. 80) describe a similar grading of layers and a gradual coarsening upward sequence as characteristic of the infilling of embayments by fluvial progradation.

Grading in the silt laminae is believed to develop when suspended sediment of different grain sizes and settling velocities are brought into the embayment, during stream flooding. Grading of laminae may also be from differential settling produced when waves and/or tides resuspend sediments. Perhaps waves and/or tides exerted a greater affect on the upper sediments (subfacies 6 lithologies) as the embayment filled in and shallowed. Storms would also resuspend sediments, which could lead to the grading of laminae. The rhythmic nature of these laminae suggest cyclic events. Seasonal flooding, tides, and storms could all be considered cyclic over geologic time.

The clay clasts found in subfacies 6 indicate vigorous currents necessary to rip up the clasts, as in the case of those described in subfacies 5.

The lenticular laminations probably represent impoverished current ripples formed on a clay bottom, which were later covered by an influx of

clay. Lenticular laminations are common in embayments near deltas where rapid mud deposition is interrupted by coarse silt deposition (Coleman and Gagliano, 1965).

Many of the quartz silt lenses and laminae display load casts due to density differences between the coarser silt layer above and the clay layer below. The pseudo-nodules are the result of quartz silt lenses sinking into, and becoming partially or completely isolated in the clay layer below. The load casts and pseudo-nodules of subfacies 6 are similar to those of subfacies 5, except for their slightly larger size. Pseudo-nodules, as noted before, may look like horizontal burrows if they are isolated within a clay layer.

In general, the small-scale slump structures, pseudo-nodules, dewatering (as vertical fluid-escape channels), and load casts all point to rapid sedimentation rates with alternating clay and coarse silt deposition (Lowe, 1975; Reineck and Singh, 1980, p. 86; and Allen, 1982, p. 363). Features such as those described above are common in shallow marine bays where delta progradation occurs (Lowe, 1975; and Coleman, 1969).

Finally, the lack of bioturbation (with the exception of the one large horizontal burrow) also indicates rapid sedimentation, because otherwise the environment would probably have supported organisms (Reineck, 1967).

Subfacies 7

Description

Subfacies 7 lithologies occur within subfacies 6 and are exposed at outcrops A, B, and C in the study area. Subfacies 7 lithologies are

gray, laminated siltstones which show soft-sediment deformation folding and liquifaction (Fig. 2.6A). These lithologies are 7 to 20 centimeters thick and are comprised of 68% quartz silt, 20% clay, 10% macerated carbonaceous material and 2% muscovite. Thus, subfacies 7 has almost the exact same overall composition as the rocks of subfacies 6. Where laminae can be distinguished in subfacies 7, they are medium to thick, quartz-rich silt that alternate with more clay-rich layers. The macerated carbonaceous material and muscovite is distributed throughout, but is more dominant in the clay-rich layers.

Soft-sediment folds are common in subfacies 7 lithologies. The folds are irregularly spaced and often have flat-lying or steeply inclined axial planes (Fig. 2.6B). Also, the folds have their greatest amplitude at the base of subfacies 7 lithologies. Small fluid-escape structures (Fig. 2.6C) and mud volcanoes, are abundant. More common are places in subfacies 7 lithologies where nearly complete liquifaction has "churned" the sediment. Commonly, structures produced from rolling of strata can be observed. When these structures are ball-shaped they may be called "slump balls," (Fig. 2.6D), as described by Blatt, Middleton, and Murray (1972, p. 172).

The upper and lower boundaries of subfacies 7 lithologies are flat and abrupt.

Environmental Interpretation

Numerous authors have studied soft-sediment deformational features, and in particular, soft-sediment folding (Dzulynski and Smith, 1963; Elliot, 1965; Sanders, 1965; McKee and Goldberg, 1969; and Middleton and

Fig. 2.6. Photographs pertaining to subfacies 7 of the Dorton Formation. The small arrow indicates stratigraphic up.

- A. Field photograph illustrating a subfacies 7 slump zone. Note the horizontal bedding above and below the slump zone. Scale is 20 centimeters.
- B. Photograph of a polished slab (sample A-93) showing the nose of an inclined soft-sediment fold. Scale is in centimeters.
- C. Photograph of a polished slab (sample A-84) illustrating numerous fluid-escape structures produced from slumping. Note the horizontal laminae above the slump. Bar equals 2 centimeters.
- D. Field photograph showing a "slump ball" directly above the scale. Scale is 20 centimeters.

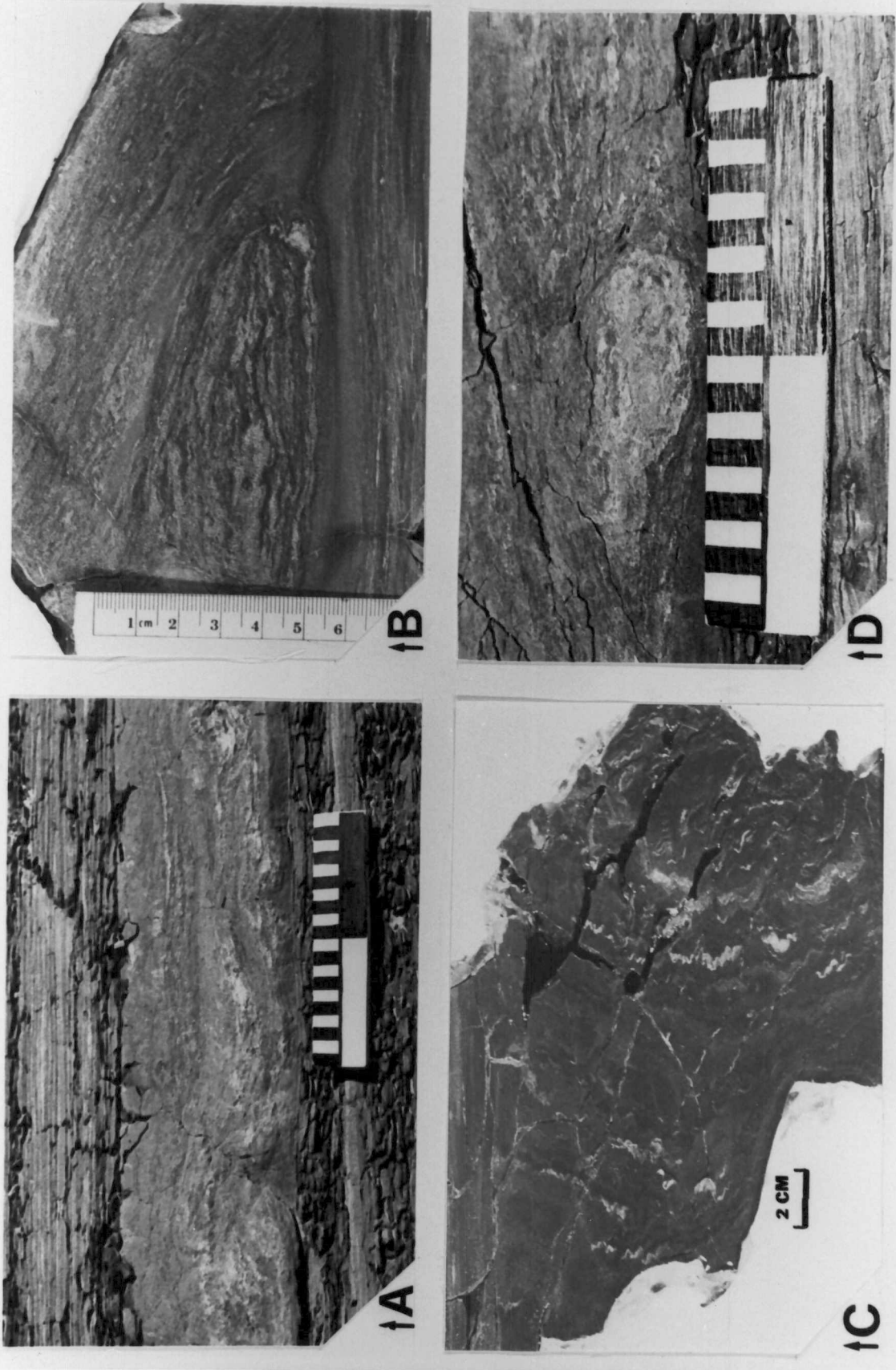


Fig. 2.6

Hamton, 1973). However, no comprehensive classification scheme has evolved so far, although Elliot (1965), Swarbrick (1968), and Lowe (1975) have all contributed towards this important task.

Following the criteria of the authors listed above, the soft-sediment deformational features of subfacies 7 lithologies are interpreted as the result of soft-sediment slumping of the sediments (subfacies 6 lithologies) which were deposited ahead of the prograding delta front sands.

Slump zones and convolute laminations typically have similar characteristics. However, the following evidence was used to distinguish the two:

1. The folds in subfacies 7 lithologies are irregularly spaced, flat-lying, or steeply inclined. Folding in convolute lamination is almost always symmetrical, upright, and regularly spaced (Dzulynski and Smith, 1963; McKee and Goldberg, 1969; and Tyler, 1972).

2. Slumps show features that resemble rolled-up carpets and balled-up strata, called "slump balls" (Fig. 2.6D). Convolute laminae do not show these structures (Blatt, Middleton, and Murray, 1972, p. 171).

3. Subfacies 7 lithologies were very water-charged, as evidenced by the complete liquifaction of some parts of subfacies 7 lithologies, the "mud volcanoes," and the fluid-escape structures (Fig. 2.6C). Convolute lamination is usually characterized by discrete fluid-escape zones, rather than the intense liquifaction that often results in the "churned" appearance of subfacies 7 lithologies.

4. When soft-sediment folding occurs, the greatest fold amplitude is the lowest part of subfacies 7 lithologies. In convolute lamination,

the greatest folding is usually in the middle of the deformed zone (Dunbar and McCall, 1971; and Banks, 1973).

Taken together, these lines of evidence suggest that the sedimentary structures of subfacies 7 resulted from slumping. Such slumps would be common in sediments deposited ahead of prograding delta front sands (Coleman and Gagliano, 1965; Coleman, 1969; Williams, 1969; Coleman et al., 1974; and Allen, 1982, p. 380). Water-charged sediments could easily slump on slopes as low as 0.5° (Allen, 1982, p. 384). Earthquakes can also trigger slumping (Allen, 1982, p. 384). However, given the environmental setting, slumping resulting from gravitationally unstable sediments would probably be more common.

Summary of the Dorton Formation

In summary, the Dorton Formation within the study area can be seen to represent the following:

1. An initial peat-forming environment (represented by the Rex coal) was inundated, probably by marine waters (marine fossils found in subfacies 2 above the coal).

2. Quiet, reducing conditions and slow sedimentation followed (subfacies 1), with very little bioturbation. The reducing conditions were deleterious for burrowing organisms, but probably aided the early formation of the siderite beds of this subfacies just below the sediment water interface.

3. Subfacies 2 marks a time of continued slow deposition, but increased oxygenation, as bioturbation is intense, and siderite absent.

4. Subfacies 3 records a storm event, which swept coarse silt and fossil debris into the embayment.

5. Following the storm event, very slow clay deposition dominated with very little quartz silt introduced (subfacies 4 lithologies). Siderite nodules formed early and bioturbation was absent. The "nodular" appearance of slabbed subfacies 4 lithologies may be due to nonsutured seam solution, a process described by Wanless (1979).

6. With subfacies 5 and 6, depositional rates, quartz silt abundance, and evidence of soft-sediment deformation all increase upward. Bioturbation increased in subfacies 5 over subfacies 4, reflecting more oxygenated conditions, but decreased in subfacies 6, reflecting the increased sedimentation rates of that subfacies.

7. Subfacies 7 lithologies, which occur within subfacies 6, are discrete zones showing soft-sediment folding and deformation. These zones are interpreted as slump zones which developed on a gentle (0.5 to 3 degree), water-charged slope.

CHAPTER III

DEPOSITIONAL ENVIRONMENTS OF THE CROSSVILLE, BURNT MILL, AND COALFIELD FORMATIONS

Introduction

The petrology, sedimentologic features, and paleoenvironments of the Crossville, Burnt Mill, and Coalfield Formations within the study area are discussed in this chapter. Because a detailed analysis of the Dorton was presented in Chapter II, that formation is only briefly summarized in this chapter. Since the highway and railroad outcrops exposing formations of the lower Crooked Fork Group form two sides of a triangle (Fig. 1.4, p. 7); a fence diagram could be constructed linking together the facies interpretation of these outcrops (Fig. 3.1).

It should be noted that the Burnt Mill and Coalfield Formations are very poorly exposed along the railroad. Therefore, the interpretation of these units is based mainly on the highway exposures. The Crossville and Dorton Formations were generally well exposed at both highway and railroad outcrops.

Formational names should be used with caution when reconstructing paleoenvironments, especially where many facies interfinger and overlap. However, it was found that formational names could generally be used in the small study area described here. Within each formation the different environmental facies found are described and discussed. Interpretations are based on detailed field work, acetate peels, thin sections, and

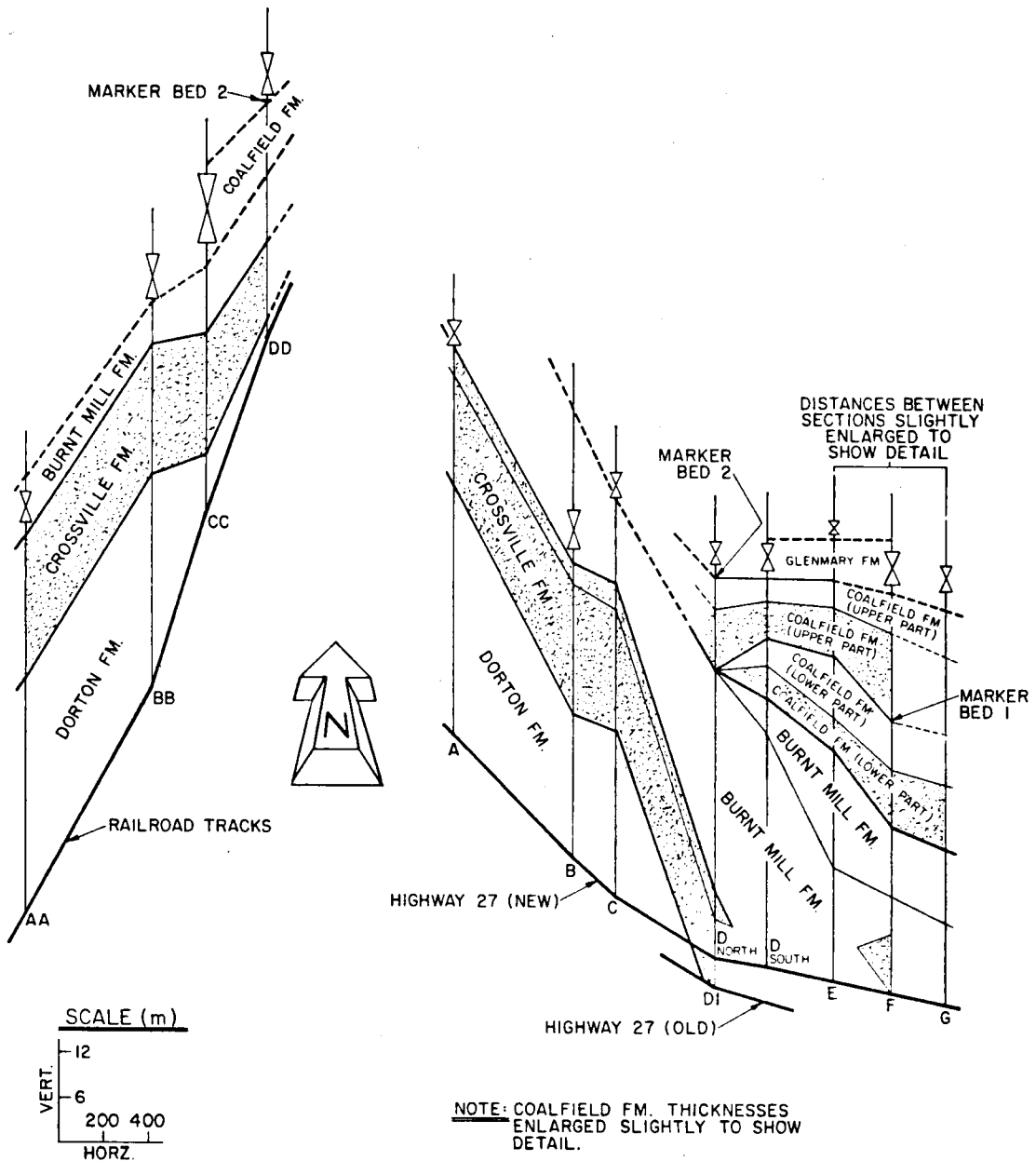


Fig. 3.1. Fence diagram linking the formations of the study area together by outcrop. Formations are separated by heavy lines. Lighter lines within formations indicate some of the main facies present.

paleocurrent analyses. Classification schemes and terminology used in the descriptions can be found in Appendix A. Sample locations are shown on the photo-mosaic sketches in Appendix D.

General

The lower Crooked Fork Group in the study area was deposited in environments located at the distal margin of a lower delta plain, and influenced by waves and/or tides. The Dorton Formation discussed in Chapter II was seen to represent an embayment at least partially open to the sea, which was filled by sediments deposited ahead of the approaching delta front sands. The delta front sands are represented by the Crossville Formation which shows reworking and modification by wave and/or tidal activity.

Following the cessation of Crossville deposition in the area, probably due to channel switching, stagnant bay deposition represented by the Burnt Mill Formation, (which overlies and interfingers with the top of the Crossville Formation), took place.

Finally, the overlying Coalfield Formation and the upper part of the Burnt Mill Formation are thought to reflect a renewed fluvial influence, with little or no reworking by marine processes.

Crossville Formation

The Crossville Formation unconformably overlies the Dorton Formation in the study area. Complete sections of the Crossville can be seen at outcrops B, C, D1, BB, CC and DD. Outcrops A, AA, A1, A2 and D also contain partial exposures of the Crossville (20 to 95%)

Within the study area the Crossville is a complex sand body which often displays rapid lateral facies changes. Seven different facies were recognized within the formation. In order to illustrate the spacial distribution of the different facies and subfacies within the Crossville, two highly stylized diagrams for the Crossville outcrops along the railroad tracks (Fig. 3.2) and along the highway (Fig. 3.3) were prepared. These diagrams are not intended for use in thickness determination, and correlations are oversimplified. The diagrams are for general reference to accompany the discussion of the different facies and subfacies presented below. For a more accurate representation of each outcrop the reader should refer to the outcrop sketches from the photo-mosaics in Appendix E. In order to relate facies and subfacies discussed in the text to the field "units" from the measured sections, Appendix F should be used.

In general, the Crossville represents delta front sands that prograded across bay sediments (Dorton Formation) that were at least partially open to the sea. Marine waves and/or tides reworked and redistributed some of the sands of the Crossville. Eventually, progradation stopped (perhaps from channel switching) and the stagnant bay environment represented by the Burnt Mill Formation dominated. Sedimentary features within the Crossville record channels, reworked distributary mouth bar sands, effects of alternating marine and fluvial processes, abandoned sand bodies, and washover fans.

The Crossville Formation has characteristics of both fluvial and marine processes; assigning this formation strictly to one or the other

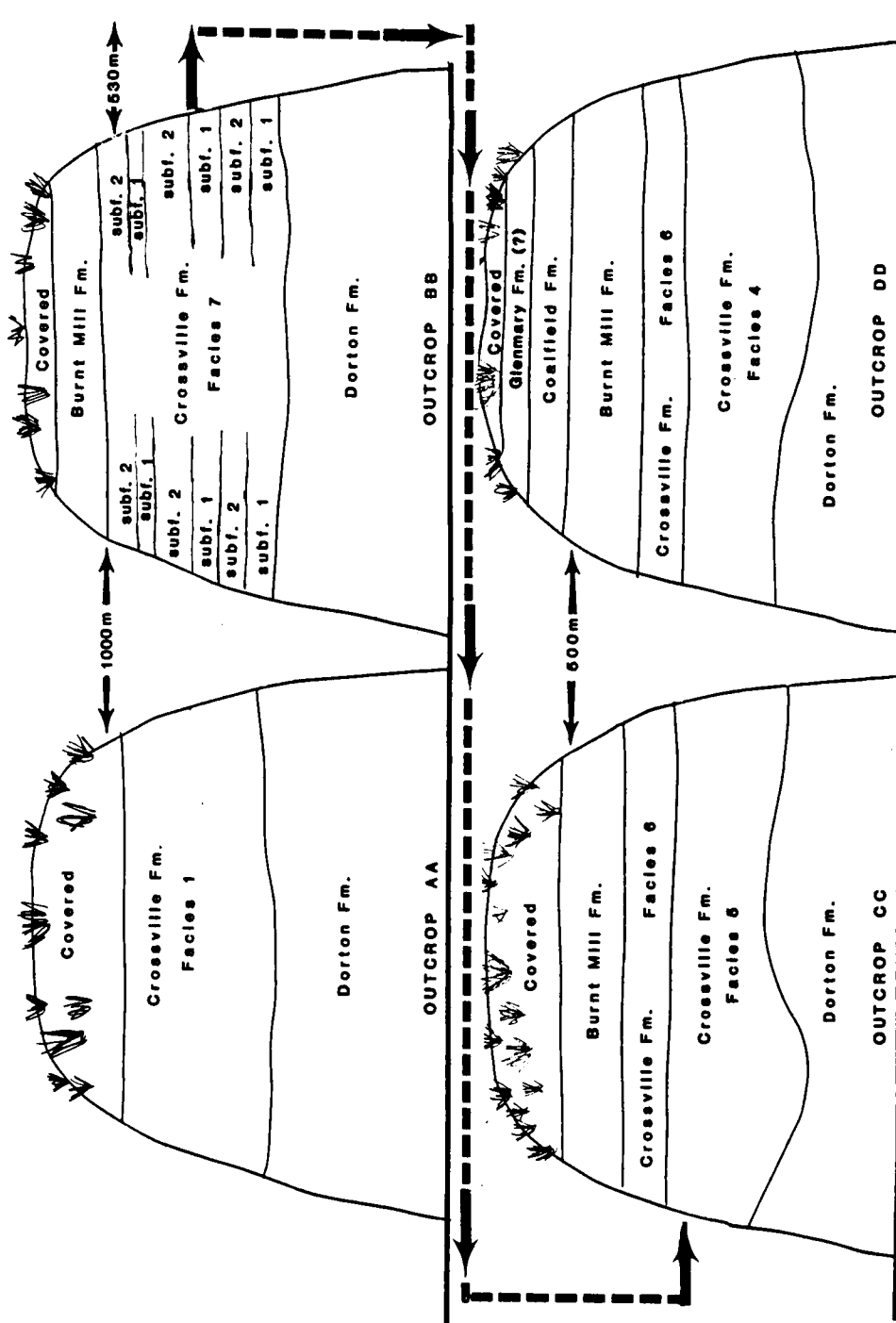


Fig. 3.2. Stylized diagram illustrating the facies and subfacies of the Crossville Formation for the railroad outcrops.

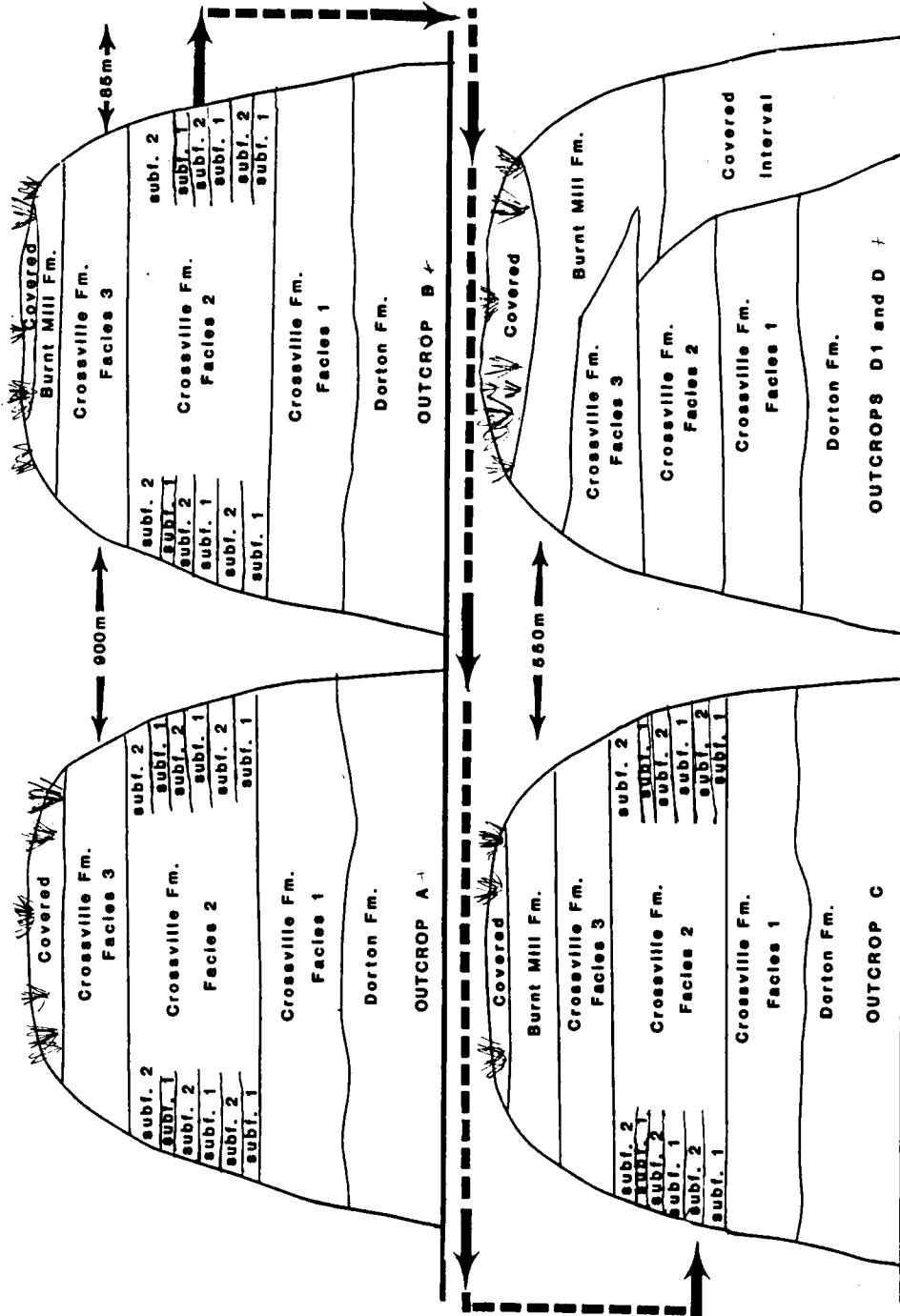


Fig. 3.3. Stylized diagram illustrating the facies and subfacies of the Crossville Formation for the highway outcrops.

environmental setting is impossible. In support of the conclusion that the Crossville Formation in the study area represents distal delta deposition (mouth bar/delta front sands reworked by currents, waves, and/or tides), a short discussion of the evidence follows.

At first appearance, the abundant quartzarenites and generally tabular nature of the Crossville Formation suggest a barrier island setting. However, several lines of evidence refute a strictly barrier island hypothesis. First, the detailed examination of the underlying Dorton Formation revealed several units which are more characteristic of deltaic deposits than a barrier island setting. The Dorton displays a general coarsening-upward trend with the upper units showing grading of laminae, rapid deposition (increased dewatering, pseudo-nodules, decrease in bioturbation), and distinct slump zones. Marine fossils found within the Dorton Formation indicate at least brackish water conditions. These features are all characteristic of the infilling of an embayment or prodelta sedimentation (Horne and Ferm, 1978; Saxena, 1976; Coleman and Gagliano, 1965; Ferm, 1970; and others). The distinct slump zones (subfacies 7 lithologies) within the Dorton show evidence of having occurred on some sort of slope (rollup structures, overturned folds, etc.). In a barrier island setting one would not expect evidence of rapid sedimentation rates, abundant dewatering structures, graded laminae, and distinct slump zones in shales underlying barrier sandstones.

Another line of evidence arguing against a strictly barrier island setting is the nature of the Crossville/Dorton contact. It is sharp,

flat, and slightly scoured (10-25 cm). Where the channel facies are present, the contact is more concave upward with scours up to 1 meter. The lag (when present) near the base of the Crossville/Dorton contact often contains macerated organic debris, coalified plant remains, and some mudrock clasts. In a barrier setting, the Crossville/Dorton contact would probably be gradational and would have a lag consisting of fossil fragments, rather than coalified plant and organic debris which indicates fluvial processes. The continuous, fairly flat nature of the Crossville/Dorton contact across most of the study area would also suggest reworking of fluvial deposits by waves and/or tides. The quartzarenites of the Crossville are composed of subrounded, very fine quartz grains, with muscovite, sedimentary rock fragments, and macerated carbonaceous material comprising the rest of the lithology. In a barrier setting, the sedimentary rock fragments, muscovite, and macerated carbonaceous material probably would not be present and the quartz grains would show more rounding. The channel facies in the Crossville Formation are characteristic of fluvial channels (coalified plant/organic debris at their base, massive sands and multistory sands, unidirectional current cross-laminae); and do not exhibit the features characteristic of tidal channels (fossil shell lag, bimodal crossbeds, reactivation surfaces, etc.) described by several authors (Land, 1972; Kumar and Sanders, 1974; Carter, 1978; and others).

The marine trace fossils found in the top of the Crossville Formation at outcrops B, C, D1, and D points to sand deposition in or near a marine setting.

Crossville Formation; Facies 1: Reworked
Delta Front Sand Deposits

Facies 1 of the Crossville Formation

Description. Facies 1 is a buff, medium- to thick-bedded quartzarenite, which is exposed at outcrops A, AA, B, C, and D1. Facies 1 lithologies have a sharp, flat, slightly scoured base (10-25 cm of relief) into the underlying Dorton Formation (Fig. 3.4A). Facies 1 is gradational with facies 2 of the Crossville which overlies it. Facies 1 ranges from 500 to 870 centimeters thick, with the lower 10 to 25 centimeters in most cases, containing coalified plant material and/or abundant macerated carbonaceous material. The lower 10 to 25 centimeters of facies 1 at outcrop B is a shale arenite, containing abundant mudrock clasts (1 to 2 cm in size) (Fig. 3.4B). Facies 1 lithologies are composed of 95% very fine quartz sand, 2% sedimentary rock fragments, 1% chert, 1% macerated carbonaceous material, and 1% muscovite. The quartz sand grains are very fine-grained, well-sorted, and subrounded. The lower half of the facies is dominated by thick-bedding, lensoid shaped sands (Fig. 3.4C), and large planar crossbeds (sets of 50 to 100 centimeters); these generally show paleocurrent directions to the southeast, with 20 to 22 degree dips (Fig. 3.5A). Appendix C lists and describes the paleocurrent indicators used for the Crossville Formation.

Typically, facies 1 lithologies show abundant pressure solution features in the form of sutured grains contacts. Quartz overgrowths are common. Also at outcrops B and C numerous bedding-plane parallel stylolites are present. These stylolites are marked by stylocumulate

Fig. 3.4. Photographs pertaining to facies 1 of the Crossville Formation. The small arrows indicate stratigraphic up.

- A. Field photograph from outcrop A illustrating the abrupt, typically flat, Crossville-Dorton contact. 1.25 meter stick for scale.
- B. Field photograph from outcrop B illustrating the mudrock lag at the base of the Crossville Formation (facies 1). Scale is 20 centimeters.
- C. Field photograph from outcrop A illustrating a lensoid shaped sand body (outlined in black) in the Crossville Formation, (facies 1). 1.25 meter stick for scale.
- D. Field photograph from outcrop C illustrating bedding plane parallel stylolites of facies 1, in the Crossville Formation. Scale is in centimeters.

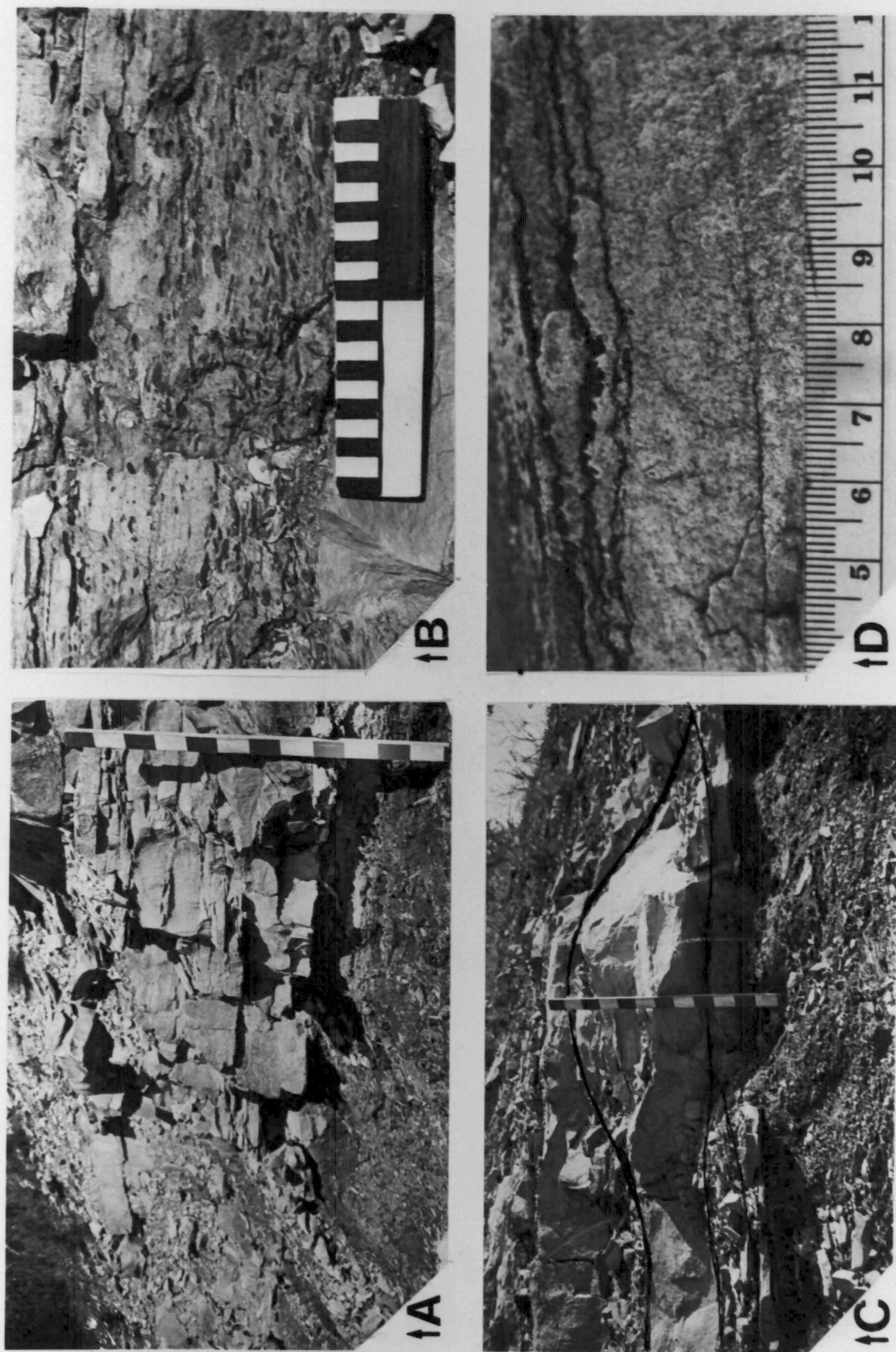
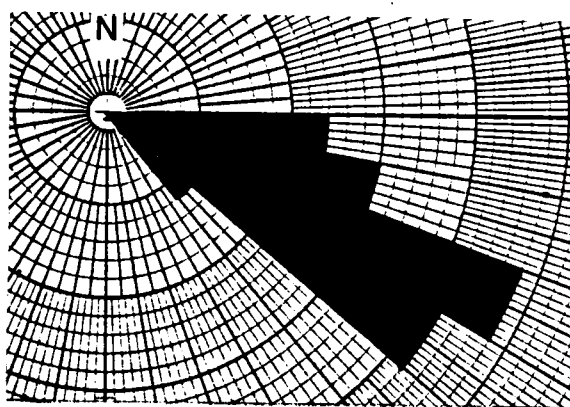
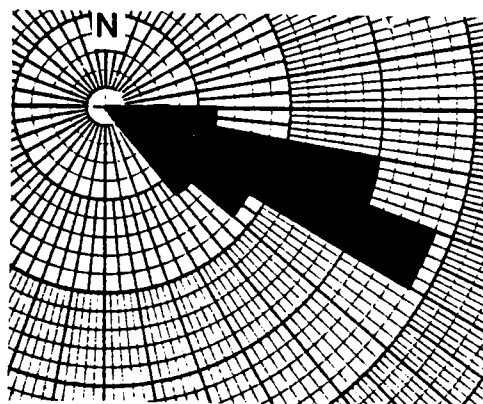


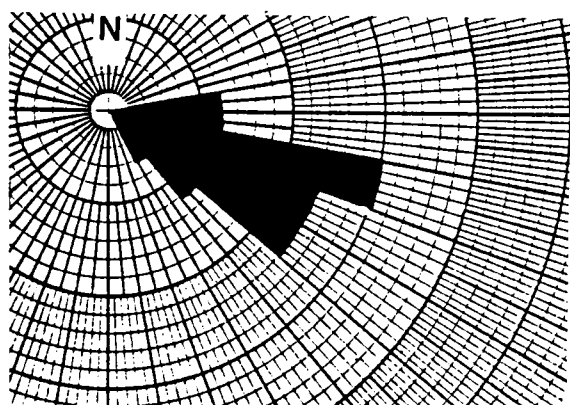
Fig. 3.4



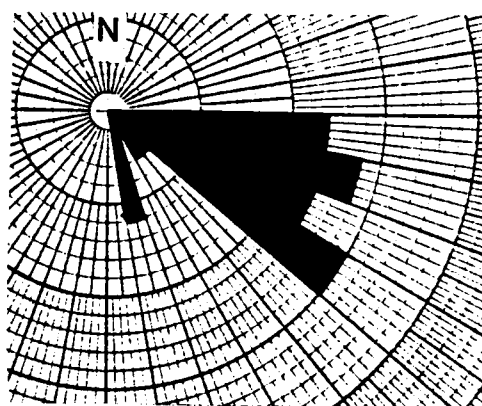
FACIES 1 OUTCROP A



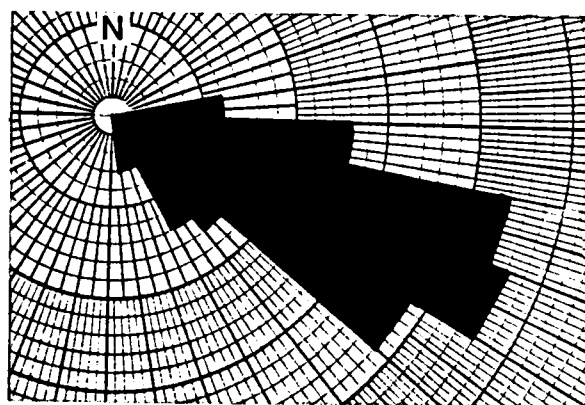
FACIES 1 OUTCROP B



FACIES 1 OUTCROP C



FACIES 1 OUTCROP D1



FACIES 1 GRAND TOTAL

Fig. 3.5. Paleocurrent rose diagram for each outcrop of the Crossville (facies 1) and the grand total. Each measurement equals 5 mm on the grand total and 7 mm on the other diagrams. See Appendix C for the types of measurements made and procedures that were followed.

laminae 0.03 to 1 mm thick (Fig. 3.4D). The stylocumulate is usually a dark, coaly material with some calcite or dolomite, and some muscovite. On some planar crossbed surfaces, particularly at outcrop B, small current ripples (length—2 cm, height—1 cm) show paleocurrent directions nearly opposite to the planar crossbed surface that they are formed on. In many cases, these ripples appear to be "planed off." In the upper half of facies 1 bedding decreases in thickness to medium-bedding. Generally, planar crossbed sets are smaller (20-50 cm) than those in the lower half of facies 1. At outcrop A the planar crossbed sets in the upper half of facies 1 appear to have been "planed off." Sometimes a few mudrock clasts (1-2 cm in size) occur along these "planed off" zones. At outcrops C and D1 the upper half of facies 1 contains some overlapping trough crossbeds, which may have a few scattered mudrock clasts (1-2 cm in size) at their bases. Paleocurrent directions for the upper and lower parts of facies 1 are similar.

Environmental Interpretation. Facies 1 deposits are thought to represent reworked distributary mouth bar sands similar to the delta front sheet sands described by Fisk (1955). The sharp, flat, slightly scoured lower contact of facies 1 into the underlying Dorton Formation would be characteristic of delta front sheet sands which prograded across muddy bay sediments (Fisk, 1955; and Coleman et al., 1969). The abundant planar crossbeds, many of which have lensoid shapes in cross-section (Fig. 3.4C), probably represent coalescing bar sands. The decrease in crossbed size (sets 50-100 cm thick to sets 20-50 cm thick) upward in facies 1 suggests decreasing energy conditions, possibly due to a decrease

in fluvial progradation. The general southeastward unidirectional dips of the crossbeds (Fig. 3.5), probably reflect not only fluvial progradation but longshore currents as well. This is confirmed by some of the paleocurrent readings in the channel facies of the Crossville within the study area which show paleocurrent directions more to the west. Longshore paleocurrents would have generally been to the southeast if Horne (1979) is correct (see Fig. 1.8, p. 25).

The small current ripples present on some bedding surfaces of the planar crossbed sets probably formed from the small scale movement of sand down the front of the bar crests. Perhaps wave or tidal activity would cause the slightly opposite paleocurrent flow directions of these ripples as compared to the bar sands. Planar crossbeds which have their tops "planed off" and contain a few small mudrock clasts along these surfaces may indicate scour from tides, waves, or currents. These "planed off" crossbeds were only seen at outcrop A, indicating the sediments deposited there were exposed to higher-energy conditions than at the other outcrops.

The "clean" nature of the sands of facies 1 (quartzarenites) attests to the winnowing action of currents, waves, and/or tides. This is characteristic of mouth bar sands subject to high physical energy processes (Fisk, 1955; and Allen, 1965). The quartz grains of facies 1 are subrounded and a few are subangular, thus reworking by currents, waves, and/or tides winnowed most of the clay away, but did not proceed far enough to round the quartz grains. However, many authors believe that rounded or well-rounded quartz grains require several generations

of deposition, erosion, and transportation to achieve the rounding. The gentle nature of the winnowing is also evidenced by the presence of macerated carbonaceous material, mica, and sedimentary rock fragments which would have been destroyed under intense reworking. The general absence of current ripples in facies 1 would also suggest fairly high energy conditions (Allen, 1965). Thus, even as progradation decreases, energy levels are still above ripple formation.

The stylocumulate laminae, the sutured quartz grain boundaries, and abundant quartz overgrowths point to intense pressure solution. Stylolites in "clean" sandstones are not uncommon (Pettijohn, 1975, p. 245). Heald (1955) has also described bedding plane stylolites similar to those in the Crossville.

Crossville Formation; Facies 2; Subfacies 1 and 2:
Ripples, Flasers, and Wavy Bedding Deposits

Facies 2 is divided into 2 subfacies: subfacies 1—a sublitharenite dominated by wavy bedding, and subfacies 2—a sublitharenite to quartzarenite which commonly contains simple or bifurcated wavy flasers. Facies 2 is completely exposed at outcrops A, B, C, and D1 where it ranges from 3.0 to 5.0 meters thick. Outcrops B and C have subfacies 1 and 2 interbedded with abrupt, flat, nonscoured boundaries between them (Fig. 3.6A). Outcrop A is dominated by subfacies 2 lithologies, and subfacies 1 at outcrop A does not display wavy bedding, only ripple cross lamination. Outcrop C does not contain subfacies 2 lithologies and subfacies 1 lithologies dominate.

Fig. 3.6. Photographs pertaining to facies 2 of the Crossville Formation. The small arrows indicate stratigraphic up.

- A. Field photograph from outcrop B illustrating the interbedded nature of subfacies 1 and 2 of facies 2. Note the decrease in thickness of subfacies 1 lithologies upward. Scale is 1.25 meter stick.
- B. Field photograph from outcrop B showing a close up of subfacies 1 and 2 of facies 2. Note the wavy bedding in subfacies 1. Scale is 20 centimeters.
- C. Field photograph from outcrop C illustrating 2 opposing ripple trains within facies 2. Scale is 20 centimeters.
- D. Field photograph of a possible gastropod trail on a rippled surface of facies 2 at outcrop B. Scale is in centimeters, 14 centimeters shown.

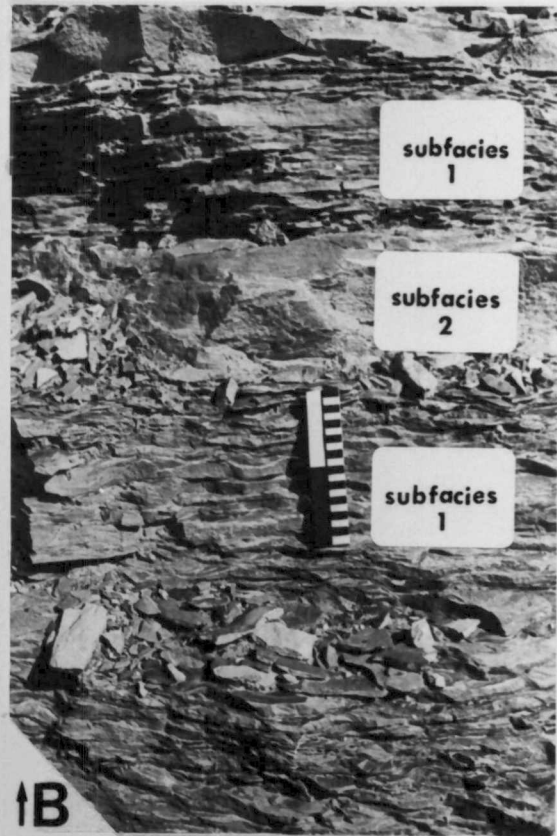
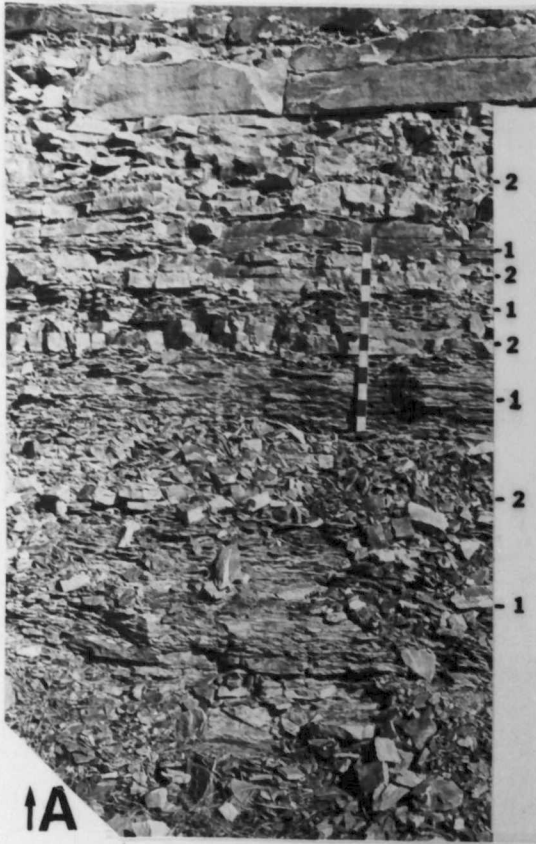


Fig. 3.6

Facies 2; Subfacies 1 of the Crossville Formation

Description. Subfacies 1 is a light-gray sublitharenite which exhibits very thin- to thin-wavy bedding and some bifurcated wavy flasers (Fig. 3.6B). The wavy bedding is caused by small cusate ripples (length—5 cm, height—2 cm), which are draped by 2-6 millimeter clay layers, which also contain some macerated organic material and muscovite. Usually the cusate ripples show internal cross laminae of very thin (0.5 mm) clay-rich layers. Bifurcated wavy flasers are also present in subfacies 2 lithologies. Subfacies 1 at outcrop A is nearly devoid of clay drapes, though a few thin ones (1 mm) are present.

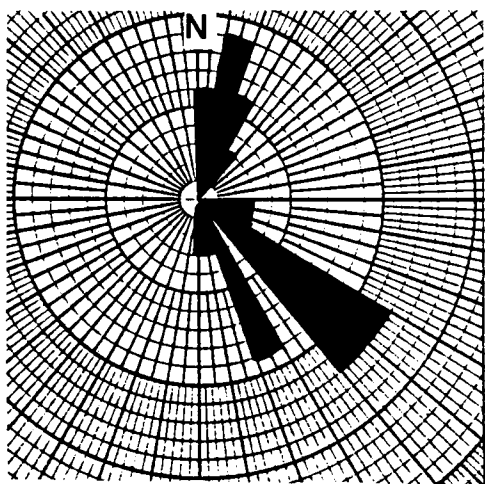
Subfacies 1 lithologies at outcrop D1, display small undulatory ripples (length—4 cm, height—1 cm) rather than the cusate ripples of subfacies 1 seen at outcrops A, B, and C. Also, the rippled lithology of subfacies 1 at outcrop D1 is finer grained and more clay-rich. The cusate ripples of subfacies 1 are composed of 94% very fine quartz sand, 2% sedimentary rock fragments, 2% muscovite, 1% chert, and 1% macerated organics. The drapes over the ripples are composed of 60% clay, 34% silt, 4% muscovite, and 2% macerated organic. At outcrop D1, the undulatory ripples and clay drapes alternate as thin (1 mm), ripple cross laminae. Subfacies 1 lithologies at outcrop D1 are composed of 50% very fine quartz sand, 25% quartz silt, 15% clay, 5% muscovite, and 5% macerated carbonaceous material. Where subfacies 1 lithologies are interbedded with subfacies 2, they range from 10 to 80 centimeters thick, decreasing in thickness upwards within facies 2 (Fig. 3.6A).

At outcrop D1, where subfacies 2 lithologies are not present, subfacies 1 is 2.30 meters thick.

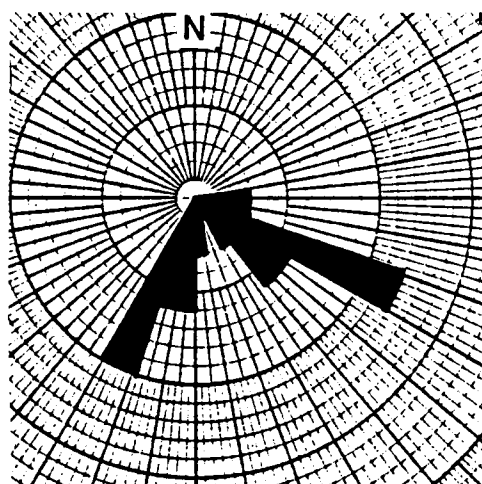
Paleocurrent data from the ripple cross-lamination of subfacies 1 indicates a general southeastern transport direction (Fig. 3.7) though some ripple trains show transport directions nearly opposite to this. Some surface trails which are similar to many recent gastropod trails were found on rippled surfaces (Fig. 3.6D) though the origin of these is unknown.

Facies 2; Subfacies 2 of the Crossville Formation

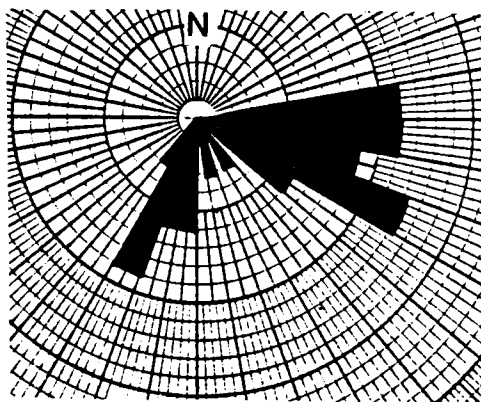
Description. Subfacies 2 lithologies are thin-bedded, light-gray sublitharenites to quartzarenites which contain bifurcated wavy and simple flasers. Subfacies 2 lithologies are exposed at outcrops A, B, and C where they are interbedded with subfacies 1 lithologies. Subfacies 2 lithologies are not present in facies 2 at outcrop D1. Subfacies 2 lithologies have flat, abrupt, nonscoured upper and lower contacts with subfacies 1 lithologies. Subfacies 2 lithology beds range from 10 to 80 centimeters thick, increasing in thickness and becoming more dominant upward within facies 2 (Fig. 3.6A). Subfacies 2 is composed of 86% very fine quartz sand, 6% clay, 5% macerated carbonaceous material, and 3% muscovite. The flasers are thin (1 mm) and are composed of clay, macerated carbonaceous material, and scattered muscovite flakes. The quartz sand grains are very fine, moderately sorted, and subrounded.



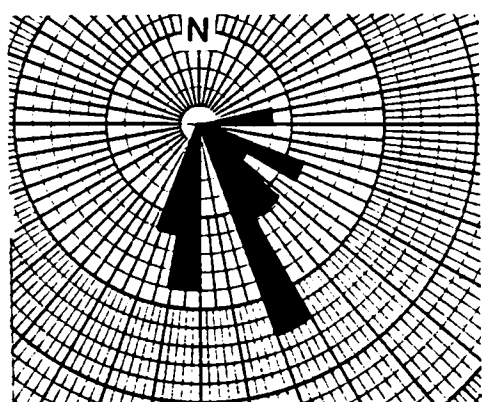
FACIES 2 OUTCROP A



FACIES 2 OUTCROP B



FACIES 2 OUTCROP C



FACIES 2 OUTCROP D1



FACIES 2 GRAND TOTAL

Fig. 3.7. Paleocurrent rose diagram for each outcrop of the Crossville (facies 2) and the grand total. Each measurement equals 5 mm on the grand total and 7 mm on the other diagrams. See Appendix C for the types of measurements made and procedures that were followed.

Facies 2; Subfacies 1 and 2 of the
Crossville Formation

Environmental Interpretation. Facies 2 lithologies, in general, record a decrease in current and sedimentation rates from facies 1 which underlies it stratigraphically. A lateral transition within facies 2 from higher to lower hydrodynamic conditions is recorded from outcrops A to D1. Also, a general upward-shoaling sequence is recorded within facies 2.

Subfacies 2 lithologies are fairly clean and contain some flasers which reflect higher energy conditions than subfacies 1 lithologies, which are dominated by wavy bedding. Wavy bedding requires conditions for the preservation of both sand and mud. The decrease of wavy bedding and mud drapes upward in facies 2 indicates shoaling conditions upward.

Higher hydrodynamic conditions (probably more turbulence) are thought to be represented at outcrop A as the cusate ripples have thin (1 mm) or no clay drapes and subfacies 2 lithologies dominate. At outcrops B and C, cusate ripples have well-developed clay drapes and subfacies 1 and 2 are about equal in dominance. Finally, at outcrop D1, subfacies 2 is not present, the grain size of subfacies 1 is finer, and lower-energy, undulatory rather than cusate, ripples are present. It may be that outcrops B, C, and D1 were more landward or in a more protected area than outcrop A. Thus, mud deposition dominated at outcrops B, C, and D1. The wavy bedding and flaser bedding may have formed from tidal action (Reineck and Wunderlich, 1968). Another explanation for the wavy bedding may be alternating periods of high

sand sedimentation from fluvial sources followed by periods of more quiescence when mud was deposited. Hawley (1981) points out that mud layers would have to accumulate over several tidal cycles with large amounts of mud available to get a thick (1 cm) accumulation of mud over the ripples. The cusped ripples of subfacies 1 lithologies show interference patterns probably caused by waves or some other interference such as currents or tides (Fig. 3.6C, p. 78).

Crossville Formation; Facies 3: Washover Deposits
and A Shoaling Upward Sequence

Facies 3 of the Crossville Formation

Description. This facies is a buff, medium- to thick-bedded, tabular, quartzarenite which is completely exposed at outcrops B, C, D, D1 and partially exposed at outcrop A. Facies 3 ranges from 150 to 350 centimeters thick and pinches out to the south into facies 1 (stagnant bay deposits) of the Burnt Mill Formation at outcrops D and D1 (Fig. 3.8A). The boundary between facies 3 and facies 2 (which underlies it) is defined as that level at which the rippled zones (subfacies 1 of facies 2) are no longer present. Facies 3 is composed of medium- to thick-beds which have sharp, slightly undulatory (2-4 cm) lower contacts, and flat, sharp, upper contacts. Facies 3 sandstones are strikingly tabular (Fig. 3.8B) at outcrops B, C, D1, and D; however, at outcrop A, facies 3 (where exposed) contains large (50-80 cm thick) planar crossbed sets.

The sands at outcrops B, C, D1, and D are massive and heavily bioturbated. At outcrop A, bioturbation is absent with large planar

Fig. 3.8. Photographs pertaining to facies 3 of the Crossville Formation. The small arrows indicate stratigraphic up.

- A. Field photograph of the Crossville (facies 3) "pinching out" into the Burnt Mill Formation at outcrop D. Scale is 1.25 meter stick.
- B. Field photograph of the Crossville (facies 3) at outcrop B illustrating the flat, tabular, nature of this sandstone. Scale is 1.25 meter stick.
- C. Field photograph of a Rhizocorallium surface trace (directly above the sacle) in facies 3 of the Crossville at outcrop B. Scale is 20 centimeters.
- D. Field photograph of a Zoophycus surface trace in facies 3 at outcrop D1. Scale is in centimeters.

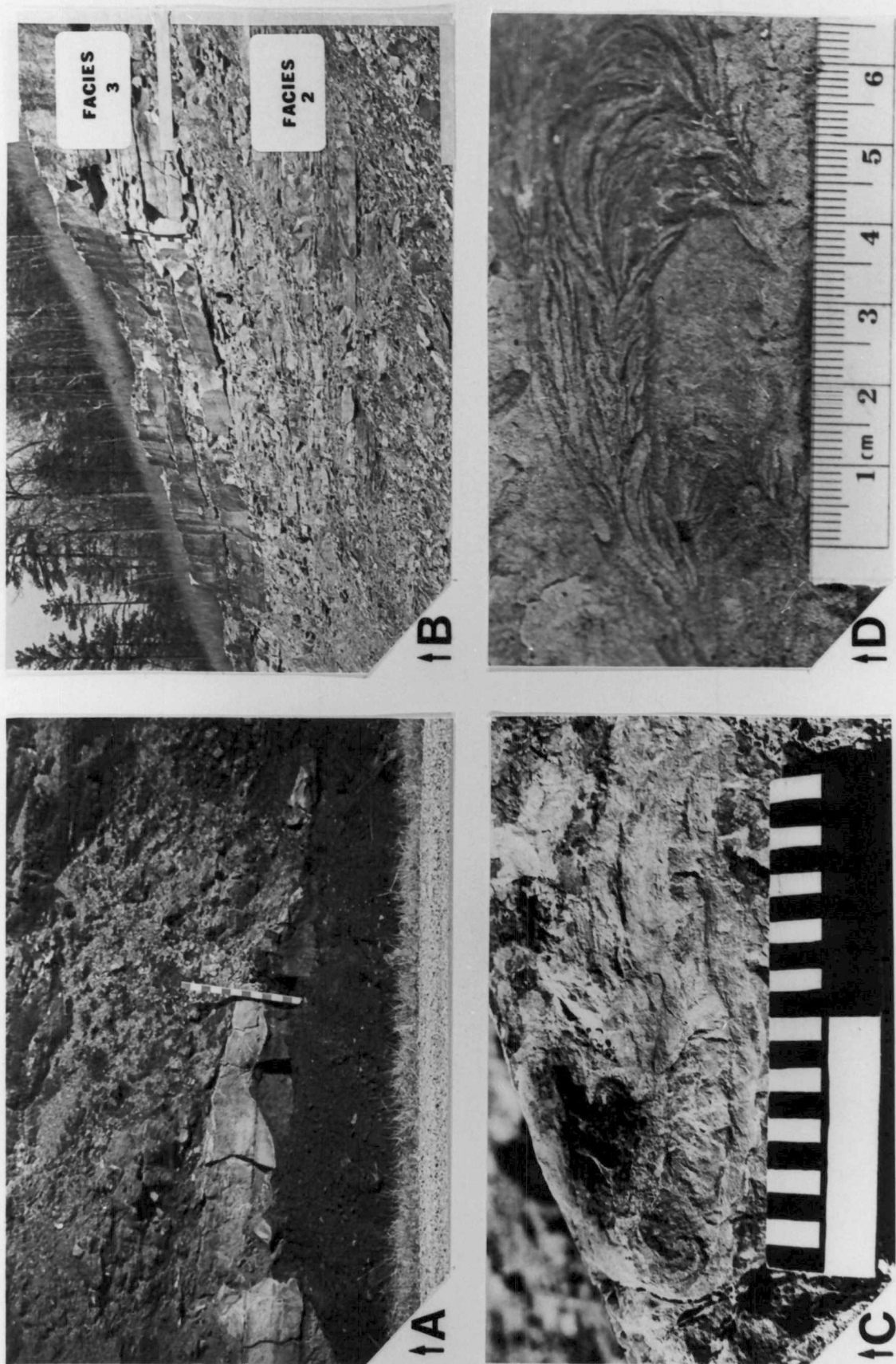


Fig. 3.8

crossbeds the only sedimentary structures present. Typically the heavily bioturbated sands are more weathered and friable. The burrows in the bioturbated sands in the lower part of facies 3 show both vertical and branching burrows, unlined with organic matter. These burrows have diameters of 2 to 3 millimeters, and lengths of 5 to 8 centimeters. In the uppermost sands of facies 3 (particularly at the Crossville-Burnt Mill contact) vertical and branching burrows are lined with organic material and clay, and range from 3 to 5 millimeters in diameter and 5 to 10 centimeters in length. On top of bedding planes (particularly near the Crossville/Burnt Mill contact) surface traces of Rhizocorallium and Zoophycus are abundant (Figs. 3.8C and 3.8D).

Environmental Interpretation. Facies 3 rocks are interpreted as successive washover fan deposits. Evidence for a washover origin include their "clean" nature (quartzarenites); flat, tabular, thick-bedding; slightly erosive (2-5 cm) lower contacts between beds; bioturbated tops; and lateral "pinch out" into the Burnt Mill (stagnant bay deposits) at outcrop D. These features have been described by other authors (Hayes, 1967 and Schwartz, 1975) from similar washover deposits. The massive nature of facies 3 deposits may be due to rapid deposition, but much of facies 3 lithologies are "homogenized" by bioturbation. The top of each sandstone bed in facies 3 is heavily bioturbated with bioturbation decreasing in intensity downward. The burrows in the lower sand beds of facies 3 are difficult to recognize as they are not lined with clay or organic material. In the upper sands of facies 3 (at the Burnt Mill-Crossville contact), organisms were able to line their burrows with clay

and organic material; as slow clay and organic deposition occurred at the top of facies 3. The abundant traces of Rhizocorallium (both vertical and horizontal) and Zoophycus traces on the upper beds of facies 3 point to marine conditions, probably subtidal, but not subaerially exposed (Frey, 1975). At the Burnt Mill-Crossville contact at outcrops D1 and D, where washovers fine laterally into the Burnt Mill, bioturbation is abundant. However, in the Burnt Mill at some distance from the washover deposits bioturbation is rare to absent. This suggests that washovers into the stagnant Burnt Mill deposits may have provided more oxygenated waters or perhaps a firmer substrate on which organisms could live. Also, at outcrops D1 and D near the Burnt Mill-Crossville contact, plant roots were apparently covered by washover sediments. These plant roots were replaced by siderite, and many of these root structures are clearly in-situ (Fig. 3.9A).

Facies 3 is not well exposed at outcrop A, but would indicate higher energy conditions as thick crossbed sets (50-80 cm thick; 15° dip to the southeast) are present. It is not known exactly which cross-section of the washover deposit is present from A to D. However, it must be a cut near the edge of the washovers in order to show them pinching out at outcrops D1 and D into the stagnant bay sediments of the Burnt Mill.

Fig. 3.9. Photographs pertaining to facies 3, 4, and 5 of the Crossville Formation. The small arrows indicate stratigraphic up.

- A. Field photograph of an in-situ siderite replaced plant root structure near the Crossville-Burnt Mill contact at outcrop D. Scale is 20 centimeters.
- B. Field photograph showing part of facies 4 of the Crossville Formation at outcrop DD. Note the channel outlined in black. Scale is 1.25 meter stick.
- C. Field photograph showing part of facies 5 of the Crossville Formation at outcrop CC. Note the medium-bedding caused by "stacked" lensoid sands and trough crossbeds. Scale is 1.25 meter stick.
- D. Field photograph illustrating the base of a facies 5 channel deposit of the Crossville at outcrop CC. Note the 1 meter of scour into the underlying Dorton Formation. Scale is 1.25 meter stick.

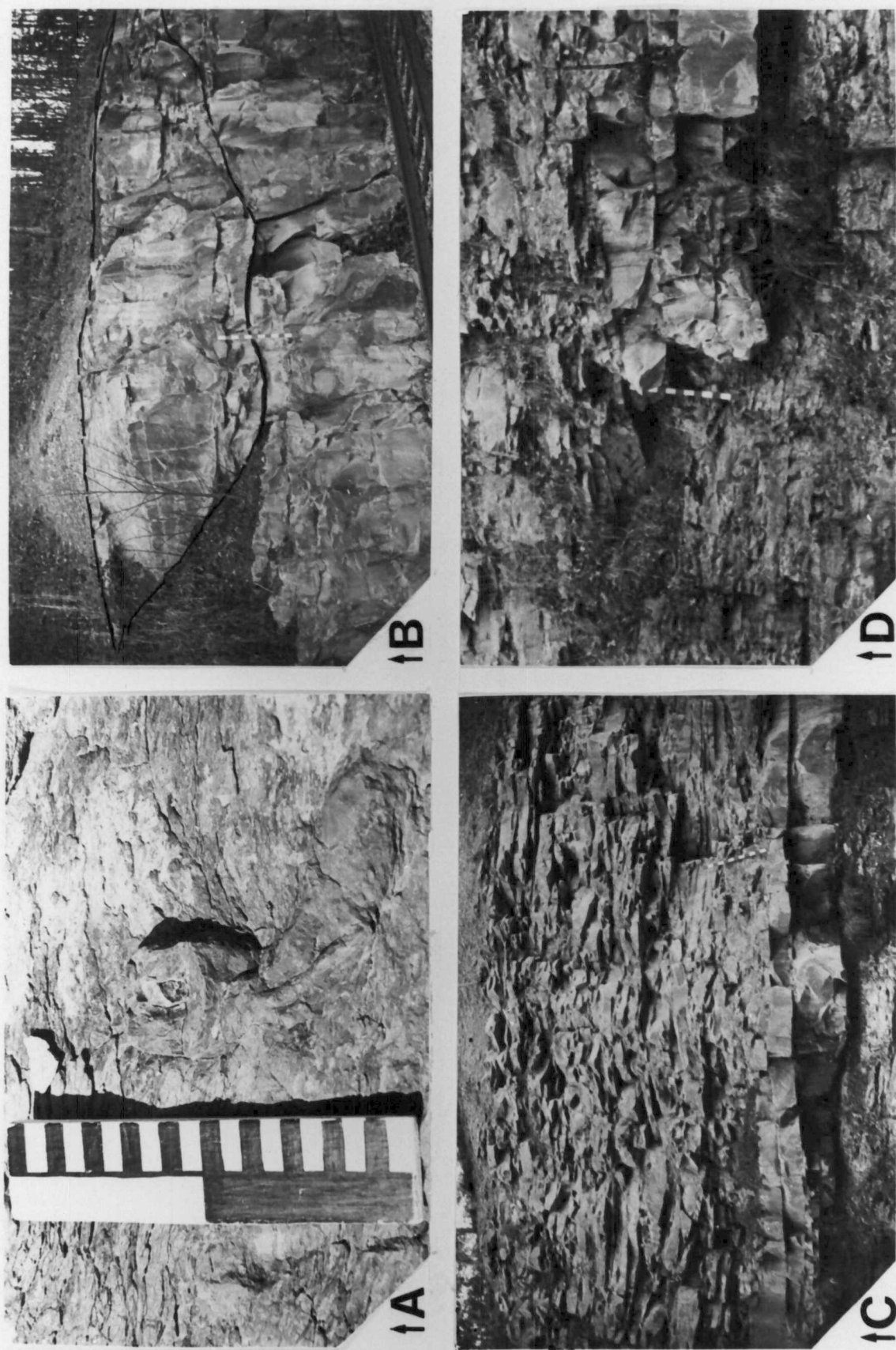


Fig. 3.9

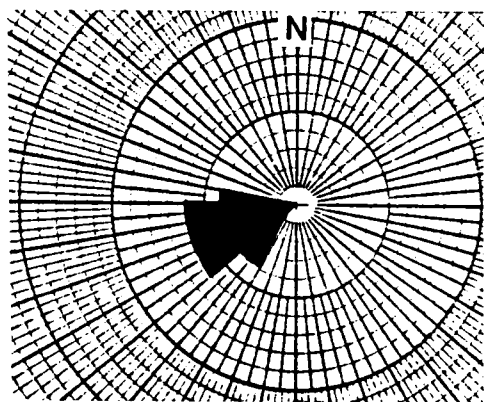
Crossville Formation; Facies 4:
Thick-Bedded Channel Deposits

Facies 4 of the Crossville Formation

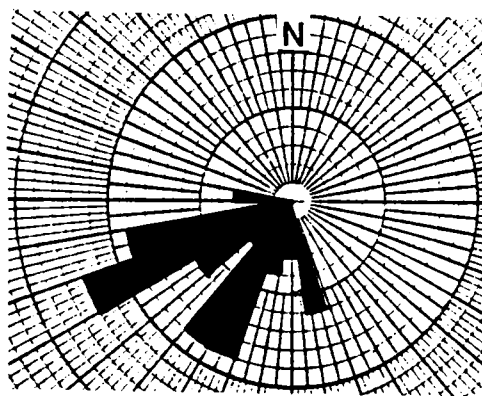
Description. Facies 4 is a buff, sublitharenite to quartzarenite and is only exposed at outcrop DD where it is approximately 550 cm thick. This facies displays large (8 m wide and 2 m deep) channel forms. These channels display thick- to very thick-bedding (Fig. 3.9B), and are scoured 50 to 90 centimeters into the underlying Dorton Formation. The lithologies of this facies are composed of 85-95% fine to medium quartz sand, 2-4% chert, 1-6% sedimentary rock fragments, 1-4% muscovite and 2% macerated carbonaceous material. The quartz sand grains are subrounded and moderately sorted. The sand grains fine upward from medium sand near the base of channels to fine sand at the top. In places at the base of the channels a few mudrock clasts (1 to 2 cm in size) may be seen. Facies 4 grades upward into the channel-abandonment deposits (facies 6) which overlie it. Paleocurrent data (Fig. 3.10) indicate a general east to west current flow.

Environmental Interpretation. Facies 4 represents channel deposits as evidenced by the concave upward channel form, the scoured base which contains a mudrock lag, and the fining-upward sequence within channels. Facies 4 lithologies must have formed under fairly constant flow conditions which would yield the thick- to very thick-bedding.

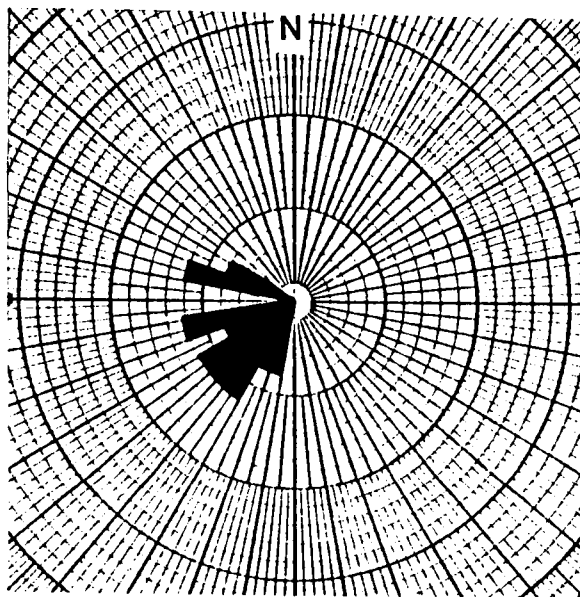
Facies 4 shows paleocurrent directions nearly perpendicular to the other sand facies in the Crossville. Because of the massive nature of



FACIES 4 OUTCROP DD



FACIES 5 OUTCROP CC



FACIES 7 OUTCROP BB

Fig. 3.10. Paleocurrent rose diagram for facies 4, 5, and 7 of the Crossville Formation. Each measurement equals 5 mm on the grand total and 7 mm on the other diagrams. See Appendix C for the types of measurements made and procedures that were followed.

this facies, not as many crossbed measurements were collected as in the other facies of the Crossville.

The best explanation for facies 4, from the data available, is a distributary channel on the distal lower delta plain. Saxena and Ferm (1976) show that such channels are straight and exhibit little tendency to migrate laterally. This would explain the lack of levee deposits or point bar accretion beds in facies 4. If such a straight channel received a continuous input of sediment, thick, massive bedding could be produced. If these channels are in fact distributary channels, paleocurrent directions recorded from them would agree with the general east to west progradation of channel distributaries thought to occur on a more regional scale (Milici et al., 1979).

The paleocurrents for the channel deposits (facies 4 and facies 5) may indicate that these deposits were influenced more by fluvial progradation, while other paleocurrents in the Crossville (which are nearly perpendicular to those) show sediments influenced more by longshore drift from marine-dominated processes.

Another explanation for facies 4 may be a tidal channel. A tidal channel origin would also explain paleocurrent directions nearly perpendicular to these in the rest of the Crossville sands. However, a lack of any tidal channel features (bidirectional crossbeds, shell lag, slump blocks, falling water marks, etc.) would argue against this interpretation. Tidal channels are not thick-bedded and massive, but show a series of trough and/or planar crossbeds (commonly bidirectional). Thus, these tidal channel features described by several authors

(Land, 1972; Kumar and Sanders, 1974; and Carter, 1978) are not present in facies 4. Therefore, the best explanation for the origin of facies 4 seems to be one of distributary channels.

Crossville Formation; Facies 5:
Multistory Channel Deposits

Facies 5 of the Crossville Formation

Description. This facies is a buff, medium-bedded, sublitharenite to quartzarenite and is only exposed at outcrop CC where it ranges from 420 to 480 cm thick. This facies displays large (12 m wide and 4 m deep) channel forms with scoured bases up to one meter high (Fig. 3.9D). The channel sands of facies 5 exposed at outcrop CC are very different than those of facies 4 exposed at outcrop DD. Facies 5 channel sands are composed of numerous, multistory trough crossbeds with sets ranging in size from 50 to 100 centimeters wide and 20 to 60 centimeters deep. Lenoid-shaped sand deposits (1 m long—50 to 80 cm thick) comprised of numerous planar and trough crossbeds (50–80 cm thick sets) are "stacked" within the channel forms (Fig. 3.9C). The lower 20 centimeters of facies 5 channels may contain abundant mudrock clasts, macerated carbonaceous material and/or coalified plant remains. In one place, the underlying Dorton Formation has been "squeezed" upward into the overlying Crossville sands of facies 5. Paleocurrent directions show a wider "scatter" than those of facies 4, but transport is dominantly to the west (Fig. 3.10).

Environmental Interpretation. Facies 5 represents channel deposits as evidenced by the concave upward channel forms; the scoured bases

typically show a mudrock-clast lag and/or coalified plant remains and a fining-upward sequence within channels. Facies 5 channels are very different from facies 4 channels. Facies 5 channel deposits were built up by bar migration within the channels as shown by the numerous stacked, lenticular bars, and overlapping trough-crossbed sets within the channels. Evidently, more irregular current conditions were present in the facies 5 channels as compared to facies 4, perhaps causing the wider paleocurrent "scatter" of facies 5 as compared to facies 4. Again, paleoflow directions for facies 5 are nearly perpendicular to those of the other Crossville outcrops. Facies 5 is also thought to represent distributary channels, thus yielding more perpendicular flow directions than the other outcrops which display a stronger marine influence. A tidal channel explanation is refuted for the same arguments given under the interpretation of facies 4.

One explanation for the "stacked" sands of facies 5, is that these channels did not meander much since lower delta plain channels are rather straight (Saxena and Ferm, 1976). Thus, facies 5 may have been similar to the low sinuosity channels described by Moody-Stuart (1966) which would produce abundant cut and fill structures, as well as a "stacking" arrangement within the channels. This is caused by the currents within the channel oscillating back and forth between fairly straight banks. This would explain the lack of levee and point bar accretionary surfaces in facies 5 deposits.

Crossville Formation; Facies 6:
Channel Abandonment Deposits

Facies 6 of the Crossville Formation

Description. Facies 6 lithologies are dominated by a dark-gray, sandy, bedded siltstone which contains a few thin- to medium-beds of sublitharenites. Facies 6 ranges from 320 to 400 centimeters thick and is usually slightly thinner directly over the channels. At outcrop DD, facies 6 deposits are capped by a 80 to 120 cm thick quartzarenite. Facies 6 is only exposed at outcrops CC and DD where it overlies the channel deposits (facies 4 and 5).

The gray laminated siltstones of facies 6 contain medium to thick, parallel, discontinuous to continuous, quartz-rich silt laminae which alternate (2-8 mm spacings) with more clay-rich layers. Facies 6 lithologies contain 40-50% quartz silt, 10-15% very fine quartz sand, 20-35% clay, 10-20% macerated carbonaceous material, and 5% muscovite.

The quartz-rich silt laminae have fairly diffuse upper and lower boundaries. The thin- to medium-beds of sublitharenites consist of very fine, moderately-sorted, subrounded quartz grains. Some small current ripple cross laminations (length—4 cm, height—1 cm) are present. The contacts of the sublitharenite interbeds with the sandy siltstones of facies 6 are slightly gradational (over a 5-6 cm interval).

The sandstone capping facies 6 at outcrop DD is a quartzarenite and contains very fine, rounded, well-sorted quartz sand grains. This lithology is massive and composed of 95% very fine quartz sand, 2% chert,

1% sedimentary rock fragments, 1% macerated carbonaceous material, and 1% muscovite.

Environmental Interpretation. Facies 6 lithologies are gradational with the underlying channel deposits (facies 4 and 5) and reflect deposition after the active channels were abandoned. Facies 6 deposits are dominated by siltstone lithologies and have high percentages of clay, silt, and organic matter that settled out of suspension when more ponded conditions prevailed after channel abandonment. The fairly diffuse nature of the silt laminae suggests little reworking of the silt grains. The interbedded sandstones of facies 6, which contain small current ripples, probably reflect overbank flooding (Horne et al., 1978). The fact that facies 6 deposits are slightly thinner directly over the channels rather than off the channel margins would be expected for overbank deposits.

The quartzarenite that caps facies 6 at DD is massive and may represent flood deposits that were later winnowed by currents and/or waves.

Crossville Formation; Facies 7; Subfacies 1 and 2:
Interbedded Quartzarenites and Rippled
Sublitharenites

Facies 7; Subfacies 1 of the
Crossville Formation

Description. Subfacies 1 of facies 7 is a buff, medium-bedded quartzarenite and is only exposed at outcrop BB. Subfacies 1 lithologies are interbedded with subfacies 2 lithologies of facies 7

and range from 90 to 200 cm thick (Fig. 3.11A). Subfacies 1 is the first subfacies of facies 7 in contact with the underlying Dorton Formation; the lower contact is abrupt, flat, slightly scoured (10-15 cm of relief) and contains some coalified plant material. Subfacies 1 lithologies are composed of 95% very fine quartz sand, 1% chert, 1% macerated carbonaceous material, 1% clay, and 1% muscovite. Subfacies 1 lithologies contain planar crossbeds with sets ranging from 20-60 centimeters thick. Crossbed directions are dominantly to the southeast with 10 to 20 degree dips (Fig. 3.10, p. 88). Subfacies 1 lithologies show a slight increase in thickness upwards in the lower three-quarters of facies 7, with subfacies 2 lithologies in the upper-quarter getting slightly thicker.

Facies 7; Subfacies 2 of the
Crossville Formation

Description. This subfacies is a very thin lenticular to wavy bedded sublitharenite, and is only exposed at outcrop BB. Subfacies 2 lithologies are interbedded with subfacies 1 lithologies within facies 7; range from 100 to 170 cm thick, and have sharp, flat, nonscoured contacts with subfacies 1 lithologies. Subfacies 2 lithologies display alternating very thin-beds of small current ripples (length—4 cm, height—1 cm), with clay-rich layers (5-6 mm thick) over them. In places the ripples and clay drapes display wavy bedding, but typically lenticular bedding is more dominant (Fig. 3.11B). The ripples are composed of 92% very fine quartz sand, 5% clay, and 3% macerated organics. The clay-rich layers over the

Fig. 3.11. Photographs pertaining to facies 7 of the Crossville Formation. Small arrows indicate stratigraphic up.

- A. Field photograph of facies 7 at outcrop BB illustrating the alternating subfacies (1 and 2) within that facies. Scale is 1.25 meter stick.
- B. Field photograph illustrating the lenticular bedding common to subfacies 1 of facies 7 at outcrop BB. Scale is 20 centimeters.

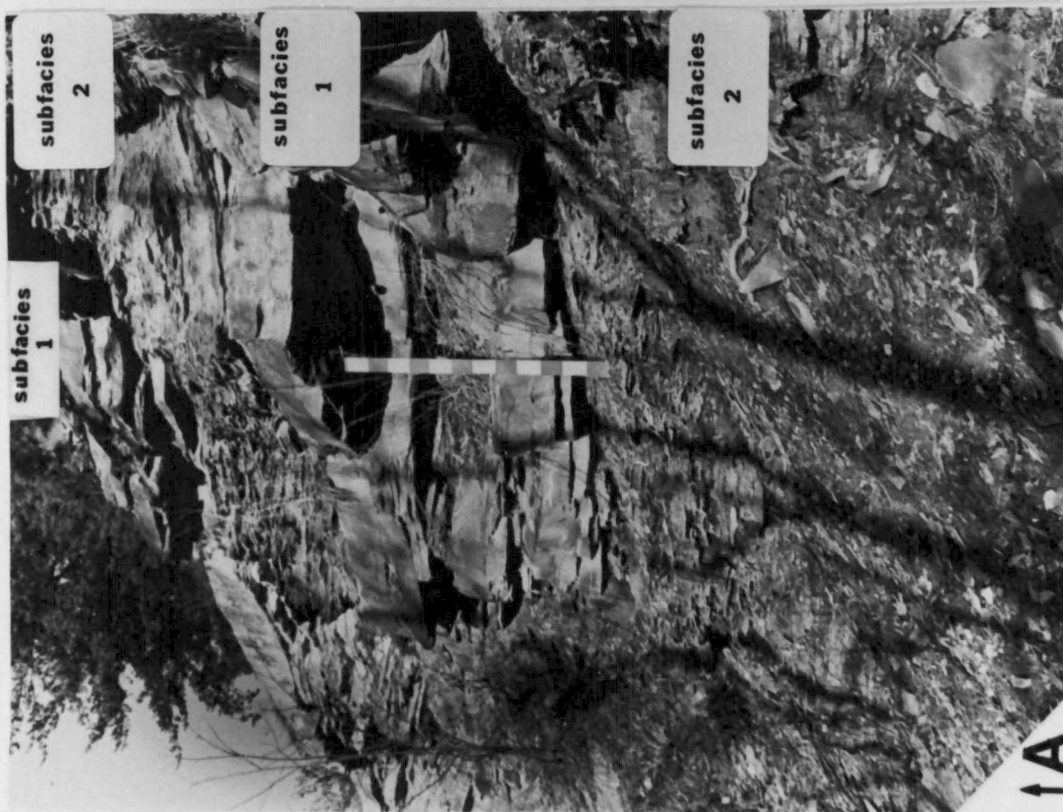
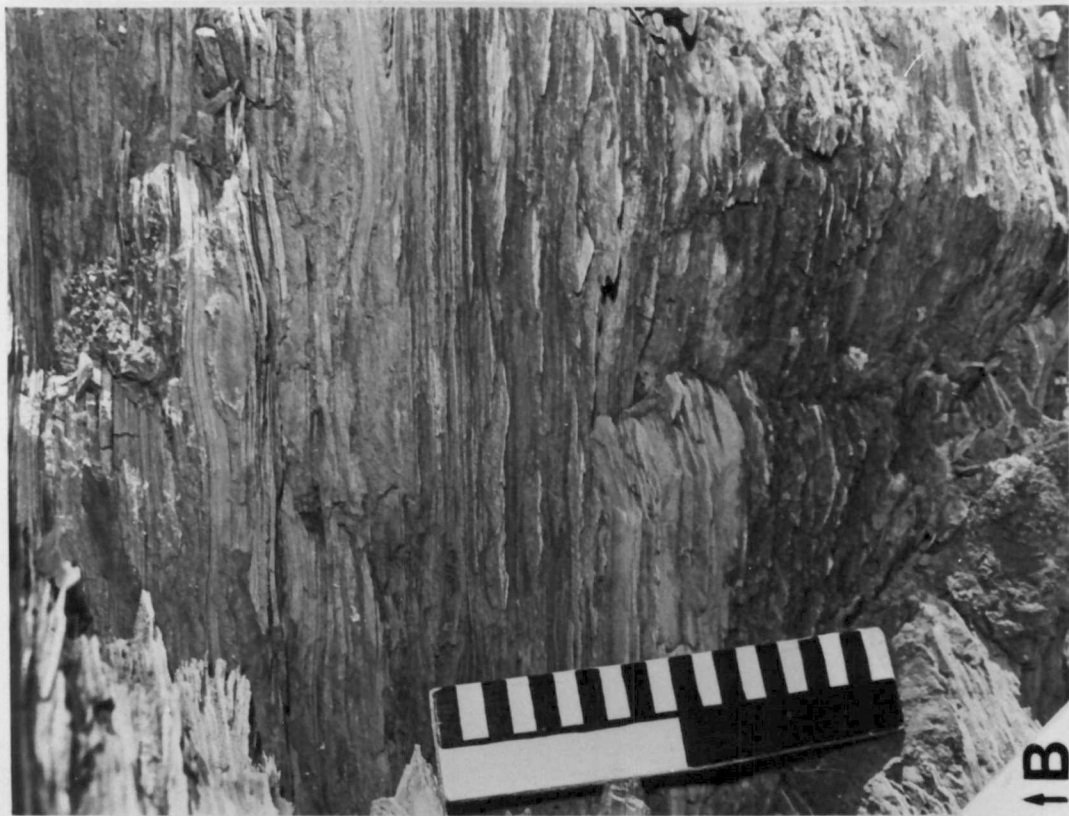


Fig. 3.11

ripple cross lamination are composed of 60% clay, 20% quartz silt, 15% macerated organics, and 5% muscovite.

Facies 7; Subfacies 1 and 2 of the
Crossville Formation

Environmental Interpretation. Facies 7 interbeds of subfacies 1 and 2 reflect alternating depositional and/or hydrodynamic conditions. Assigning a particular environment to facies 7 is difficult based on only one exposure of this facies (outcrop BB). However, it is thought that facies 7 reflects more quiet conditions as it is laterally adjacent to the channel deposits (facies 4 and 5).

Subfacies 1 lithologies reflect sand-dominated deposition and fairly high energy conditions as compared to subfacies 2, as subfacies 1 contains medium- to thick-sets (60-80 cm) of planar crossbeds and "clean" sand. The "clean" sands of subfacies 1 (quartzarenites) may be due to wave and/or tidal reworking. The paleocurrent directions (Fig. 3.10, p. 92) generally agree with those of outcrops A, B, C, and D, perhaps suggesting longshore currents were redistributing the sands of the channel deposits (facies 4 and 5).

Subfacies 2 lithologies reflect conditions more favorable for the deposition of mud rather than sand. This is seen by the lenticular bedding in these lithologies, marked by sand-starved, small current ripples. When enough sand is available, these ripples are joined and wavy bedding is produced.

Increased fluvial deposition may be reflected in the lower three-quarters of facies 2; there subfacies 1 lithologies generally

increase in thickness while subfacies 2 lithologies decrease in thickness upward. The upper one-quarter of facies 7 reflects more quiet conditions as subfacies 2 lithologies dominate in this upper-quarter.

Burnt Mill and the Lower Part of the Coalfield Formation

The Burnt Mill Formation in the study area overlies the Crossville Formation and at outcrop D the Burnt Mill also interfingers with the top of the Crossville Formation. A complete section of Burnt Mill can be seen at outcrop D and a complete, but heavily weathered section is present at outcrop DD. Outcrops D1, E, F, G, BB, and CC in the study area also contain partial exposures of the Burnt Mill (20-50%).

The lower part of the Coalfield Formation is discussed here with the Burnt Mill because the sandstones of the lower part of the Coalfield are environmentally related to upper siltstones of the Burnt Mill. The lower part of the Coalfield is completely exposed at outcrops D, E, F, G, and DD, the latter outcrop is heavily weathered as noted above in reference to the Burnt Mill. The lack of lateral exposure and heavy weathering at outcrop DD obscured most sedimentological information in the lower Coalfield at this outcrop. Consequently, outcrop DD was not of any real use in reconstructing facies from the lower part of the Coalfield Formation.

Five different facies were recognized in the Burnt Mill and lower part of the Coalfield Formation, mainly from the more complete highway outcrops (D1, D, E, F, and G). The dominant facies in the Burnt Mill

Formation is inferred to have been deposited in a stagnant, poorly-drained bay environment; though splay, minor mouth bar, and splay abandonment deposits were also recognized.

The lower Coalfield Formation represents the last stages of splay progradation seen in the top of Burnt Mill; followed by the subsequent formation of shallow, anoxic "ponds" resulting from splay abandonment.

In order to illustrate the spacial distribution of the different facies and subfacies within the Burnt Mill and Coalfield Formations; a highly stylized diagram (Fig. 3.12) was prepared from the outcrops along the highway (D, E, F, and G). This diagram is not intended for use in thickness determination and correlations are oversimplified. The diagram is for general reference to accompany the discussion of the different facies and subfacies presented below. For a more accurate representation of each outcrop the reader should refer to the outcrop sketches from the photo-mosaics in Appendix E.

Burnt Mill Formation; Facies 1:
Stagnant Bay Deposits

Facies 1 of the Burnt Mill
Formation

Description. This facies is a black, laminated mudshale which is completely exposed only at outcrops D and DD where it ranges from 10 to 12 meters thick. It is partially exposed at outcrops D1, E, F, G, BB, and CC (10-30%). Facies 1 is the only facies present in the Burnt Mill Formation at outcrops BB, CC, and DD. This facies is composed of 60% fibrous organic material (fibers 1-2 mm thick), 20% quartz silt,

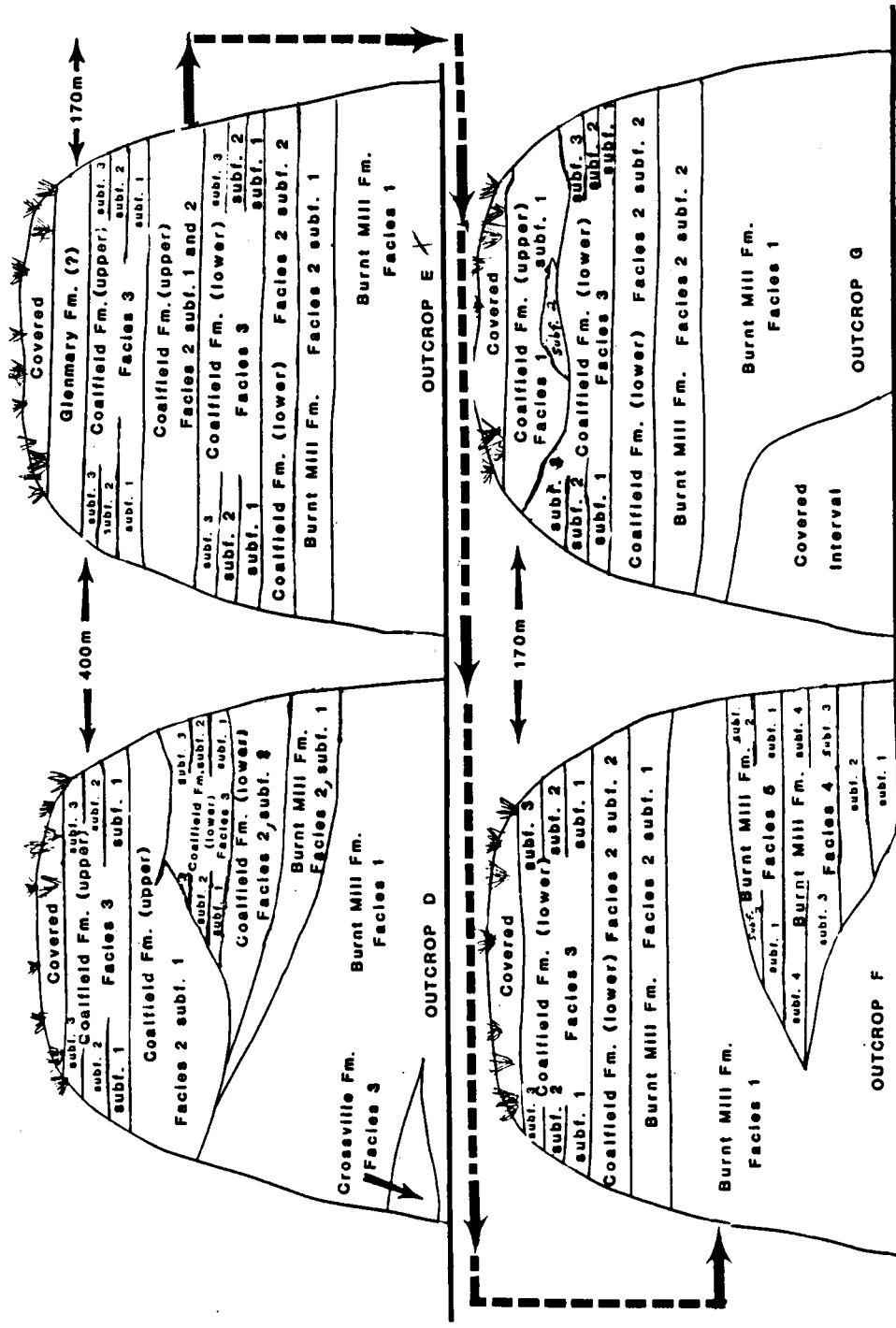


Fig. 3.12. Stylized diagram illustrating the facies and subfacies of the Burnt Mill and Coalfield Formations, for the highway outcrops.

15% clay, and 5% muscovite. The long axes of the carbonaceous material, which occurs as fibers are aligned parallel to bedding. Some thin (1 mm), even, parallel, continuous quartz-rich silt laminae with diffuse upper and lower boundaries alternate (1-2 mm spacing) with more clay-rich laminae. Figure 3.8A (p. 85) illustrates the clay and organic-rich nature of facies 1. A few of the samples from facies 1 display two grain size class distributions with scattered quartz silt grains set in a "matrix" of clay and fibrous carbonaceous material.

Fine cubes (0.2-0.5 mm) of disseminated pyrite are commonly seen in thin sections. Some pyrite is in nodular form (1-2 cm in diameter). A few small (1-3 cm) irregularly shaped siderite nodules that formed around in-situ plant root structures were noted in places (Fig. 3.9A, p. 89). These nodules are dominant near the Crossville-Burnt Mill contact at outcrops D1 and D. Bioturbation is absent in facies 1 except for an infrequent small (1-2 mm in diameter) horizontal burrow.

No marine fossils were found by the writer in the Burnt Mill across the study area, but Wilson and Stearns (1960) report the collection of a few marine fossils from the Burnt Mill 3.2 kilometers south of Wartburg, Tennessee.

Environmental Interpretation. Facies 1 represents a stagnant, poorly-drained bay which had started to form near the end of fluvial progradation (reworked delta front sands of the Crossville); and became prominent after fluvial dominated sand deposition ceased. This

relationship can be seen at outcrop D; there, facies 1 of the Burnt Mill interfingers with and overlies the top of the Crossville Formation (Fig. 3.12).

The interpretation of facies 1 as a stagnant, poorly-drained bay is supported by several lines of evidence. The abundant fibrous carbonaceous material dominant in facies 1 (60%) indicates water stagnation and slow sedimentation rates. The high toxicity resulting from water stagnation would arrest the oxidation of plant material, resulting in its preservation and consequent high abundance (Twenhofel, 1961, p. 367). Also, the fibrous nature of this carbonaceous material indicates much of it accumulated in-situ as it is not highly macerated. The alignment of the carbonaceous fibers long axes probably resulted from deposition, enhanced by compaction. Many of the root structures, which have been replaced by siderite, are clearly in growth position (Fig. 3.9A, p. 89); this would also argue for most of the carbonaceous material accumulating in-situ. These irregular root structures are found near the Crossville-Burnt Mill contact at outcrop D where washover fan deposits smothered some of the vegetation.

The abundant disseminated pyrite and the few irregular pyrite nodules would support the idea of stagnant, anoxic conditions, perhaps in slightly brackish waters (Berner, 1970).

The absence of burrows (except for an infrequent horizontal burrow) would also indicate conditions too anoxic for organisms to live, as sedimentation rates were low and abundant food (organic material) would have been available. The quartz silt laminae were

probably introduced by floods into the stagnant bay area, a process detailed by Coleman (1966). The diffuse nature of the quartz silt boundaries (upper and lower) as well as their parallel, even, and continuous nature indicate little reworking by currents or waves. The quartz silt grains which are not present as silt laminae, but are scattered throughout the clay-rich layers can best be explained by a wind-blown origin. This supports the idea of stagnant, quiet water conditions similar to wind-blown silt described by Taylor (1963).

The Hooper coal was reported to occur at the base of the Burnt Mill Formation (Wilson et al., 1956), but was not observed in the study area. The stagnant bay area in which facies 1 was deposited may not have been conducive for peat-forming conditions, for a variety of reasons. Perhaps the bay area was too deep or too brackish for peat to form. Also, the clay and silt influx, though low, may have been just enough to retard peat formation.

Burnt Mill and the Lower Part of the Coalfield Formation;
Facies 2; Subfacies 1 and 2: Splay Deposits

Facies 2; Subfacies 1 of the
Burnt Mill Formation

Description. Subfacies 1 of facies 2 is a light-gray, sandy, laminated siltstone and is completely exposed at outcrops D, E, F, and G. Subfacies 1 is the lowest subfacies within facies 2 and is gradational with facies 1 below over a short (50 cm) interval. Subfacies 1 is thickest at outcrop E (380 cm), thinning to 180 centimeters at outcrop G, and pinching out at outcrop D. The lower-half of subfacies 1 is composed

of 65% quartz silt, 15% clay, 15% macerated carbonaceous material, and 5% muscovite. The upper-half of subfacies 1 lithologies are composed of 40% very fine quartz sand, 30% quartz silt, 13% muscovite, 10% clay, and 7% macerated carbonaceous material.

The laminations of subfacies 1 are even, wavy, discontinuous to continuous, parallel, and thin (1 mm) to thick (8 mm). The laminations are quartz silt to very fine sand which alternate with clay-rich laminae containing abundant organic material.

The laminations show a fairly regular spacing of 1 to 2 mm in the lower-half of subfacies 1, but thicken gradually to 2 to 8 mm in the upper-half. Grain-size also increases upward from silt dominated in the lower-half of subfacies 1 to very fine sand/silt-dominated in the upper-half. Normal grading of the silt/very fine sand laminae into the next overlying clay-rich laminae is common. Figure 3.13A illustrates a typical subfacies 1 lithology.

Small slumps (centimeter scale) are seen within subfacies 1 lithologies. Characteristic of subfacies 1 are numerous light-gray, highly weathered, calcium carbonate nodules and some siderite nodules, both nodules range from 1 to 3 centimeters in diameter. The calcium carbonate nodules are more dominant in the upper-half of subfacies 1 while the siderite nodules are more dominant in the lower-half of subfacies 1. Laminations are deformed around both types of nodules (Figs. 3.13B and 3.13C), indicating that nodule formation predated early compaction.

Fig. 3.13. Photographs pertaining to facies 2 of the Burnt Mill Formation. The small arrows indicate stratigraphic up.

- A. Field photograph from outcrop E illustrating a typical subfacies 1 lithology of facies 2. Note that some of the calcium carbonate nodules have weathered out. Scale is 65 centimeters.
- B. Field photograph from outcrop E illustrating laminae deformed around a calcium carbonate nodule of subfacies 1, facies 2. Scale is 1 centimeter.
- C. Field photograph from outcrop E illustrating laminae deformed around a siderite nodule, of subfacies 1, facies 2. Scale is 11 centimeters.
- D. Field photograph from outcrop D illustrating dewatering in subfacies 5 of facies 2. Note development of a "ball and pillow" structure to the far right of the photograph. Scale is 20 centimeters.

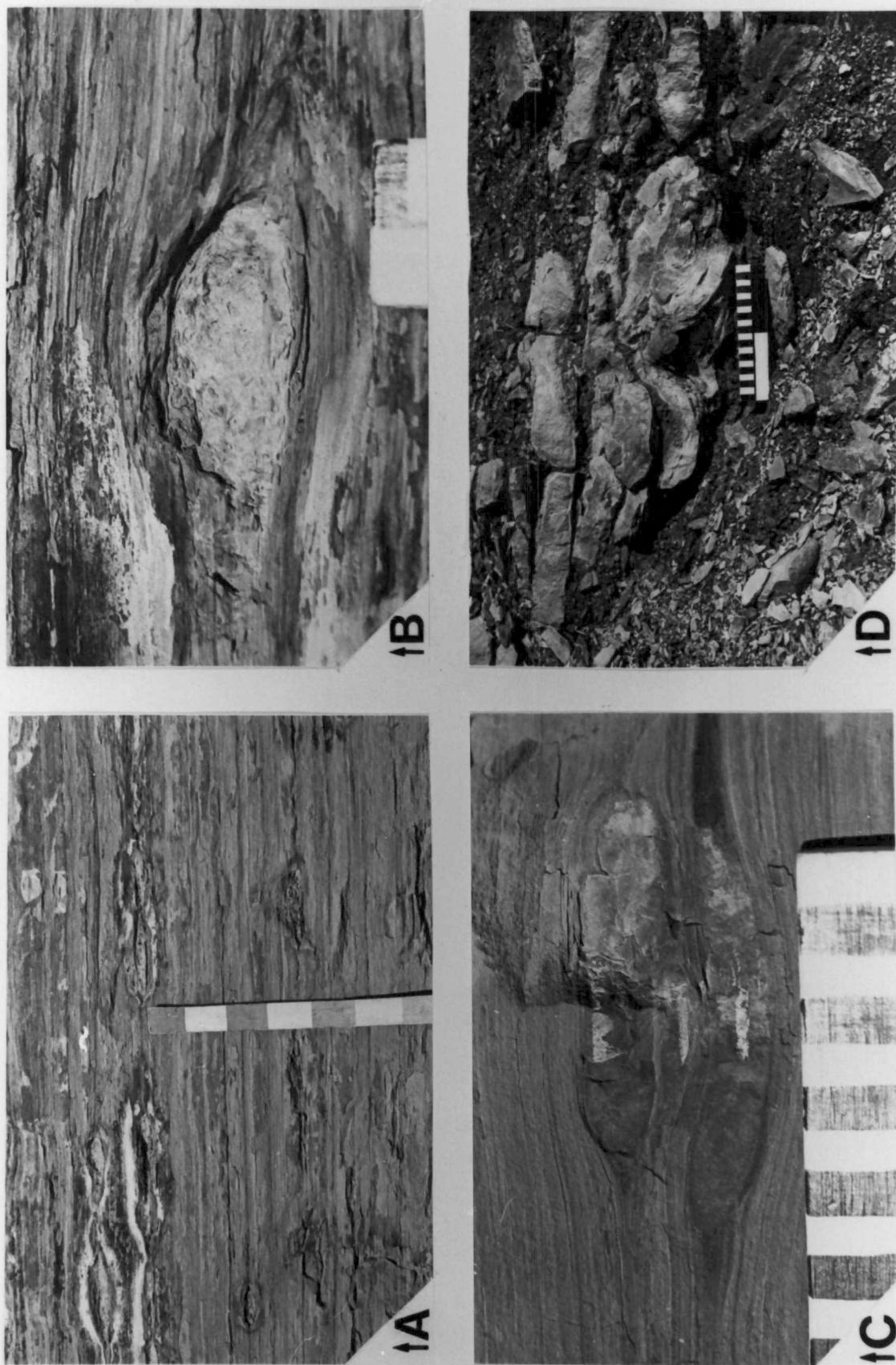


Fig. 3.13

Facies 2; Subfacies 2 of the Lower
Part of the Coalfield Formation

Description. Subfacies 2 lithologies of facies 2 are light-gray, thin- to medium-bedded sublitharenites and are completely exposed at outcrops D, E, F, and G. Subfacies 2 lithologies are gradational with subfacies 1 below and range from 120 to 250 centimeters thick. These lithologies are composed of 70-85% very fine quartz sand, 5-13% clay, 5-10% muscovite, and 5-7% macerated carbonaceous material. The quartz sand in subfacies 2 lithologies is very fine, moderately-sorted, and subrounded. Subfacies 2 lithologies may show wavy, discontinuous, parallel laminations (2-8 mm) of very fine quartz sand which alternate with more clay-rich layers. However, subfacies 2 lithologies are typically "clean" and massive. Some subfacies 2 lithologies show climbing ripples with a low angle of climb. Other subfacies 2 lithologies show evidence of dewatering in the form of ball and pillow structures and contorted zones (Fig. 3.13D). Sometimes, fossil twig fragments (1-3 cm in diameter) are present in subfacies 2. The top 10-15 cm of subfacies 2 lithologies are heavily bioturbated at outcrops D, E, and F.

Facies 2; Subfacies 1 and 2 of the
Burnt Mill and Lower Part of the
Coalfield Formation

Environmental Interpretation. Facies 2 records splay events of which subfacies 1 represents initial sheet floods into the stagnant bay (facies 1), and with continued progradation the splay coarsens upward

into subfacies 2 lithologies. Subfacies 2 lithologies record the last and coarsest (sand not silt) pulses of splay progradation. Facies 2 thins laterally to outcrop G and can be seen to pinch out at outcrop D (Fig. 3.12, p. 104). This shape is similar to many other splay deposits (Elliot, 1974).

Sedimentary features characteristic of splay deposits are described by several authors (Elliot, 1974; Saxena, 1976; Horne and Ferm, 1978). Splay features described by these authors and others were used in interpretation of facies 2.

Subfacies 1 of facies 2 has a gradational contact with facies 1 below, which suggests initial sheet flooding into the stagnant bay area, rather than a sudden crevasse which would have a sharper base (Elliot, 1974). During flooding, fine-grained sediment was deposited over the bay, and normal grading occurred due to the different settling rates of silts and clays. Numerous, successive floods would explain the alternating quartz silt and clay lamination of subfacies 1.

The soft sediment slumps probably occurred during the rapid deposition of water-charged sediments. As noted previously, calcium carbonate and siderite nodules must have started to form early as the laminae are deformed around them (Fig. 3.13B and 3.13C). The formation of calcium carbonate nodules is favored by more oxidizing conditions, with siderite favored by more reducing conditions (Krumbein and Garrels, 1952). Thus, in subfacies 1 of facies 2, geochemical conditions must have been on the border of the "geochemical fence" separating the two. Perhaps at times the microenvironmental conditions would have favored the

precipitation of calcium carbonate and at other times siderite. The general decrease in siderite nodules upward in subfacies 1 may indicate more oxidizing conditions as the splay prograded across the stagnant marsh, described in similar deposits by Coleman (1966). Some of the siderite nodules were formed around plant remains, which may also explain why more siderite is present in the lower sequence of subfacies 1. The plant remains found in the center of many of the siderite nodules may indicate micro-reducing environments set up by decay processes (Raiswell, 1976). More siderite was precipitated in the lower-half of subfacies 1, where organic material is more abundant. Thus, it seems likely that this association of decay and reducing conditions favors siderite formation.

The general coarsening upward sequence of subfacies 1 indicates progradation of the splay with time. Finally, subfacies 2 lithologies reflect the coarser deposition (very fine sand vs. silt/clay) marking the last pulses of splay progradation. Rapid deposition of subfacies 2 lithologies are evidenced by the ripple drift lamination, dewatering structures (Fig. 3.13D), and fossil twig debris seen in these lithologies.

Abandonment of the splay sequence is marked by the heavy bioturbation in the top of subfacies 2, which is overlain in turn by a black mudshale.

Lower Part of the Coalfield Formation; Facies 3;
Subfacies 1, 2, and 3: Deposits of Splay
Abandonment, Shallow Anoxic "Ponds,"
and A Small Splay Event

Facies 3; Subfacies 1 of the Lower
Part of the Coalfield Formation

Description. Subfacies 1 of facies 3 is a black mudshale and is exposed at outcrops D, E, F, and G. Subfacies 1 occurs at the base of facies 3 and is gradational (5 cm) in places with subfacies 2 of facies 2 below it. Subfacies 1 ranges from 30 to 40 centimeters thick. Subfacies 1 lithologies are 55% fibrous carbonaceous material, 20% clay, 20% quartz silt, and 5% muscovite. The fibrous carbonaceous material has the long axes of fibers aligned parallel to bedding. Some thin (1-2 mm), even, parallel, continuous, quartz-rich silt laminae alternate (1-2 mm spacing) with more clay-rich laminae. The quartz-rich silt laminae have diffuse upper and lower boundaries. A few disc-shaped siderite concretions were found (1 to 19 cm in size) with laminations deformed around them. No bioturbation was found in subfacies 1 lithologies, except at the base.

Facies 3; Subfacies 2 of the Lower
Part of the Coalfield Formation

Description. Subfacies 2 of facies 3 is a dark-gray, sandy, bedded siltstone, and is exposed at outcrops D, E, F, and G. This subfacies has a sharp, slightly scoured base (2-5 cm of relief) into subfacies 1 below. Subfacies 2 ranges from 30 to 40 cm thick. Lithologies of this subfacies are composed of 35% very fine quartz sand, 30% quartz silt,

18% macerated carbonaceous material, 12% clay, and 5% muscovite.

Subfacies 2 contains discontinuous, wavy, nonparallel, thick-laminations to very thin-bedding. The laminated to very thin-beds consist of quartz silt to very fine sand alternating with organic-rich clay layers.

The carbonaceous material is in thin (2-5 mm) "lenses" which cause the layering to be irregular. These irregular laminations are composed of three grain size classes (organic "lenses," silt, and very fine sand).

Facies 3; Subfacies 3 of the Lower
Part of the Coalfield Formation

Description. Subfacies 3 of facies 3 is a black, carbonaceous mudshale to clayshale and is exposed at outcrops D, E, F, and G. This subfacies has a gradational contact with subfacies 2 below, and ranges from 20 to 40 centimeters thick. Subfacies 3 lithologies are composed of 65% fibrous carbonaceous material, 15% clay, 15% quartz silt, and 5% muscovite. Subfacies 3 has very thin to thin (0.5-1.0 mm), parallel, even, continuous fabric laminations caused by the abundant fibrous carbonaceous material. A few scattered silt grains are present which are set in a "matrix" of clay and carbonaceous material. Sometimes a thin (5-8 cm) coal is found on top of subfacies 3 lithologies. No bioturbation is present in subfacies 3.

Facies 3; Subfacies 1, 2, and 3
of the Lower Part of the
Coalfield Formation

Environmental Interpretation. Subfacies 1 of facies 3 represents shallow, ponded conditions after the splay system of facies 2 was abandoned. These stagnant conditions were interrupted by an overbank flood or a small splay represented by subfacies 2 which is scoured into subfacies 1 below it. Subfacies 3 was slowly deposited over subfacies 2 and marks a return to shallow, stagnant, "pond" conditions which accumulated even more carbonaceous material than subfacies 1.

Stagnant shallow ponds forming after the abandonment of a splay system are common, according to Elliot (1974) who worked on Mississippi River splay deposits. Subfacies 1 of facies 3 is very similar to the stagnant bay sediments deposited in facies 1, only on a smaller scale.

The gradational lower contact of subfacies 1, facies 3 shows that quiet "ponded" conditions returned after splay abandonment. The bioturbation at the top of subfacies 2, facies 2 incorporates sediments of the overlying subfacies 1, facies 3 lithologies into it. This indicates bioturbation occurred after splay abandonment, until conditions became too anoxic for organisms to live. The lack of any other bioturbation in subfacies 1 confirms this as sedimentation rates were low and food (organic material) would have been plentiful.

The fibrous nature of the carbonaceous material suggests much of it may have accumulated in-situ. The quartz silt was probably introduced during flooding in a process detailed by Coleman (1966). The diffuse

nature of the quartz silt laminae boundaries, as well as their continuous, even, parallel nature suggests little reworking by waves or currents. The aligned long axes of the fibrous carbonaceous material probably resulted from deposition, and was enhanced by compaction. Subfacies 2 is interrupted as an overbank flood deposit or a very small splay. This is evidenced by the sharp erosive lower contact (2 to 5 cm of relief) and the fairly coarse grain size (very fine sand) relative to subfacies 1 below and 3 above. The carbonaceous material that occurs as small lenses (2 to 5 mm thick) probably represents masses of organic matter that were transported during flood conditions. The irregular nature of the laminations indicates fairly high flow regimes; and perhaps most of the sediment was deposited at once, yielding the three grain size classes. Subfacies 2 has a fairly regular thickness (30 to 40 cm) and is widespread (outcrops D, E, F, and G), common features of sheet floods or splays.

Subfacies 3 has a gradational contact (3-5 cm) with subfacies 2 below. Subfacies 3 represents a return to shallow, stagnant, "ponded" conditions that were similar to subfacies 1. However, subfacies 3 records conditions that were even more stagnant than those of subfacies 1, as fibrous carbonaceous material comprises 65% of subfacies 3 lithologies. The lack of maceration of the carbonaceous material suggests it was not transported far and probably accumulated in-situ. The very thin to thin, even parallel nature of the fabric laminations could only form under very quiet conditions and low sedimentation rates. No bioturbation was found in subfacies 3 lithologies.

The terrigenous clastic input into subfacies 3 environments was even lower than in subfacies 1, silt laminations are rare. The very stagnant conditions were favorable for preserving the abundant carbonaceous material (Twenhofel, 1961, p. 367). The stagnant anoxic conditions were probably responsible for the absence of any bioturbation as sedimentation rates were low and abundant food (organic material) would have been available. The scattered silt grains, set in the "matrix" of fibrous carbonaceous material and clay are probably best explained by a wind-blown origin, a process described by Taylor (1963).

Burnt Mill Formation; Facies 4; Subfacies 1, 2, 3,
and 4: Minor Mouth Bar or Splay Deposits,
Capped with Seatearth and Coal

Facies 4; Subfacies 1 of the
Burnt Mill Formation

Description. Subfacies 1 of facies 4 is a light-gray, thin-bedded sublitharenite; only the upper part is exposed at outcrop F. Subfacies 1 of facies 4 pinches out at the north end of outcrop F into facies 1 (stagnant bay deposits). Subfacies 1 is incompletely exposed at its base, but where exposed at outcrop F, it is 120 centimeters thick, and is composed of 80% very fine quartz sand, 10% clay, 7% macerated carbonaceous material, and 3% muscovite. The quartz grains are very fine, moderately-sorted, and subrounded. Ripple cross lamination is common, with some low-angle climbing ripple cross lamination (Fig. 3.14B). Some simple flasers (0.25 to 0.5 mm thick) of clay and macerated carbonaceous material are present on cross laminae surfaces. Fossil

Fig. 3.14. Photographs pertaining to facies 4 of the Burnt Mill Formation. The small arrows indicate stratigraphic up.

- A. Field photograph illustrating the "pinch out" of facies 4 and 5 of the Burnt Mill into the stagnant bay deposits (facies 1 of the Burnt Mill) at outcrop F. Subfacies 1 through 4 of facies 4 and subfacies 1 through 2 of facies 5 labeled at the right. Scale is 1.25 meter stick.
- B. Photograph of a polished slab from subfacies 1 of facies 4 illustrating low-angle climbing ripples. Scale is in centimeters.

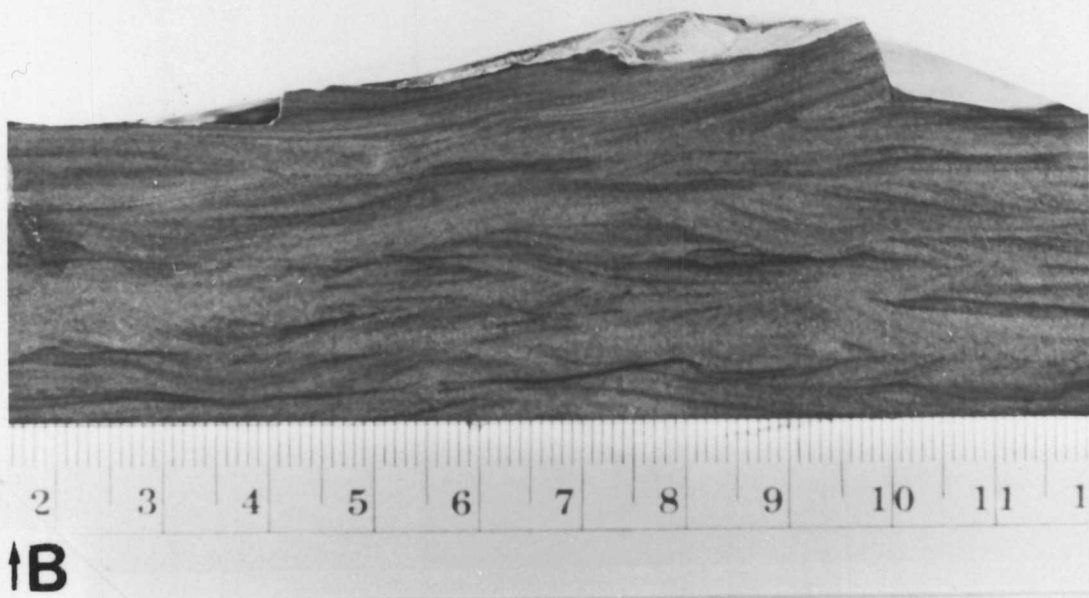


Fig. 3.14

twigs (1-3 cm in diameter) are sometimes found on bedding surfaces.

Subfacies 1 coarsens upward into subfacies 2. Figure 3.14A illustrates subfacies 1 lithologies as well as the other subfacies of facies 4.

Facies 4; Subfacies 2 of the
Burnt Mill Formation

Description. Subfacies 2 of facies 4 is a light-gray to buff, thin- to medium-bedded sublitharenite to quartzarenite. This subfacies is completely exposed at outcrop F, but only the top 20 cm is exposed at outcrop G. Subfacies 2 also pinches out to the north at outcrop F into facies 1 (stagnant bay deposits) (Fig. 3.14A).

Subfacies 2 gradationally overlies subfacies 1. Subfacies 2 is composed of 85-95% very fine quartz sand, 2-7% clay, 2-5% macerated carbonaceous material, and 1-3% muscovite. The quartz sand grains are very fine to fine, moderately-sorted, and subrounded. Subfacies 2 is fairly massive, though some ripple cross laminations are present. It is gradationally overlain by subfacies 3.

Facies 4; Subfacies 3 of the
Burnt Mill Formation

Description. Subfacies 3 of facies 4 is a very light-gray to cream, sublitharenite. It is completely exposed at outcrop F, but only the top 10 cm of this subfacies is exposed at outcrop G. Subfacies 3 is 100 cm thick at outcrop F and pinches out at the north end of outcrop F into facies 1 (stagnant bay deposits). Subfacies 3 is gradational from subfacies 2 below. Subfacies 3 rocks are composed of 80% very fine

quartz sand, 10% clay, and 10% carbonaceous material. The carbonaceous material is in the form of root structures in the top 10 to 15 cm of subfacies 3. Subfacies 3 has a characteristic "bleached appearance" in outcrop.

Facies 4; Subfacies 4 of the
Burnt Mill Formation

Description. Subfacies 4 is a coal which is completely exposed at outcrop F and partially exposed at outcrop G. This coal occurs directly above the root structures in the seatearth below (subfacies 3) but pinches out to the north at outcrop F.

Facies 4; Subfacies 1, 2, 3 and 4 of
the Burnt Mill Formation

Environmental Interpretation. Subfacies 1 and 2 of facies 4 represent the top part of a splay event or a minor mouth bar which prograded into the stagnant bay area represented by facies 1. With abandonment of the splay or minor mouth bar, the top part (subfacies 3) was leached and provided the rooting medium for the growth of plants of the peat swamp (represented by subfacies 4).

Determining whether subfacies 1 and 2 represent a splay event or a minor mouth bar is difficult because of poor exposure to the south (outcrop G). Subfacies 1 and 2 seem to have a mouth bar shape (planoconvex upward) and pinch out to the north at outcrop F. However, it is impossible to tell whether these subfacies also pinch out at outcrop G. The generally "clean" nature of subfacies 2 sands might

argue for a minor mouth bar origin. However, a splay event and the more channelized mouth bar would be too similar to distinguish just from the limited exposure at outcrops F and G.

Subfacies 1 shows evidence of moderate- to high-flow regimes as low-angle climbing ripple cross laminations are seen. The fossil twig debris interbedded with the low-angle climbing ripple cross lamination, also appears to have been transported during a period of fairly rapid deposition. The simple flasers of clay and macerated organics only occur in the troughs of ripple cross-lamination; deposition was rapid enough to erode the drapes of the ripple crests. This implies intermittently operating currents (Raaf et al., 1977). Subfacies 1 coarsens upward into subfacies 2 which represents the final stages of splay or minor bar progradation (Elliot, 1974).

Subfacies 3 is gradational with subfacies 2 below and is lithologically similar, yet it has a "bleached" appearance in outcrop. Subfacies 3 is thought to represent a seatearth which developed when the splay or minor mouth bar (subfacies 1 and 2) deposits were leached in the acid swamp environment which developed over these deposits, a process described by Huddle and Patterson (1961). The top 14 cm of subfacies 3 contains root structures. Above this rooted zone is the coal of subfacies 4 which represents the peat-forming swamp. Rooted zones look like burrowed horizons, but the root structures in subfacies 3 are thicker at the top and taper downward to a point; they also occur in seatearth under a coal. These features distinguish these structures as evidence of root growth and not burrowing.

The development of a seatearth and coal overlying the top of the splay or minor mouth bar indicates favorable peat-forming conditions on this surface.

The splay or minor mouth bar (subfacies 1 and 2), the seatearth (subfacies 3), and the coal (subfacies 4) all pinch out to the north at outcrop F into stagnant bay deposits (facies 1), and probably also pinch out to the south into facies 1 at outcrop G. This suggests the splay or minor mouth bar provided a "platform" where conditions were conducive to coal formation. Deposits similar to facies 4 have also been interpreted by other authors (Ferm and Cavoroc, 1968; and Ferm, 1970) as forming in an analogous manner. It may be that facies 1 (stagnant bay environment) was too deep or too brackish for coal to form.

Burnt Mill Formation; Facies 5; Subfacies 1 and 2:
Small Splay and Coal Deposits

Facies 5; Subfacies 1 of the
Burnt Mill Formation

Description. Subfacies 1 of facies 5 is a dark-gray, sandy, bedded siltstone, which is exposed at outcrop F; there it pinches out into facies 1 (stagnant bay deposits) at the north end of this outcrop (Fig. 3.14A). Subfacies 1 ranges from 25 to 30 centimeters thick, and has a sharp, slightly scoured base (2 to 5 cm of relief) into subfacies 4 of facies 4 below. Subfacies 1 lithologies are composed of 32% very fine quartz sand, 30% quartz silt, 18% macerated carbonaceous material, 15% clay, and 5% muscovite. This subfacies contains discontinuous, wavy, nonparallel, thick-laminations to very thin-bedding. The

laminae/very thin-beds consist of quartz silt to very fine sand alternating with carbonaceous, clay-rich layers. The carbonaceous material is often in thin (2-5 mm) "lenses" which cause the thick laminae/very thin-bedding to be very irregular. The irregular laminae have a trimodal grain size distribution (organic "lenses," silt, very fine sand).

Facies 5; Subfacies 2 of the
Burnt Mill Formation

Description. This subfacies is a subbituminous coal which is exposed at outcrop F and occurs above subfacies 1. Subfacies 2 is more of a black, carbonaceous clay-shale near its base. Subfacies 2 ranges from 7 to 10 centimeters thick, and pinches out into facies 1 (stagnant bay deposits) at the north end of outcrop F (Fig. 3.14A, p. 119).

Facies 5; Subfacies 1 and 2 of the
Burnt Mill Formation

Environmental Interpretation. Subfacies 1 of facies 5 represents an overbank flood or a small splay event which interrupted the peat-forming environment below it (subfacies 4, facies 4). After this event, peat-forming conditions again returned, forming subfacies 2 of facies 5.

Subfacies 1 is interpreted as an overbank flood deposit or a small splay for a number of reasons. The lower contact of subfacies 1 is sharp and erosive (2-5 cm of relief). The fairly coarse grain size (very fine sand) relative to the surrounding subfacies also suggests a rapid input of sand. The fibrous carbonaceous material that occurs as

small (2-5 mm thick) "lenses" probably represents masses of organic matter that were transported during flood conditions. The irregular nature of the laminations indicates fairly high flow regime conditions, under which most of the material was deposited very quickly. This would also explain the trimodal grain size distribution. The "dirty" nature of subfacies 1 lithologies also suggests little to no reworking or sediment sorting.

Subfacies 2 of facies 5 overlies the overbank flood or small splay and marks a return to peat-forming conditions after the splay or overbank flood deposits of subfacies 1 were abandoned. It is interesting to note that facies 5 (subfacies 1 and 2) both pinch out into facies 1 (stagnant bay deposits) to the north at outcrop F. This implies that the overbank flood or splay event (facies 5, subfacies 1) occurred over the larger splay event or minor mouth bar of facies 4 below. This suggests the old splay system or minor mouth bar perhaps offered a gradient advantage for the next overbank flood or splay event.

Upper Part of the Coalfield Formation

The Coalfield Formation as stated earlier was divided into a lower and an upper part since the lower Coalfield is environmentally related to the upper part of the Burnt Mill Formation. A complete section of the upper Coalfield can be seen at outcrops D and E. Outcrops F, G, and DD provide partial exposures of the upper Coalfield (50-90%).

The upper Coalfield reflects more fluvial deposition in the form of channels and may not be affected by marine processes. This is seen in

the channelized nature of the upper Coalfield, the abandoned channel clay fills, the "dirtier" nature of the sandstones, and the very abundant fossil twig debris. This interpretation would also agree with the digitate nature seen in the distribution of the Coalfield Formation described by other workers (Wilson et al., 1956; Wilson and Stearns, 1960).

Upper Part of the Coalfield Formation; Facies 1;
Subfacies 1 and 2: Small Channel Deposits

Facies 1 is composed of 2 main subfacies: subfacies 1—a buff, very thin-bedded sublitharenite which comprises the channel deposits, and subfacies 2—a light-gray, clay shale which comprises the sediment infill, within the channel deposits. Facies 1 is only exposed at outcrop G where the asymmetrical channels range from 150 to 180 centimeters thick.

Facies 1; Subfacies 1 of the Upper
Part of the Coalfield Formation

Description. Subfacies 1 lithologies are buff, very-thin bedded, sublitharenites. The lithologies are composed of 80% very fine quartz sand, 10% macerated organic material, 5% clay, 3% muscovite, 1% sedimentary rock fragments, and 1% chert. Beds of subfacies 1 range from 150 to 180 centimeters thick. These beds show the asymmetrical small channel form with fairly steep angle beds (20-30° dip) at the north end of outcrop G and low-angle (8-10° dip) beds at the south end of that same outcrop. The steeper side of channel appears to have slumped,

as there is some contorted bedding present (millimeter scale).

Infilling the center of this channel are subfacies 2 lithologies.

At the south end of outcrop G, a similar deposit is present but is partially covered.

Facies 1; Subfacies 2 of the Upper
Part of the Coalfield Formation

Description. Subfacies 2 lithologies are gray clayshales, and range from 150 to 170 centimeters thick. Subfacies 2 lithologies are composed of 70% clay, 15% macerated organic material, 10% quartz silt, and 5% muscovite. Some siderite concretions (1-4 cm in diameter) are also present. Subfacies 2 lithologies have even, parallel, medium (2 mm), fabric laminations, as a result of their high clay content. A few thin to medium (1-2 mm), parallel, even, continuous, silt laminae are also present. The laminations are deformed around the siderite concretions.

Facies 1; Subfacies 1 and 2; of the
Upper Part of the Coalfield
Formation

Environmental Interpretation. Facies 1 is difficult to interpret based on just one exposure, but it is thought to represent a small, migrating channel (in the backswamp area) away from the larger channels of the Coalfield seen at outcrops D and E. This opinion is supported by the fact that facies 1 occurs above backswamp deposits (subfacies 1 and 3 within the Burnt Mill facies 3). It is believed that facies 1 displays a low-angle, oblique, cross-section of a small channel fill;

the steeper beds representing the cut bank side and the low-angle beds the accretionary side. The material of the cut bank side is thought to have slumped downward, thus helping to preserve it (analogous to the situation reported by Laury, 1971). Also, the helicoidal flow around any meander bend develops gradually from the upstream end to the downstream end (Reading, 1978). Thus, if a cross-section were taken slightly before the meander curve, some of the cut-bank material may be seen. Eventually, this channel was cut off and subfacies 2 lithologies (clays and silts) gradually filled it in. The siderite probably formed early as the laminations are deformed around the concretions (Raiswell, 1971).

Upper Part of the Coalfield Formation; Facies 2;
Subfacies 1 and 2: Fluvial Channel Deposits (?)

Facies 2 is completely exposed at outcrops D and E, and partially exposed at outcrops F, G, and DD (10-80%). It ranges from 300 to 500 centimeters thick; and is composed of 2 main lithologies, subfacies 1 and 2, only present at outcrop E. At outcrops D, F, G, and DD only subfacies 1 lithologies are present

Facies 2; Subfacies 1 of the Upper
Part of the Coalfield Formation

Description. Subfacies 1 of facies 2 is a buff, medium-bedded, sublitharenite to quartzarenite and is the typical facies 2 lithology. Subfacies 1 is completely exposed at outcrops D and F and partially exposed at outcrops DD, F, and G (10 to 80%). Subfacies 1 beds range

from 150 to 340 centimeters thick, and consist of 80-90% very fine quartz sand, 2-4% muscovite, and 1-2% clay, 1-4% sedimentary rock fragments, 1-4% chert, and 1-3% macerated carbonaceous material.

Subfacies 1 lithologies show channel forms with numerous trough crossbeds (height—20 cm, width—40-50 cm) and planar crossbeds (10-15 cm thick sets). At the bases of these channels, abundant fossil twig debris (1-3 cm in diameter) and coalified plant material are present.

Facies 2; Subfacies 2 of the Upper
Part of the Coalfield Formation

Description. Subfacies 2 lithologies are light-gray shale arenites and are only exposed at outcrop E where they interfinger with subfacies 1 lithologies. Subfacies 2 lithologies range from 60 to 150 centimeters thick.

The shale clasts in subfacies 2 range from 0.5 to 4 centimeters in size, are angular, and comprise 50 to 65% of subfacies 2 rocks. The shale clasts frequently appear imbricated in some places. Fig. 3.15A illustrates a typical subfacies 2 lithology. The shale clasts are composed of 68% quartz silt, 26% clay, 5% macerated carbonaceous material, and 1% muscovite. The matrix material surrounding the shale clasts is composed of 84% very fine quartz sand, 6% sedimentary rock fragments, 3% chert, 3% macerated carbonaceous material, 2% clay, and 2% muscovite. The sand matrix consists of very fine, moderately-sorted, subrounded to subangular sand grains.

Fig. 3.15. Photographs pertaining to the Coalfield Formation. The small arrows indicate stratigraphic up.

- A. Photograph of sample E-11 illustrating the shale arenite lithology of subfacies 2, facies 2 at outcrop E. Scale is in centimeters.
- B. Field photograph at outcrop E showing the lensoid sands of facies 2 (see arrows) which are surrounded by shale arenites (subfacies 1). Scale is 1.25 meter stick.

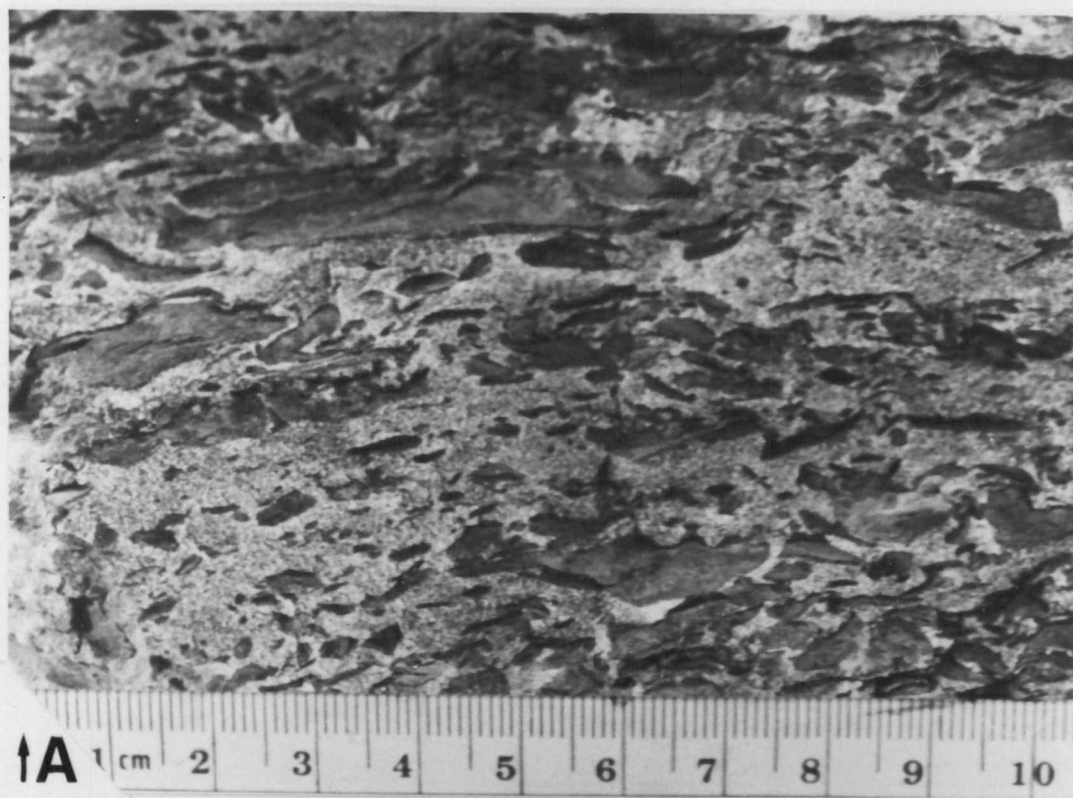


Fig. 3.15

Within subfacies 2 lithologies at outcrop E, lensoid-shaped sand bodies (10-40 cm high and 30-100 cm long) are found which contain very few shale clasts and are composed of the sand matrix material described above. These lensoid sands are surrounded by subfacies 2 lithologies (Fig. 3.15B).

Facies 2; Subfacies 1 and 2 of the
Upper Part of the Coalfield
Formation

Environmental Interpretation. Facies 2 lithologies were more fluviially dominated and were subjected to less reworking than the deposits of the Crossville Formation. This can be seen in the "dirtier" nature of facies 2 deposits, the abundant fossil twig debris in facies 2, and the thinner, less massive sandstones of facies 2. Where subfacies 1 of facies 2 is dominant (outcrops D, F, G, and DD) channel sequences with concave-upward forms, scoured bases with fossil twig debris, trough crossbeds, and fining-upward sequences dominate. These are interpreted as fluvial channels based on the above evidence. However, outcrop E where subfacies 2 also occurs (the shale arenite) presents an enigma. Here planar and trough crossbeds, an abandoned channel, and a fining-upward sequence are present. The base of facies 2 is scoured and contains coalified plant remains, yet it is flatter than at outcrops D and G. Clearly, subfacies 2 is too thick to be any sort of channel lag. Also, it is too thick and not widespread enough to represent any sort of storm event. One possibility for subfacies 1 and 2 may be low sinuosity channels (Moody-Stuart, 1966). These channels would be wide and shallow

and probably present in the lower delta plain. If such channels migrated across a mudflat type of deposit or shallow pond area they could rip up numerous clay clasts. Within these low sinuosity channels longitudinal bars would be present, but containing fewer mudclasts as they would be sitting slightly higher. During times of flood, these bars would be covered. Eventually, pure sand deposition would increase as aggradation over the mudflat continued. This scenario may offer a possible explanation for subfacies 2 lithologies. The lensoid-shaped bars, containing few shale clasts within subfacies 2 rocks, may be the longitudinal bars of low sinuosity streams.

Another explanation to account for facies 2 deposits would be fluvial progradation across a marsh area near the sea to produce chenier-like deposits containing abundant shale clasts. Cavoroc (1969) used such an explanation for a similar sandstone containing numerous shale clasts. However, Cavoroc (1969) also described large accretionary planes in his deposits which are not present in facies 2 rocks of the present study. He further noted a few cleaner sandstone lenses in the deposits resulting from local scour. These lenses were composed of trough crossbeds which were not found in the lensoid-shaped "cleaner" sands of subfacies 2. Thus, the interpretation of facies 2 remains a puzzle because of the limited outcrop available.

Upper Part of the Coalfield Formation; Facies 3;
Subfacies 1, 2, and 3: Channel
Abandonment Deposits

Facies 3 deposits occur as channel "plugs" within the channels of facies 2, and as fining-upward sequences from facies 2 channel deposits.

Facies 3 lithologies are exposed at outcrops D, E, and DD where they range in thickness from 100 to 180 centimeters thick.

Facies 3; Subfacies 1 of the Upper
Part of the Coalfield Formation

Description. Subfacies 1 is a gray, laminated siltstone, which is gradational with facies 2 below. Subfacies 1 lithologies range from 60 to 130 centimeters thick, and internally show parallel, even, fairly continuous, medium-laminations. Rocks of this subfacies are composed of 65% quartz silt, 25% clay and 10% macerated organics. The lamination is produced by alternating medium (2 mm) quartz-rich silt and clay laminae (spacing of 2-4 mm); these have diffuse upper and lower boundaries. Subfacies 1 grades upward into subfacies 2.

Facies 3; Subfacies 2 of the Upper
Part of the Coalfield Formation

Description. Subfacies 2 is a gray clayshale which is gradational with subfacies 1 below and ranges from 40 to 50 centimeters thick. Rocks of subfacies 2 have parallel, even, continuous, thin-lamination, and are composed of 75% clay, 20% quartz silt, and 5% macerated organics. The lamination is a fabric lamination produced by the abundant clay. At outcrops D and DD the top 10-20 centimeters of subfacies 2 has a "bleached" appearance, and at outcrop DD a rooted zone is present.

Facies 3; Subfacies 3 of the Upper
Part of the Coalfield Formation

Description. This subfacies varies from a black, coaly, mudshale to subbituminous coal. Subfacies 3 ranges from 30 to 40 centimeters thick, and is exposed at outcrops D, E, and DD. Subfacies 3 marks the top of the Coalfield Formation. Where subfacies 3 is more of a carbonaceous mudshale, its composition is 80-90% organic matter, 5-10% clay, and 5-10% quartz silt.

Facies 3; Subfacies 1, 2, and 3 of
the Upper Part of the Coalfield
Formation

Environmental Interpretation. Facies 3 clearly represents sediments deposited after the channels (facies 2) in the upper Coalfield were abandoned. This is evidenced by the gradational fining-upward nature of facies 3 from facies 2 below it, and the presence of facies 3 as sediment infill within a concave-upward channel form. At outcrop DD the underlying facies 2 was not well enough exposed to determine whether it represented a channel. Thus, facies 3 at outcrop DD may or may not represent sediments deposited after channels were abandoned. However, facies 3 at outcrop DD was clearly deposited in quiet water conditions similar to facies 3 at outcrops D and E. The "bleached" zone in the upper 10-20 cm of subfacies 2 of facies 3 is thought to represent a seatearth because it occurs below a coal, and at outcrop DD roots are present within it.

Summary of the Crossville, Burnt Mill,
and Coalfield Formations

1. The Crossville Formation unconformably overlies the Dorton Formation and is a complex sand body. The Crossville represents delta front sands which were reworked by waves and/or tides. Seven facies were recognized within the Crossville. These facies record both marine and fluvial processes.

2. The Burnt Mill Formation overlies, and at one place, interfingers with the Crossville Formation. The Burnt Mill is dominated by stagnant bay deposits, though splay and minor mouth bar sedimentation are also recorded. Five facies were present in the Burnt Mill and the lower part of the Coalfield Formation.

3. The Coalfield Formation unconformably overlies the Burnt Mill Formation, and it appears to be more fluvial dominated than the Crossville. The Coalfield contains 3 facies, with a peat-swamp marking the end of Coalfield deposition. Table 3.1 compares the Crossville and Coalfield sandstones.

Table 3.1. Comparison of the Crossville and Coalfield Formations

Features of the Crossville Formation	Features of the Coalfield Formation
1. Quartzarenites are the dominant lithology. Sand grains are subrounded, well-sorted, and very fine. 2. Seven main facies and numerous subfacies comprise a complex sand body. 3. Little scour into the underlying Dorton was observed. A basal lag is rare. 4. Marine trace fossils (<u>Zoophycus</u> and <u>Rhizocorrellium</u>) were often abundant. 5. Fossil twig debris was absent, though macerated organic material was often present. 6. Large planar crossbeds are common, contributing to the tabular nature of the Crossville. Trough crossbeds and channel deposits were found, though not abundant.	1. Sublitharenites are the dominant lithology. Sand grains are very fine to fine, moderately-sorted, and subangular to subrounded. 2. Three main facies and several subfacies are present. From limited outcrop the Coalfield appears less complex than the Crossville. 3. Scour into the underlying Burnt Mill is always observed. A basal lag is always present. 4. Marine trace fossils were absent, a few <u>Zoophycus</u> like traces were seen in the lower part of the Coalfield at outcrop E. 5. Fossil twig debris and macerated organics were common. 6. Trough crossbeds and channel deposits were dominant. Planar crossbeds were found, though rare.

Table 3.1 (cont'd)

Features of the Crossville Formation	Features of the Coalfield Formation
7. Bidirectional paleocurrents were recorded.	7. Detailed paleocurrent analysis was not performed due to lack of data. However, field measurements did not spot any bidirectional paleocurrent directions.

CHAPTER IV

SUMMARY AND CONCLUSIONS

1. The relatively unstudied lower Crooked Fork Group was examined in detail from 14 outcrops near Wartburg in Morgan County, Tennessee. The formations studied are Early Pennsylvanian in age and include the Dorton Shale, Crossville Sandstone, Burnt Mill Shale, and Coalfield Sandstone. The Crooked Fork Group is only exposed in the northern Cumberland Plateau.

2. Previous workers (Ferm et al., 1972; Ferm et al., 1974, and Milici et al., 1979) have regarded the Crooked Fork Group as transitional between the marine barrier island deposits below (Gizzard and Crab Orchard Mountain Groups) and the more deltaic deposits above (Slatestone through Cross Mountain Groups). Horne (1979) visualized a Carboniferous coastal embayment in east Tennessee. Deposition of Early Pennsylvanian sediments occurred as barrier islands migrated northwest-southeast, with the sea to the south and west of these barriers. Delta progradation occurred from the east as evidenced by the Middle Pennsylvanian strata.

3. The Dorton Formation across the study area is thought to represent embayment deposits formed near the distal margins of a delta that was at least partially open to the sea, as evidenced by the marine fauna collected from the formation. Initially, this embayment was very shallow (perhaps protected by barriers), and dominated by marsh deposits (represented by the Rex coal). Inundation of the marsh and deepening of the embayment resulted from a local transgression, perhaps due to

decreased sediment supply coupled with subsidence, or to increased communication across barrier islands.

4. The lower one-third of the Dorton Formation (subfacies 1 to 4) record fairly anoxic conditions, a low sediment supply, and slight current or wave/tidal activity. Subfacies 2 in this lower sequence indicates a break in anoxic conditions as this unit is completely bioturbated. Subfacies 3 also records a break in the lower sequence as this unit records a storm event that swept into the embayment.

5. The upper two-thirds of the Dorton Formation (subfacies 5 to 7) record an increased sediment supply, more current with some wave/tidal activity and soft-sediment deformation. These subfacies record the increased sedimentation rates as the delta front prograded into the embayment. Normal grading of the silt laminae of subfacies 6 may have resulted from differential settling rates out of suspension clouds caused by seasonal flooding or increased wave/tidal activity as the embayment shallowed.

6. The Dorton Formation, which initially appeared to be a monotonous shale, was found to contain seven subfacies, five were traceable across the study area. By examining the Dorton in detail not only was more information obtained about mudrocks, but this also helped in the interpretation of the overlying Crossville Formation.

7. The Crossville Formation is a complex sand body that unconformably overlies the Dorton. In general, the Crossville records delta front sands which prograded across the bay sediments of the Dorton. These delta front sands were reworked and redistributed by marine waves and/or tides. This accounts for the heterogeneous nature seen within the Crossville across the study area.

8. Seven facies were recognized in the Crossville. They are as follows: Facies 1—reworked distributary sands, with flat, sharp contacts with the Dorton below, which contain numerous planar crossbeds and lensoid-shaped sand bodies. Facies 2—interbedded wavy bedding and sublitharenites which occur above facies 1 and records a decrease in sediment supply from facies 1, or perhaps more quiet conditions. Also, facies 2 records a shoaling-upward sequence and decreased energy conditions from outcrops A to D1. Facies 3—washover deposits which have sharp, flat bases, tabular shape, bioturbated tops, and "pinch out" into the Burnt Mill from outcrop C to D. Facies 4—thick bedded channel sands which fine upward. Facies 5—multistory channel sands composed of numerous trough crossbeds and lensoid-shaped sands. Facies 6—channel abandonment deposits dominated by siltstones. Facies 7—interbedded sublitharenites and lenticular bedding reflected alternating energy conditions and/or sediment supply.

9. Paleocurrent directions of the Crossville channel facies (4 and 5) are nearly perpendicular to those of the other Crossville facies, indicating that longshore currents redistributed the sand from the channel deposits.

10. The Burnt Mill overlies and interfingers with the top of the Crossville. The Burnt Mill has five facies. They are as follows: Facies 1—stagnant bay shales, dominated by macerated organic material. Facies 2 and 3—splay deposits and abandonment sediments marked by a coarsening-upward sequence overlain by black, organic-rich shales. Facies 4 and 5—a small splay or minor mouth bar sand which prograded

into stagnant bay sediments (facies 1), allowing coal to form over the splay.

11. The Coalfield Formation unconformably overlies the Burnt Mill and is more fluvial dominated than the Crossville, as indicated by fossil twig debris, "dirty sandstones," and channel forms all common in the Coalfield. The Coalfield contains three facies. They are as follows: Facies 1—sands deposited in small channels, interpreted as occurring in the backswamp area. Facies 2—sands of large fluvial, possibly low sinuosity channels, or cheiner-like deposits. Facies 3—channel abandonment deposits dominated by mudrocks.

12. The stratigraphy of the Crooked Fork Group was more complex than originally thought. Over the small study area many different facies and subfacies were seen to intertongue and pinch out. Figures 4.1 and 4.2 illustrates some of the paleoenvironments for major facies of the study area. Figures 4.1 and 4.2 are diagramatic and care should be used in applying them in detail to the study area.

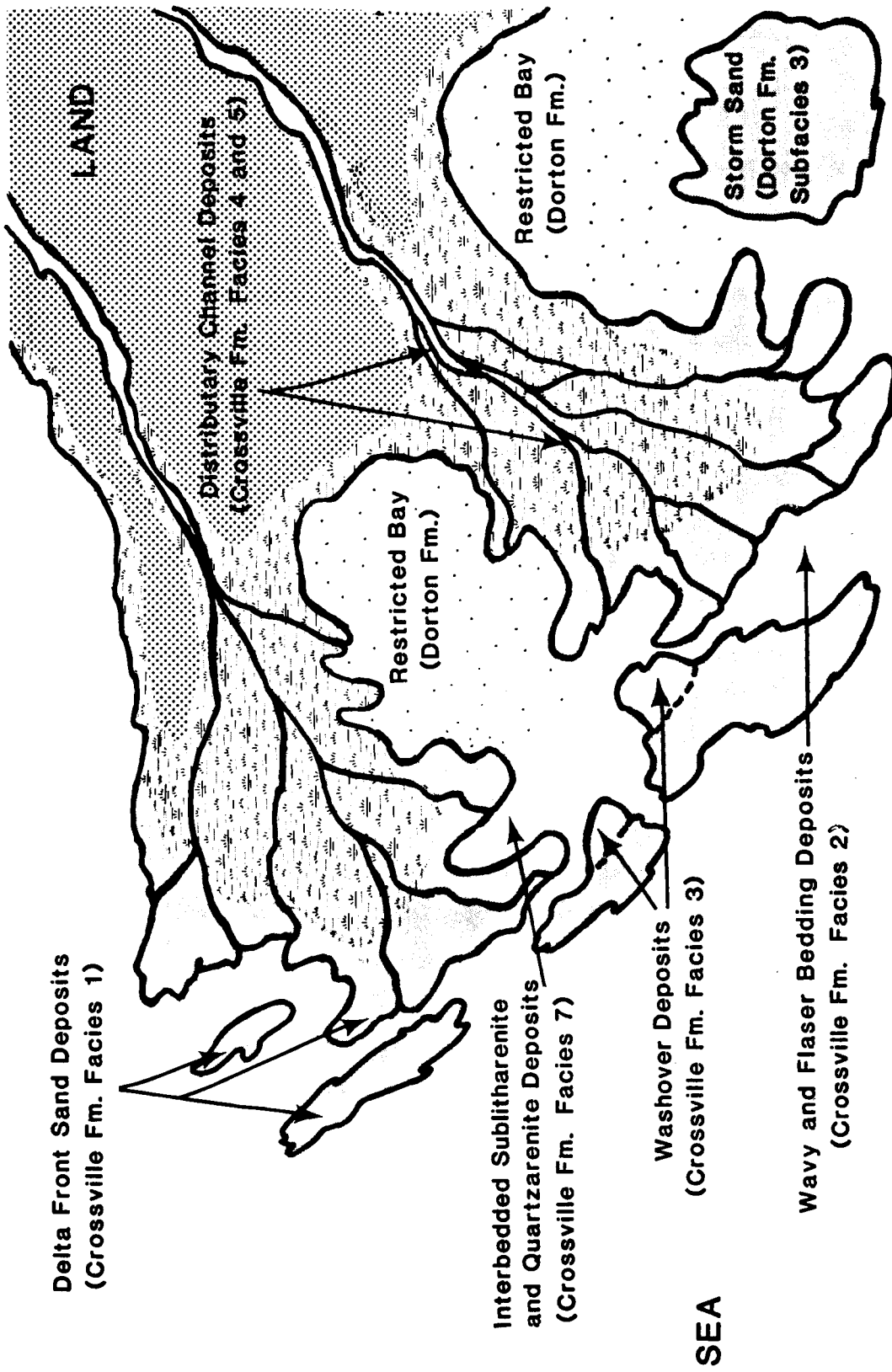


Fig. 4.1. Summary schematic diagram illustrating paleoenvironments for some of the major facies of the Dorton and Crossville Formations.

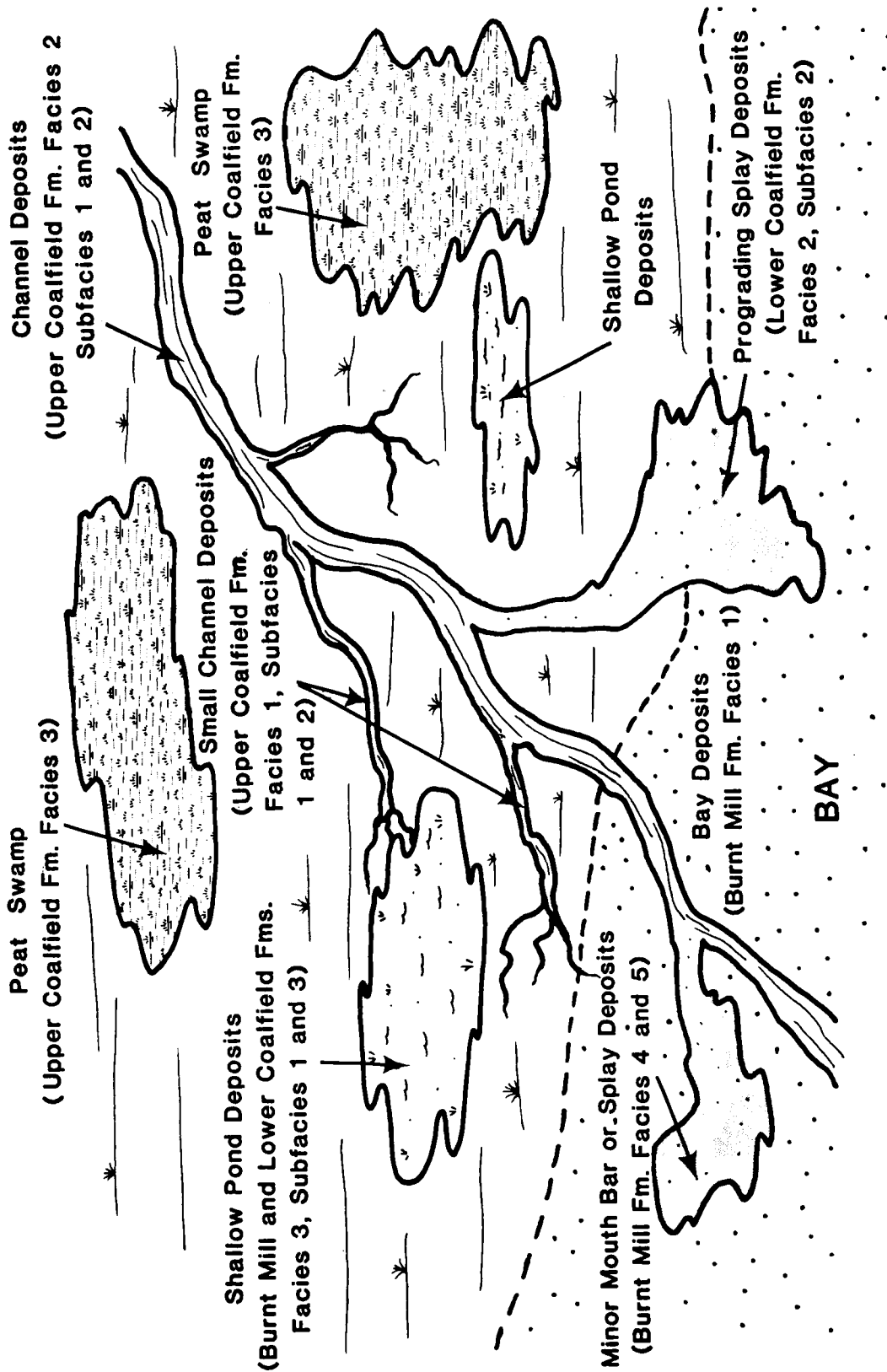


Fig. 4.2. Summary schematic diagram illustrating paleoenvironments for some of the major facies of the Burnt Mill and Coalfield Formations.

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APPENDICES

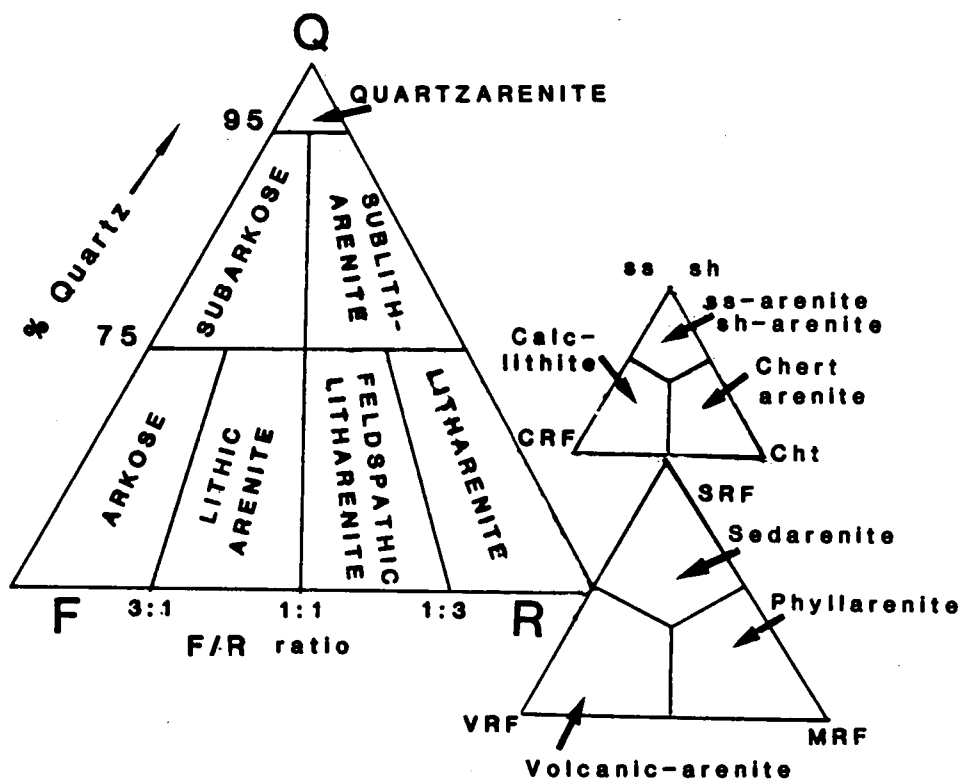
APPENDIX A

CLASSIFICATION SCHEMES AND MEASUREMENT CONVENTIONS

Appendix A describes the classification schemes for sandstones, mudrocks, stratification, and laminae shapes as used in this study. A classification for lenticular, wavy, and flaser bedding is listed, as well as all measurement conventions.

Sandstone Classification

All sandstones were named using the classification of Folk (1968) which is shown below.



- Q - Quartz
- F - Feldspars, granite, and gneiss fragments
- R - All other rock fragments (incl. chert)
- VRF - Volcanic rock fragments
- MRF - Metamorphic rock fragments
- CRF - Carbonate rock fragments
- SRF - Sedimentary rock fragments
- Cht - Chert
- ss - Sandstone
- sh - Shale

Fig. A.1. Sandstone classification.

Mudrock Classification

All mudrocks were named using the classification of Potter et al. (1980), shown below. This classification was slightly modified by adding the prefix sandy to any siltstones containing more than 10% sand. Note that all macerated organic material was included under clay-size constituents.

Percentage clay-size constituents			0-32	33-65	66-100
Field Adjective			Gritty	Loamy	Fat or Slick
INDURATED	Beds	Greater than 10 mm	BEDDED SILTSTONE *	MUDSTONE	CLAYSTONE
	Laminae	Less than 10 mm	LAMINATED SILTSTONE *	MUDSHALE	CLAYSHALE

* If more than 10% sand
add the prefix sandy.

Fig. A.2. Mudrock classification.

Stratification Classification

Strata were classified according to the classification shown below. This is a classification proposed by Potter et al. (1980) which has been modified by using the bedding thicknesses of Ingram (1954).

THICKNESS	STRATIFICATION		PARTING	COMPOSITION
> 100 cm 100 cm 30 cm 10 cm 3 cm 10 mm	Very Thick	BEDDING	Blocky	↑ Clay and Organic Content ↓ ↑ Sand and Silt Content ↓
	Thick			
	Thick			
	Medium			
	Thin			
	Very Thin			
10 mm 5 mm 1 mm 0.5 mm	Thick	LAMINATION	Flaggy	
	Medium		Platy	
	Thin		Fissile	
	Very Thin		Papery	

Fig. A.3. Stratification classification.

Classification of Laminae Shapes

The classification of laminae shapes used in this study is after Campbell (1967) and is shown below.

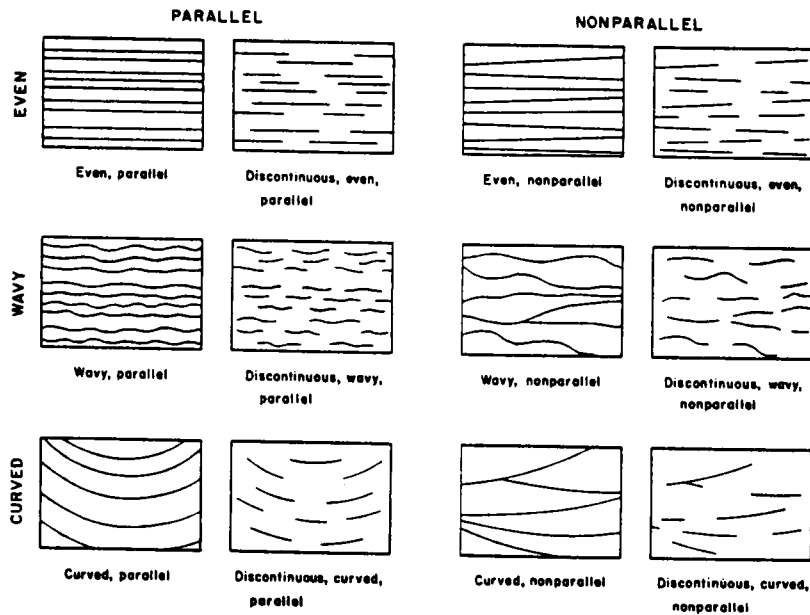


Fig. A.4. Classification of laminae shapes.

Classification for Lenticular, Wavy,
and Flaser Bedding

The classification of lenticular, wavy, and flaser bedding is shown below. This classification is from Reineck and Singh (1980).

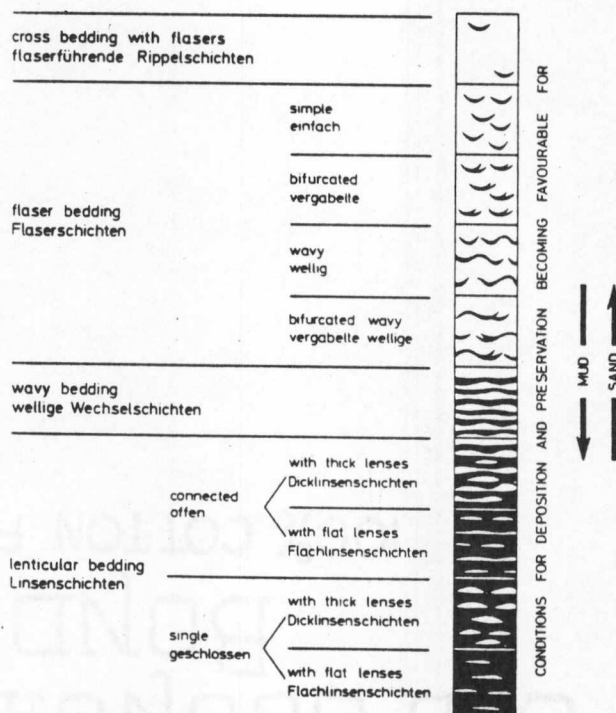


Fig. A.5. Classification for lenticular, wavy, and flaser bedding.

Measurement Conventions

Grain size measurements used in this study are listed below and are after Wentworth (1922). Terms for the degree of roundness of grains are from Powers (1953). Terms used in describing the amount of grain sorting are after Folk (1968).

Grain Size

Pebbles	4 - 64 mm
Granules	2 - 4 mm
Sand	
Very coarse	1 - 2 mm
Coarse	1/2 - 1 mm
Medium	1/4 - 1/2 mm
Fine	1/8 - 1/4 mm
Very fine	1/16 - 1/8 mm
Silt	1/256 - 1/16 mm
Clay	less than 1/256 mm

APPENDIX B

MEASURED SECTION DESCRIPTIONS

The study area is located near Wartburg, Morgan County, Tennessee, within part of the Pilot Mountain, Gobey, and Lancing Quadrangles (Fig. 1.3, p. 4). Nine road and four railroad outcrops were measured and described in detail. Outcrop locations are shown in Fig. 1.4 (p. 7) with each outcrop designated by a letter.

The Dorton Formation at outcrops A1 and A2 was so heavily weathered that any detailed sedimentologic information was obscured. The Burnt Mill Formation and the lower 400 cm of the Coalfield Formation at outcrop DD, were measured in a ravine and very highly weathered, again, most sedimentologic information was obscured. The reader should also note that outcrop D was split into 2 parts with the south and north end of this outcrop measured separately.

Each measured section is described below. Sections were measured to the nearest centimeter for convenience, but the author realizes that the measurements are not that precise. Field "units" were assigned from the bottom, to the top of each outcrop, from oldest to youngest units. Numbered units are informal and were determined dominantly from field work, supplemented by acetate peel, and thin section study. Numbered units are not necessarily correlative between the measured sections. The colors referred to in the measured sections are not standardized. Terms used in the descriptions of the measured sections are listed in Appendix A.

Field unit numbers can be related to the facies described in the text by using the tables in Appendix F. These tables list the field "units" for each facies at each outcrop.

<u>UNIT</u>	<u>UNIT THK(m)</u>	<u>CUML. THK(m)</u>	<u>DESCRIPTION</u>
<u>OUTCROP AA</u>			
<u>Rockcastle Formation (incomplete at base)</u>			
1	23.00	23.00	Buff quartzarenite, medium- to thick-bedded, medium, well-sorted, well-rounded, quartz grains. Excellent induration, blocky to slabby parting, weathers to light rust-brown slabs and blocks. Large (1-2 m), low angle (6-8°) planar crossbeds. Also trough and smaller planar crossbeds. Unit fines upward.
	9.00	32.00	—Covered Interval—
<u>Dorton Formation</u>			
2	2.14	34.14	Gray laminated siltstone, even, parallel, continuous, medium-lamination. Some bioturbation, fair induration, platy parting, weathers to brown chips (1-4 cm in size). Laminae are alternating quartz silt and clay with macerated carbonaceous material. Mica flakes evident on bedding surfaces. Lower contact is covered. Sample: AA-1
3	.60	34.74	Gray, calcareous, bedded siltstone, medium-bedding. Good induration, blocky weathering to a dark-gray. Fossil debris and macerated carbonaceous material scattered throughout. Sharp, flat, lower contact. Unit fines upward and the top 10 cm is bioturbated. Sample: AA-2
4	6.50	41.24	Gray clayshale, fair induration, platy parting, weathers to light-gray chips (1-2 cm) where heavily weathered, a light-brown. Numerous siderite concretions (2-5 cm in diameter). Flat, gradational contact with unit 3 below. This unit has a nodular appearance when slabbed. Samples: AA-3 through AA-10
5	8.34	49.58	Gray laminated siltstone, even, parallel, discontinuous to continuous, medium-lamination. Some laminae of quartz silt are

<u>UNIT</u>	<u>UNIT THK(m)</u>	<u>CUML. THK(m)</u>	<u>DESCRIPTION</u>
<u>OUTCROP AA (cont'd)</u>			
			lenticular, with flat lenses. Good induration, platy parting. Weathers to small (2-3 cm) light gray chips; where heavily weathered, a light-brown. Laminae are alternating white quartz silt and gray clay with macerated carbonaceous matter. Mica flakes and macerated carbonaceous material evident on bedding planes. Some horizontal burrows present. Gradational contact with Unit 4 below. Samples: AA-11 through AA-18.
6	7.56	57.14	Gray laminated siltstone, even, parallel, discontinuous to dominantly continuous medium- to thick-laminations, most of which are graded. Many lenticular laminae with flat and thick lenses. Good induration, platy parting, weathers to small light gray chips (1-4 cm), where heavily weathered, a light-brown. Macerated carbonaceous material and scattered mica flakes throughout. Laminae are alternating white quartz silt and gray clay with macerated carbonaceous material. Samples: AA-19 through AA-22
<u>Crossville Formation (incomplete at top)</u>			
7	9.24	66.38	Buff quartzarenite, medium- to thick-bedded, very fine, well-sorted, well-rounded grains. Some scattered mica flakes throughout. Excellent induration, blocky weathering to a light-brown. Numerous trough and planar crossbeds. Sharp, flat, slightly erosive (10-12 cm) lower contact.
<u>OUTCROP BB</u>			
<u>Dorton Formation (incomplete at base)</u>			
1	8.68	8.68	Gray laminated siltstone, even, parallel discontinuous, medium-lamination. Some laminae are lenticular with flat lenses.

<u>UNIT</u>	<u>UNIT THK(m)</u>	<u>CUML. THK(m)</u>	<u>DESCRIPTION</u>
<u>OUTCROP BB (cont'd)</u>			
			Good induration, platy parting, weathers to small (2-3 cm) light-gray chips. Laminae are alternating white quartz silt and gray clay with macerated carbonaceous material. Mica flakes and carbonaceous material evident on bedding planes. Samples: BB-1 through BB-5
2	6.92	15.60	Gray laminated siltstone, even, parallel, discontinuous medium- to thick-lamination, most laminae show normal grading. Many lenticular laminae with flat and thick lenses. Good induration, platy to flaggy parting, weathers to small light-gray chips (1-3 cm). Laminae are alternating white quartz silt and gray clay with macerated carbonaceous material. The top 328 cm of this unit contain the thick laminae, with very coarse quartz silt to very fine sand. Macerated carbonaceous material and mica evident on bedding planes. Gradational contact with unit 1 below. Samples: BB-6 through BB-9
<u>Crossville Formation</u>			
3	1.35	16.95	Buff quartzarenite, medium- to thick-bedded, very fine, well-sorted, subrounded grains. Excellent induration, blocky weathering to a light-brown. Planar and trough crossbeds. The top 40 cm is thin-bedded. Flat, slightly scoured base (10 cm) which usually contains coal spar. Sample: BB-10
4	1.70	18.65	Gray sublitharenite, very thin-bedded to thick-lamination. Laminae are alternating quartz silt and gray clay with macerated carbonaceous material. Laminae are wavy, parallel, discontinuous, and usually lenticular, with flat and thick lenses. Good induration, weathers to small (5 cm) slabs. Flat, gradation contact with unit 3 below. Sample: BB-11

<u>UNIT</u>	<u>UNIT THK(m)</u>	<u>CUML. THK(m)</u>	<u>DESCRIPTION</u>
<u>OUTCROP BB (cont'd)</u>			
5	1.61	20.26	Buff sublitharenite to quartzarenite, medium-bedded, very fine, well-sorted subrounded grains. Excellent induration, blocky weathering to a rust-brown. Some mica flakes and macerated carbonaceous material. Some planar and trough crossbeds. Flat, fairly abrupt, nonscoured lower contact.
6	1.00	21.26	Gray sublitharenite, very thin-beds which are quartz silt and gray clay. Bedding is wavy, parallel, and discontinuous. Bedding is usually lenticular with flat lenses. Excellent induration, weathers to small (2-5 cm) slabs. Macerated carbonaceous material and mica scattered throughout, though dominant in the clay layers. Flat gradational contact with unit 5 below.
7	2.11	23.37	Buff sublitharenite to quartzarenite, medium-bedded, very fine, well-sorted, rounded quartz grains. Excellent induration, blocky weathering to a light-brown. Planar crossbeds, macerated carbonaceous material and mica flakes scattered throughout. Flat, fairly abrupt, nonscoured lower contact.
8	.25	23.62	Black, medium-bedded siltstone, abundant carbonaceous material, and some mica. Fair induration, cobbly weathering to a light-gray. Some coal spar. Lower contact is gradational with unit 7 below.
9	1.61	25.23	Gray sublitharenite, medium-bedding which is often separated by 5 cm mica and organic-rich wavy and parallel beds. Carbonaceous material and mica scattered throughout. Good induration, weathers to small (5 cm) light-gray slabs. Flat, abrupt, nonscoured contact with unit 8 below.
10	.95	26.18	Gray sublitharenite, thick-bedded, and massive. Excellent induration, blocky weathering to a light olive-gray. Macerated carbonaceous material, clay, and mica throughout. Flat, abrupt, nonscoured contact with unit 9 below.

<u>UNIT</u>	<u>UNIT THK(m)</u>	<u>CUML. THK(m)</u>	<u>DESCRIPTION</u>
<u>OUTCROP BB (cont'd)</u>			
<u>Burnt Mill Formation(?) (incomplete at top)</u>			
11	3.04	29.22	Gray mudshale, even, parallel, continuous, medium-lamination. Laminae are alternating quartz silt and clay. Macerated carbonaceous material dominant, mica flakes evident on bedding planes. Fair induration, weathers to light-gray chips. Flat, abrupt contact with unit 10 below.
<u>OUTCROP CC</u>			
<u>Dorton Formation (incomplete at base)</u>			
1	5.73	5.73	Gray laminated siltstone, even, parallel, discontinuous, medium- to thick-lamination, most of which show grading. Numerous small scale (millimeter to centimeter) slumps and dewatering structures. Good induration, platy parting, weathers to small (1-3 cm) light-gray chips, where heavily weathered a light-brown. Macerated carbonaceous material and mica flakes scattered throughout. Laminae are alternating quartz silt and gray clay. Some laminae are lenticular with flat lenses. Samples: CC-1 through CC-6
<u>Crossville Formation</u>			
2	4.83	10.56	Buff quartzarenite, medium-bedded, numerous trough crossbeds and a few planar crossbeds. The quartz grains are very fine, well-sorted, and well-rounded. Excellent induration, slabby weathering to a light rust-brown. This sandstone occurs as channel. The base is sharp, erosive with a lag of mudrock chips, and coalified plant fragments. Sample: CC-7

<u>UNIT</u>	<u>UNIT THK(m)</u>	<u>CUML. THK(m)</u>	<u>DESCRIPTION</u>
<u>OUTCROP CC (cont'd)</u>			
3	3.18	13.74	Dark-gray sublitharenite/litharenite to a bedded siltstone. Thin-bedded, high in macerated carbonaceous material. The quartz grains are very fine and subrounded. Some mica is present. Often parallel, discontinuous, medium- to thick-laminae of quartz silt are present. The top 124 cm of this unit contains 1 cm thick regularly spaced (6 cm) very fine quartz sandstone interbeds. These sandstone interbeds are thicker (2-5 cm) near the center of the outcrop. Gradational contact with unit 1 below. Sample: CC-8
<u>Burnt Mill Formation(?) (incomplete at top)</u>			
4	4.57	18.31	Gray mudshale, medium, parallel, even, continuous to discontinuous laminae. Fair induration, weathers to light-gray chips, platy parting. Laminae are alternating quartz silt and clay. Some mica flakes and macerated carbonaceous material evident on bedding planes.
<u>OUTCROP DD</u>			
<u>Dorton Formation (incomplete at base)</u>			
1	6.14	6.14	Gray laminated siltstone, even, parallel, discontinuous to continuous laminae. Quartz silt laminae alternate with clay-rich layers. Macerated carbonaceous material and mica flakes evident on bedding planes. Normal grading of the silt laminae. Most of this unit is very heavily weathered to rust-brown chips. Fair to good induration.
<u>Crossville Formation</u>			
2	5.53	11.67	Buff quartzarenite, very thick-bedding, fine, well-sorted, well-rounded quartz grains. Some mica flakes and clay. Excellent induration, weathers to a rust brown. This

<u>UNIT</u>	<u>UNIT THK(m)</u>	<u>CUML. THK(m)</u>	<u>DESCRIPTION</u>
<u>OUTCROP DD (cont'd)</u>			
			sandstone occurs as large channels. Grain size fines upward in the channel fill (medium to fine sand). Occasional mudrock pebbles seen as a channel lag. Contact with unit 2 below is sharp and erosive. Samples: DD-1, DD-2
3	3.78	15.45	Light-gray, sandy bedded siltstone. Very thin-bedding, some macerated carbonaceous material and mica scattered throughout. Fair induration, this unit is very heavily weathered to small (2-3 cm) light-brown, chips. Gradational lower contact.
4	.85	16.30	Buff quartzarenite to sublitharenite thick-bedded, very fine, well-sorted, well-rounded quartz grains. Some mica and macerated carbonaceous material are present. Excellent induration, blocky weathering to a rust-brown. Sharp, flat, nonscoured contact with unit 3 below.
<u>Burnt Mill Formation</u>			
5	10.10	26.40	Gray mudshale, thin, even to wavy, parallel, continuous lamination. The alternating laminae are quartz silt and clay. This unit is extremely weathered, but appears to have been high in macerated carbonaceous material. Fair to poor induration, weathers to small (1-2 cm) brown chips. Abrupt, flat, nonscoured contact with unit 4 below.
<u>Coalfield Formation</u>			
6	2.68	29.08	Light-gray sublitharenite to quartzarenite. Medium- to thin-bedded, very fine, well-rounded, well-sorted quartz grains. Very heavily weathered to small (2-3 cm) brown slabs, fair induration. Clay, macerated carbonaceous material, and mica scattered throughout. Fairly sharp contact with unit 5 below.
	1.25	30.33	—Covered Interval—

<u>UNIT</u>	<u>UNIT THK(m)</u>	<u>CUML. THK(m)</u>	<u>DESCRIPTION</u>
<u>OUTCROP DD (cont'd)</u>			
7	2.73	33.06	Light-brown laminated siltstone. Very heavily weathered to small (1-2 cm) brown chips, fair induration. Laminae are alternating quartz silt and clay layers which are wavy, discontinuous, and parallel. Lower contact is covered.
8	2.00	35.06	Very light-gray, bedded siltstone, medium-bedded, fairly massive, some macerated carbonaceous material, the upper 20 cm of this unit appears rooted. Fair to good induration, cobbly weathering to a cream. Gradational contact with unit 7 below.
<u>Coalfield Formation (top of formation)</u>			
9	.35	35.41	Unnamed coal.
<u>Glenmary Formation(?) (incomplete at top)</u>			
10	2.68	38.09	Dark-gray, sandy laminated siltstone, even, parallel, continuous, thin-laminations. Laminae are quartz-rich silt that alternate with clay and macerated carbonaceous material. Good induration, weathers to light-gray chips. Some mica evident on bedding planes. Gradational contact with the coal below.
11	1.10	39.19	Dark-gray, laminated siltstone, with very thin, buff, sublitharenite interbeds. The siltstone is similar to unit 10, only slightly coarser. The sandstone interbeds are a sublitharenite with very fine, well-sorted, well-rounded quartz grains. Good induration, slabby weathering to a light-gray. Gradational contact with unit 10 below.
12	1.80	40.99	Buff quartzarenite, thin- to medium-bedded. Very fine, well-sorted, rounded quartz grains. Some scattered mica flakes throughout. This unit has thin beds in the upper 80 cm. Good induration, weathers to small (3-4 cm) light rust-brown slabs. Lower contact is gradational.

<u>UNIT</u>	<u>UNIT THK(m)</u>	<u>CUML. THK(m)</u>	<u>DESCRIPTION</u>
<u>OUTCROP DD (cont'd)</u>			
13	2.25	43.24	Gray clayshale, even, parallel, continuous lamination. Scattered quartz silt, macerated carbonaceous material and clay are dominant. Fair to good induration, weathers to small (1-3 cm) light-gray chips. Flat, slightly gradational contact with unit 12 below.
<u>OUTCROP A</u>			
<u>Rockcastle Formation (incomplete at base)</u>			
1	2.40	2.40	Buff quartzarenite, medium-bedded, medium, well-sorted, well-rounded, quartz grains. Excellent induration, flaggy parting, weathers to light rust-brown slabs. Some planar crossbeds, fines upward.
2	4.20	6.60	<u>Rex Coal</u>
<u>Dorton Formation</u>			
3	3.55	10.15	Gray laminated siltstone, even, parallel, continuous, thin- to very thin-lamination. Very thin-bedded siderite rhythmically spaced (4-8 cm) throughout this unit. Good induration, fissile parting, weathers to small (2-3 cm) light-gray chips. Where heavily weathered this unit is a light rust-brown. Laminae are alternating white quartz silt and gray clay with macerated carbonaceous material. Mica flakes and macerated carbonaceous material evident on bedding planes. The lower 20 cm in contact with the coal is clay and carbonaceous rich. Samples: A-1 through A-24
4	1.79	11.94	Gray laminated siltstone, even, parallel, continuous to discontinuous medium- to thick-lamination. The lower 100 cm of this unit is heavily bioturbated, the upper 79 cm is relatively unbioturbated. Fair to good

<u>UNIT</u>	<u>UNIT THK(m)</u>	<u>CUML. THK(m)</u>	<u>DESCRIPTION</u>
<u>OUTCROP A (cont'd)</u>			
			induration, platy to flaggy parting, weathers to olive-gray cobbles and chips (1-4 cm in size). Laminae (where present) are alternating white quartz silt and gray clay with macerated carbonaceous material. Mica flakes and macerated carbonaceous material evident on bedding planes. Trilobite collected. Samples: A-25 through A-30.
5	1.00	12.94	Buff, calcareous quartz arenite, medium-bedded, very fine, well-sorted, subrounded grains. Good induration, blocky weathering to a light rust-brown. Sharp, flat, slightly scoured lower surface with a few scattered mudrock clasts (.5-1 cm in size). Straight cephalopod, several small gastropods collected. Samples: A-31 through A-33
6	3.30	16.24	Gray clayshale, fair induration, platy parting, weathers to light-gray chips (1-2 cm); where heavily weathered, a light-brown. Numerous siderite concretions (2-5 cm in diameter) which become less abundant and smaller (.5-1 cm in diameter) in the top 50 to 70 cm of this unit. Flat, slightly gradational contact with unit 5 below. Samples: A-34 through A-39
7	5.66	21.90	Gray laminated siltstone, even, parallel, discontinuous, medium lamination. Some laminae are lenticular with flat lenses. Good induration, platy parting, weathers to small (2-3 cm) light-gray chips; where heavily weathered, a light brown. Laminae are alternating white quartz silt and gray clay with macerated carbonaceous matter. Mica flakes and macerated carbonaceous material evident on bedding planes. Some vertical and horizontal burrows present. Samples: A-40 through A-81

<u>UNIT</u>	<u>UNIT THK(m)</u>	<u>CUML THK(m)</u>	<u>DESCRIPTION</u>
<u>OUTCROP A (cont'd)</u>			
8	.20	21.10	Gray bedded siltstone, contorted bedding. Good induration, blocky weathering to a light gray. Some white quartz medium silt laminae can be seen through these, are contorted. Macerated carbonaceous material and some mica flakes are present. Sharp, fairly flat, nonscoured base. Samples: A-82 through A-84
9	1.54	23.64	Gray laminated siltstone, even, parallel, discontinuous to continuous medium- to thick-lamination. Some lenticular laminae with flat to thick lenses. Good induration, platy parting weathers to small (2-3 cm) light-gray chips; where heavily weathered a light brown. Laminae are alternating white quartz silt and gray clay with macerated carbonaceous material. Mica flakes and macerated carbonaceous material evident on bedding planes. Samples: A-85 through A-93
10	.32	23.96	Gray sandy bedded siltstone, contorted beds. Good induration, blocky weathering to a light gray and brown where heavily weathered. Macerated carbonaceous material and some mica flakes present. Sharp, fairly flat, slightly scoured (1 cm) base. Sample: A-94
11	8.44	32.40	Gray laminated siltstone, even, parallel, discontinuous to dominantly continuous medium- to thick-lamination, most of which are graded. Most laminae are lenticular with flat and thick lenses. Good induration, platy to flaggy parting, weathers to small light-gray chips (1-4 cm), where heavily weathered, a light-brown. Macerated carbonaceous material and scattered mica flakes throughout. Laminae are alternating white quartz silt and gray clay with macerated carbonaceous material. Abrupt, flat nonscoured contact with unit 10 below. Samples: A-95 through A-159

<u>UNIT</u>	<u>UNIT THK(m)</u>	<u>CUML. THK(m)</u>	<u>DESCRIPTION</u>
<u>OUTCROP A (cont'd)</u>			
<u>Crossville Formation</u>			
12	6.29	38.69	Buff quartzarenite, medium-bedded, very fine, well-sorted, well-rounded grains. Excellent induration, blocky weathering to a light rust-brown. Color lamination and liesegang banding common. Numerous trough and planar crossbeds. Bedding becomes more thin-bedded in the upper 300 cm. Flat, sharp, erosive (10-20 cm) lower contact. Sample: A-160
13	3.90	42.59	Buff quartzarenite, interbedded of quartzarenite, which alternate with thin beds of quartzarenite containing cusped ripples. Very fine, moderately-sorted, subrounded quartz grains. Excellent induration, slabby weathering to a brown. Gradational contact with unit 12 below.
<u>Crossville Formation (incomplete at top?)</u>			
14	1.00	43.59	Buff quartzarenite, thick-bedded, very fine, well-sorted, subrounded grains. Excellent induration, blocky weathering to a light-brown. Planar crossbeds. Sharp, flat contact with unit 13 below.
<u>OUTCROP A1</u>			
<u>Dorton Formation (incomplete at base)</u>			
1	13.68	13.68	Gray laminated siltstone, even, parallel, discontinuous to continuous medium-lamination. Fair induration, highly weathered to rust-brown chips (2-4 cm) in size. Laminae are often lenticular with flat to thick lenses of quartz silt. High in macerated carbonaceous material with some mica flakes.

<u>UNIT</u>	<u>UNIT THK(m)</u>	<u>CUML. THK(m)</u>	<u>DESCRIPTION</u>
<u>OUTCROP A1 (cont'd)</u>			
<u>Crossville Formation</u>			
2	10.80	24.48	Light-gray to buff quartzarenite, medium- to thick-bedded, very fine, well-sorted, sub-rounded grains. Excellent induration, blocky weathering to a light rust-brown, and gray. Numerous large planar crossbeds. Sharp, flat, erosive (10-20 cm) lower contact.
<u>OUTCROP A2</u>			
<u>Dorton Formation</u>			
1	10.82	10.82	Gray laminated siltstone, even, parallel, discontinuous to continuous medium-lamination. Fair induration, highly weathered to small rust-brown chips (2-4 cm in size). Laminae are often lenticular with flat to thick lenses of quartz silt. High in macerated carbonaceous material with some mica flakes.
<u>Crossville Formation</u>			
2	6.84	17.66	Light-gray to buff quartzarenite, medium- to thick-bedded, very fine, well-sorted, subrounded grains. Excellent induration, blocky weathering to a light rust-brown and gray. Numerous planar crossbeds. Sharp, flat, erosive (10-20 cm) lower contact.
<u>OUTCROP B</u>			
<u>Dorton Formation (incomplete at base)</u>			
1	3.72	3.72	Gray laminated siltstone, even, parallel, wavy, discontinuous medium- to thick-lamination. Laminae are often lenticular with flat and thick lenses, laminae often show grading. Good induration, platy parting, weathers to light-gray chips (2-4 cm in size), where heavily weathered this unit is rust-brown. Laminae are alternating white quartz

<u>UNIT</u>	<u>UNIT THK(m)</u>	<u>CUML. THK(m)</u>	<u>DESCRIPTION</u>
<u>OUTCROP B (cont'd)</u>			
			silt and gray clay with macerated carbonaceous material. Samples: B-1 through B-7
<u>Crossville Formation</u>			
2	6.86	10.58	Buff quartzarenite, medium-bedded, very fine, well-sorted, well-rounded grains. Excellent induration, blocky weathering to a light rust-brown. Color lamination and liesegang banding common. Numerous trough and planar crossbeds. Sharp, erosive lower contact, 30 cm of which is a shale arenite containing mudrock clasts (.5-1 cm) and coal spar. Sample: B-8
3	1.29	11.87	Gray sublitharenite, very thin, wavy-bedding, and some bifurcated wavy-flasers. Sand grains are very fine, subrounded, and well-sorted. Good to fair induration, slabby parting, weathers to light-gray. Very fine sand ripple cross-lamination alternates with clay and macerated carbonaceous-rich, dark-gray layers. Mica flakes and organic-rich layers present on the top of rippled surfaces. Abrupt, flat, nonscoured base. Sample: B-9
4	.35	12.22	Gray sublitharenite to quartzarenite, very thin- to thin-bedded, with some bifurcated wavy-flasers. Sand grains are very fine, well-sorted, and subrounded. Excellent to good induration, slabby to blocky weathering to a light-gray. Some mica scattered throughout, though usually present as bifurcated flasers. This unit has flat, abrupt, nonscoured base. Sample: B-10
5	.50	12.72	Gray sublitharenite, very thin wavy-flasers. Sand grains are very fine, subrounded, and well-sorted. Good to fair induration, slabby parting, weathers to light olive-gray slabs (2-6 cm). Light-gray, very fine sand, ripple

<u>UNIT</u>	<u>UNIT THK(m)</u>	<u>CUML. THK(m)</u>	<u>DESCRIPTION</u>
<u>OUTCROP B (cont'd)</u>			
			cross-lamination alternates with dark-gray organic-rich clay layers. Mica flakes and organic-rich clay layers present on the top of rippled surfaces.
6	.32	13.04	Gray sublitharenite to quartzarenite, very thin- to thin-bedded with bifurcated wavy-flasers. Sand grains are very fine, well-sorted, and subrounded. Excellent to good induration, slabby to blocky weathering to a light-gray. Mica flakes and some organic-rich material scattered throughout, though usually present as bifurcated wavy-flasers. This unit has a flat, abrupt, nonscoured base.
7	.27	13.31	Gray sublitharenite, very thin, wavy-bedding and some bifurcated wavy-flasers. Sand grains are very fine, subrounded, and well-sorted. Good to fair induration, slabby parting, weathers to light-gray slabs (2-6 cm). Light-gray, very fine sand, ripple cross-lamination alternates with dark-gray organic-rich clay layers. Mica flakes and organic-rich clay on the top of rippled surfaces. Abrupt, flat, nonscoured base.
8	.40	13.71	Gray sublitharenite, thin-bedded, bifurcated wavy-flasers. Sand grains are very fine, well-sorted, and subrounded. Excellent to good induration, slabby to blocky weathering to a light-gray. Some planar crossbeds, some mica flakes and macerated carbonaceous material scattered throughout, though usually present as bifurcated wavy-flasers. This unit has a flat, abrupt, nonscoured base.
9	.25	13.96	Gray sublitharenite, very thin, wavy-bedding and some bifurcated wavy-flasers. Sand grains are very fine, subrounded, and well-sorted. Good to fair induration, slabby parting, weathers to light-gray slabs (2-6 cm). Light-gray very fine sand and ripple cross-lamination alternates with dark-gray organic clay-rich layers. Mica flakes and organic-rich clay on the top of rippled surfaces. Abrupt, flat, nonscoured base.

<u>UNIT</u>	<u>UNIT THK(m)</u>	<u>CUML. THK(m)</u>	<u>DESCRIPTION</u>
<u>OUTCROP B (cont'd)</u>			
10	2.21	16.17	Gray quartzarenite, thick-bedded, very fine, well-sorted, well-rounded grains. Excellent induration, blocky weathering to a light rust-brown. Sharp, slightly erosive (2-4 cm) lower contact, some mudrock clasts (0.5-4 cm) in the lower 10 cm of this unit.
11	1.00	17.17	Olive-gray sublitharenite, medium-bedded, very fine, well-sorted, well-rounded grains. Excellent induration, blocky weathering to a light olive-gray. Macerated carbonaceous material, and clay throughout. Flat, abrupt, nonscoured lower surface. Sample: B-11
<u>Burnt Mill Formation (incomplete at top)</u>			
12	8.71	25.88	Gray mudshale, even, parallel, discontinuous to continuous medium-lamination. Fair induration, platy parting, heavily weathered to rust-brown chips (2-4 cm). Mica flakes and macerated carbonaceous material scattered throughout. Flat, abrupt, nonscoured, contact with the unit below.
<u>OUTCROP C</u>			
<u>Dorton Formation (incomplete at base)</u>			
1	5.52	5.52	Gray laminated siltstone, even, parallel, wavy, discontinuous medium- to thick-lamination. Good induration, platy parting, weathers to light-gray chips (2-4 cm in size), where heavily weathered, this unit is rust-brown. Laminae are alternating white quartz silt and gray clay with macerated carbonaceous material. Laminae are often lenticular with flat to thick lenses. Many laminae show grading. In the last 60 cm of this unit, the laminae are thicker and more lenticular than below. Mica and macerated carbonaceous material evident on bedding planes. Some horizontal burrowing evident on the outcrop. Samples: C-1-C-8.

<u>UNIT</u>	<u>UNIT THK(m)</u>	<u>CUML. THK(m)</u>	<u>DESCRIPTION</u>
<u>OUTCROP C (cont'd)</u>			
2	.20	5.72	Gray bedded siltstone, with dewatering structures and contorted bedding. Good induration, blocky weathering to a light-gray. This unit is high in macerated carbonaceous material, much of which is imbricated. This unit has a sharp, slightly scoured base (1-2 cm) and an abrupt upper surface. Sample: C-9
3	1.27	6.99	Gray laminated siltstone, even, parallel, wavy, discontinuous, often lenticular thick-lamination. Good induration, flaggy parting, weathers to light-gray chips (2-6 cm in size), where heavily weathered, this unit is rust-brown in color. Laminae are quartz silt and very fine sand usually lenticular with thick lenses alternating with gray-clay and macerated material. Many laminae show grading. This unit is similar to unit 1 below, only with thicker laminations. Mica flakes and macerated carbonaceous material evident on bedding planes. Sample: C-10
<u>Crossville Formation</u>			
4	4.96	11.95	Buff quartzarenite, medium-bedded, very fine, well-sorted, well-rounded quartz grains. Excellent induration, blocky weathering to a light rust-brown. Color lamination and liesegang banding common. Numerous trough and planar crossbeds. Some siderite pebbles at the base of trough crossbeds. Scattered mica flakes throughout this unit. Some parallel, even, continuous, medium-laminations of macerated carbonaceous material. Sharp, erosive (10-30 cm), fairly flat lower contact often with siderite pebbles and coal spar. Sample: C-11

<u>UNIT</u>	<u>UNIT THK(m)</u>	<u>CUML. THK(m)</u>	<u>DESCRIPTION</u>
<u>OUTCROP C (cont'd)</u>			
5	.15	12.10	Light-gray, silty sublitharenite, very thin-bedded, very fine, subrounded, moderately-sorted quartz grains. Good induration, flaggy parting, weathers to light-gray thin (2 mm) slabs. Slight ripple cross-lamination with coarse silt and mica drapes (1 mm thick), as simple flasers. Abrupt, flat, nonscoured contact with the unit below.
6	.85	12.95	Light-gray sublitharenite to quartzarenite medium-bedded. Fine, subrounded, and well-sorted quartz grains. Excellent induration, blocky weathering to a gray. A few simple flasers (1 mm thick) of mica flakes and macerated carbonaceous material. Abrupt, flat, nonscoured base.
7	.32	13.27	Gray sublitharenite, very thin- to thin-bedded, bifurcated wavy-flaser, and wavy bedding. Sand grains are very fine, well-sorted and subrounded. Good to fair induration, slabby parting, weathers to light-gray slabs (2-6 cm). Mica flakes and organic-rich clay as bifurcated wavy-flasers and as drapes on the tops of rippled surfaces. Abrupt, flat, nonscoured base.
8	.45	13.72	Gray sublitharenite, very thin- to thin-bedded, bifurcated wavy-flasers. Sand grains are very fine, well-sorted, and subrounded. Good induration, slabby parting, weathers to olive-gray slabs (2-6 cm). This unit is similar to unit 7 below only this unit does not have wavy-bedding. Mica flakes and organic-rich clay scattered throughout, though usually present as bifurcated wavy flasers. Abrupt, flat, nonscoured lower contact.
9	.56	14.28	Light-gray, quartzarenite, thick-bedded, very fine, well-sorted, subrounded quartz grains. Some bifurcated wavy-flasers. Excellent induration, blocky weathering to a buff color. Abrupt, flat, nonscoured contact with the unit below.

<u>UNIT</u>	<u>UNIT THK(m)</u>	<u>CUML. THK(m)</u>	<u>DESCRIPTION</u>
<u>OUTCROP C (cont'd)</u>			
10	.30	14.58	Gray sublitharenite, thin-bedded, bifurcated wavy-flasers. Sand grains are very fine, well-sorted, and subrounded. Good induration, slabby parting, weathers to olive-gray slabs (2-6 cm). Mica flakes, clay, and macerated carbonaceous material scattered throughout. Flat, abrupt, nonscoured base.
11	.60	15.18	Gray sublitharenite, thin-bedded, very fine, subrounded, well-sorted sand grains. Wavy bedding and ripple cross-lamination without silt drapes. Good induration, slabby parting, weathers to light-gray slabs (2-6 cm). This unit has an abrupt, flat, nonscoured base, with a gradational contact above.
12	2.56	17.74	Buff, quartzarenite, thin- to medium-bedded, very fine, rounded, well-sorted sand grains. Excellent induration, blocky weathering to a rust-brown color. Gradational contact with the unit below.
13	.60	18.34	Light-gray, sandy bedded siltstone, parallel, even, discontinuous medium laminations. Fair induration, platy parting, weathers to cream colored slabs and chips (1-8 cm). Gradational contact with the unit below, and fines upward becoming less silty near the top 30 cm.
<u>Crossville Formation (top of section)</u>			
14	1.33	19.67	Cream sublitharenite to quartzarenite, thick-bedded, very fine, well-sorted, subrounded quartz grains. Excellent induration, blocky weathering to a buff color. Mica flakes, clay, and macerated carbonaceous material scattered throughout. Abrupt, flat, slightly scoured base (2-4 cm). Sample: C-12

<u>UNIT</u>	<u>UNIT THK(m)</u>	<u>CUML. THK(m)</u>	<u>DESCRIPTION</u>
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OUTCROP D1Dorton Formation (incomplete at base)

1	3.10	3.10	Gray laminated siltstone, even, parallel, continuous to discontinuous medium- to thick-lamination. Laminae are alternating white quartz silt and gray clay to silt with macerated carbonaceous material. Some laminae are lenticular with flat lenses and many laminae are graded. Good induration, platy parting, weathers to small (1-3 cm) light-gray chips, where heavily weathered, a light rust-brown. Samples: D1-1 through D1-3
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Crossville Formation

2	8.68	11.78	Buff quartzarenite, medium-bedded, very fine, well-sorted, well-rounded quartz grains. Excellent induration, weathers to light rust-brown slabs and blocks. Numerous planar and trough crossbeds. Leisegang banding common. The lower contact is slightly undulatory and scoured 10-15 cm into unit 1 below.
3	2.34	14.12	Gray sublitharenite, continuous wavy, parallel, thick-lamination to very thin-bedding. Mica flakes, silt, and macerated carbonaceous material occurs on the top of ripple cross-lamination. The quartz sand grains are very well-sorted, subrounded and very fine. Good to fair induration, flaggy parting, weathers to light-gray chips (2-3 cm).
4	1.69	15.81	Buff quartzarenite, medium-bedded, very fine, well-sorted, well-rounded quartz grains. Excellent induration, weathers to light-brown blocks. Scattered mica flakes throughout. Abrupt, flat, nonscoured, lower contact, top 10 cm fines upward into unit 5 above.
5	1.24	17.05	Gray mudshale, parallel, even, discontinuous, medium-lamination. Fair induration, flaggy to cobbly weathering to light-gray chips and small (1-2 cm) blocks. This unit has a gradational base with unit 5 below.

<u>UNIT</u>	<u>UNIT THK(m)</u>	<u>CUML. THK(m)</u>	<u>DESCRIPTION</u>
<u>OUTCROP D1 (cont'd)</u>			
<u>Crossville Formation (top of formation)</u>			
6-	1.00		Cream sublitharenite, thick-bedded, very fine, well-sorted, subrounded, quartz grains. Excellent induration, blocky weathering to an olive-gray. Macerated organics and scattered mica flakes throughout. Flat, slightly scoured (2-5 cm) base. This unit pinches out at the south end of this outcrop.
<u>OUTCROP D (NORTH HALF)</u>			
<u>Crossville Formation (incomplete at base)</u>			
1	.70	.70	Light gray, sublitharenite, very thin-bedded, very fine, subrounded, moderately-sorted, quartz grains. Good to fair induration, slabby parting, weathers to cream colored slabs and chips (1-8 cm in size). Macerated carbonaceous material increases upward. This unit is covered at the south end of this outcrop. Sample: D-1
2	.75	1.45	Gray mudshale, parallel, even, discontinuous medium lamination. Fair induration, platy parting, weathers to small (1 cm) rust brown chips. This unit is gradational with the unit below and the top 10 cm of this unit is very organic rich with a thin 5 cm discontinuous coal. This unit is covered at the south end of the outcrop. Sample: D-2
3	.97	2.42	Cream sublitharenite, thick-bedded, very fine, well-sorted, subrounded quartz grains. Excellent induration, blocky weathering to an olive-gray. This unit has a flat, slightly scoured base (2-5 cm) and is heavily bioturbated, with vertical burrows and horizontal burrows. Scattered mica flakes and organic material throughout. This unit fines upward and pinches out at the south end of this outcrop. Sample: D-3

<u>UNIT</u>	<u>UNIT THK(m)</u>	<u>CUML. THK(m)</u>	<u>DESCRIPTION</u>
<u>OUTCROP D (NORTH HALF) (cont'd)</u>			
4	3.00	5.42	Gray sublitharenite and sandy bedded siltstone, medium-bedded to thick-lamination, which are wavy, discontinuous, and nonparallel. Many of the beds are contorted, some are lenticular with thick lenses. Good induration, weathers blocky to an olive-gray. Some siderite nodules and macerated carbonaceous material. This unit has a gradational contact with the unit below, and pinches out at the south end of the outcrop. Samples: D-4 through D-8
<u>Burnt Mill Formation</u>			
5	11.65	17.07	Black mudshale, even, parallel, continuous lamination. Fair to poor induration, platy parting, weathers to small (1 cm) light-gray chips, where heavily weathered it is rust-brown. Some pyrite concretions (1-3 cm in diameter) and disseminated pyrite (0.5 mm) present on bedding planes. This unit contains abundant macerated carbonaceous material, giving it an organic odor on the outcrop. Flat, abrupt, contact with the unit below. Samples: D-9 through D-15.
<u>Coalfield Formation</u>			
6	2.50	19.57	Light-gray sublitharenite, thin-bedded, very fine, moderately-sorted, subrounded, quartz grains. The lower 125 cm of this unit contains scattered mudrock clasts (1-2 cm in size), numerous coal spar and macerated carbonaceous material throughout. This unit has a scoured base which curves downward from north to south across the outcrop. The lower 20 cm of this unit contains thin beds of siderite. Trough and planar crossbeds are common throughout this unit. The lower 125 cm of unit 6 contains some contorted beds and mudrock clasts. The upper 125 cm does not contain the mudrock clasts, or as much coal spar and macerated carbonaceous material as the lower 125 cm. This unit has good

<u>UNIT</u>	<u>UNIT THK(m)</u>	<u>CUML. THK(m)</u>	<u>DESCRIPTION</u>
<u>OUTCROP D (NORTH HALF) (cont'd)</u>			
			induration, weathering to light rust-brown slabs (2-8 cm in size). Sample: D-16
7	3.80	23.37	Light-gray to buff quartzarenite, medium-bedded, very fine, well-sorted, subrounded quartz grains. Excellent induration, weathers to light rust-brown blocks. Some planar crossbeds, not as much macerated carbonaceous material as in unit 6 below. The contact with unit 6 below is gradational and the upper 40 cm of this unit fines upward to a very thin-bedded sandy siltstone.
8	.94	24.31	Gray clayshale, discontinuous, even, parallel, medium-lamination. Fair to poor induration, weathers to light-gray cobbles and chips, where heavily weathered this unit is a light-brown in color.
<u>Coalfield Formation (top of formation)</u> <u>(Marker Bed 2)</u>			
9	.67	24.98	Black carbonaceous-coaly mudshale, even, parallel, continuous, thin- to medium-lamination. Good induration, fissile parting, weathers to 1-2 mm thick, light-gray sheets.
<u>OUTCROP D (SOUTH HALF)</u>			
<u>Burnt Mill Formation (incomplete at base)</u>			
1	12.79	12.79	Black mudshale, even, parallel, continuous, medium-lamination. Fair to poor induration, platy parting, weathers to small (1 cm) light-gray chips, where heavily weathered this unit is a rust-brown. Some scattered pyrite concretions (1-3 cm in diameter) and some disseminated pyrite (0.5 mm) on bedding planes. This unit is very high in macerated carbonaceous matter, giving it an organic odor on the outcrop.

<u>UNIT</u>	<u>UNIT THK(m)</u>	<u>CUML. THK(m)</u>	<u>DESCRIPTION</u>
<u>OUTCROP D (SOUTH HALF) (cont'd)</u>			
2	1.80	14.59	Light-gray, sandy laminated siltstone to a very fine-grained sublitharenite, wavy, discontinuous parallel, thin- to thick-lamination. Some lenticular laminae with flat to thick lenses. The alternating laminae are quartz silt, very fine sand and black, clay-silt with macerated carbonaceous matter. Scattered mica flakes on bedding surfaces. Excellent induration, flaggy parting, weathers to light-gray slabs (2-8 cm). Numerous siderite and calcerous concretions (1-5 cm in diameter) which are wrapped by bedding. The calcerous concretions are usually weathered away. This unit has a gradational contact with the unit below. The top of this unit is more of a sublitharenite as grain size coarsens upward very slightly. Sample: D-17
<u>Coalfield Formation</u>			
3	.90	15.49	Buff quartzarenite, medium-bedded, very fine grained, well-sorted, subrounded quartz grains. Excellent induration, blocky weathering to a light rust-brown color. Abrupt, flat, non-scoured lower surface. This unit grades upward into the overlying unit. The lower 30 cm of this unit exhibits dewatering structures. Sample: D-18
4	.86	16.35	Gray sublitharenite, thin-bedded becoming thickly-laminated in the top 15 cm. Rippled and wavy bedding, with alternating beds of very fine, well-sorted, subrounded quartz sand and black clay-silt and macerated carbonaceous material. Excellent induration, blocky weathering to a light rust-brown color. This unit has a gradational contact with unit 3 below.
5	1.10	17.45	Buff quartzarenite, medium-bedded, very fine, well-sorted, subrounded quartz grains. Excellent induration, blocky weathering to a light rust-brown. Abrupt flat, nonscoured

<u>UNIT</u>	<u>UNIT THK(m)</u>	<u>CUML. THK(m)</u>	<u>DESCRIPTION</u>
<u>OUTCROP D (SOUTH HALF) (cont'd)</u>			
			contact with the unit below. The top 10 cm of this unit is bioturbated. The top 30 cm of unit 5 fines upward into the overlying unit.
6	.84	18.29	Black mudshale, even, parallel, continuous, medium-lamination. Fair induration, platy parting, weathers to small (1-3 cm) light-gray chips. This unit is high in macerated carbonaceous material. The lower contact is gradational with the unit below, is more sandy, and contains coalified plant remains. Unit 6 pinches out at the north end of the outcrop.
7	.27	18.56	Black, sandy bedded siltstone, medium, discontinuous, nonparallel very thin-bedding. Good induration, cobbly weathering to an olive-gray color. High in macerated carbonaceous material with scattered mica grains throughout. Alternating wavy layers of macerated organics and quartz silt to very fine quartz sand. Unit 7 has a slightly scoured (2-4 cm) lower surface and grades upward into the overlying unit. Unit 7 pinches out at the north end of the outcrop.
<u>Coalfield Formation (Marker Bed 1)</u>			
8	.46	19.02	Black carbonaceous mudshale, even, parallel, continuous, medium-laminae. Good induration, papery parting, weathers to dark-gray 1 mm thick sheets. This unit is very high in macerated carbonaceous material. Unit 8 has a gradational contact with unit 7 below it and pinches out near the north end of the outcrop.
9	1.98	21.00	Buff quartzarenite, medium- to thin-bedding. The quartz grains are fine, well-sorted, and subrounded. Excellent induration, blocky weathering to a light rust-brown color. The lower contact is slightly scoured (2-6 cm) into the unit below. The upper 50 cm is thin-bedded and starts to fine upward. Sample: D-19

<u>UNIT</u>	<u>UNIT THK(m)</u>	<u>CUML. THK(m)</u>	<u>DESCRIPTION</u>
<u>OUTCROP D (SOUTH HALF) (cont'd)</u>			
10	.92	21.92	Gray mudshale, even, parallel, continuous thick-lamination. Fair induration, cobbly weathering to a light-gray. Gradational contact with unit 9 below.
<u>Coalfield Formation (top of formation)</u> <u>(Marker Bed 2)</u>			
11	.30	22.22	Black carbonaceous mudshale, thin to medium, even, parallel, continuous, lamination. Good induration, weathers to light-gray thin (1 mm) sheets, fissile parting. This unit is high in macerated carbonaceous material. The lower contact is gradational.
<u>OUTCROP E</u>			
<u>Burnt Mill Formation (incomplete at base)</u>			
1	2.19	2.19	Black mudshale, parallel, even, continuous, lamination. Platy parting, fair to poor induration, weathers to small (1-3 cm) light-gray chips, where heavily weathered, these are rust-brown in color. This unit is high in carbonaceous material and contains scattered mica grains. Some very thin-bedded siderite lenses (1 cm thick and 5-20 cm long), and also some siderite concretions (2-4 cm in diameter). Gradational contact with the unit above. Unit 1 coarsens upward rapidly. Distinct organic order on the outcrop. Samples: E-1, E-2, and E-3
2	4.25	6.44	Light-gray, sandy laminated siltstone to very fine grained sublitharenite, wavy, discontinuous, parallel, thin- to thick-lamination. Some lenticular bedding with flat to thick lenses. The alternating layers are quartz silt to very fine sand and black clay to silt with macerated carbonaceous material. Scattered mica flakes on bedding surface. Excellent induration, slabby parting,

<u>UNIT</u>	<u>UNIT THK(m)</u>	<u>CUML. THK(m)</u>	<u>DESCRIPTION</u>
<u>OUTCROP E (cont'd)</u>			
			weathers to light-gray slabs (3-10 cm). Numerous siderite and calcerous concretions (1-8 cm in diameter) are wrapped by bedding. The calcerous concretions are usually weathered away. Some very thin-bedded siderite. Contorted beds and small slumps (30-60 cm) are often present. The upper 150 cm of this unit contain the thick laminae. Samples: E-4 through E-8
<u>Coalfield Formation</u>			
3	.80	7.24	Light-gray quartzarenite, thin- to medium-bedded, very fine, subrounded, moderately-sorted quartz grains. Excellent induration, weathers to light-gray blocks. The contact with the unit below is abrupt, flat, and nonscoured. The laminae seen in unit 2 below are gone, instead there are bifurcated wavy-flasers, (1 mm thick, of black silt). The top 25 cm of this unit is heavily bioturbated, giving it a "bleached" appearance on the outcrop. Sample: E-9
4	.32	7.56	Black mudshale, thin, parallel, even, continuous, lamination. Fair to poor induration, fissile parting, weathers to small (1-2 cm) chips. Large siderite concretions (up to 20 cm) are traceable in a zone across this outcrop. Unit 4 is high in macerated carbonaceous material, giving this unit a distinct organic order on the outcrop. The lower contact (5 cm) of unit 4 has been reworked by bioturbation into the top of the underlying unit (3). Sample: E-9A
5	.60	8.16	Black, sandy bedded siltstone, discontinuous, wavy, nonparallel, thin-bedding. Slabby and blocky weathering to an olive-gray. High in macerated carbonaceous material with scattered mica grains. Alternating layers are macerated organics/clay and quartz silt to very fine

<u>UNIT</u>	<u>UNIT THK(m)</u>	<u>CUML. THK(m)</u>	<u>DESCRIPTION</u>
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OUTCROP E (cont'd)

sand. This unit has a slightly scoured lower surface (2-5 cm) and grades up into the unit 6 above.

Sample: E-9B

Coalfield Formation (Marker Bed 1)

6	.35	8.51	Black carbonaceous mudshale, even, parallel, continuous, thin- to medium-lamination. Good induration, fissile parting, weathers to light-gray 1 mm thick sheets. Gradational contact with unit 6 below. This unit is very high in macerated carbonaceous material and often has an 8 cm discontinuous coal on top of it. Sample: E-9C
7	.45	8.96	Gray, sandy laminated siltstone, even, parallel, continuous, medium-lamination. Fair induration, platy parting, weathers to small olive-gray slabs and chips (1-6 cm). Laminae are alternating white quartz silt to very fine sand with black mud and macerated organics. This unit has an abrupt, flat, nonscoured base. Unit 7 pinches out at the north end of this outcrop.
8	1.50	10.46	Gray shale arenite, thin- to medium-bedded. The very fine quartz sand grains are well-sorted and subrounded. The angular shale clasts range in size from 1 mm to 5 cm in length and are often imbricated. Good induration, cobbly weathering to an olive-gray. This unit has a scoured base and the lower 70 cm often contains lenses of very fine grained sandstone with few shale clasts. The middle 80 cm of this unit is dominated by shale clasts, while the upper 100 cm has a few scattered shale clasts. To the south end of this outcrop the shale clasts become less dominant. Samples: E-10 and E-11

<u>UNIT</u>	<u>UNIT THK(m)</u>	<u>CUML. THK(m)</u>	<u>DESCRIPTION</u>
<u>OUTCROP E (cont'd)</u>			
9	1.65	12.11	Buff quartzarenite to sublitharenite, thin- to medium-bedded, very fine, well-sorted, subrounded quartz grains, a few shale clasts in the lower 20 cm. This unit has an abrupt, nonscoured contact with the unit below, though in places it appears more gradational. Trough crossbeds are common. Excellent induration, with blocky weathering to a light rust-brown. The top 50 cm of this unit starts to fine upward and bedding becomes thin to very thin. Sample: E-12.
10	.50	12.61	Gray laminated siltstone, even, parallel, continuous, medium- to thick-lamination. Fair induration, platy parting, weathers to small (2-4 cm) light rust-brown chips. Gradational contact with the unit below. Sample: E-12A
11	.45	13.06	Gray clayshale, even, parallel, continuous, medium-lamination. Poor induration, fissile parting, weathers to small (2 cm) rust-brown chips. Gradational contact with unit 10 below. Sample: E-12B
12	.10	13.16	Black bedded siltstone, thin-bedded (2 cm). Good induration, flaggy parting, weathers dark-gray. High in macerated carbonaceous material. Abrupt, nonscoured contact with the unit below.
<u>Coalfield Formation (top of formation)</u> <u>(Marker Bed 2)</u>			
13	.32	13.48	Black carbonaceous mudshale, even, parallel, continuous, thin- to medium-lamination. Good induration, fissile to papery parting, weathers to light-gray 1-2 mm sheets. This unit fines upward from the unit below. High in macerated carbonaceous material, coaly in places.

<u>UNIT</u>	<u>UNIT THK(m)</u>	<u>CUML. THK(m)</u>	<u>DESCRIPTION</u>
<u>OUTCROP E (cont'd)</u>			
14	.60	14.08	Gray mudshale, even, parallel, medium-lamination. Fair induration, platy parting, weathers to small (2-6 cm) light-gray chips. This unit grades up from the unit below and is similar, but does not contain as much macerated carbonaceous material as unit 13 below. Capping this unit is a thin (5 cm) zone of siderite.
<u>Glenmary Formation (?)</u>			
15	4.22	18.30	Dark-gray, sandy bedded siltstone, discontinuous, wavy, nonparallel, thick-lamination to very thin-bedding. Good induration, slabby parting, weathers to light-gray small slabs (208 cm). Laminae are often very fine quartz silt to sand alternating with organic-rich black clay to silt. Lenticular bedding with flat to thick lenses. Some siderite concretions (1-3 cm in diameter). This unit is high in macerated carbonaceous material. Unit 15 has a sharp, flat, and abrupt contact with the unit below and it fines upward into unit 16 above. Samples: E-13, E-13A, E-14, and E-15
<u>Glenmary Formation(?) (incomplete at top)</u>			
16	10.87	29.17	Dark-gray, laminated mudshale, even, parallel, continuous, medium-lamination. Fair induration, platy parting, and weathers to small (1-4 cm) light-gray chips, where heavily weathered, a light rust-brown. High in macerated carbonaceous material, gradational contact with the unit below.
<u>OUTCROP F</u>			
<u>Burnt Mill Formation (incomplete at base)</u>			
1	1.25	1.25	Light-gray, sublitharenite, very thin, nonparallel, wavy, discontinuous, bedding. Simple flasers, and some 1 mm thick silt and

<u>UNIT</u>	<u>UNIT THK(m)</u>	<u>CUML. THK(m)</u>	<u>DESCRIPTION</u>
<u>OUTCROP F (cont'd)</u>			
			mica rich drapes on the top of ripple cross-lamination. Flaggy parting, good induration, this unit weathers to buff colored slabs and chips. Disseminated, macerated carbonaceous material, and some molds of tree limbs are present. This unit pinches out at the north end of this outcrop. Samples: F-1 and F-1A
2	.56	1.81	Buff, medium-bedded, quartzarenite, very fine, well-sorted, subrounded, quartz grains. This unit is gradational from the unit below, with the silt flasers from unit 1 mostly gone. Good induration, weathers to a light-tan. The top 10 cm contains vertical burrows. This unit pinches out at the north end of this outcrop. Samples: F-2 and F-2A
3	1.04	2.85	Light-gray, sandy bedded siltstone, even, parallel, very thin-bedding. Fair induration, cobbly weathering to a cream color. This unit is gradational with unit 2 below and is heavily bioturbated, and thus distinct in outcrop. Unit 2 pinches out at the north end of this outcrop. Sample: F-3
4	.17	3.02	Coal. Abrupt contact with the unit below.
5	.60	3.62	Dark-gray, sandy bedded siltstone, discontinuous, nonparallel, medium-bedding. Blocky weathering to an olive-gray, well-indurated. High in macerated carbonaceous material with scattered mica grains. This unit has a slightly scoured surface (1-2 cm) into the coal below. This unit contains rippled and contorted beds, and pinches out at the north end of this outcrop. Sample: F-4
6	.10	3.72	Coal. Abrupt contact with the unit below.

<u>UNIT</u>	<u>UNIT THK(m)</u>	<u>CUML. THK(m)</u>	<u>DESCRIPTION</u>
<u>OUTCROP F (cont'd)</u>			
7	1.15	4.87	Black mudshale, medium-lamination, platy parting, fair induration, weathers to light-gray small (1-5 cm) chips, where heavily weathered a red-brown. Scattered siderite concretions (2-4 cm in diameter). Abrupt, flat, contact with unit 6 below, but non-scoured. A few scattered pyrite nodules (1-2 cm in diameter), some disseminated pyrite (0.5 mm) and mica flakes on bedding planes. Samples: F-5 and F-6
8	3.20	8.07	Gray, sandy laminated siltstone to a very fine grained sublitharenite. Wavy, discontinuous, nonparallel, alternating medium-lamination of white quartz silt to very fine sand and black silt with macerated organic material. Scattered mica flakes on bedding planes, good induration, flaggy parting, weathers to small (5-15 cm) light-gray slabs. Scattered siderite concretions present (2-5 cm in diameter). This unit is gradational from unit 7 below and at the south end of the outcrop it rests directly on unit 6.
<u>Coalfield Formation</u>			
9	1.00	9.07	Light-gray sublitharenite, moderately-sorted, subrounded, very fine quartz grains. Medium, parallel, continuous, and wavy lamination, often lenticular with flat lenses. Alternating layers of white quartz sand and black silt with macerated carbonaceous material. Mica flakes on bedding planes. Good induration, flaggy parting, weathers to small (2-5 cm) light-gray chips. The lower part of this unit is gradational with the unit below and in the upper 50 cm of this unit the layers become thicker (5 mm - 3 cm). Sample: F-7
10	1.30	10.37	Buff quartzarenite, thin- to medium-bedded, very fine, very well-sorted, subrounded quartz grains. Excellent induration, blocky

<u>UNIT</u>	<u>UNIT THK(m)</u>	<u>CUML. THK(m)</u>	<u>DESCRIPTION</u>
<u>OUTCROP F (cont'd)</u>			
			weathering to a light rust-brown. Liesegang banding common. The contact with the unit below is abrupt, flat, and nonscoured. Unit 10 fines upward into the unit above. Sample: F-8
11	.45	10.82	Dark-gray mudshale, parallel, even, continuous medium-lamination. Fair induration, fissile parting, weathers to small (1-4 cm) light-gray chips. This unit has a gradational contact with unit 11 below. Sample: F-8A
12	.30	11.12	Dark-gray sandy bedded siltstone, medium, discontinuous, wavy, nonparallel bedding. Blocky weathering to an olive-gray, abundant macerated carbonaceous material, with some scattered mica flakes. Wavy layers consist of alternating quartz silt and dark clay organics. Unit 12 has a slightly scoured lower surface (1-2 cm) into unit 11 below.
<u>Coalfield Formation (Marker Bed 1)</u>			
13	.25	11.37	Black carbonaceous mudshale, thin to medium, even, parallel, lamination, papery parting. Good induration, weathers to dark-gray thin (1 mm thick) sheets. Gradational contact with unit 12 below. Sample: F-9
	2.50	13.87	—Covered Interval—
<u>Coalfield Formation (incomplete at top)</u>			
14	.30	14.17	Buff quartzarenite, thin- to medium-bedded, very fine, well-sorted, subrounded quartz grains. Good induration, blocky weathering to a light-brown. The lower and upper contacts of this unit are covered.

<u>UNIT</u>	<u>UNIT THK(m)</u>	<u>CUML. THK(m)</u>	<u>DESCRIPTION</u>
<u>OUTCROP G</u>			
<u>Burnt Mill Formation (incomplete at base)</u>			
1	2.00	2.00	Dark-gray bedded siltstone, very thin, even, parallel, bedding. Slabby parting, good induration, weathers to light-gray, small (2-5 cm) slabs and chips. Numerous siderite concretions (1-15 cm in diameter), irregularly shaped concretions are probably root casts as they cut across bedding. Some thin-bedded siderite occurring as lenses (5 cm thick and 5-60 cm long). The top 45 cm of this unit fines upward to a mudshale, with thin- to medium-lamination, platy parting, good induration, and splintery weathering. Macerated carbonaceous debris is common along bedding planes (15-20%). Sample: G-1
2	1.88	3.88	Light-gray, sandy laminated siltstone to very fine-grained sublitharenite, thin to medium, even, parallel, and wavy parallel laminae. Laminae are alternating white quartz coarse silt to very fine sand and gray clay to mud. This unit is very well indurated, with platy to flaggy parting, weathering to small (5-10 cm) light-gray slabs. Numerous siderite concretions (1-50 cm in diameter), are present. Bedding wraps around the concretions. The contact with the unit below is abrupt, flat and nonscoured. The top 60-80 cm of this unit is dominated by medium-laminae, which are parallel, wavy and sometimes lenticular. These laminae are thicker and more sandy than those below. Sample: G-2
<u>Coalfield Formation</u>			
3	1.35	5.23	Buff quartzarenite, medium- to thick-bedded, very fine, subrounded, well-sorted quartz grains. Well indurated, weathers to light rust-brown blocks. Some ripple cross lamination, scattered mica flakes, the top

<u>UNIT</u>	<u>UNIT THK(m)</u>	<u>CUML. THK(m)</u>	<u>DESCRIPTION</u>
<u>OUTCROP G (cont'd)</u>			
			10 cm contains vertical burrows. This unit has an abrupt, flat, nonscoured contact with unit 2 below.
4	.43	5.66	Black clayshale, thin to medium, even, parallel, lamination and fissile parting. Fair induration, weathering to small (1 mm) light-gray chips, where heavily weathered a rust-brown. Abundant macerated carbonaceous material, decay-like odor on the outcrop. Scattered mica flakes on bedding planes. Contact with unit 3 below is nonscoured, abrupt, and flat.
5	.20	5.86	Black, sandy bedded siltstone, medium, discontinuous, wavy, nonparallel, bedding. Blocky weathering to an olive-gray. Well indurated, abundant macerated carbonaceous material, scattered mica grains along bedding planes. Wavy alternating layers of macerated organics and quartz silt to very fine sand. This unit has a slightly scoured (2-3 cm) lower surface and grades upward into the overlying unit.
<u>Coalfield Formation (Marker Bed 1)</u>			
6	.30	6.16	Black carbonaceous mudshale, thin to medium, even, parallel, continuous, lamination. Papery parting, good induration, weathers to dark-gray (1 mm) thin sheets. Very high in macerated carbonaceous material, this unit has gradational contacts with the units above and below.
7	1.20	7.36	Light-gray clayshale, even, parallel, medium-lamination. Platy parting, fair induration, weathers to small (2 cm) light-brown chips. Numerous siderite concretions (2-20 cm in diameter). Sample: G-3

<u>UNIT</u>	<u>UNIT THK(m)</u>	<u>CUMUL. THK(m)</u>	<u>DESCRIPTION</u>
<u>OUTCROP G (cont'd)</u>			
8	.30	7.66	Buff sublitharenite, very thin-bedded, very fine, subrounded, well-sorted quartz grains. This unit contains mica and macerated carbonaceous material along low angle planar bedding. Some contorted beds. This unit has an abrupt, nonscoured lower base and thickens to 124 cm laterally across the outcrop. This unit weathers to light-gray slabs. Some siltstone clasts present in this unit. Sample: G-4
9	1.25	8.91	Light-gray sublitharenite, thin-bedded. Alternating layers of very fine white quartz sand with gray silt and clay. Good induration, platy parting, weathers to small (5-10 cm) light-gray slabs. This unit has a gradational contact with the units below and above.
<u>Coalfield Formation (incomplete at top)</u>			
10	2.35	11.26	Buff, quartzarenite, thin- to medium-bedded, very fine, well-sorted, subrounded, quartz grains. Excellent induration, weathers blocky to a light rust-brown. This unit has a slight unglutatory scoured surface (10-15 cm) into the unit below. The top 100 cm of this unit becomes more thin-bedded.

APPENDIX C

PALEOCURRENT DATA

The paleocurrent directional indicators used in this study include the following:

1. The maximum dip azimuth of the axes of trough cross-bedded sets. Data were collected only from well-exposed trough sets in which the three-dimensional morphology of the set could be ascertained. Trough cross-bed sets are indicated by a (t) in the following tables.

2. The maximum dip azimuth of cross-laminae from planar cross-bedded sets, again from three-dimensional morphologies. Planar cross-bed sets are indicated by a (p) in the following tables.

3. Azimuth indicated by the crests of ripple marks. All ripples were of the asymmetrical current type. Ripple measurements are indicated by an (r) in the following tables.

All paleocurrent measurements were collected by using a Brunton pocket transit, from standard procedures described in Potter and Pettijohn (1977).

Table C.1. Paleocurrent Measurements; Crossville Formation;
Facies 1; Outcrop A; Facies 1; Outcrop B

Facies 1; Outcrop A		Facies 1; Outcrop B	
Azimuth	Dip	Azimuth	Dip
S 68° E	23° (p)	S 75° E	18° (p)
S 40° E	16° (p)	S 50° E	10° (p)
S 80° E	18° (p)	S 75° E	26° (p)
S 81° E	10° (p)	S 70° E	26° (p)
S 60° E	24° (p)	S 60° E	23° (p)
S 52° E	21° (p)	S 66° E	26° (p)
S 68° E	27° (p)	S 68° E	15° (p)
S 55° E	21° (p)	S 60° E	20° (p)
S 75° E	21° (p)	S 50° E	16° (p)
S 80° E	10° (p)	S 80° E	14° (p)
S 52° E	20° (p)	S 75° E	18° (p)
S 60° E	15° (p)	S 52° E	26° (p)
S 72° E	18° (p)	S 71° E	29° (p)
S 65° E	16° (p)	S 68° E	21° (p)
S 45° E	24° (p)	S 66° E	18° (p)
S 65° E	22° (p)	S 41° E	13° (p)
S 78° E	5° (p)	S 85° E	10° (p)
S 55° E	5° (p)	S 79° E	20° (p)
S 60° E	6° (p)	S 41° E	12° (p)
S 80° E	16° (p)	S 65° E	19° (p)
S 55° E	19° (p)	S 51° E	23° (p)
S 70° E	15° (p)		
S 72° E	16° (p)		

Table C.2. Paleocurrent Measurements; Crossville Formation;
Facies 1; Outcrop C; Facies 1; Outcrop D1

Facies 1; Outcrop C		Facies 1; Outcrop D1	
Azimuth	Dip	Azimuth	Dip
S 80° E	19° (p)	S 63° E	10° (p)
S 90° E	25° (p)	S 62° E	12° (p)
S 90° E	16° (p)	S 59° E	16° (p)
S 70° E	21° (p)	S 78° E	21° (p)
S 68° E	20° (p)	S 82° E	18° (p)
S 61° E	22° (p)	S 53° E	9° (p)
S 85° E	10° (p)	S 75° E	7° (p)
S 35° E	17° (p)	S 41° E	22° (p)
S 37° E	15° (p)	S 33° E	24° (p)
S 78° E	19° (p)	S 81° E	12° (p)
S 50° E	26° (p)	S 67° E	15° (p)
S 45° E	15° (p)	S 66° E	13° (p)
S 52° E	12° (p)	S 59° E	19° (p)
S 75° E	9° (t)	S 70° E	7° (p)
S 68° E	10° (p)	S 55° E	10° (p)
S 57° E	17° (p)	S 81° E	11° (p)
S 49° E	13° (p)	S 53° E	15° (p)
S 78° E	20° (p)	S 72° E	20° (p)
S 72° E	13° (p)	S 80° E	18° (p)
S 60° E	6° (t)	S 77° E	15° (p)
S 41° E	10° (p)	S 15° E	14° (p)
		S 19° E	17° (p)
		S 11° E	21° (p)

Table C.3. Paleocurrent Measurements; Crossville Formation;
Facies 2; Outcrop A; Facies 2; Outcrop B

Facies 2; Outcrop A		Facies 2; Outcrop B	
Azimuth	Dip	Azimuth	Dip
S 20° E	0° (r)	S 5° W	0° (r)
S 80° E	0° (r)	S 21° W	0° (r)
S 20° E	0° (r)	S 3° W	0° (r)
S 50° E	0° (r)	S 85° E	0° (r)
N 10° E	0° (r)	S 20° W	0° (r)
S 75° E	0° (r)	S 50° E	0° (r)
S 25° E	0° (r)	S 10° E	0° (r)
N 15° E	0° (r)	S 5° E	0° (r)
N 22° E	0° (r)	S 65° E	0° (r)
N 25° E	0° (r)	S 40° E	0° (r)
N 20° E	0° (r)	S 10° W	0° (r)
N 30° E	0° (r)	S 55° E	0° (r)
N 35° E	0° (r)	S 62° E	0° (r)
N 42° E	0° (r)	S 68° E	0° (r)
S 60° E	0° (r)	S 70° E	0° (r)
S 68° E	0° (r)	S 65° E	0° (r)
S 61° E	0° (r)	S 40° E	0° (r)
S 52° E	0° (r)	S 25° E	0° (r)
S 59° E	0° (r)	S 30° E	0° (r)
S 57° E	0° (r)	S 22° W	0° (r)
S 41° E	0° (r)	S 15° W	0° (r)
S 49° E	0° (r)	S 90° E	0° (r)
S 5° E	0° (r)		

Table C.4. Paleocurrent Measurements; Crossville Formation;
Facies 2; Outcrop C; Facies 2; Outcrop D1

Facies 2; Outcrop C		Facies 2; Outcrop D1	
Azimuth	Dip	Azimuth	Dip
S 90° E	0° (r)	N 10° W	0° (r)
S 20° W	0° (r)	N 12° W	0° (r)
S 18° W	0° (r)	N 8° W	0° (r)
S 50° E	0° (r)	S 20° E	0° (r)
S 30° W	0° (r)	S 21° E	0° (r)
S 20° W	0° (r)	S 45° E	0° (r)
S 17° E	0° (r)	N 20° W	0° (r)
S 31° E	0° (r)	N 18° W	0° (r)
S 80° E	0° (r)	S 41° E	0° (r)
S 90° E	0° (r)	S 30° E	0° (r)
S 75° E	0° (r)	S 29° E	0° (r)
S 74° E	0° (r)	S 28° E	0° (r)
S 65° E	0° (r)	S 32° E	0° (r)
S 65° E	0° (r)	S 60° E	0° (r)
S 63° E	0° (r)	S 61° E	0° (r)
S 21° W	0° (r)	S 56° E	0° (r)
S 16° W	0° (r)	S 90° E	0° (r)
S 80° E	0° (r)		
S 78° E	0° (r)		
S 66° E	0° (r)		
S 50° E	0° (r)		
S 49° E	0° (r)		
S 31° E	0° (r)		

Table C.5. Paleocurrent Measurements; Crossville Formation;
Facies 4; Outcrop DD; Facies 5; Outcrop CC

Facies 4; Outcrop DD		Facies 5; Outcrop CC	
Azimuth	Dip	Azimuth	Dip
S 60° W	7° (t)	S 90° W	12° (t)
S 61° W	8° (t)	S 70° W	16° (t)
S 54° W	10° (t)	S 40° W	12° (t)
S 40° W	12° (t)	S 68° W	10° (t)
S 35° W	15° (t)	S 8° W	11° (t)
S 80° W	12° (t)	S 75° W	21° (t)
S 50° W	15° (t)	S 10° W	10° (t)
S 90° W	25° (t)	S 23° W	12° (t)
S 70° W	13° (t)	S 10° E	5° (t)
S 81° W	7° (t)	S 15° E	15° (t)
		S 20° W	10° (t)
		S 30° W	8° (t)
		S 30° E	17° (t)
		S 5° E	8° (t)
		S 75° W	14° (t)
		S 62° W	13° (t)
		S 61° W	18° (t)
		S 53° W	9° (t)
		S 65° W	10° (t)

Table C.6. Paleocurrent Measurements; Crossville Formation;
Facies 7; Outcrop BB

[illegible]

APPENDIX D

POINT COUNT DATA

For this study a minimum of 300 points per slide were counted to achieve an approximation of the different constituents present. The distance between any two points was larger than the grain size of the rock components (Van der Plas and Tobi, 1965).

The table below lists the percent variation for various component percentages based on 300 point counts with a 95% confidence. For example, if quartz sand comprises 50% of the rock volume as determined by point counting; the true quartz sand volume percent actually lies between 44.3% and 55.7% or $50 \pm 5.7\%$.

<u>% Constituent</u>	$\pm$	<u>Value (%)</u>
1.5		1.0
10.0		3.6
50.0		5.7
90.0		3.6
98.5		1.0

Thus, the reader should realize that when small percentages of constituents are expressed they may exceed the error values, when using a point count of 300.

Also, since mudrocks are very fine grained, this makes them difficult to point count. Therefore, constituent percentages obtained from the mudrock samples should be viewed with caution.

Both of the following tables list constituents by percent.

Table D.1. Point Count Data; Sandstone Samples

Sample No.	Quartz Sand	Quartz Silt	Clay	Macerated Organics	Sedimentary Rock Frag.	Chert	Mica
B-8	94.0	0.0	0.0	1.0	2.0	2.0	1.0
C-10	94.3	0.0	0.0	1.1	1.6	2.0	1.0
	85.0	0.0	5.6	5.0	0.0	0.0	3.4
E-7	40.0	30.0	6.0	14.0	0.0	0.0	10.0
E-9	83.9	0.0	5.0	5.4	0.0	0.0	5.7
E-9B	35.0	30.0	12.0	18.0	0.0	0.0	5.0
E-12	85.0	0.0	2.0	6.0	2.0	2.0	3.0
F-1	80.0	0.0	10.0	7.1	0.0	0.0	2.9
F-2	90.0	0.0	2.0	5.0	0.0	0.0	3.0
F-3	83.4	0.0	7.6	8.8	0.2	0.0	0.0
F-4	31.3	29.1	15.7	17.9	0.0	1.4	4.6
G-4	78.6	2.4	4.8	10.2	1.0	1.0	3.2
BB-10	94.0	0.0	0.0	2.0	0.8	2.0	0.2
BB-11	92.0	0.0	5.1	2.9	0.0	0.0	0.0
CC-8	10.3	40.1	34.6	10.1	0.0	0.0	4.9
DD-2	88.2	2.1	0.0	1.9	3.0	3.0	1.8

Table D.2. Point Count Data; Mudrock Samples

Sample No.	Clay	Quartz Silt	Macerated Organics	Mica	Fossil Debris
A-5	35.0	40.1	20.0	4.9	0.0
A-25	39.2	40.3	13.8	6.7	0.0
A-30	10.1	74.9	5.0	9.8	10.2
A-37	68.2	10.8	21.0	0.0	0.0
A-63	21.3	66.2	10.8	2.7	0.0
A-98	18.0	69.8	11.2	2.0	0.0
D-12	13.9	21.1	60.0	5.0	0.0
E-2	15.0	19.3	61.1	4.6	0.0
E-5	14.2	65.2	14.8	5.8	0.0
E-6	10.0	70.0	6.7	13.3	0.0
E-9C	14.7	15.3	65.2	4.8	0.0
F-8A	24.1	20.9	55.0	5.0	0.0
G-3	81.0	9.8	14.2	5.0	0.0
AA-9	70.0	11.2	10.1	8.7	0.0
AA-17	4.4	72.1	5.9	8.2	9.4
CC-3	19.0	68.5	9.5	3.0	0.0

APPENDIX E

PHOTO-MOSAIC SKETCHES

These photo-mosaic sketches were constructed by placing frosted mylar over a photo-mosaic composed for each outcrop. Field "units" were drawn in and sample locations were also recorded. Thus, the field "units" labeled on the photo-mosaic sketches correspond to those in the measured section descriptions (Appendix B). In order to relate field "units" to a particular facies or subfacies discussed in the text the tables listed in Appendix F must be used.

Since the photo-mosaic sketches were usually very long, outcrops are often split in half. Thus, the north half of outcrop A will be on one page, and the south half of outcrop A on the following page. Since samples were only collected at the far ends of outcrops B, C, and D1 only the ends of those outcrops are shown. Often, to save space the ends of outcrops are tapered off sharply.

Contacts separating formations are marked by a heavier line than those separating the field units.

The reader should note that due to parallax problems when photographing steep outcrops; the scale from the base to the top of the sketch taken from these photos may decrease. This should not pose too much of a problem as the main purpose of these sketches is to show the sample locations for each outcrop.

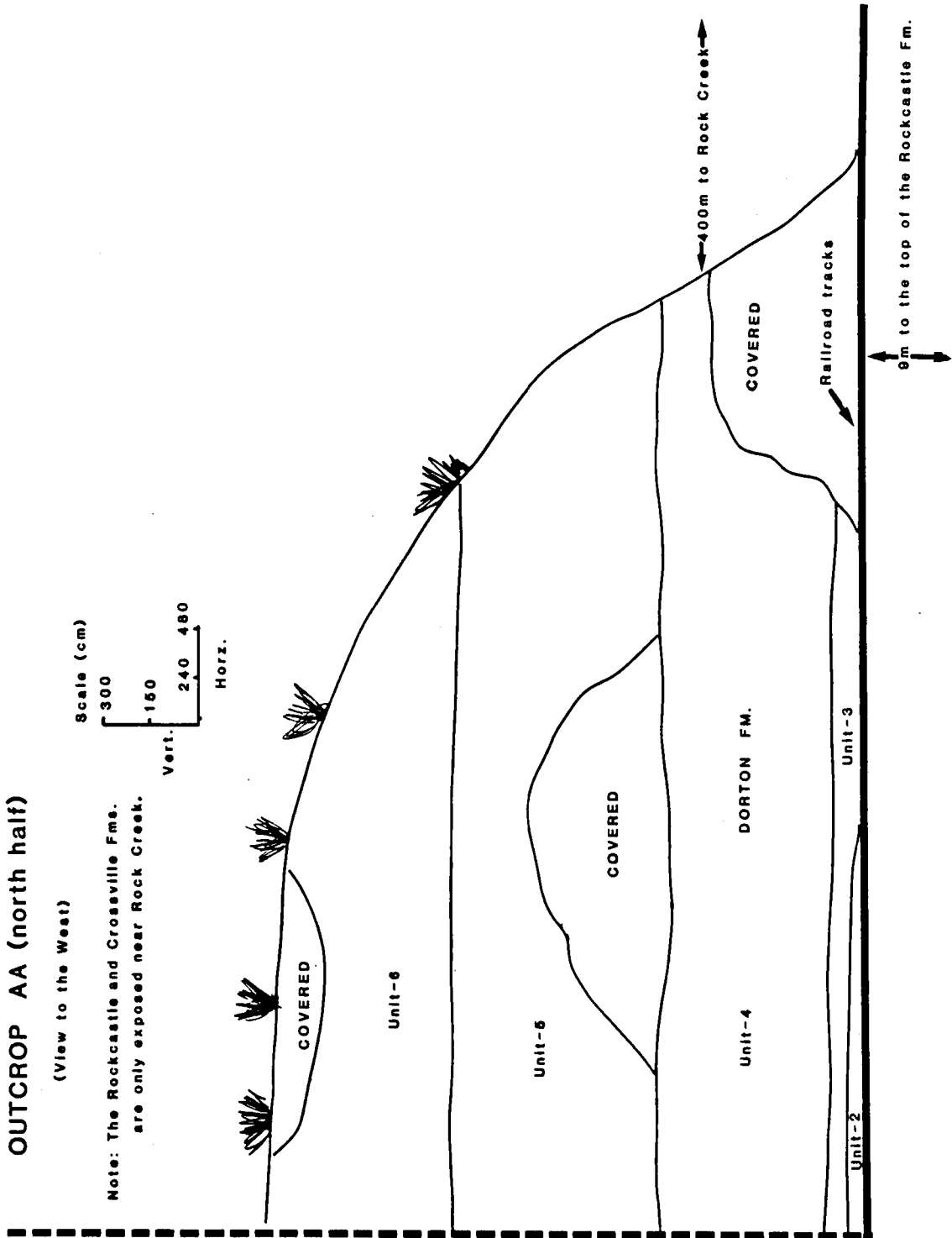


Fig. E.1. Photo-mosaic sketches of outcrops in the study area.

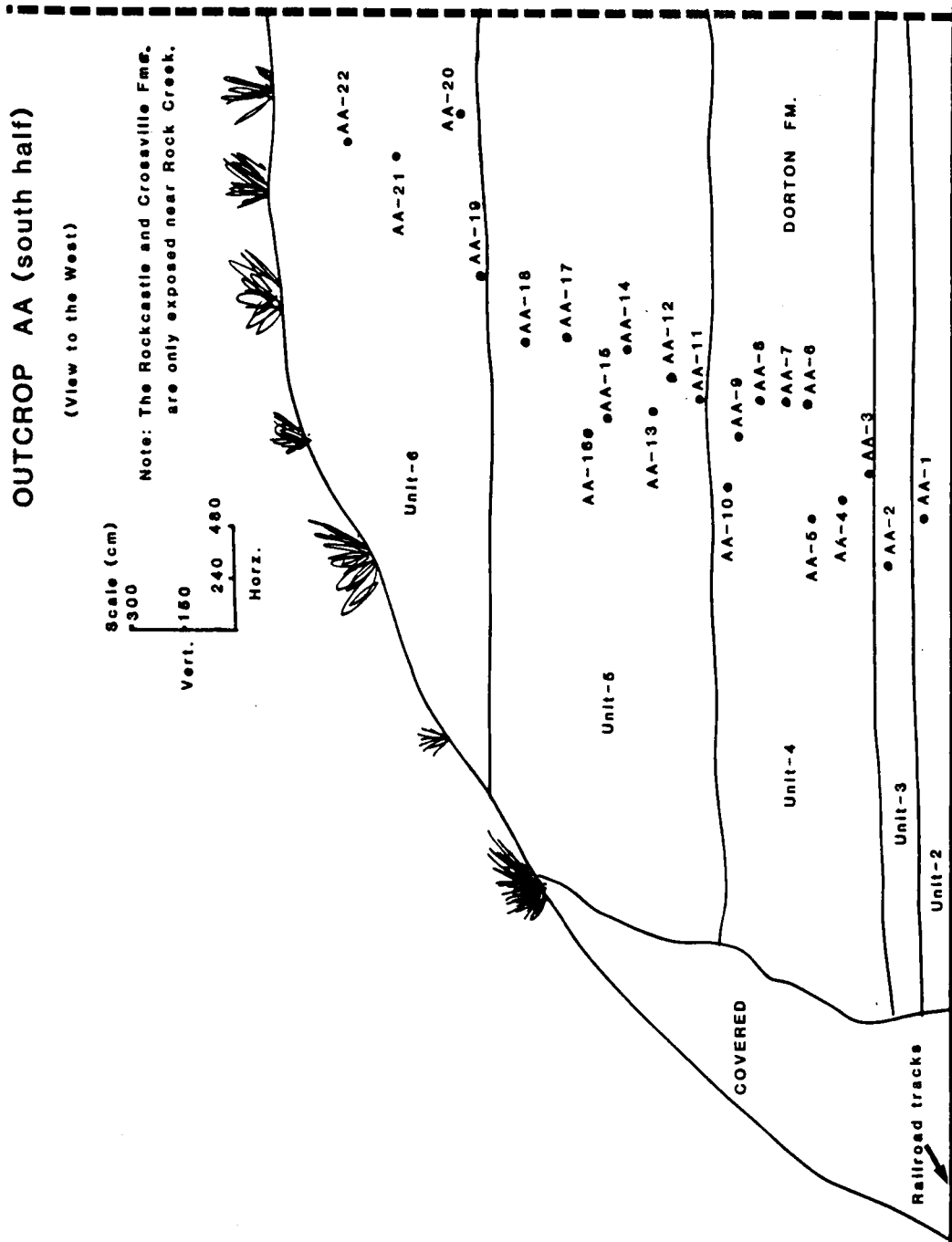


Fig. E.1 (cont'd)

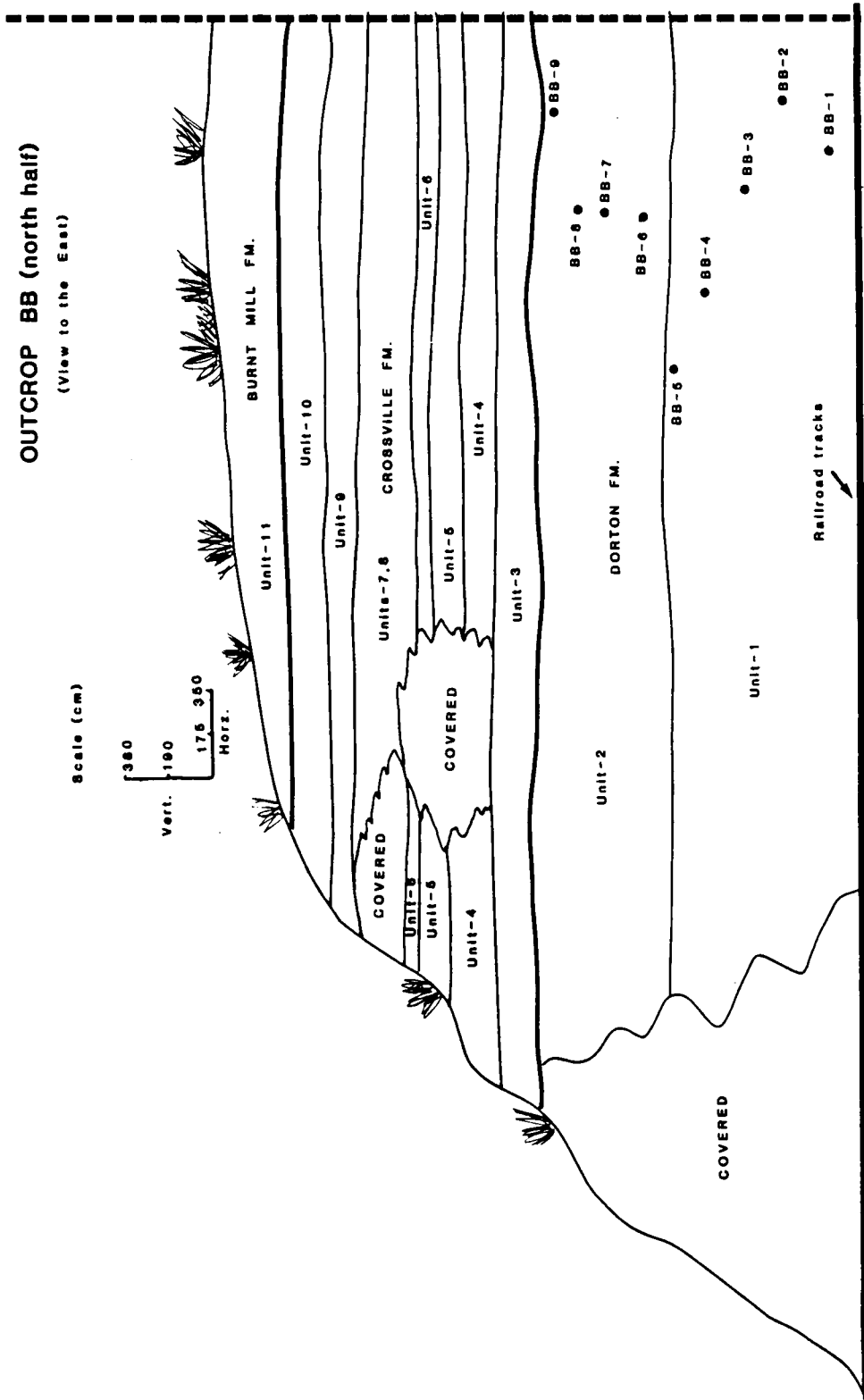


Fig. E.1 (cont'd)

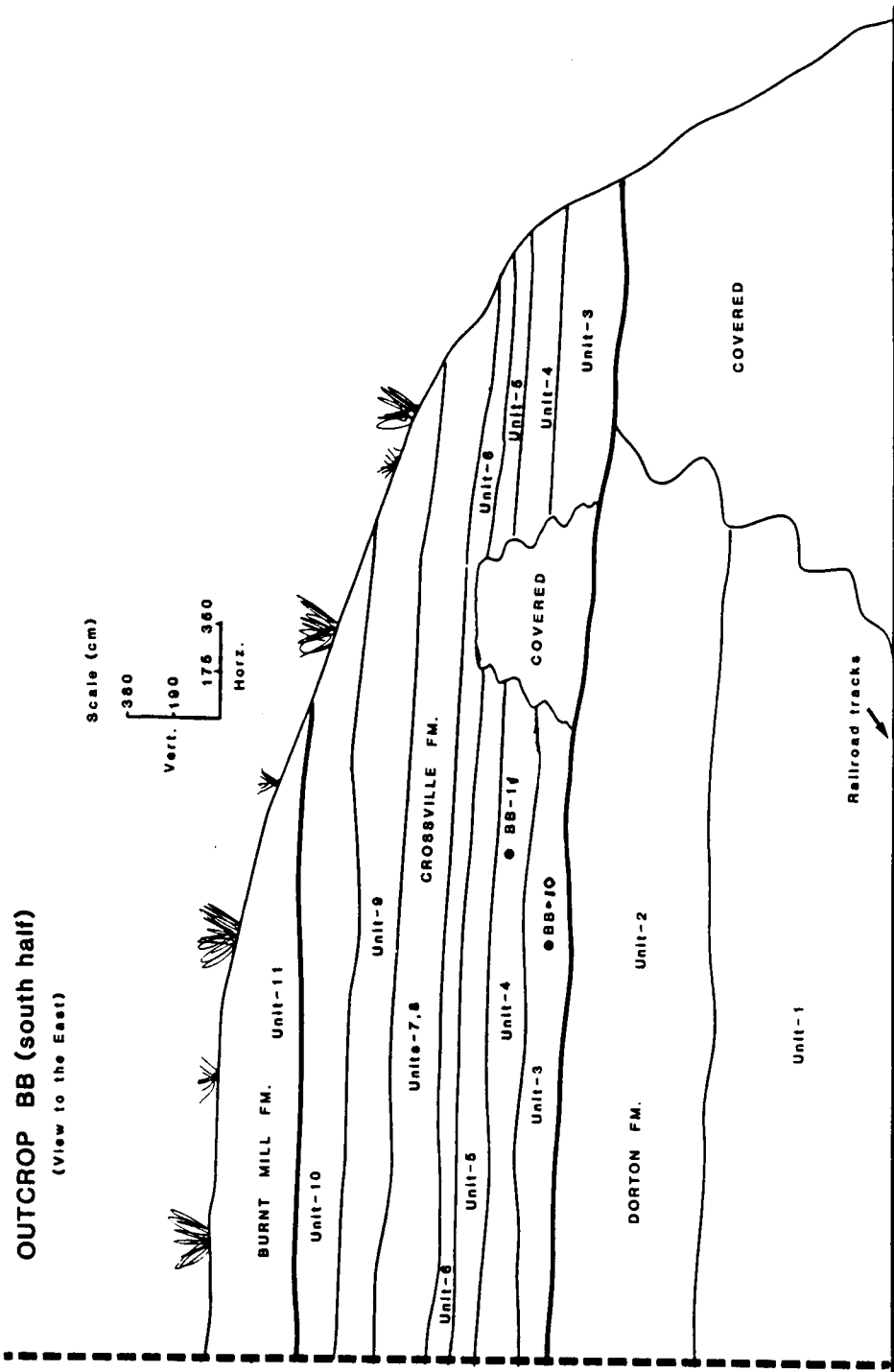


Fig. E.1 (cont'd)

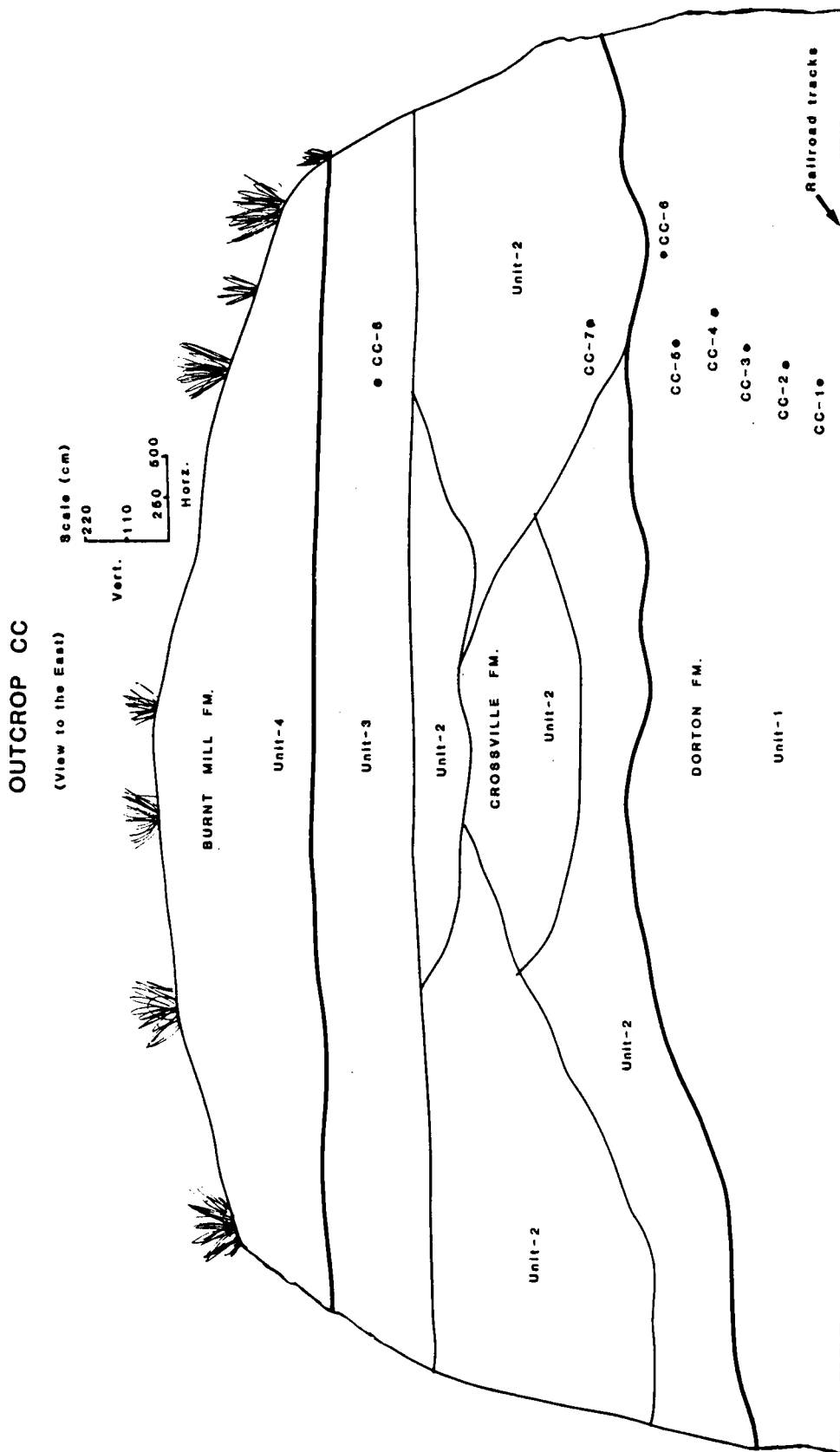


Fig. E.1 (cont'd)

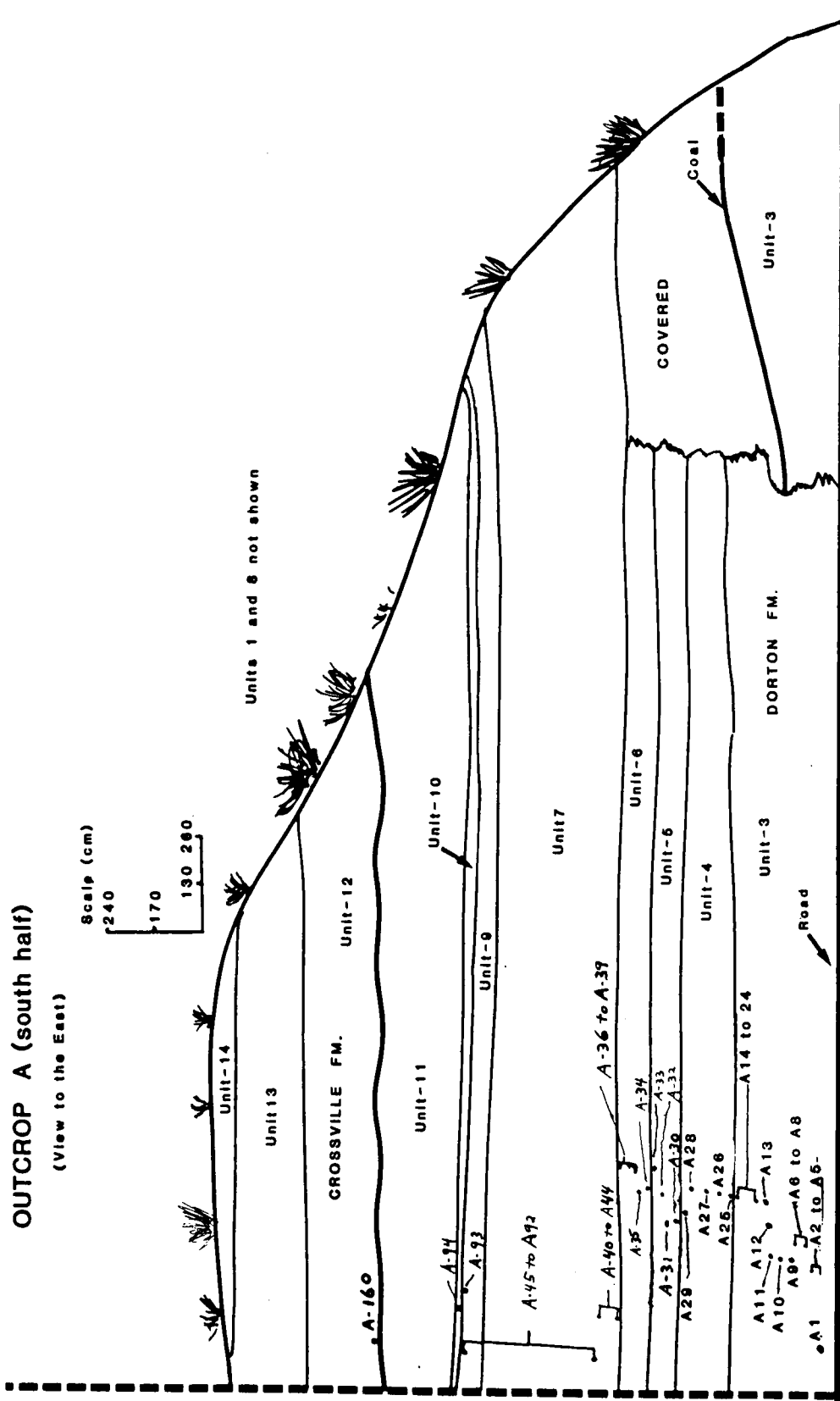


Fig. E.1 (cont'd)

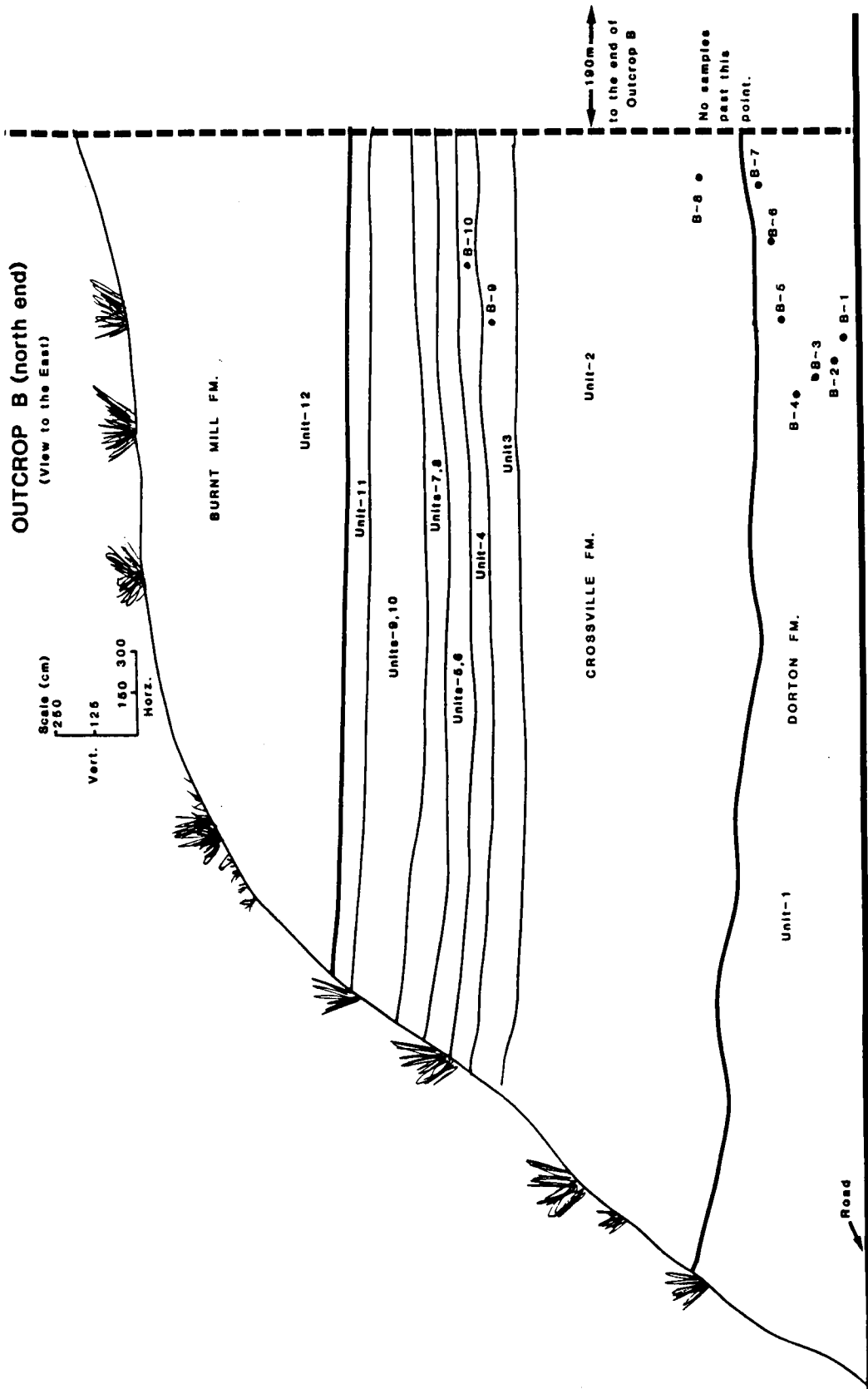


Fig. E.1 (cont'd)

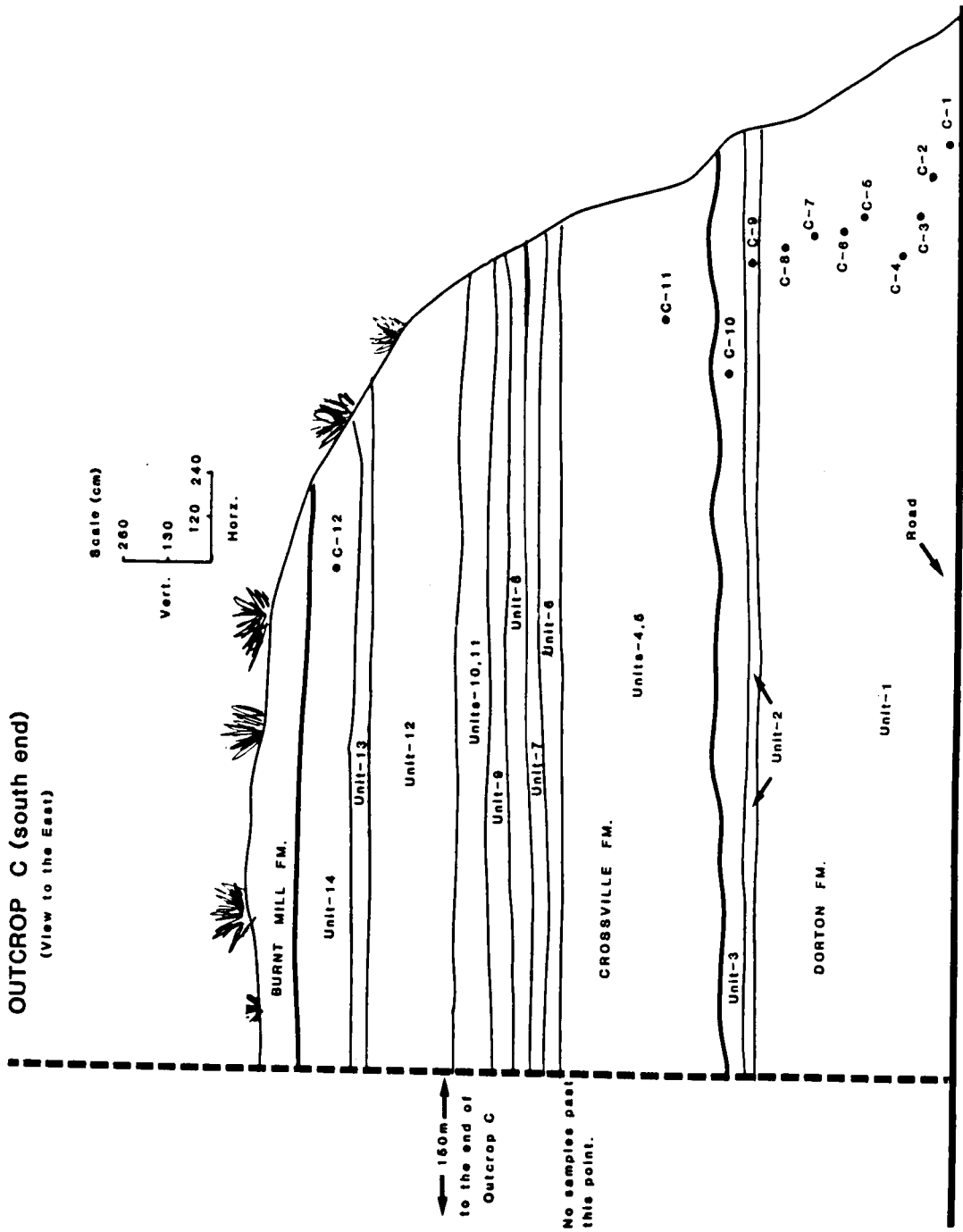


Fig. E.1 (cont'd)

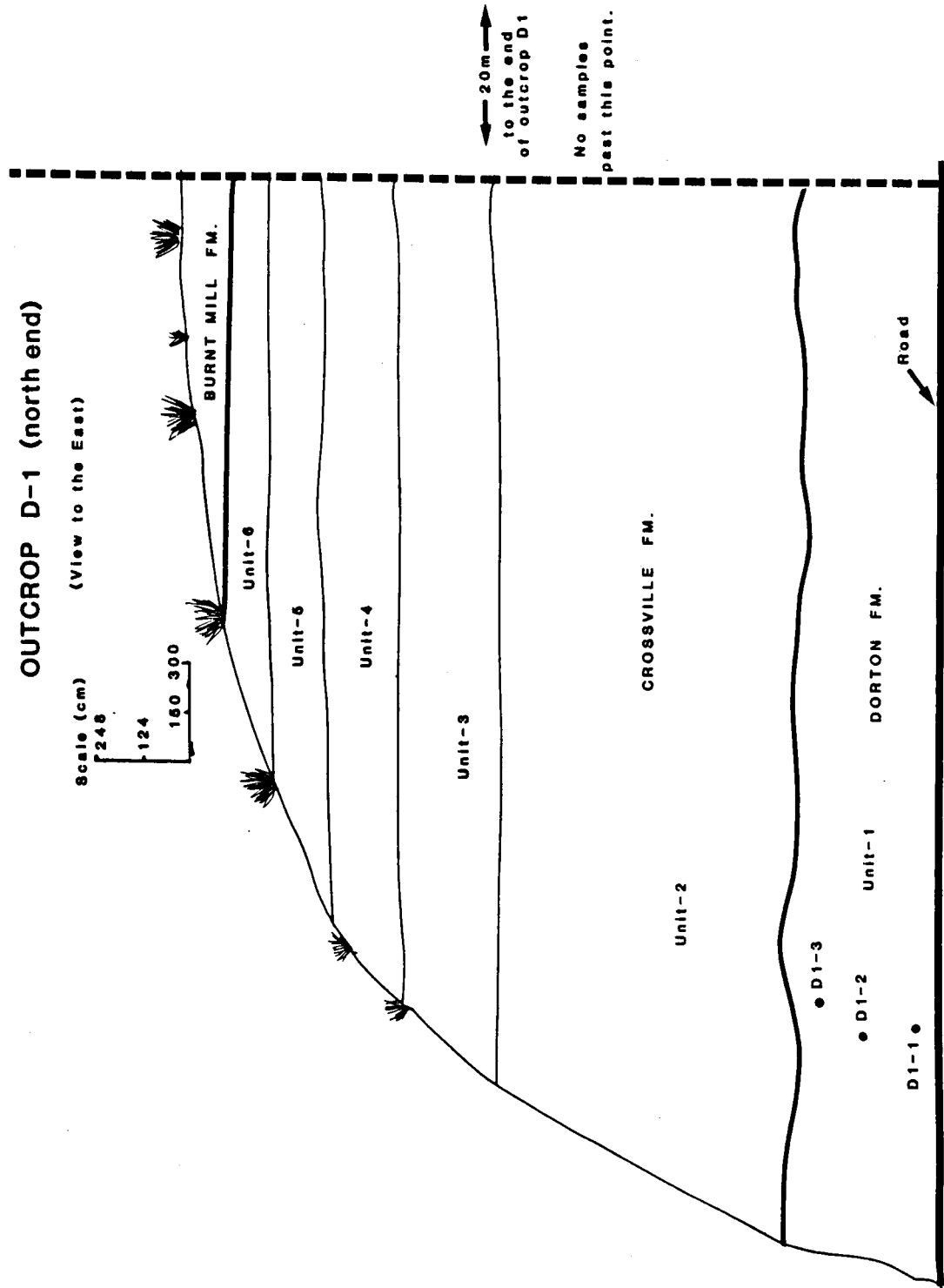


Fig. E.1 (cont'd)

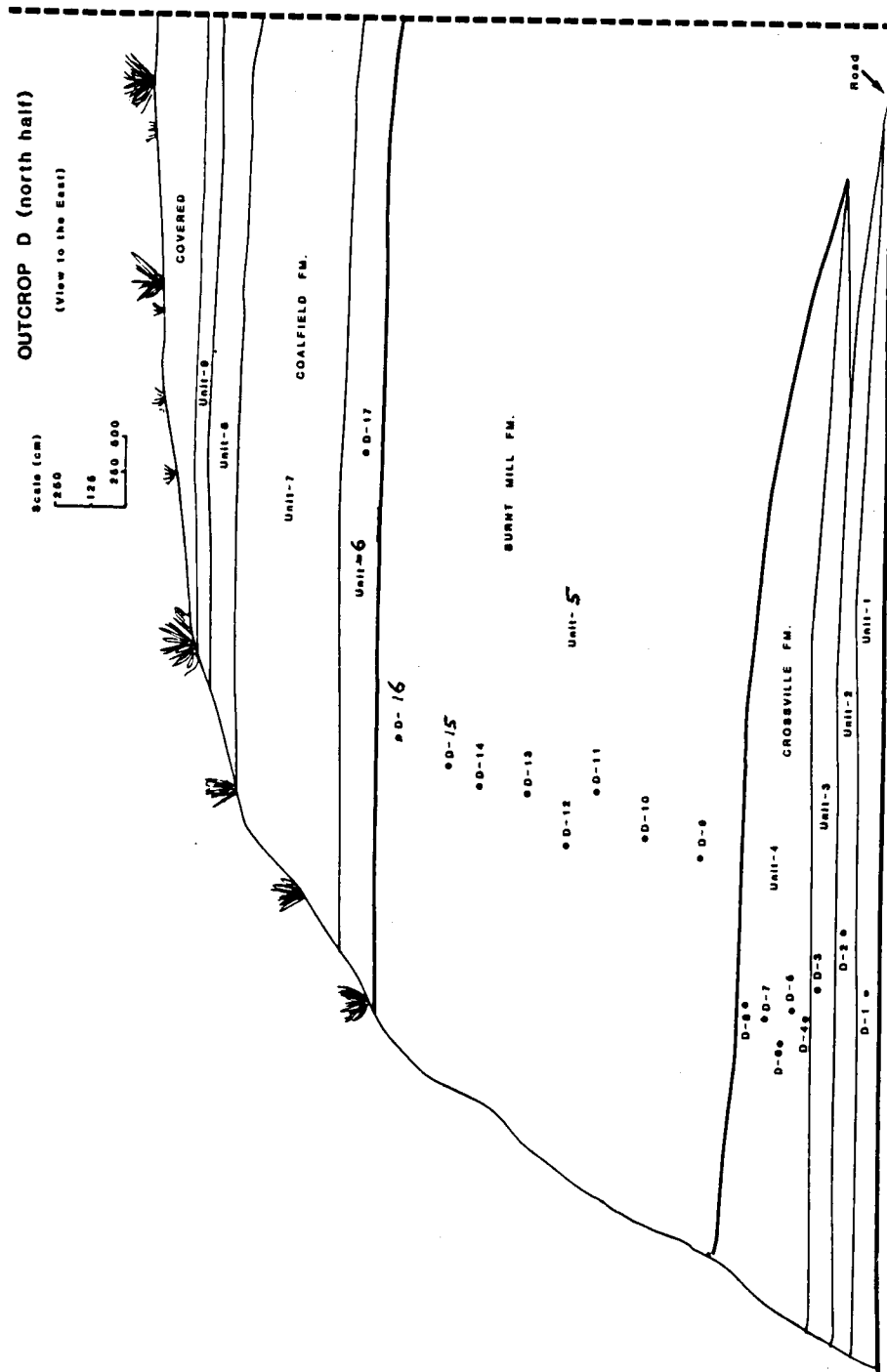


Fig. E.1 (cont'd)

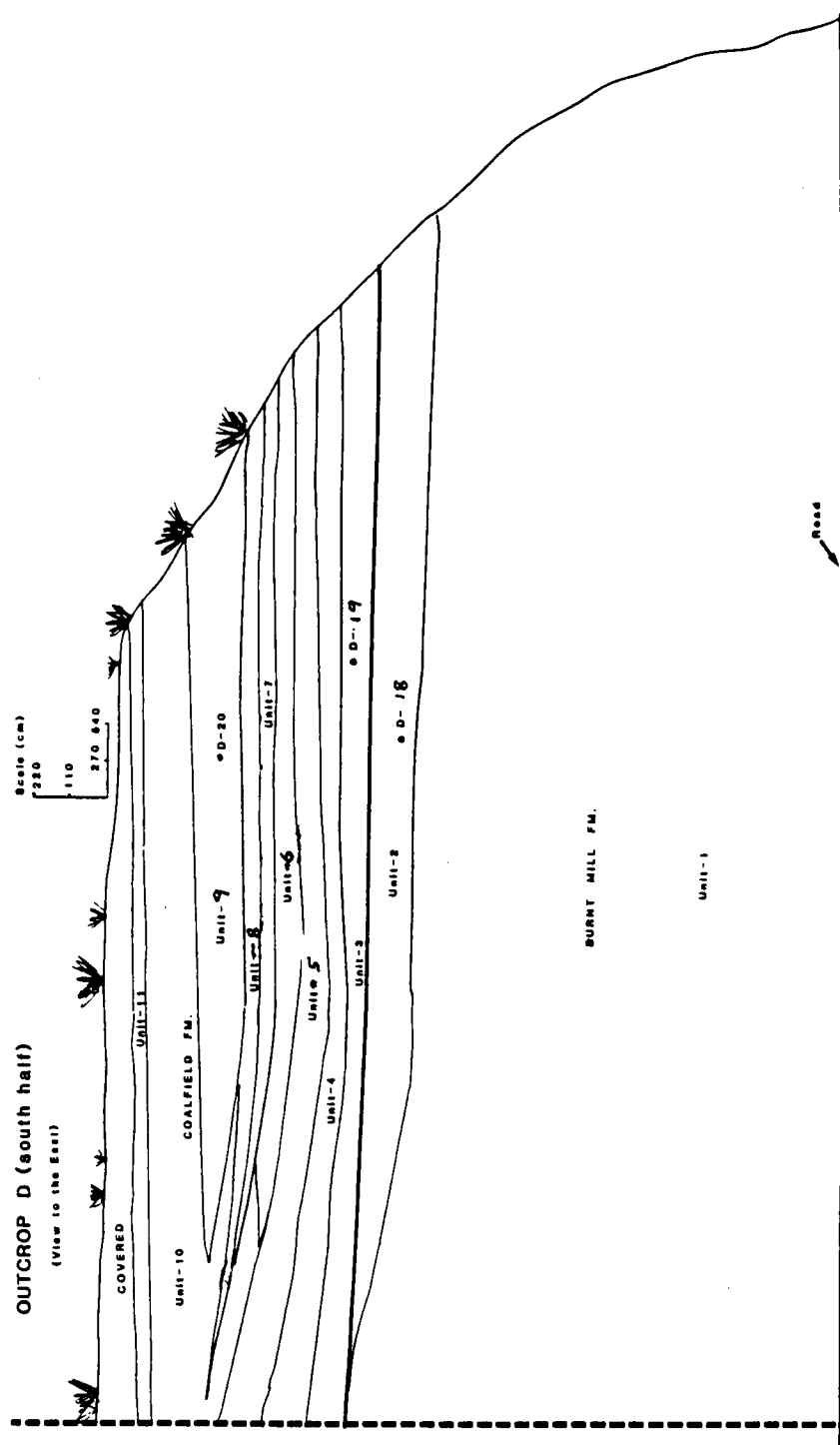


Fig. E.1 (cont'd)

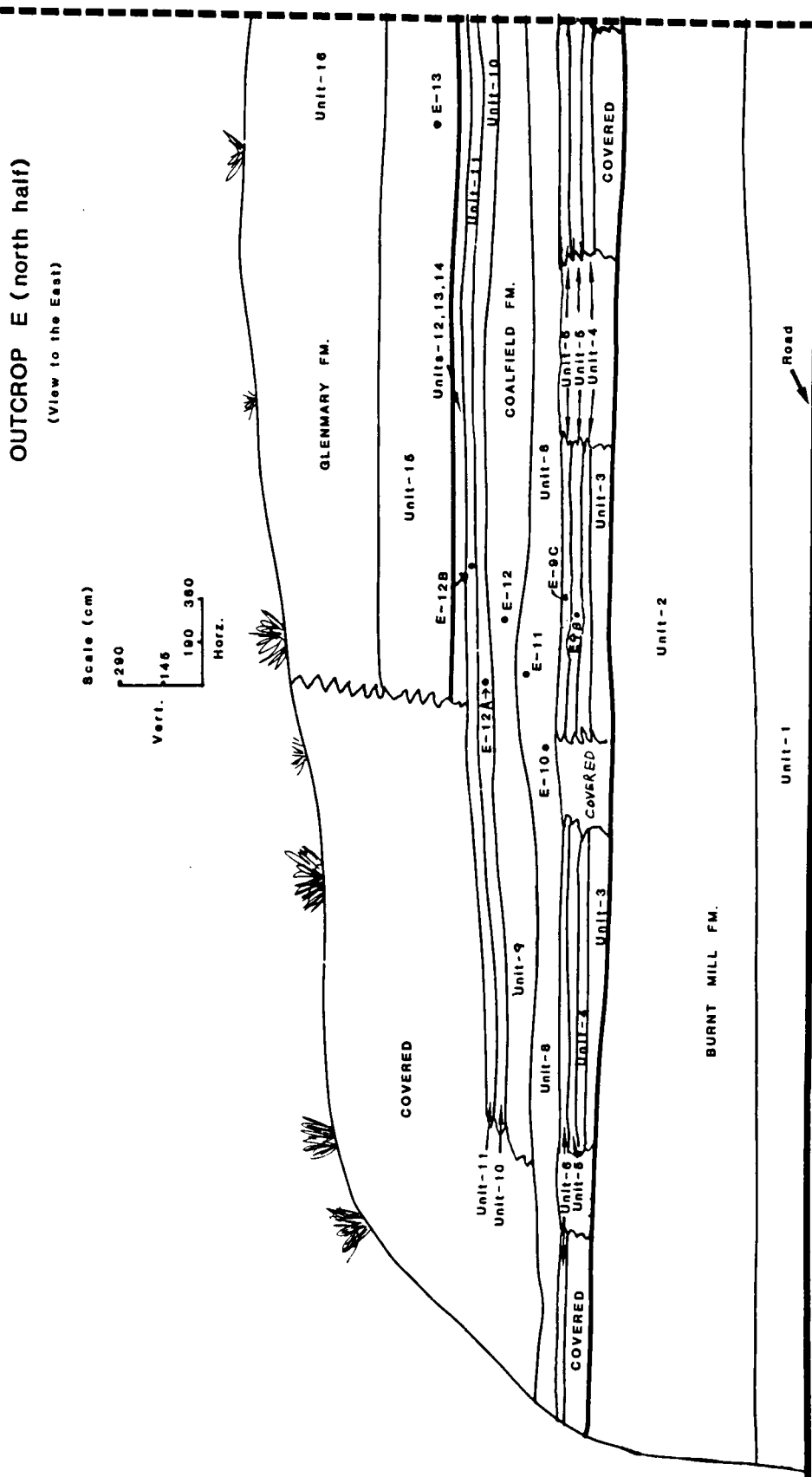


Fig. E.1 (cont'd)

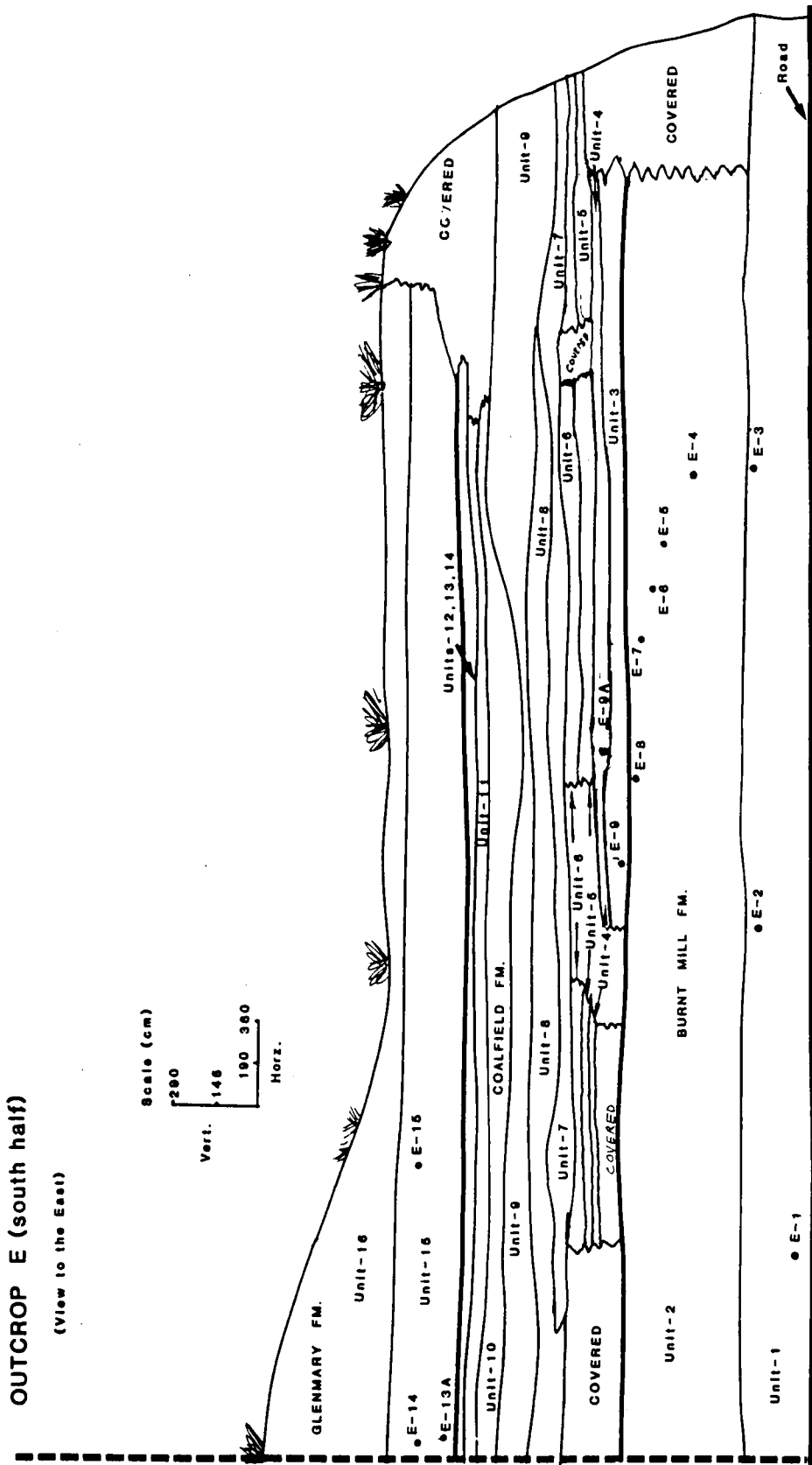


Fig. E.1 (cont'd)

OUTCROP F

(View to the East)

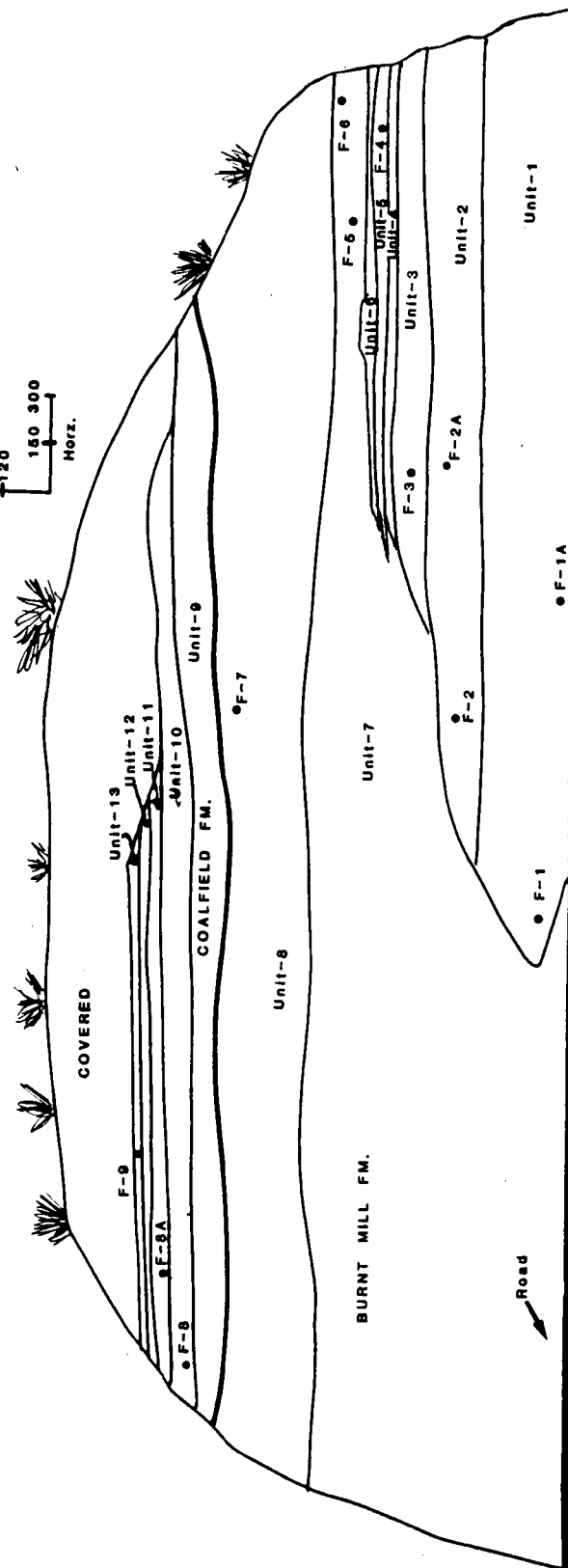
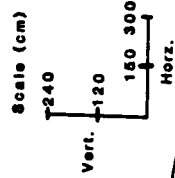


Fig. E.1 (cont'd)

OUTCROP G (north half)

(View to the East)

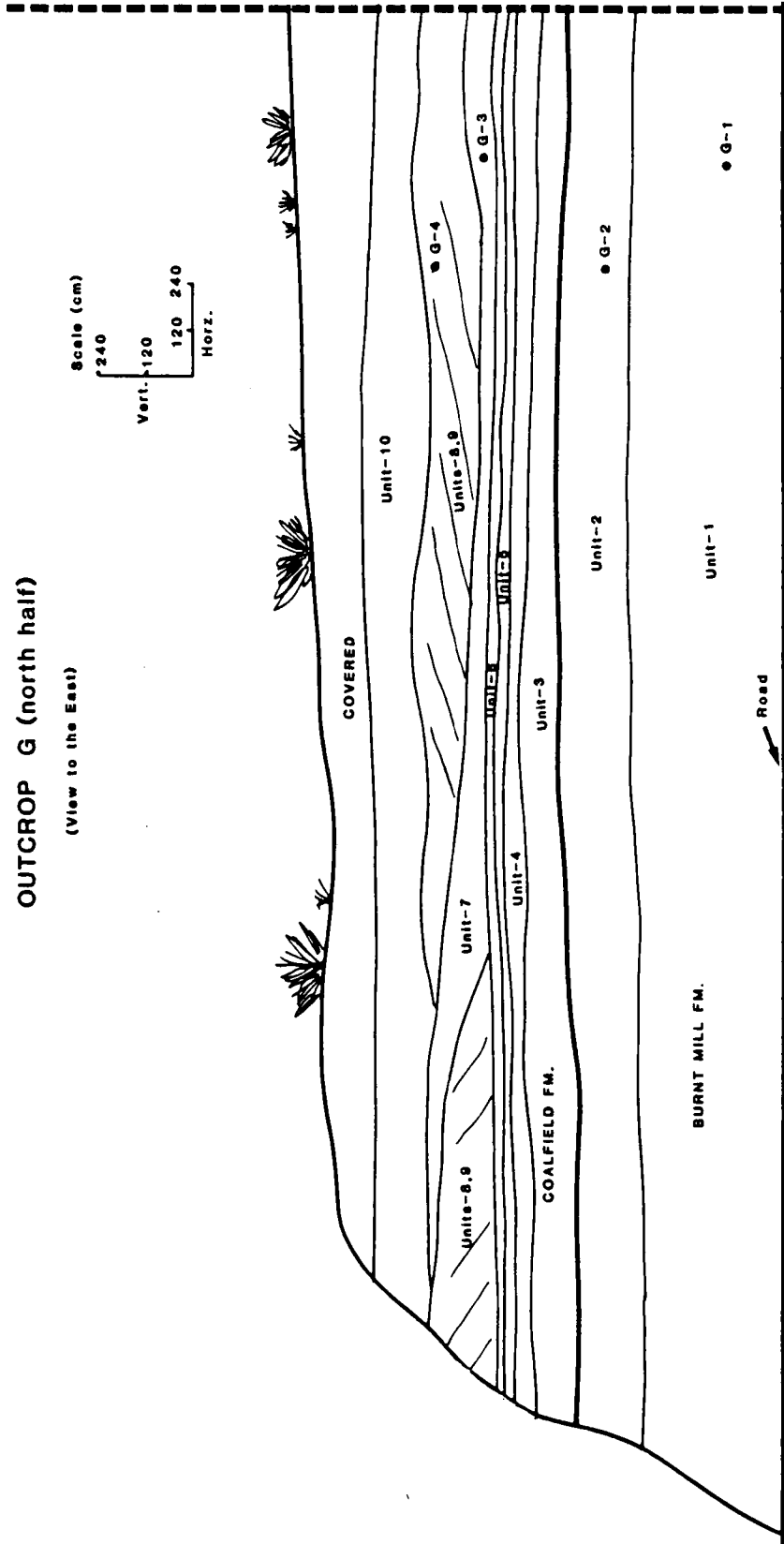
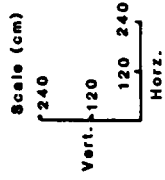


Fig. E.1 (cont'd)

OUTCROP G (south half)
(View to the East)

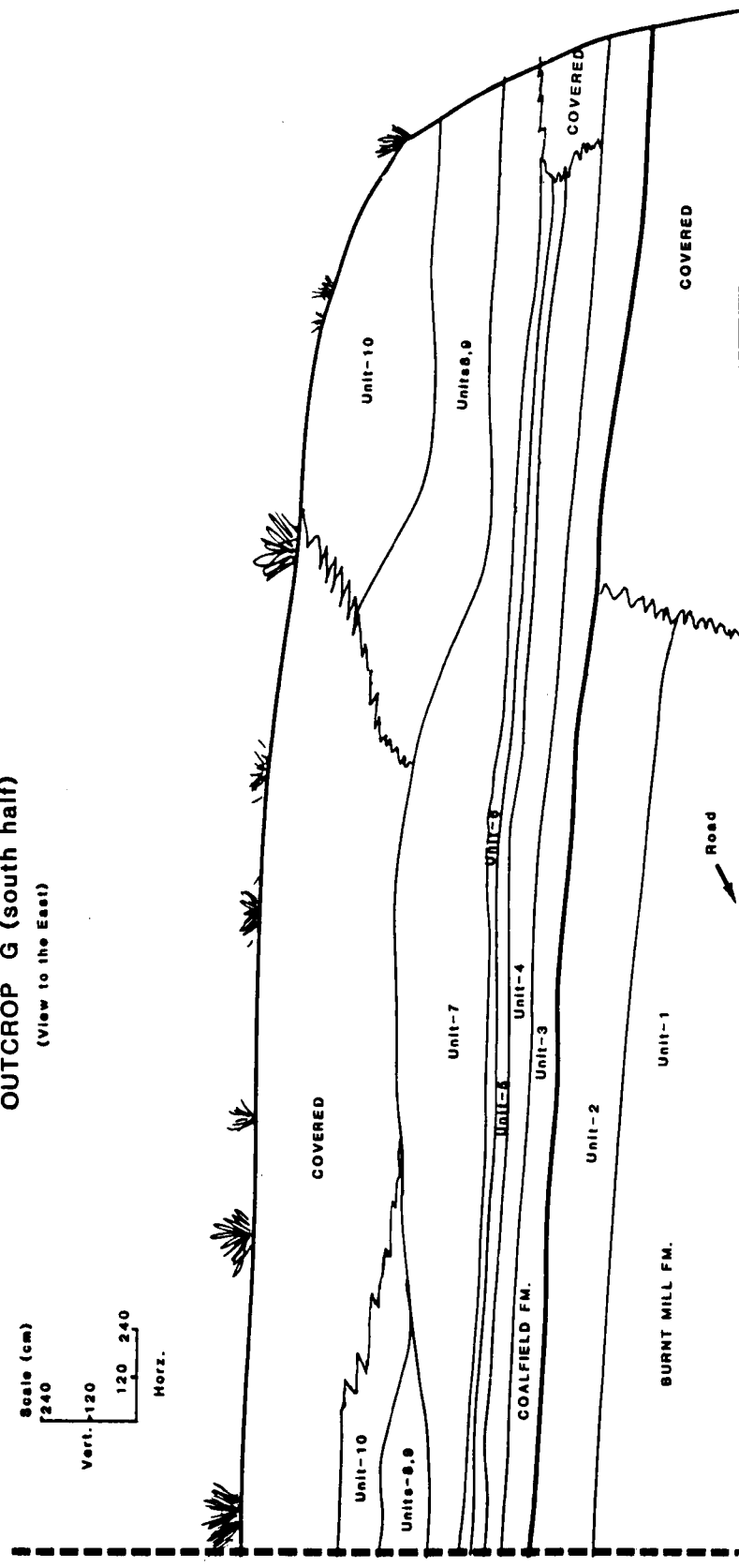
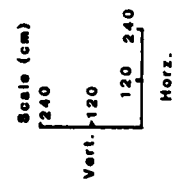


Fig. E.1 (cont'd)

APPENDIX F

FIELD UNITS AND THEIR CORRESPONDING
FACIES AND/OR SUBFACIES

Appendix F relates field units to their corresponding facies and/or subfacies. Field "units" are used in the measured section descriptions (Appendix B) and the photo-mosaic sketches (Appendix F). Facies and/or subfacies are described in the text and may be one or several of these field "units." Thus, this appendix enables the reader to relate a particular field "unit" to a facies and/or subfacies. Facies and/or subfacies can also be related to their corresponding field "unit(s)" with this appendix. Formation names are also listed to further aid the reader.

OUTCROP AA

<u>Field Unit</u>	<u>Facies and/or Subfacies</u>	<u>Formation Name</u>
1	(not in study interval)	Rockcastle*
2	Subfacies 2	Dorton
3	Subfacies 3	Dorton
4	Subfacies 4	Dorton
5	Subfacies 5	Dorton
6	Subfacies 6	Dorton
7	Facies 1	Crossville**

OUTCROP BB

1	Subfacies 5	Dorton*
2	Subfacies 6	Dorton
3	Facies 7; Subfacies 1	Crossville
4	Facies 7; Subfacies 2	Crossville
5	Facies 7; Subfacies 1	Crossville
6	Facies 7; Subfacies 2	Crossville
7	Facies 7; Subfacies 1	Crossville
8	Facies 7; Subfacies 2	Crossville
9	Facies 7; Subfacies 2	Crossville
10	Facies 7; Subfacies 1	Crossville
11	Facies 1	Burnt Mill**

OUTCROP CC

1	Subfacies 6	Dorton*
2	Facies 5	Crossville
3	Facies 6	Crossville
4	Facies 1	Burnt Mill**

*The formation is incomplete at its base.

**The formation is incomplete at its top.

OUTCROP DD

<u>Field Unit</u>	<u>Facies and/or Subfacies</u>	<u>Formation Name</u>
1	Subfacies 6	Dorton*
2	Facies 4	Crossville
3	Facies 6	Crossville
4	Facies 1 (?)	Burnt Mill
5	Facies 2; Subfacies 1 (?)	Coalfield
6	Facies 2; Subfacies 1 (?)	Coalfield
7	Facies 3; Subfacies 2	Coalfield
8	Facies 3; Subfacies 3	Coalfield (coal)
9	(not in study interval)	Glenmary
10	(not in study interval)	Glenmary
11	(not in study interval)	Glenmary
12	(not in study interval)	Glenmary

OUTCROP A

1	(not in study interval)	Rockcastle
2	(start of study interval)	Rex Coal
3	Subfacies 1	Dorton
4	Subfacies 2	Dorton
5	Subfacies 3	Dorton
6	Subfacies 4	Dorton
7	Subfacies 5	Dorton
8	Subfacies 7	Dorton
9	Subfacies 6	Dorton
10	Subfacies 7	Dorton
11	Subfacies 6	Dorton
12	Facies 1	Crossville
13	Facies 2	Crossville
14	Facies 3 (?)	Crossville

OUTCROP A1

1	Subfacies undifferentiated	Dorton
2	Facies undifferentiated	Crossville

*The formation is incomplete at its base.

**The formation is incomplete at its top.

OUTCROP A2

<u>Field Unit</u>	<u>Facies and/or Subfacies</u>	<u>Formation Name</u>
1	Subfacies undifferentiated	Dorton
2	Facies undifferentiated	Crossville

OUTCROP B

1	Subfacies 6	Dorton*
2	Facies 1	Crossville
3	Facies 2; Subfacies 2	Crossville
4	Facies 2; Subfacies 1	Crossville
5	Facies 2; Subfacies 2	Crossville
6	Facies 2; Subfacies 1	Crossville
7	Facies 2; Subfacies 2	Crossville
8	Facies 2; Subfacies 1	Crossville
9	Facies 2; Subfacies 2	Crossville
10	Facies 3	Crossville
11	Facies 3	Crossville
12	Facies 1	Burnt Mill**

OUTCROP C

1	Subfacies 6	Dorton*
2	Subfacies 7	Dorton
3	Subfacies 6	Dorton
4	Facies 1	Crossville
5	Facies 2; Subfacies 2	Crossville
6	Facies 2; Subfacies 1	Crossville
7	Facies 2; Subfacies 2	Crossville
8	Facies 2; Subfacies 1	Crossville
9	Facies 2; Subfacies 2	Crossville
10	Facies 2; Subfacies 1	Crossville
11	Facies 2; Subfacies 2	Crossville
12	Facies 2; Subfacies 1	Crossville
13	Facies 2; Subfacies 2	Crossville
14	Facies 3	Crossville

*The formation is incomplete at its base.

**The formation is incomplete at its top.

OUTCROP D1

<u>Field Unit</u>	<u>Facies and/or Subfacies</u>	<u>Formation Name</u>
1	Subfacies 6	Dorton
2	Facies 1	Crossville
3	Facies 2; Subfacies 2	Crossville
4	Facies 2; Subfacies 2	Crossville
5	Facies 3	Crossville
6	Facies 3	Crossville
7	Facies 3	Crossville

OUTCROP D (North End)

1	Facies 3	Crossville*
2	Facies 3	Crossville
3	Facies 3	Crossville
4	Facies 1	Burnt Mill
5	Facies 1	Burnt Mill
6	Facies 2; Subfacies 2	Coalfield (upper)
7	Facies 3; Subfacies 2	Coalfield (upper)
8	Facies 3; Subfacies 2	Coalfield (upper)
9	Facies 3; Subfacies 3	Coalfield (upper)

OUTCROP D (South End)

1	Facies 1	Burnt Mill
2	Facies 2; Subfacies 1	Burnt Mill
3	Facies 2; Subfacies 2	Burnt Mill
4	Facies 2; Subfacies 2	Coalfield (lower)
5	Facies 2; Subfacies 2	Coalfield (lower)
6	Facies 2; Subfacies 3	Coalfield (lower)
7	Facies 2; Subfacies 3	Coalfield (lower)
8	Facies 2; Subfacies 3	Coalfield (lower)
9	Facies 2; Subfacies 3	Coalfield (upper)
10	Facies 3; Subfacies 2	Coalfield (upper)
11	Facies 3; Subfacies 3	Coalfield (upper)

*The formation is incomplete at its base.

**The formation is incomplete at its top.

OUTCROP E

<u>Field Unit</u>	<u>Facies and/or Subfacies</u>	<u>Formation Name</u>
1	Facies 1	Burnt Mill*
2	Facies 2; Subfacies 1	Burnt Mill
3	Facies 2; Subfacies 2	Coalfield (lower)
4	Facies 3; Subfacies 1	Coalfield (lower)
5	Facies 3; Subfacies 2	Coalfield (lower)
6	Facies 3; Subfacies 3	Coalfield (lower)
7	Facies 2; Subfacies 2	Coalfield (upper)
8	Facies 2; Subfacies 2	Coalfield (upper)
9	Facies 2; Subfacies 1	Coalfield (upper)
10	Facies 3; Subfacies 1	Coalfield (upper)
11	Facies 3; Subfacies 1	Coalfield (upper)
12	Facies 3; Subfacies 2	Coalfield (upper)
13	Facies 3; Subfacies 3	Coalfield (upper)
14	Facies 3; Subfacies 3	Coalfield (upper)
15	(not in study area)	Glenmary
16	(not in study area)	Glenmary

OUTCROP F

1	Facies 4; Subfacies 1	Burnt Mill*
2	Facies 4; Subfacies 2	Burnt Mill
3	Facies 4; Subfacies 3	Burnt Mill
4	Facies 4; Subfacies 4	Burnt Mill
5	Facies 4; Subfacies 1	Burnt Mill
6	Facies 5; Subfacies 2	Burnt Mill
7	Facies 1	Burnt Mill
8	Facies 2; Subfacies 1	Burnt Mill
9	Facies 2; Subfacies 2	Coalfield (lower)
10	Facies 2; Subfacies 2	Coalfield (lower)
11	Facies 3; Subfacies 1	Coalfield (lower)
12	Facies 3; Subfacies 2	Coalfield (lower)
13	Facies 3; Subfacies 3	Coalfield (lower)
14	Facies 2; Subfacies 2	Coalfield (upper)**

*The formation is incomplete at its base.

**The formation is incomplete at its top.

OUTCROP G

<u>Field Unit</u>	<u>Facies and/or Subfacies</u>	<u>Formation Name</u>
1	Facies 1	Burnt Mill
2	Facies 2; Subfacies 1	Coalfield (lower)**
3	Facies 2; Subfacies 2	Coalfield (lower)
4	Facies 3; Subfacies 1	Coalfield (lower)
5	Facies 3; Subfacies 2	Coalfield (lower)
6	Facies 3; Subfacies 3	Coalfield (lower)
7	Facies 1; Subfacies 2	Coalfield (lower)
8	Facies 1; Subfacies 1	Coalfield (lower)
9	Facies 1; Subfacies 1	Coalfield (lower)
10	Facies 1; Subfacies 1	Coalfield (lower)

**The formation is incomplete at its top.

VITA

Douglas James Schnoebelen was born in Fort Riley, Kansas, on February 4th, 1957. His parents moved to Riverside, Iowa, when he was four years old. There he attended St. Mary's elementary school and graduated from Highland High School in May of 1975.

In August of that same year he entered The University of Iowa, to pursue a major in geology. He was active in the geology club, and was also a member of the University concert band. Doug funded his education by working as a groundskeeper during his undergraduate career. He graduated from The University of Iowa with a major in geology in July, 1979.

On September 15th, 1979 Doug married the former Nancy Cushing, also of Riverside, Iowa. He accepted a teaching assistantship at The University of Tennessee and entered their graduate program in September that same year. He received his Master of Science degree in June, 1983.

The author is a member of the American Association of Petroleum Geologists and the Society of Economic Mineralogists and Paleontologists. He served as chapter president for Sigma Gamma Epsilon (honor society for the earth sciences) while at Tennessee.

At this writing, Doug is employed as a production geologist with Exxon in Midland, Texas.