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CHEROKEE SANDSTONES AND RELATED FACIES OF CENTRAL IOWA
AN EXAMINATION OF TECTONIC SETTING AND DEPOSITIONAL ENVIRONMENTS

a field trip guide with research papers for the meeting of the North-Central Section of the Geological Society of America.

Edited by John Lemish, Daniel R. Burggraf, Jr., and Howard J. White
with additional papers by R.E. Chamberlain, C.G. Lindsay, E.W. Mason, and R.C. Palmquist

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With additional contributions
by Rick E. Chamberlain, Curtis G. Lindsay,
Edward W. Mason, and Robert C. Palmquist

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A field trip guide prepared for the 1981 North-Central Section Meeting of the Geological Society of America, sponsored by the Department of Earth Sciences, Iowa State University.

IOWA GEOLOGICAL SURVEY
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The stratigraphic nomenclature and classification used in portions of this report do not necessarily conform to the current formal usage of the Iowa Geological Survey.

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PART I: INTRODUCTION AND REGIONAL GEOLOGY

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INTRODUCTION

This field trip is an outgrowth of a study sponsored by the U.S. Bureau of Mines concerning the geology and occurrence of the deep coal in the Forest City Basin. The occurrence of numerous subsurface sandstone bodies in the Cherokee Group led to a study of exposed sandstone bodies and related facies in order to understand their environmental significance as a basis for interpretation of the subsurface geology.

The purpose of this field trip is to examine exposures of Middle Pennsylvanian, Desmoinesian Series strata in central Iowa (figure 1) and, in particular, of the coal-bearing Cherokee Group. Our goal is to concentrate on the sandstone and related lithofacies of these strata, observing characteristics of bedding, body geometry, lithology, texture, and primary sedimentary structures and to interpret from these the depositional environments dominant in the area during part of the Middle Pennsylvanian Period.

The field guide is divided into three major parts as follows:

Part I - Introduction and Regional Geology

Part II - Facies and Depositional Environments of the Cherokee Group in Webster County, Iowa

Part III - Road Log and Stop Descriptions

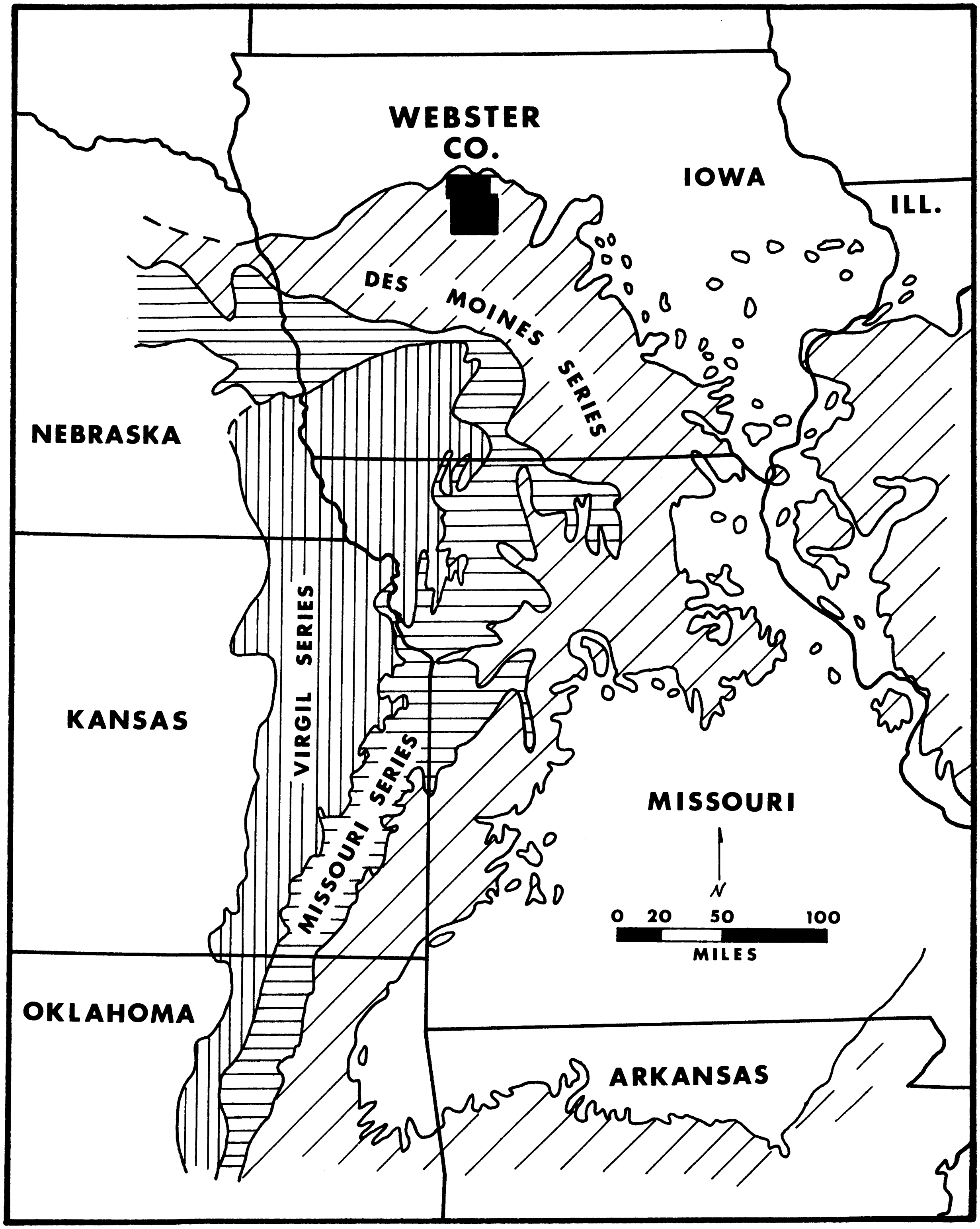

Figure 1. Index map showing field trip area in Webster County. The geologic map showing distribution of Pennsylvanian rocks is presented.

Acknowledgments

This guidebook is the culmination of the efforts of many people presently or formerly of the Iowa State University Department of Earth Sciences. Impetus for the project and its supervision resulted from the work of Dr. John Lemish. His graduate students, Rick Chamberlain and Ed Mason, located, described, and sampled outcrops along the valleys of the Des Moines and Raccoon rivers in central Iowa as part of the deep coal study for the U.S. Bureau of Mines. These outcrop studies and subsequent laboratory analyses were supervised by Daniel R. Burggraf, Jr., who, with Howard J. White, completed the outcrop examinations and provided interpretations for the stratigraphic and sedimentologic data. Preliminary mineralogical studies were undertaken by Howard J. White and Curtis Lindsay. Dr. Carl F. Vondra assisted in organization of the studies, and Dr. Robert Palmquist provided information regarding the Pleistocene geomorphology of the field trip area. Dr. Bert E. Nordlie and the Department of Earth Sciences provided financial support. Dr. Donald Biggs, chairman of the North-Central Section Meeting, is thanked for his advice. Various aspects of the field trip and guidebook were aided by Eric Nielson, John Madsen, Craig Feibel, and Sen-Chi Chang. Figures for the guidebook were prepared by the authors and by Greg Thompson. Thanks are due to the Iowa Department of Conservation for permission to collect rock samples in a number of Iowa's state parks. Sincere thanks are also extended to Mr. and Mrs. Francis Shipman, owners of the Holliday Creek Appaloosa Ranch, who permitted access to their property during all phases of this project. Typing of the original manuscript was completed by Mrs. Carla Jacobson whose help is gratefully acknowledged.

GEOLOGIC SETTING

The area of this study is located on the northwest flank of the Forest City Basin. Major structural elements of regional extent (figure 2) include the Wisconsin Dome to the north, the Mississippi Arch to the east, the Ozark Dome and Bourbon Arch to the south, and the Nemaha Ridge to the west. In Iowa, the Forest City Basin forms a shallow syncline plunging southward toward the depositional center of the Basin in northern Missouri.

The Paleozoic and younger rocks in the Basin reach a thickness of over 5,200 feet in southwestern Iowa (figure 3). The Paleozoic section includes Cambrian sands overlain by Ordovician, Silurian, Devonian, and Mississippian sediments, predominantly carbonates. Their combined thickness is about 3,400 feet. The Pennsylvanian System reaches 1,700 feet in thickness in the southwestern part of the state and covers 20,000 square miles of Iowa. These rocks are unconformably overlain by Cretaceous sandstone, shale, and limestone which have a total thickness of 500 feet but locally seldom exceed 100 feet. A cover of Pleistocene drift from 0 to 500 feet thick mantles much of the state.

Six major unconformities exist within the Paleozoic section: at the bases of the St. Peter Sandstone, Maquoketa Formation and Maple Mill Shale, and at the tops of the Gilmore City Limestone (Mississippian), the Mississippian System, and the Desmoinesian Series. Minor unconformities were developed at various intervals throughout the Paleozoic section. The unconformity of greatest importance influencing subsequent deposition of the Pennsylvanian System is the widespread erosion surface with over 200 feet of relief which developed on the exposed Mississippian rocks during the Chester-Morrowan interval.

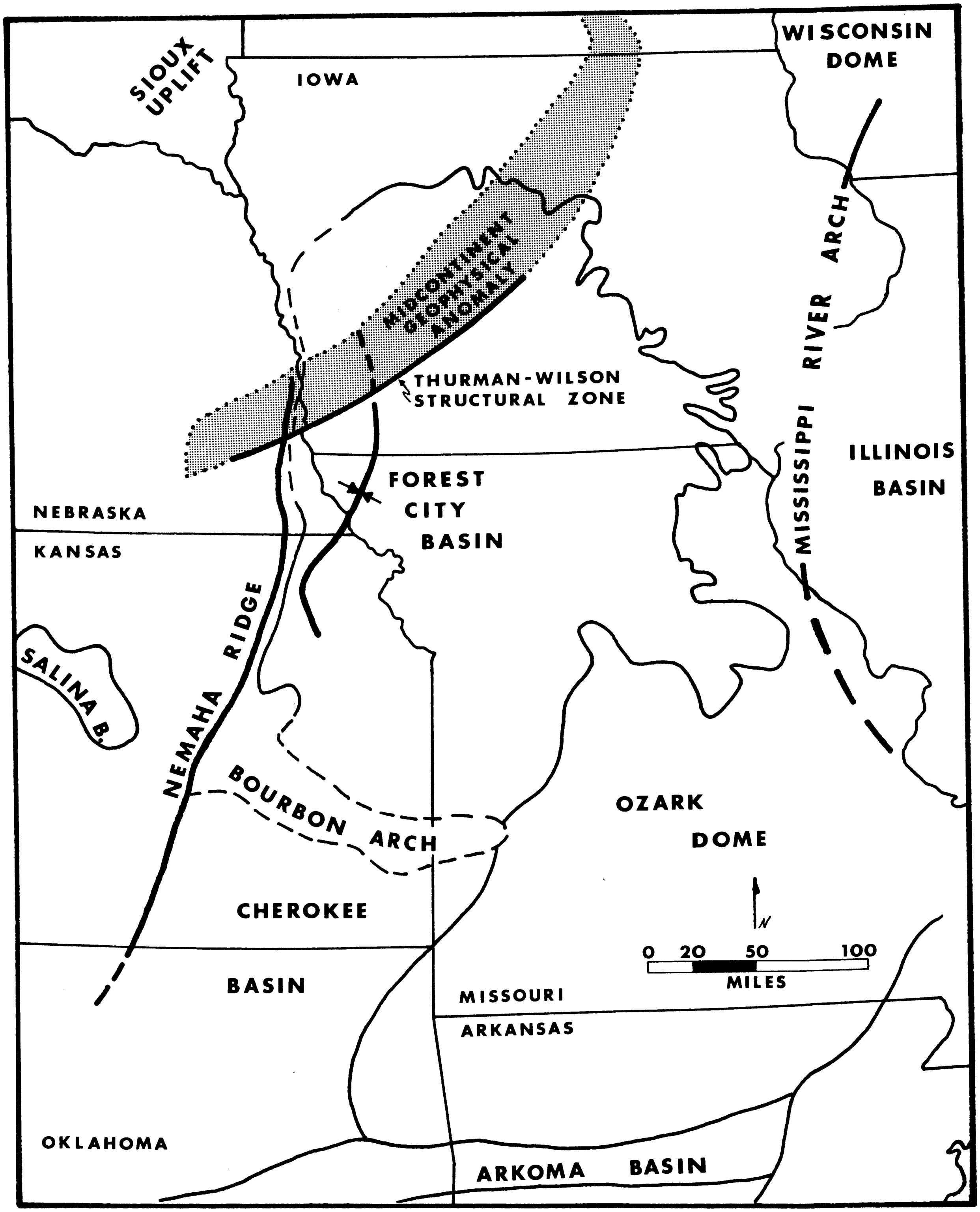

Figure 2. Major structural features of the midcontinent region.

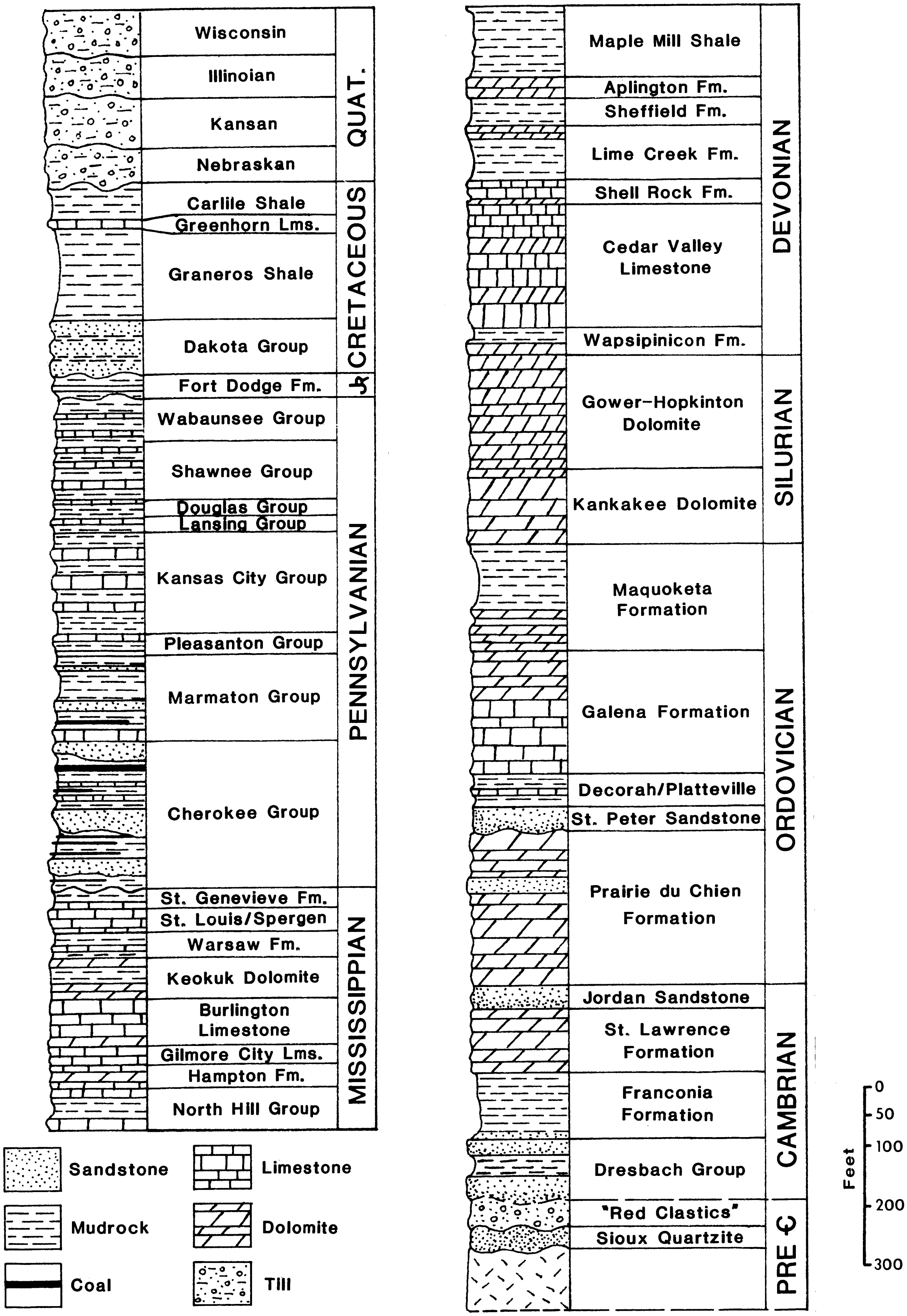

Figure 3. Generalized stratigraphic column for Iowa.

The major subsurface feature in the basin is the Midcontinent Geophysical Anomaly (figure 2) trending northeast across Iowa from Nebraska to the Duluth area of Minnesota (Coons, et al., 1967; Van Eck, et al., 1979). This feature consists of a series of gravity and magnetic highs and has been interpreted as a rift containing basalts and associated sediments of Keweenawan age. It presently is considered to be a fault-bounded horst about 40 or more miles wide flanked by a great thickness of clastic fill. This feature has been tectonically active exerting basement control on structural development within the basin since the Precambrian. A series of northwest trending structures along the southern flank, called the Thurman-Wilson Structural Zone, includes faults and anticlines (i.e. -- the Redfield and Ames anticlines). Over 400 feet of structural relief in Paleozoic rocks have been related to this positive element in the basement (figures 2 and 4). The study area of the field trip is situated on the northern margin of this feature.

DESMOINESIAN SERIES STRATIGRAPHY

The Desmoinesian Series consists of two groups, the predominantly clastic Cherokee Group and the overlying Marmaton (figure 5). The Marmaton and Cherokee Groups are of major economic importance because of their coal deposits. With the exception of the Mystic seam in the Marmaton and a minor amount of production from the Nodaway seam in the Wabaunsee Group (Virgilian Series), the bulk of Iowa's coal resources base occurs within the Cherokee.

Stratigraphic study by Wanless (1975) and McKee and Crosby (1975) indicates that Atokan Series sediments occur in the subsurface beneath the Desmoinesian Series. Up to 400 feet of Atokan sediments may be present as sandstone and shale similar to Lower Cherokee clastic rocks. The Atokan is recognized in Illinois and Missouri. It is difficult to separate these units in the subsurface records in Iowa, and as a result, Atokan sediments are tentatively included as part of the Cherokee Group.

The overlying Missourian and Virgilian Series (figure 5) are deposited on top of the Desmoinesian as part of an overall marine transgression and represents an onlap sequence with numerous transgressive and regressive phases (related to cyclothem deposits) (Heckel, 1977). Marine deposits of the Cherokee Group occur throughout eastern Iowa and are evidence that Pennsylvanian seas traversed the entire state. By the time of deposition of the Upper Cherokee, the Illinois and Forest City Basins were connected. Thus, the present boundaries of the Cherokee Group represent the erosional remnants rather than actual aerial extent of Cherokee Seas in the midcontinent (Dapples and Hopkins, 1969).

The Cherokee Group is composed primarily of deltaic sediments deposited on an irregular Mississippian erosion surface of considerable relief. As a result, lithologies are extremely variable laterally and vertically and consist of mudrocks with subordinate sandstone and limestone and localized coal seams. Factors contributing to basal lithologic variability include inherited Mississippian paleotopography, pre-Pennsylvanian structural trends, contemporaneous structural movement, and differential subsidence and related sediment compaction. These elements exerted a major control on the distribution of the Cherokee sand bodies.

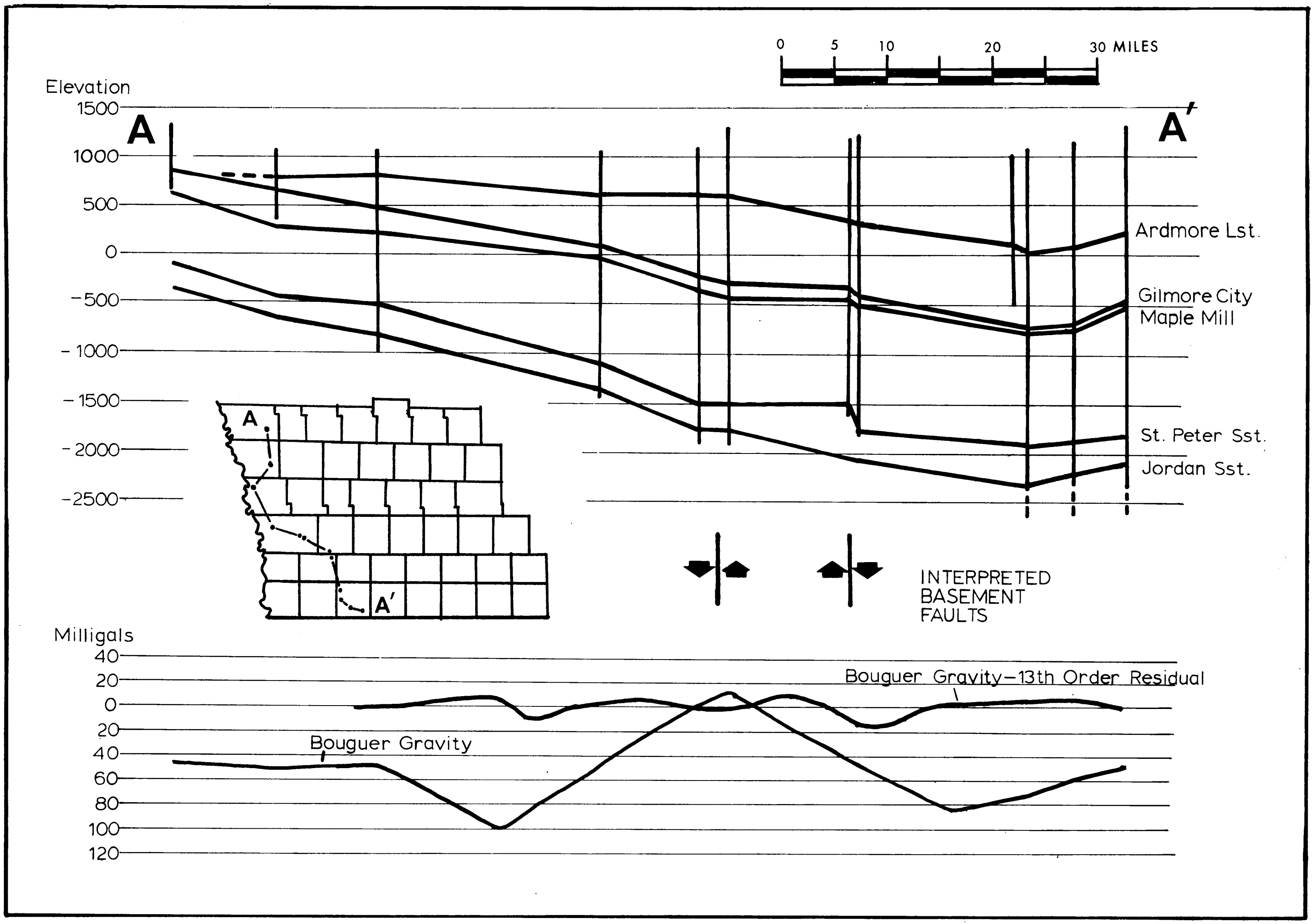

Figure 4. Structure section on NW-SE direction across the Thurman-Wilson structural zone showing the structure and corresponding gravity anomaly. Displacement in the lower Paleozoic is greater than displacement in the upper Paleozoic indicating continued tectonic activity along the zone.

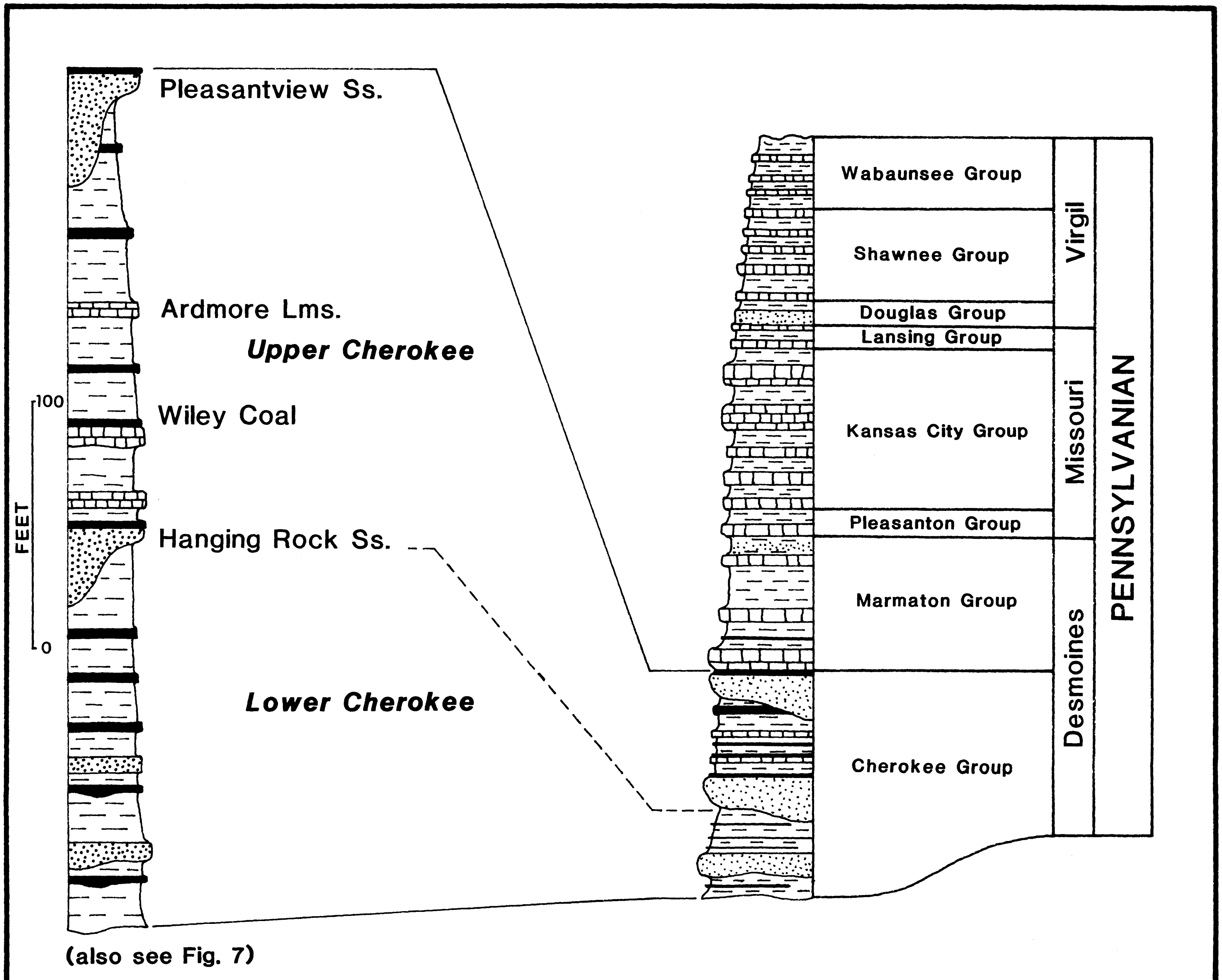

Figure 5. Detailed stratigraphy of the Cherokee Group and its relationship to other Pennsylvanian rocks of Iowa.

The overlying Marmaton Group, in general, exhibits the characteristics of marine-dominated sedimentation. It has been divided into four cyclothems: the St. David, Bereton, Sparland, and Gimlet (Wanless and Wright, 1978), and these were subdivided into seven formations which can be generally recognized over wide areas (figure 6). The Marmaton Group is composed of two basic lithologic associations: a marine transgressive phase represented by their persistent limestones and minor black shales and a regressive phase represented by thin sandstones, shales, underclays, and coals. The coals and carbonaceous zones occur at several stratigraphic horizons representing distal deltaic platforms built up during regressive phases. The coals tend to be thin, and only two have been mined, the Lonsdale and the Mystic (Keys, 1894). The Mystic averages 2 1/2 to 3 feet in thickness across south-central Iowa and nothern Missouri. Correlative deltaic coals of the Illinois Basin are much thicker; the Herrin (No. 6) coal represents one of the most widely mined coals in Illinois and is the equivalent of the Mystic coal seam (Lexington in Missouri).

Characteristics of the Cherokee Group

In Iowa the Cherokee Group (Haworth and Kirk, 1894) is defined as those rocks between the overlying Ft. Scott Formation of the Marmaton Group and the erosional surface formed on the Mississippian aged rocks. Cherokee Group nomenclature varies according to location in Iowa. The correlations are tenuous because of lateral and vertical lithologic variability prevalent in the lower Cherokee. Many of the units of the upper portion of the Cherokee in southeastern and south-central Iowa where they were named may extend to north-central Iowa. Nevertheless, the Cherokee has been subdivided into an Upper and Lower unit (figure 7) with an indistinct boundary; it is generally agreed that the base of the Upper Cherokee coincides with the Hanging Rock Sandstone (Landis and Van Eck, 1965).

In subsurface studies of the geology of the deep coal in the Iowa portion of the Forest City Basin, correlations with the Cherokee units, shown in figure 7, are difficult to achieve. The one prominent unit which serves as a marker bed is the Ardmore limestone, readily recognizable throughout the subsurface from Iowa to Oklahoma. Thus, it is used to establish the position of sandstone bodies in the subsurface.

Cherokee Lithologies

Derynck (1980) analyzed the "undifferentiated" Cherokee Group (Cherokee Group and rocks of the Atokan Series combined) for lithologic composition based on well log information in southwestern Iowa. His results indicate that the group is composed of 80% shales, 17% sandstones and siltstones, 3% limestones, dolomites, coals, and underclays; 14% of the shales are black. Approximately 3.2 feet of coal occur per 400 feet of section, less than 1% in overall composition.

Shales are commonly gray, silty, and/or sandy with interlaminations of gray siltstone or fine-grained sandstone common throughout. Some gray shales are calcareous with fossils or calcareous ironstone concretions. The black shales are laminated, phosphatic in part, and commonly pyritic.

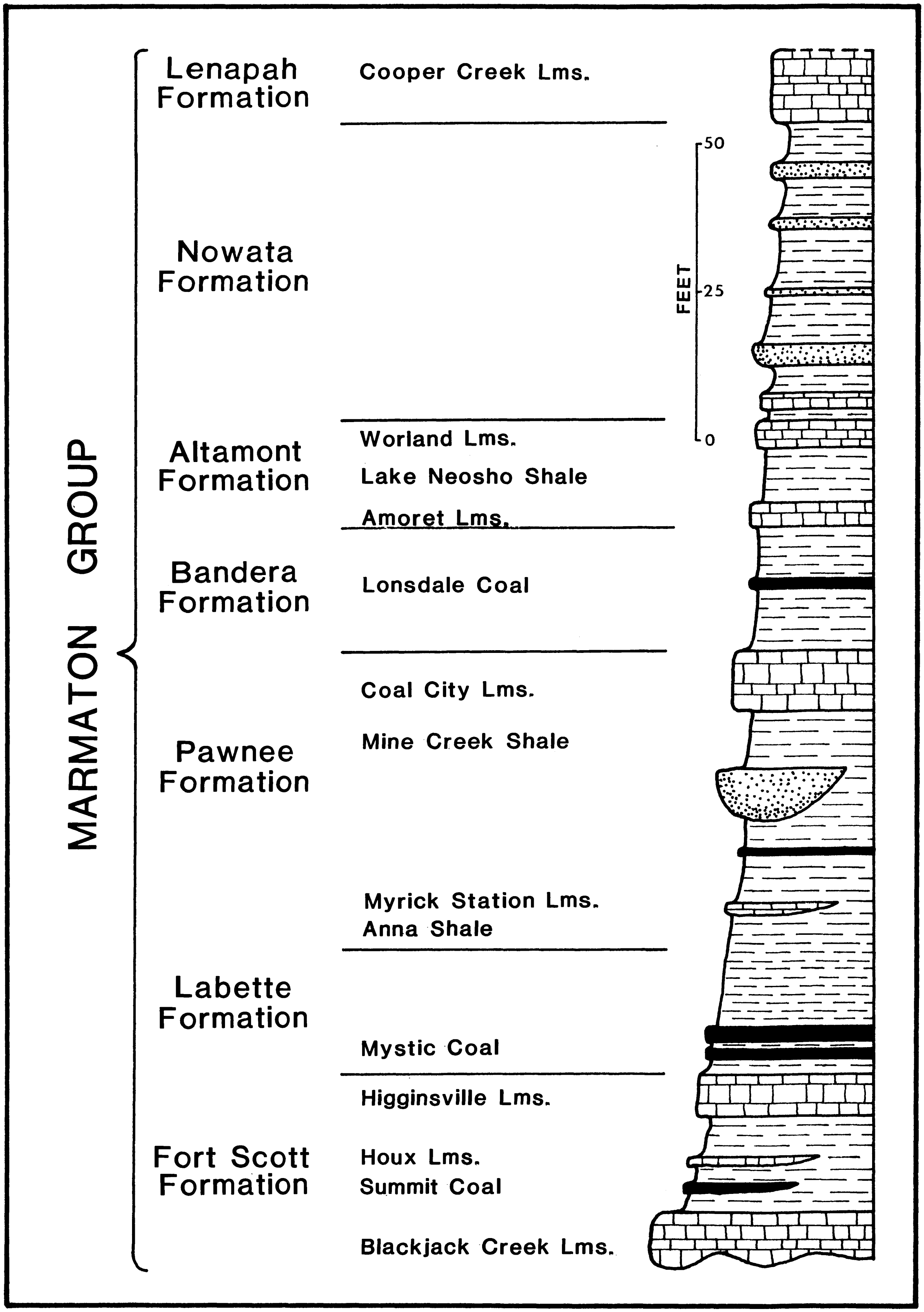

Figure 6. Detailed stratigraphy of the Marmaton Group.

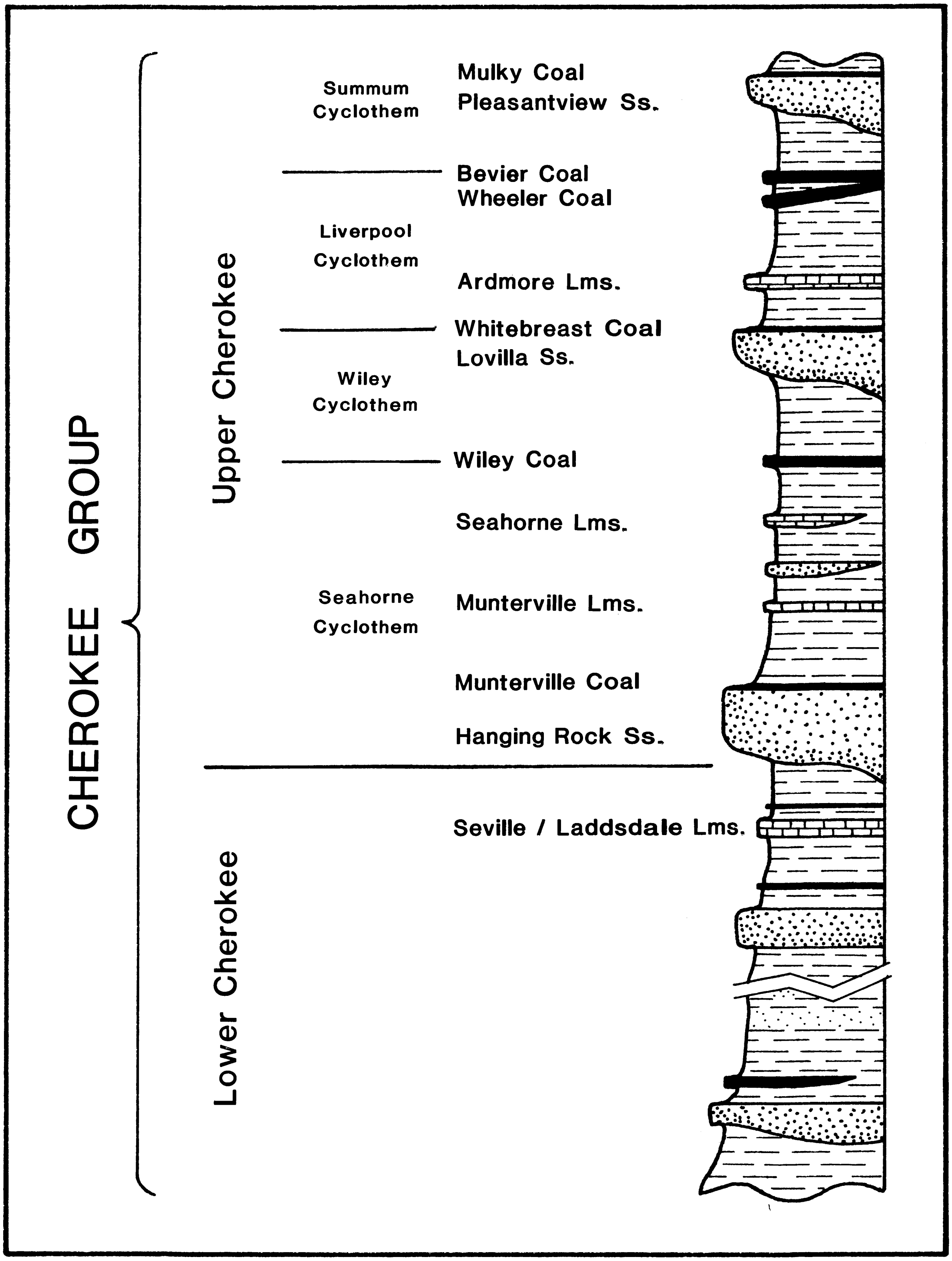

Figure 7. Detailed stratigraphy of the Cherokee Group and component cyclothems.

The sandstones are generally very fine-grained to fine-grained and argillaceous. Thin sand units typically grade into thicker units, which are commonly massive to cross-bedded with erosional basal contacts. Thick units consist of vertically stacked sand bodies typified by the sandstone exposed at Redrock Reservoir, Marion County, Iowa, and likely indicate possible structural or topographic control on sedimentation (Brown, 1975). Offsetting of sand units within the Cherokee may be evidence of compactional influence as well (Derynck, 1980; Mason, 1980).

Limestones are light gray, fossiliferous, and generally less than one foot thick. Frequently, limestones are represented by isolated nodules embedded in a shale or mudstone. Underclays are light gray, silty, and/or sandy and generally about two to four feet in thickness (Derynck, 1980).

Subsurface studies by Reese (1977) and Mason (1980) in the Madrid area of central Iowa provide evidence of the distribution of Cherokee lithologies. Their studies indicate that the Cherokee section averages 350 feet in thickness with limestone units occurring only in the uppermost 80-100 feet of the section. Thus, the Cherokee strata appear to become more dominated by continental sedimentation to the northeast.

Experience to date indicates that the Lower Cherokee, especially in Central Iowa, is characteristically more clastic than the Upper Cherokee. It is characterized by a scarcity of key marker horizons and consists of units of variable thickness and lithology, including lenticular and local sandstones, marine limestones (characteristically represented by isolated concretionary masses within shale units), and localized lenticular coal beds. The one limestone which is recognizable and persistent is the Laddsdale or Seville Limestone. It is characteristically dark gray, hard to earthy, fossiliferous, and lenticular, grading locally to a fossiliferous sandstone. It is known to exist in southeast Iowa (Davis Co.), but its presence has not been recognized in the Fort Dodge area.

The Upper Cherokee is far more consistent in lithologic character and demonstrates cyclothemic characteristics. It consists of several persistent limestone, sandstone, and coal units (figure 7). In southeastern Iowa the basal unit is the Hanging Rock Sandstone (Landis and Van Eck, 1965) which directly underlies the Munterville Coal (figure 7). Recognizable marine and continental units alternate throughout the section with the Whitebreast Coal and Ardmore Limestone representing the most widespread deposition during Cherokee times. The Whitebreast and its correlative units comprise one of the most widespread coals in North America; during its deposition, a vast vegetated plain extended from eastern Kansas to western Indiana (Wanless and Wright, 1978). The Whitebreast Coal in Iowa is the equivalent of the Colchester (No. 2) Coal of Illinois and the Croweburg Coal of Missouri.

In summary, the Cherokee Group consists of variable lithologies representing numerous cyclothems. These grade upward into more continuous units as the topographic irregularities of the Mississippian unconformity became less dominant. Typical lithologies include a basal sandstone (with channel and sheet phases) overlain by an underclay-coal sequence. These lithologies are typically restricted geographically to a one to three county area (Landis and Van Eck, 1965). Succeeding this sandstone-underclay-coal sequence are black shales and limestones representing minor transgressive sequences over coal swamps and deltaic platforms. Correlations over large areas are tenuous, and detailed descriptions are valid only on a local paleontologic and palynologic scale. Studies initiated as part of the Iowa Coal Program (conducted by the Iowa Geological Survey) under the direction of Dr. Matthew Avcin are essential to the solution of this problem.

Coal

According to the Iowa Geological Survey (Avcin, pers. com., 1978), up to 19 individual coal beds occur in Iowa. Characteristically the lowermost coal seams are thickest and, therefore, most often mined. The upper coals tend to be thinner but more widespread. Detailed studies at Madrid (Reese, 1977) confirm this. The recognized coal seams are presented in figure 7; the nomenclature shown is that used for those coals in south-central and southeastern Iowa.

Field experience and other studies confirm the economic importance of the lower coals. Work by Chamberlain (1980), Derynck (1980), and Robertson (1976) indicates that the Cherokee represents an overall onlap sequence and that basal coals get younger to the east as the basin was filled.

In the Madrid area (Reese, 1977; Mason, 1980), a total of 10 coals were recognized; the two mineable seams occur in the lower part of the section 80 to 125 feet above the Mississippian erosion surface. Again, the upper coals tend to be thinner and more widespread than the lower coals.

Two coal beds in the Lower Cherokee were mined in the Fort Dodge area of Webster County. According to Landis and Van Eck (1965), the local names were the Pretty (also known as the Big or Upper Bitumunous) coal and a bed known as the Big Seam (also Calhoun-Camel Bed) about 35 feet below the Pretty seam. In all, up to 4 seams appear to be present. Stratigraphically these coals are believed to occur in the Lower Cherokee because of the proximity (100' or less) of the Mississippian erosion surface. The sand bodies occur lateral to the coals and occasionally can be shown to cut into the coals and other associated lithologies.

Sandstone

During studies of the deep coal in the Forest City Basin, well log records indicated the presence of sand bodies having thicknesses of greater than 100 feet. The positions of the sand bodies appear to be controlled by a well-defined drainage system developed in the uppermost Mississippian deposits. The presence of several thick sandstone bodies exposed along the Des Moines River led to a field study of their occurrence in an attempt to better understand their relationship to paleodrainage and the incidence of coal.

Exposures

Sandstone bodies outcrop discontinuously along the Des Moines River and its tributaries throughout much of central Iowa. In particular many significant exposures occur between Fort Dodge, in Webster County, and Red Rock

Reservoir in Marion County. Study of these and other sandstone outcrops in central Iowa forms the basis for the interpretations discussed in this guidebook.

In general, primary sedimentary structures identified and measured on the outcrop indicate a strong southwesterly paleocurrent direction. Sand bodies are marked by erosional basal contacts; coarse-grained basal intervals characteristically rich in fragmented clasts derived from underlying and/or lateral rock bodies; cosets of large-scale planar cross-strata; abundant carbonaceous debris, and a general fining-upward grain size. On a regional scale, it is believed that the sand bodies studied in central Iowa indicate the occurrence during deposition of the Cherokee strata of a series of predominantly southwestardly flowing rivers. Farther south, in Marion County, studies by Hansen (1978) suggest a transition from a convergent to a divergent channel pattern which is interpreted to indicate a deltaic distributary system developed basinward from an area of dominant fluvial deposition. A general paleogeographic map representing conditions prevalent during the deposition of Lower Cherokee sediments includes a pronounced southwestward drainage network throughout central Iowa (figure 8). This reconstruction is in marked contrast to the ideas of earlier workers (McKee and Crosby, 1975) which suggested a single dominantly southwardly trending river during this interval of geologic time.

Subsurface Sand Bodies

The surface distribution and the predominant southwesterly drainage directions indicated by surface sand bodies focused attention on their subsurface occurrence in the deeper part of the basin. As a result, studies were undertaken by Derynck (1980), Chamberlain (1980), and Mason (1980) in a series of Iowa State University master's theses. Derynck (1980) studied the distribution of the sands and their position in the Cherokee; Chamberlain related the distribution and stratigraphic interval to the Mississippian erosion surface; and Mason (1980) made an in-depth study of the sandstone, shale, and sandy shale occurring between coal beds in a 23-square-mile area near Madrid.

A critical aspect of the subsurface sandstone distribution is its relationship to the Mississippian erosion surface. Chamberlain (1980) studied the unconformity and constructed a paleotopographic map (figure 9A) of this critical surface to see what effect it had on the distribution of sandstone bodies and coal. The map is based partly on the work of others in the Forest City and Illinois Basins (Bretz, 1950; Lee, 1943; Lee and Payne, 1944; Bransen, 1962; Siever, 1951; Wanless, 1975; Wanless and Wright, 1978; Potter, 1979). The map shows the paleotopographic patterns developed in the Mississippian erosion surface during initial Pennsylvanian sedimentation. These patterns exerted a progressively decreasing control on sedimentation until deposition of the Ardmore Limestone during Upper Cherokee time (Wanless and Wright, 1978). At this point, paleotopographic irregularities were covered, and the Lower Cherokee deposits formed a broad platform on which the Whitebreast and later coals were deposited.

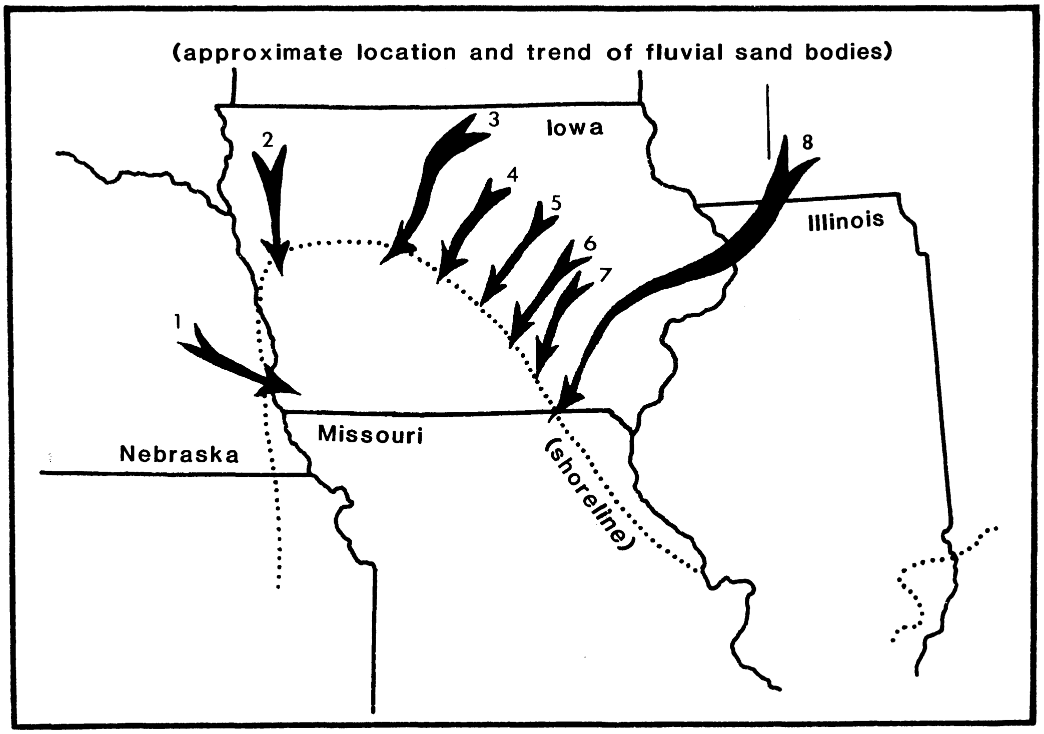

Figure 8. Inferred Cherokee paleodrainage based on outcrop and subsurface evidence of sand bodies. The sand bodies are at different stratigraphic levels within the Cherokee and are considered to be of different ages. (1) Nemaha ridge source, (2) source from the north, (3) Fort Dodge-Holiday Creek area, (4) Dolliver Park area, (5) Ledges area, (6) Altoona (subsurface) area, (7) Red Rock Dam area, (8) Southeast Iowa-northeast Missouri area.

PALEOTOPOGRAPHY

The Mississippian paleotopographic map (figure 9A) was constructed using the unconformity contour method (Andreson, 1962) which requires that the base of the valley fill must be recognized in subsurface records. Following this method, the altitude relating to the top of Mississippian strata was recorded on a map, and a structure contour map of the Mississippian surface was made with present day sea level as the reference plane. Later structural movements can distort the valley fill relations. Other methods to determine paleodrainage were not used because of the extreme variation in density of bore hole data used for control, which ranges from several points per township to none in Cass County.

Contours were drawn assuming that drainage initially developed on a relatively level surface developed on a uniform lithology, predominantly of Mississippian limestones. This results in a radial or modified dendritic drainage pattern trending to the south-southwest from the eastern margin of the basin toward the center and to the east and south under the influence of the Nemaha Ridge along the west flank of the basin. Laury (1968) used a similar approach in his study of the Upper Cherokee Pleasantview Sandstone in central and south-central Iowa.

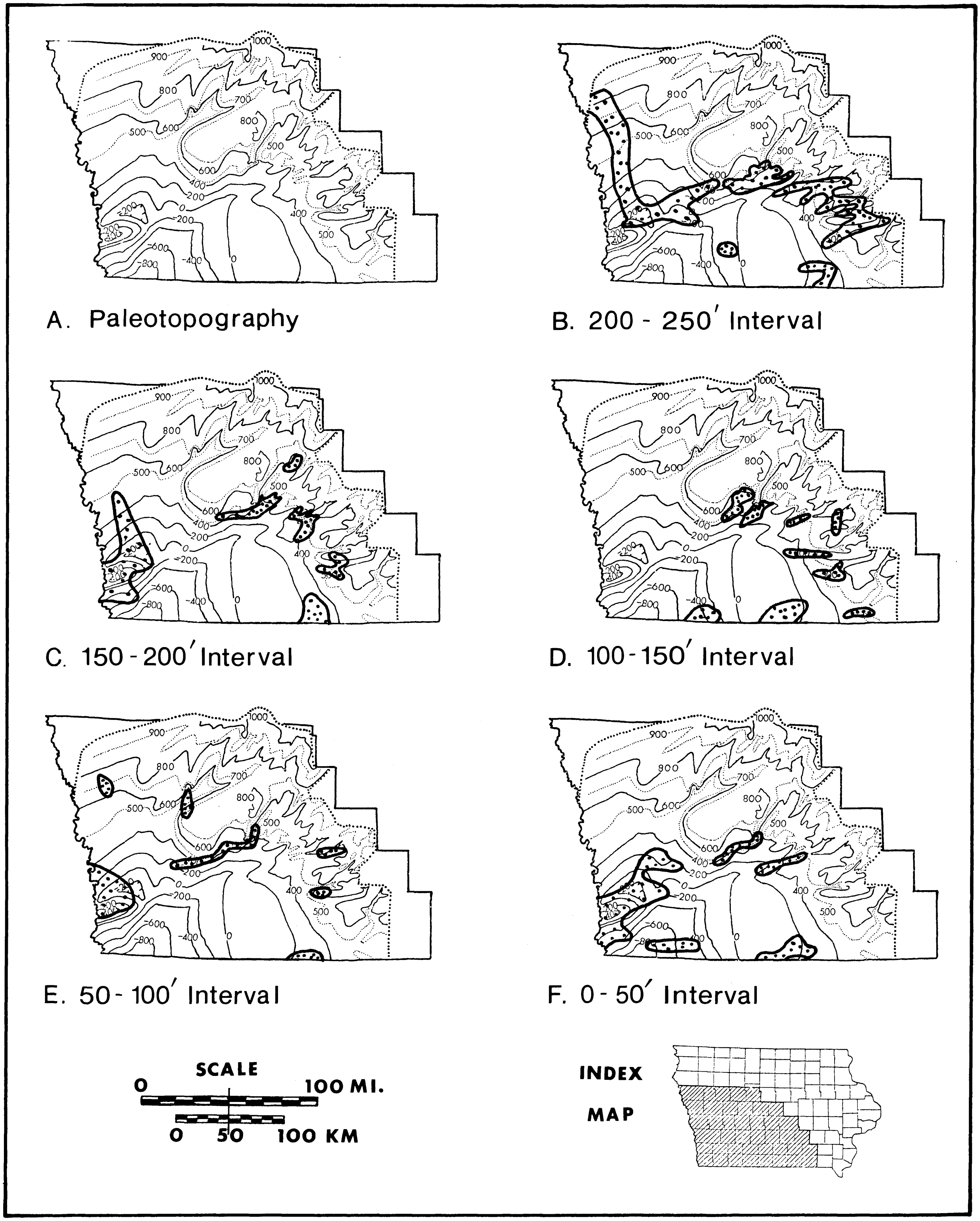

Figure 9. A. Paleotopography of the Mississippian erosion surface.
B.-F. Sand body occurrence in subsurface shown in successive 50 foot stratigraphic intervals.

Karst topography is believed to have been relatively unimportant for the present status of the study because only 22 boreholes penetrated possible karst-fill deposits. Extensive cave and sink formation probably occurred in the lower Paleozoic limestones and dolomites of northeast Iowa, similar to those documented by Bretz (1950) in the Ozark Region. Northeast Iowa, where carbonate rocks predominate, was probably emergent long enough for ground water flow to initiate substantial karst formation which may account for some of the karst present there today. Pennsylvanian deposits are not observed in the northeast Iowa karst at present suggesting either post-Pennsylvanian erosion or non-deposition. Further evidence supporting extensive karst development to the east and northeast is the evidence of Pennsylvanian-aged materials filling solution features in eastern Illinois. Siever (1951) has suggested that karst formation was not an important process deeper in the Illinois Basin because exposed thin limestones and shales were present in the basin interior. By analogy in the Forest City Basin of Iowa, the pre-Pennsylvanian surface is underlain by predominantly sandy limestones, shales, sandstones, and thin-bedded limestones comprising the St. Genevieve and St. Louis Formations. These lithologies suggest limited karst development in the Basin.

Review of additional literature on the Mississippian erosion surface in Illinois and western Kentucky by Howard (1979), Shaw and Gildersleeve (1969), and Garner (1974) provides another interpretation of the configuration of the erosion surface. This interpretation (Howard, 1979) suggests multiple erosion and sedimentation episodes under alternating arid and humid paleoclimatic conditions eventually developing a multiple anastomosing drainage system in contrast to the dendritic system favored by Siever (1959). Shaw and Gildersleeve (1969) describe an anastomosing paleodrainage system on the erosion surface in western Kentucky. Hansen (1978) and Hooper (1978), in their study of sandstone bodies in Marion County, had sufficient subsurface data to indicate that the erosion surface had aspects of a rectangular drainage pattern with valleys up to 200 feet deep incised into a predominantly Mississippian limestone surface. Comparion of their paleocontour map with that of Shaw and Gildersleeve (1969) shows remarkable similarity. This may be an indication that an anastomosing paleodrainage system is present in parts of Iowa. In view of the limited subsurface data for vast parts of the erosion surface within the Forest City Basin, the radial dendritic pattern is tentatively accepted until further data become available.

A study of the occurrence of sandstone bodies to the paleotopographic surface indicates a variable relationship. Near the Cherokee outcrop area where data are abundant, a strong correlation of sandstone bodies to paleodrainage exists (Hansen, 1978). The correlation fails in a down dip (southwesterly) direction going deeper into the basin. Paleovalley control exists, as does sand body stacking; the weaker correlation is believed to be the result of fewer data points rather than lack of paleovalley control.

Derynck (1980) approached the subsurface sand study by drawing a series of cross sections trending NW and SW and by subdividing the Cherokee into two units above and below the Ardmore Limestone, which is recognizable throughout the subsurface. Unit A includes the section below the Ardmore, unit B above the Ardmore. The sections (figure 10) show that unit A contains more sandstone than unit B and that drainage systems are confined, in many cases, to paleovalleys. Stacking of sands has occurred over valleys and sometimes over hills in the paleotopography. Unit B sandstones show little relationship

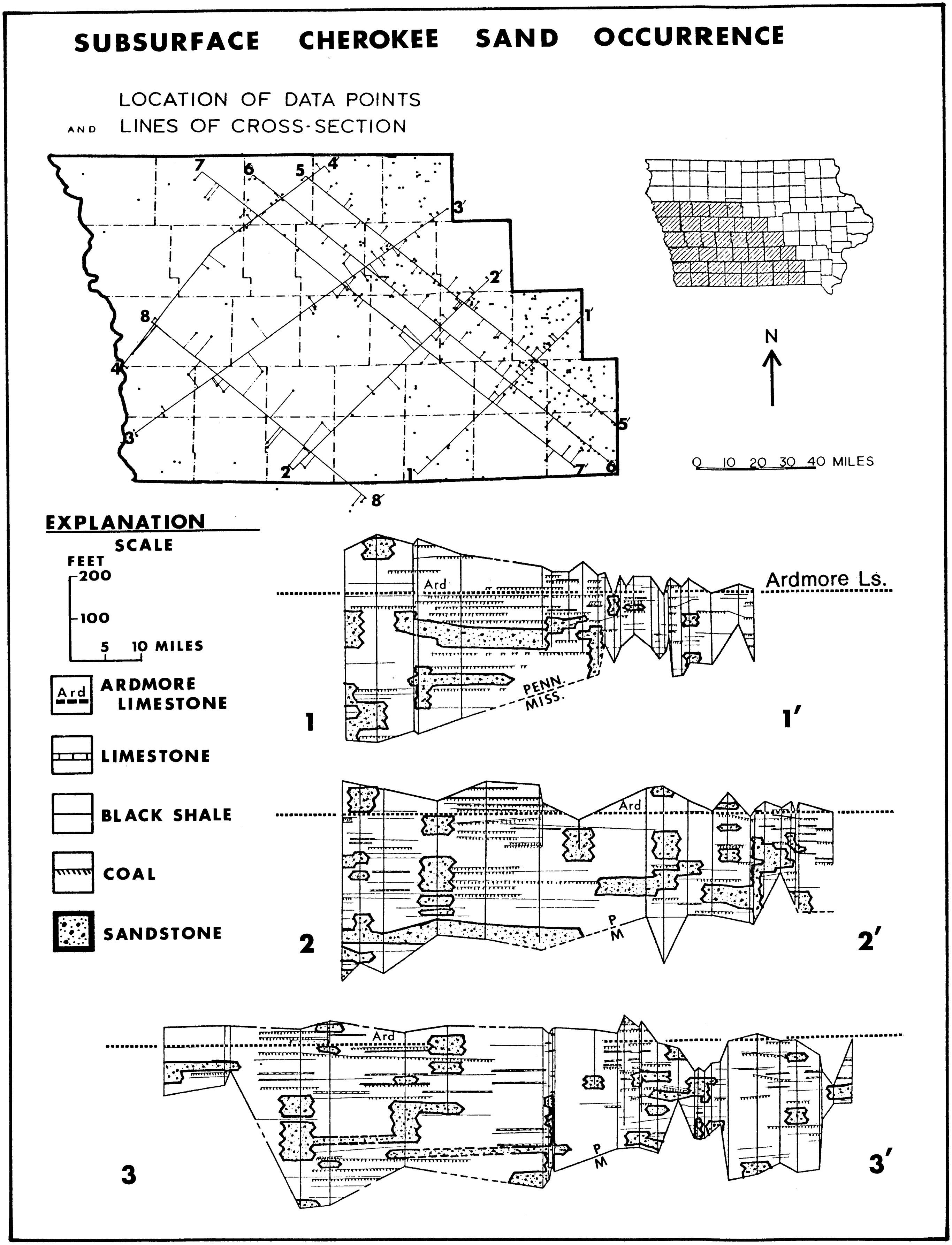

Figure 10. Index map showing well control and direction of cross-sections. 1.-8. Structure sections showing distribution and occurrence of sandstone bodies in the subsurface with reference to the Ardmore Limestone.

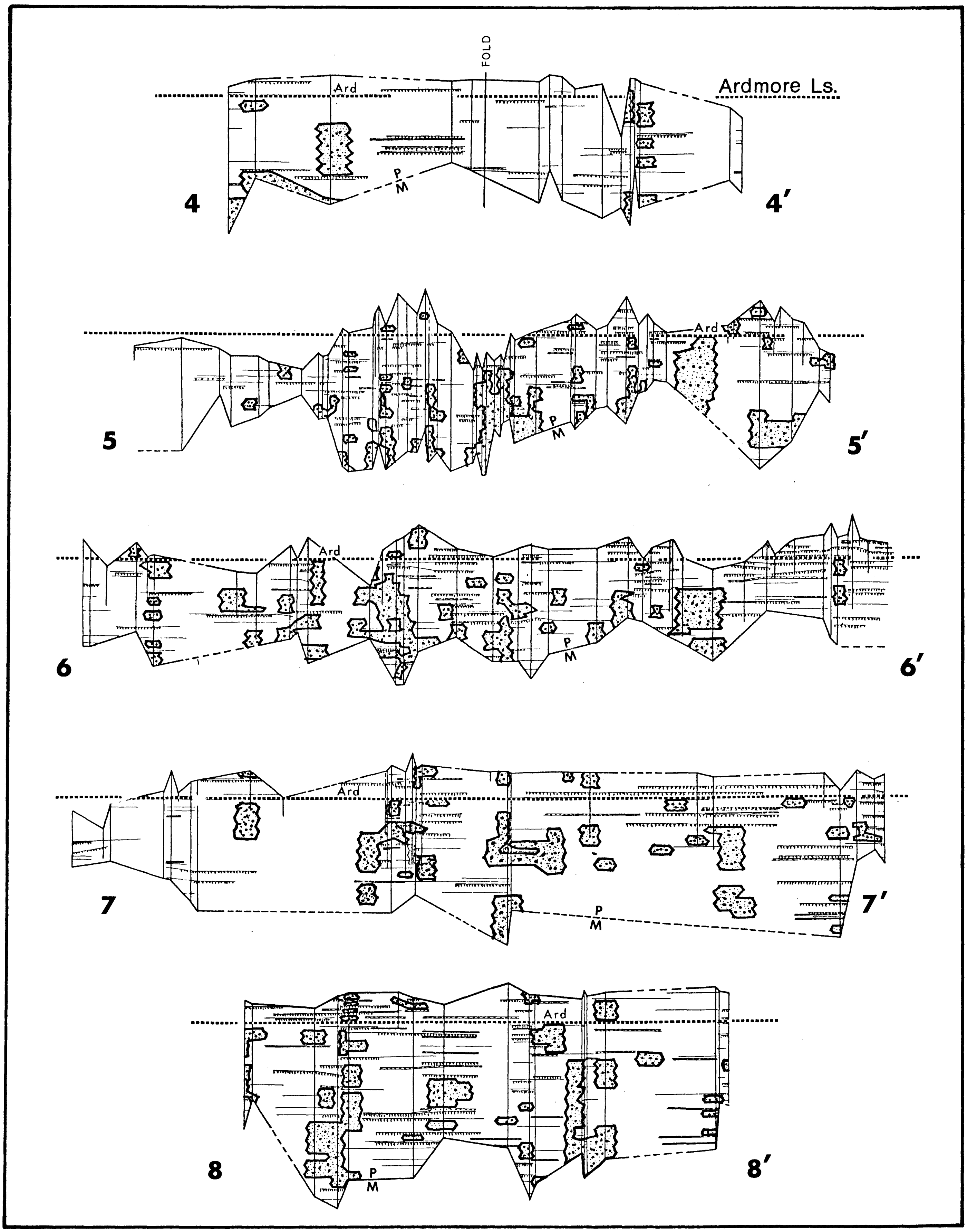

Figure 10, continued.

to paleotopography. Tracing of bodies between cross sections on the basis of thickness, vertical position, and paleovalley trends supports the idea of a dominant southwest drainage. The sand bodies occur at all stratigraphic levels in the Cherokee. This can be readily seen in the maps (figures 9B-9F) by Chamberlain (1980) in which the percent sand in each 50-foot interval below the Ardmore Limestone was plotted; the figures show the areas with greater than 25% sand in the logs superimposed on the Mississippian paleotopographic map. This study supports the following observations:

1. The basal Cherokee Group sediments contain more widely distributed sand and fewer channel sandstones.

2. A broad south-trending belt of basal sand occurs along the western edge of Iowa and probably represents sediment derived from the Nemaha Ridge to the west.

3. The 2nd and 3rd intervals between 150 and 200 feet below the Ardmore contain the most channel sands.

4. Cherokee Group sand bodies correlate closely with topographic lows on the erosion surface in the Mississippian rocks, and consequently stacked sand bodies occur within narrow geographic ranges.

It was also found that isochore contours of the Cherokee Group correlate well with paleotopographic trends and percent sand contour trends.

In a subsurface study of the continuation of the sand bodies outcropping in the Fort Dodge area of north-central Iowa with the subsurface Cherokee sand bodies in a down dip direction 60 miles distant, a strong correlation was found to exist. The sand bodies are confined to southwest trending valleys developed on the Mississippian erosion surface (figure 11). Continuing in a southwest direction into the deeper part of the basin, considerable subsurface sandstone is present. The correlation is not as strong primarily because the number of data points diminishes rapidly toward the deeper part of the basin. The strong southwest current direction indicated in the outcropping sandstone bodies and their close relationship to the subsurface sand bodies basinward strongly supports a southwest paleodrainage direction during Cherokee time.

PALEOENVIRONMENT

The encroachment of the Middle Pennsylvanian sea upon the Mississippian erosion surface led to deposition of the predominantly clastic and coal bearing Desmoinesian Series in the Forest City Basin. Paleodrainage and sandstone body occurrence suggest the existence of deltaic systems fringing the Basin during deposition of the Cherokee Group. Similar conditions probably existed during deposition of the Virgilian and Missourian Series although marine transgression is believed to have advanced farther to the northwest leaving cyclic limestone and shale deposits overlying the clastic Desmoinesian Series in the southwestern corner of Iowa. The Virgilian and Missourian clastic and coal-bearing equivalents of the Desmoinesian Series are not preserved in central Iowa.

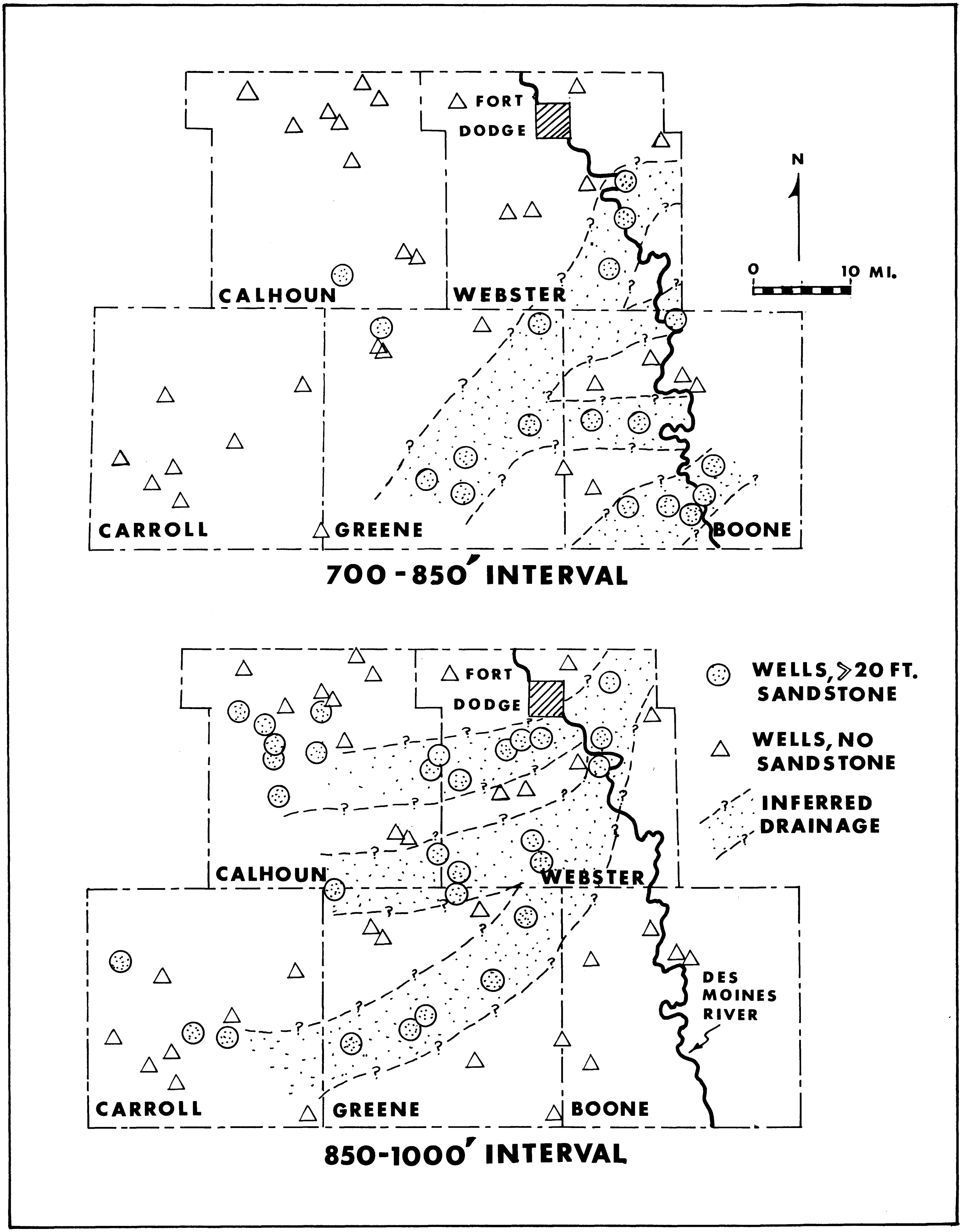

Figure 11. Maps showing the distribution of sand bodies in the subsurface in the area immediately southwest of the sandstone outcrops along the Des Moines River. The paleodrainage is inferred from well log data.

Recently published paleoenvironmental studies by Wanless and Wright (1979) on Cherokee, Marmaton, Pleasanton, Kansas City, and Lansing Groups for the northern midcontinent and Illinois Basin provide considerable information on the nature of sedimentation and geological setting of these groups. A summary of these studies includes the following:

1. Deltas composed dominantly of fine-grained sediments formed in the Forest City Basin;

2. Deltaic clastic wedges formed during periods of regression;

3. Widespread coals formed on deltaic platforms constructed by one or more deltas;

4. Most sandstone deposits over 20 feet thick are deltaic in origin;

5. The sea was present for a longer period of time in the northern midcontinent than in the southern midcontinent and Illinois Basin;

6. A marine connection developed between the northern midcontinent and Illinois Basin when the upper Cherokee was deposited.

As a result of these observations, the Iowa environment for peat deposition is considered to be a deltaic platform with interfingering marine environments. The Desmoinesian of Iowa is characteristically more marine in nature than the equivalent units in Illinois (especially true of the Marmaton Group). The deposition rates were slow in contrast to eastern or Appalachian sedimentation and probably account for the higher sulfur content and thinner coal beds in Iowa.

Because the paleoenvironment during Cherokee deposition relates to a deltaic complex, the coal-forming peat is considered to have formed in fluvial, upper delta, lower delta, and possibly, lagoonal environments. Associated sand bodies result from coarse-grained sedimentation in these environments. The various occurrences of sandstone bodies can be related to the differing depositional conditions found in deltas, alluvial channels, estuaries prior to drowning, coastal and alluvial plains.

Transition between environmental facies is believed to occur over longer distances than those observed by Horne, et al. (1978), for deltas on the Appalachians. Insead of a 10-mile wide transition zone for upper to lower delta environment in Appalachia, a 20- to 60-mile zone existed during deposition of Cherokee strata. Wanless (1975) indicates that the coals may retain their identity up to 80 miles down-dip.

PART II: FACIES AND DEPOSITIONAL ENVIRONMENTS OF THE CHEROKEE GROUP IN WEBSTER COUNTY, IOWA

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The Pennsylvanian strata of central Iowa are notoriously poorly exposed, but in certain areas recent downcutting by rivers and streams has cleared the overlying sediments to expose the rocks of the lower Desmoinesian Cherokee Group. One such area is that of Webster County where the Des Moines River Valley has been incised into the late Paleozoic deposits of the mid-continent, providing infrequent exposure of sandstones, siltstones, shales, coals, and limestones of the Cherokee Group. Because of the relative paucity of surficial exposure, most studies of these and associated strata have been limited to subsurface information sources such as water well driller's logs and mineral exploration well logs.

In order to supplement subsurface interpretations, a limited program of outcrop examination was initiated at Iowa State University in 1979 and continued through the summer of 1980. The aim of these studies included the location and description of outcrops and sample collection for laboratory testing to characterize the lower Cherokee strata lithologically and environmentally. It must be emphasized that the results of this program are preliminary in nature, being based on data collected from limited exposures in a relatively small area. While the results are applied to generalizations of depositional environments in central Iowa during deposition of the Cherokee strata, a comprehensive program of stratigraphical, sedimentological, paleontological, and petrographic studies is needed to more completely document the paleoenvironmental conditions extant in central Iowa during the Middle Pennsylvanian period.

FACIES

The outcrop studies completed to date have delineated six lithofacies in the lower Cherokee Group of Webster County which occur as complexly interfingering rock bodies. In general, they are interpreted to represent a fluvially-dominated, high-constructive deltaic system which records episodic delta progradation toward the southwest and the development of a clastic platform on which swampy conditions prevailed prior to subsequent drowning by marine transgression.

Sand Facies

Within the strata comprising the Cherokee Group of Webster County are two facies composed primarily of sand-size materials. These are the lenticular fine- to medium-grained, cross-stratified sandstone facies and the fine-grained, parallel-laminated to ripple-bedded sandstone facies.

Lenticular fine- to medium-grained cross-stratified sandstone facies

The lenticular fine- to medium-grained, cross-stratified sandstone facies consists of resistant lenticular sandstone bodies which form nearly vertical cliffs along drainage ways which have been incised into the sandstone. The sands are very pale orange (10YR8/2) to moderate yellowish brown (10YR6/4) with variable amounts of iron oxide cement, dark yellowish orange (10YR6/6) to moderate brown (5YR4/4). The basal contacts of sand bodies of this facies are sharp and erosional, very markedly truncating strata of the underlying units (figure 12) and incorporating the eroded clasts into the lower portion of sandstone. These rip-up clasts are usually well rounded fragments ranging in size from less than 1/2 inch to greater than 10 inches in diameter and consist of light gray (N7) to light olive gray (5Y6/1) argillaceous siltstone or claystone, with an oxidation rim several tenths of an inch thick of dark reddish brown (10YR3/4) to moderate brown (5YR3/4) iron oxide (figure 13). They occur in a matrix of subrounded to subangular quartz, feldspar, and micas (see section on sandstone mineralogy) but may occur in such abundance as to comprise nearly the entire basal several feet of the sandstone body (see the section for the Copperas Beds, Dolliver Park).

The lenticular fine- to medium-grained, cross-stratified sandstone facies attains a thickness in excess of 60 feet at Wildcat Den (CSE 1/4, SE 1/4, Sec. 10, T88N, R28W) and commonly occurs as outcrops of at least 30 feet in diameter. The facies is comprised of stacked sets of large-scale planar (omikron of Allen, 1963; facies Sp of Miall, 1977) cross-stratified fine- to medium-grained sandstones with set thicknesses of 1 to 2 feet common. In most cases, the lowermost set is the thickest (figure 14) with subsequent sets progressively decreasing in thickness until another thick set is reached. Most sets are marked by prominent foresets which dip to the southwest at an average of about 25° and thicken in the downstream direction. Truncation of underlying sets, internal scour features, and reactivation surfaces are quite common in outcrops of this facies. At most localities studied, successive sets are separated either by an erosional surface or by a thin set (less than 5 inches) of low-angle, parallel-laminated sand but occasionally may be separated by a thin set of ripple-laminated fine sand

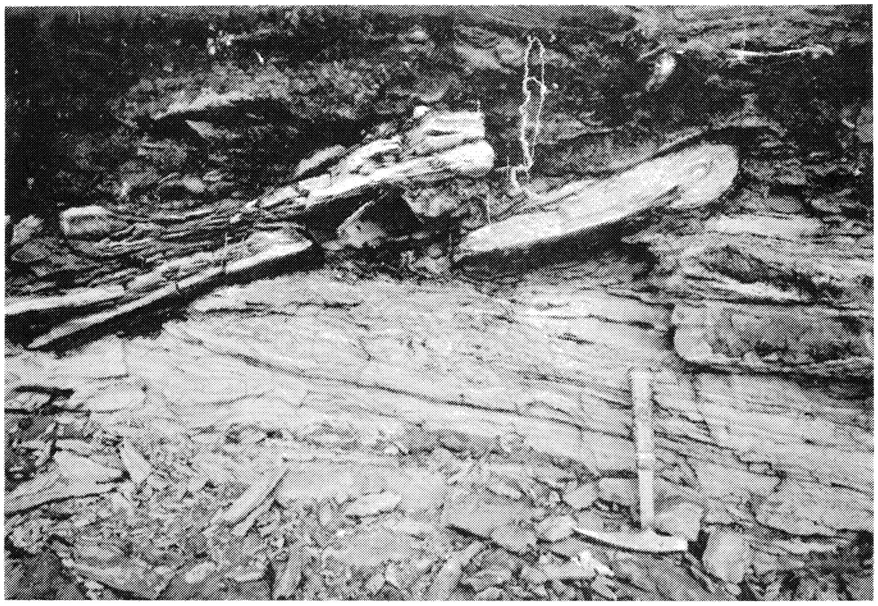
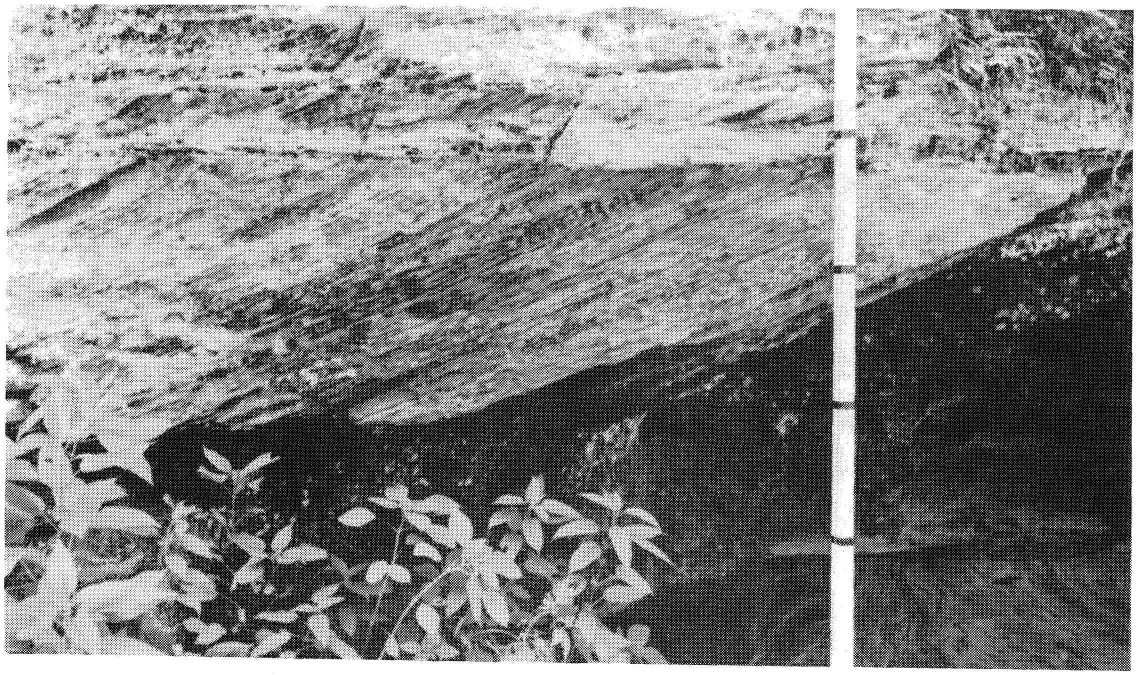


Figure 12. Erosional basal contact of the lenticular fine- to medium-grained cross-stratified sandstone facies.

Figure 13. Rounded siltstone rip-up clasts with a rind of iron oxide alteration, Copperas Beds, Dolliver Park (SW 1/4, SE 1/4, SE 1/4, Sec. 34, T.88N, R.28W).



A. Woodmans Hollow (S 1/2, NW 1/4, Sec. 22, T.88N., R. 28W)

B. Cliff bars (SE 1/4, SW 1/4, NE 1/3, Sec. 14, T.88N, R.28W)

Figure 14. Large scale planar cross-stratified sets of the lenticular fine- to medium-grained cross-stratified sandstone facies.

(facies Sr of Miall, 1977). Large-scale trough cross-stratified sandstone occurs much less commonly than the planar cross-stratified sets at most localities. One exception is the exposure at Wildcat Den where large-scale trough sets as thick as 5 feet and more than 15 feet wide occur as a coset of about 30 feet (pi cross-strata of Allen, 1963; Facies St of Miall, 1977).

An unusual, yet frequently occurring phenomenon associated with the large-scale planar cross-stratified sandstones of this facies is overturning of the upper portion of the foresets (figure 15). Such structure, also termed intraformational recumbent folding (Reineck and Singh, 1975, p. 269), is confined to a single set among a thick coset of tabular cross-strata and may be associated with other contorted and/or convolute bedding (figure 15). Many authors (Potter and Glass, 1958; Ore, 1963; Stewart, 1964; Rust, 1968) have recognized this type of deformed cross-bedding and have ascribed its occurrence to processes ranging from simple gravitational slumping to liquifaction. Allen and Banks (1972) developed a physical model which demonstrates the formation of recumbent-folded deformed cross-bedding as a function of liquifaction triggered by earthquake activity.

Also occurring with the sandstone at many localities are large carbonized and/or permineralized branch and tree trunk casts which may exceed 1 foot in width and several feet in length. Except for abundant smaller carbonized wood fragments, no other fossils have been found associated with this facies.

Sedimentologically, the sandstones of the lenticular fine- to medium-grained, cross-stratified sandstone facies are characterized by an average mean grain size of 2.58ϕ (fine sand), are well sorted (σ_I = 0.4), and fine skewed (SK_I = 0.22). The mean grain size of 39 sandstone samples from 22 localities (Table 1) ranges from 1.79ϕ (medium sand) to 3.18 (very fine sand) with sorting values (inclusive graphic standard deviation) from 0.21ϕ (very well sorted) to 0.66ϕ (moderately well sorted).

Strata of the lenticular fine- to medium-grained, cross-stratified sandstone facies disconformably overlie strata of the laminated gray claystone facies or overlie and interfinger with strata of the interbedded laminated fine-grained sandstone, siltstone, and claystone facies. They are overlain, and/or interfinger with, deposits of the laminated fine sandy siltsone, gray claystone, and coal facies. The sand bodies of the lenticular fine- to medium-grained, cross-stratified sandstone facies extend laterally (transverse to the southwestern paleo-flow direction) for as much as 1.25 miles (see figure 16).

Fine-grained parallel-laminated to ripple-bedded sandstone facies

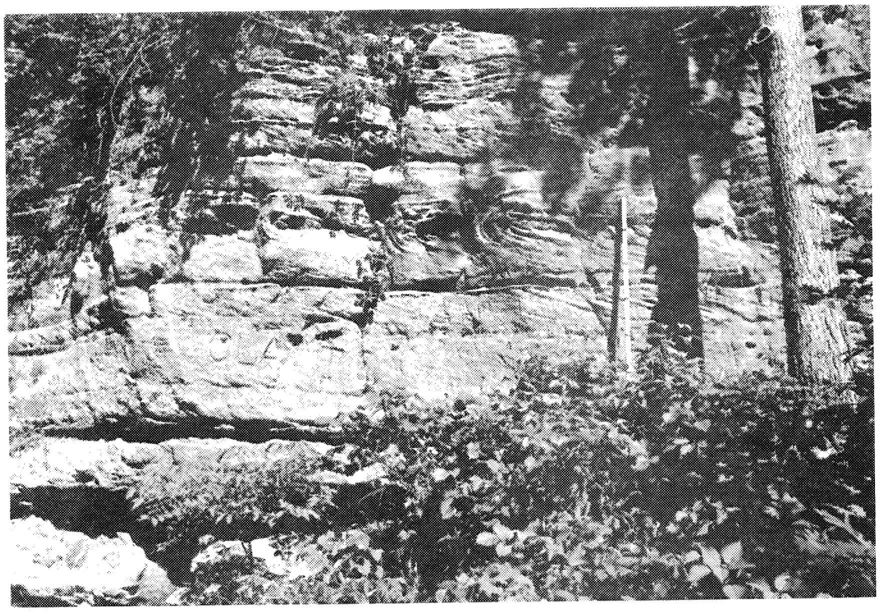
The fine-grained, parallel-laminated to ripple-bedded sandstone facies consists of tabular, planar to undulating bodies of fine-grained sandstone which extend for many tens of feet, often spanning the entire exposure of an outcrop. Unfortunately, this facies is not well exposed, precluding accurate description of lateral extents, bedding geometries, and primary structure content. Preliminary data from this outcrop study suggest that the sandstone bodies may extend for as much as several hundred feet. The basal contacts of bodies of this facies are sharp and generally conformable although in some areas minor basal scouring is present. The sands

Table 1. Grain Size Statistics for Cherokee Sandstones

	Mz (ϕ)*	σ(ϕ)*	SK*	K_G*	C (ϕ)	M (ϕ)
PCV2A	2.60	0.39	0.00	1.28	1.79	2.61
PVC4A	2.68	0.41	0.47	2.18	1.94	2.58
PVC5A	2.86	0.47	0.31	1.72	1.92	2.81
PVC5C	2.82	0.34	0.06	1.57	1.85	2.82
PVC7A	3.18				1.72	2.99
PVC10	2.95	0.40	0.04	1.58	1.44	2.93
PVC10A	2.05	0.38	0.24	1.55	1.32	2.05
PVC10E	2.30	0.35	0.03	1.11	1.23	2.31
PVC12A	2.25	0.53	0.58	1.75	1.45	2.08
PVC12B	1.79	0.45	0.32	2.89	1.15	1.77
LV2A	2.64	0.27	0.10	1.13	2.09	2.64
LV2C	2.71	0.25	0.54	1.57	2.18	2.64
SHC2A	3.10	0.39	0.32	1.75	2.58	3.09
NW3C	2.75	0.35	0.18	1.33	1.94	2.73
NW5A	2.47	0.38	0.27	1.16	1.70	2.42
NW6A	2.51	0.35	0.41	1.26	1.74	2.43
NW6B	1.79	0.48	0.25	2.68	1.04	1.79
NW6C	2.52	0.27	0.00	2.03	1.81	2.51
CBA	2.62	0.44	0.30	1.33	1.67	2.58
CBC	2.26	0.50	0.31	1.50	1.25	2.22
KBE3A	2.98	0.21	-0.18	2.34	2.11	3.01
NKB1F	2.70	0.39	0.44	1.69	1.96	2.64
HF1C	2.78	0.31	0.39	1.46	2.21	2.74
HF1D	2.28	0.66	-0.16	0.88	1.05	2.39
HF1E	2.51	0.34	0.11	1.60	1.73	2.51
WA1A	2.52	0.30	0.14	1.10	1.69	2.50
WH1B	1.88	0.32	0.76	2.46	1.47	1.81
WH2A	2.99	0.25	0.21	0.99	2.41	2.95
WH2C	3.05	0.42	0.14	1.80	2.19	3.07
WH2D1	2.97	0.63	-0.10	1.72	1.63	3.05
WH2D2	2.34	0.59	0.21	0.87	1.28	2.26
WH5B	2.47	0.48	0.05	1.00	1.54	2.45
PVE1B	2.69	0.37	0.40	1.83	1.94	2.62
PVE1A	2.72	0.32	0.12	1.22	1.96	2.71
PVE1D	2.52	0.58	-0.26	1.00	1.21	2.65
DP6A	2.49	0.38	0.67	1.37	1.75	2.32
DP9D	2.88	0.30	0.21	1.89	1.64	2.55
DP11C	2.71	0.42	0.09	1.19	1.66	2.71
DP9C	2.34	0.54	0.36	1.05	1.37	2.22

*Calculated after Folk and Ward (1957).

A.



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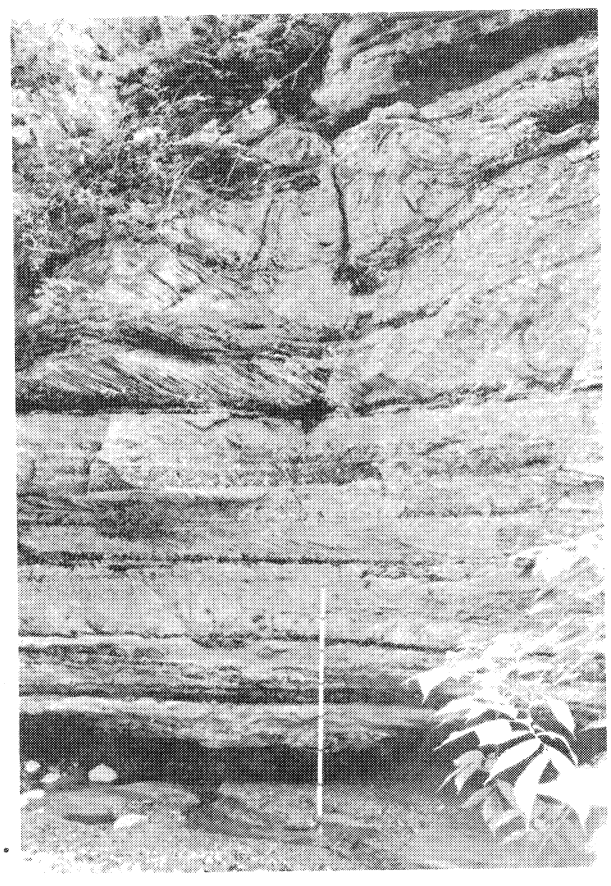


Figure 15. Deformed bedding features in strata of the lenticular fine- to medium-grained cross-stratified sandstone facies; Boneyard Hollow, Doliver Park (NW ¼, NW¼, NE¼, Sec. 35, T 88N, R 28W).

Distribution of Sandstone Bodies Along the Des Moines River, Webster County, Iowa

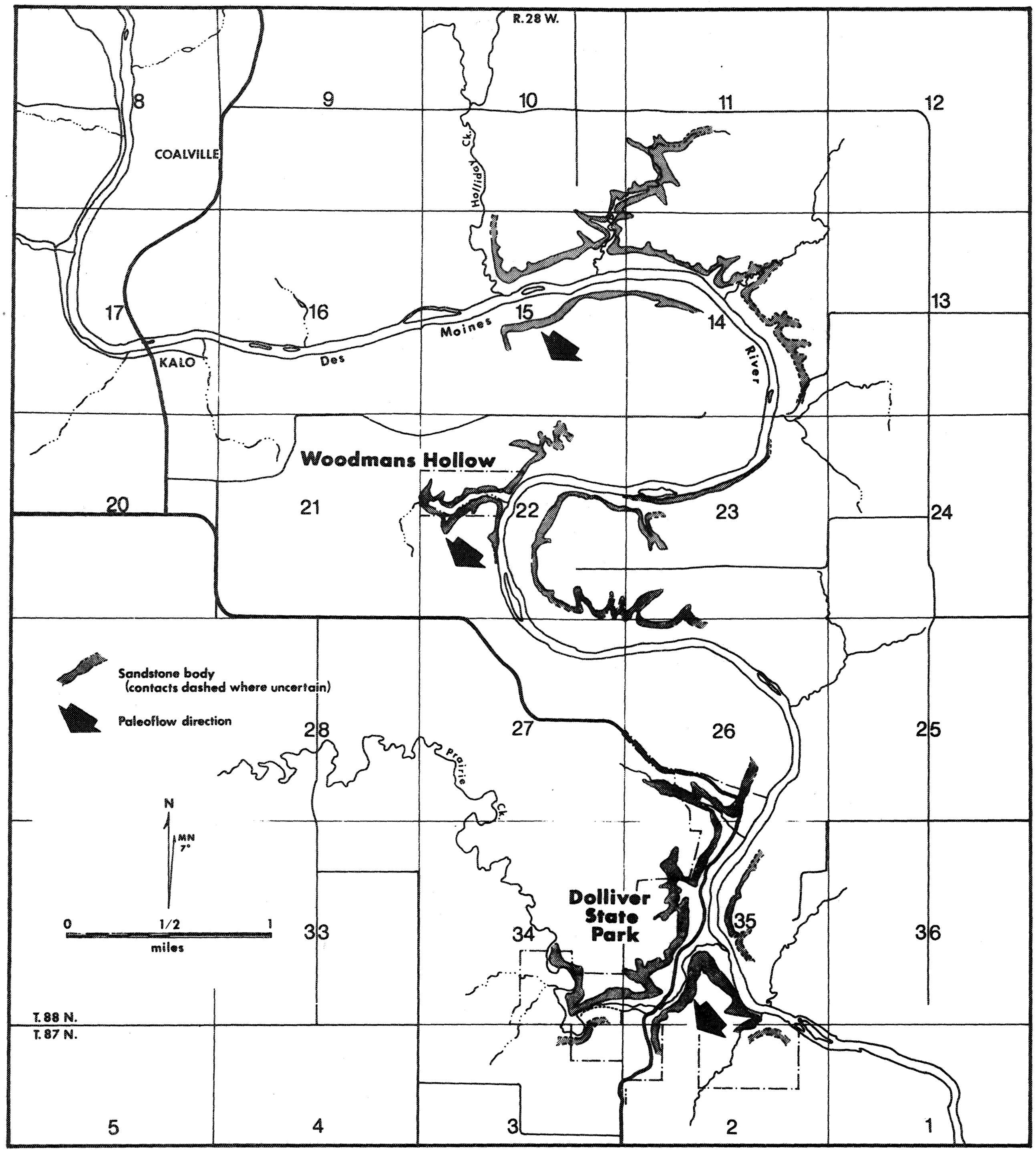


Figure 16. Map of part of southern Webster County showing the distribution of sandstone outcrops along the Des Moines River.

are moderate yellowish brown (10YR5/4) to moderate brown (5YR4/4) and are composed of parallel-laminated to indistinctly ripple-laminated fine- to very fine-grained sand, commonly with a ripple-bedded fine sandy siltstone cap.

Also found closely associated with strata of this facies are elongate sand lentils as much as 6 feet in thickness and 15 to 20 feet wide. They consist of parallel-laminated to indistinctly large-scale trough cross-stratified, fine- to very fine-grained sandstone and often include an upper zone, several inches thick, of ripple-bedded moderate yellowish brown (10YR5/4) to grayish orange (10YR7/4) fine sandy siltstone.

Both types of sand bodies of the fine-grained parallel-laminated to ripple-bedded sandstone facies are enclosed by deposits of either the laminated fine sandy siltsone, gray claystone, and coal facies or the interbedded laminated fine-grained sandstone, siltstone, and claystone facies.

Mudrock Facies

Outcrop study of the fine-grained strata comprising the lower portion of the Cherokee Group in Webster County is hindered by slumping and vegetative cover. With few exceptions, the only places in which the fine-grained deposits are exposedare those which include deposits of the coarser, more resistant sandstone facies which uphold the exposure. This difficulty notwithstanding, the fine-grained sediments have been tentatively divided into 4 facies which are the: 1) laminated fine sandy siltstone, gray claystone, and coal facies; 2) interbedded laminated fine-grained sandstone, siltstone, and claystone facies; 3) laminated siltsone and gray claystone facies; and 4) carbonaceous shale and limestone facies.

Laminated fine sandy siltstone, gray claystone, and coal facies

The laminated fine sandy siltsone, gray claystone, and coal facies consists of parallel-laminated, to thinly bedded, moderate yellowish brown (10YR5/4) to grayish orange (10YR7/4), fine sandy siltstone, light olive gray (5Y5/2) laminated argillaceous siltstone, medium gray (N5) to dark gray (N3) claystone, and brownish black (5YR2/1) to gray black (N2) and black (N1) coal and argillaceous coal. Basal contacts of beds within this facies are gradational from underlying strata and, in some cases, deposits exhibit a general fining-upward sequence from arenaceous siltstone to gray claystone and coal.

Strata of this facies include abundant plant remains as small branch and leaf fragments visible among lamination planes and as individual dark laminae between siltstone laminations. Coal and carbonaceous shale occur as beds, up to three feet thick (see Kalo Bluffs, section 1), and are invariably associated with massive to laminated gray claystones which generally underlie the former and may include rare, silty burrow fillings up to 0.5 inches thick. While the lateral relationships within this facies are obscure, because of incomplete exposure and slumping, it can be reasonably stated that the coal and carbonaceous shale units grade laterally from fine sandy laminated siltstone and gray claystone. In addition, at the Kalo Bluffs locality the upper coal horizon includes thin lentils of very dark gray (N3) carbonaceous limestone which grades to the northwest within 1/2 mile, to a 14-inch thick brachiopod-bearing limestone enclosed by parallel-laminated dark gray carbonaceous shale (see Kalo Bluffs, section 2).

Deposits of the laminated fine sandy siltstone, gray claystone, and coal facies conformably overlie strata of either the sandstone facies or the interbedded laminated fine-grained sandstone, siltstone, and claystone facies. In general, the fine sandy siltstone units are more commonly found in close proximity to the sandstone facies while the gray claystone, carbonaceous shale, and coals are closely associated with strata of the interbedded laminated fine-grained sandstone, siltstone, and claystone facies.

Interbedded laminated very fine-grained sandstone, siltstone, and claystone facies

Deposits of the interbedded laminated fine-grained sandstone, siltstone, and claystone facies consist of thin beds of light yellowish gray (5Y7/1) and yellow gray (5Y7/2) to grayish orange (10YR7/4) very fine-grained sandstone with mottled areas, dark yellowish orange (10YR6/6) in color. The sands occur as tabular to slightly lenticular bodies usually less than 4 inches thick, often with sharp mildly erosional bases, rich in carbonaceous fragment, and fining-upward into parallel and wavy-laminated silty fine sandstone (figure 17) and siltstone. The sandy intervals include alternating laminae of light gray (N8) very fine-grained sand and yellow gray to medium gray (N5) silty sand and are separated by laminations of olive gray (5Y4/1) silty claystone. Besides abundant fragmented carbonaceous debris, the sandstone beds often display contorted structure manifest as irregularly shaped bodies of the light colored sandstone enclosed by the darker, finer grained material (figure 18).

Within the facies, large-scale truncation (scour and fill?) features are common ranging in magnitude from a few inches of downcutting to greater than 15 feet (see Kalo Bluffs, section 1). Strata at the base of the fill cycle dip as much as 20°, but the dip angle progressively decreases in a vertical direction up from the base of the cycle. At Kalo Bluffs, section 1, two major cycles are visible with minor associated truncation features within each of these. At Kalo Bluffs, section 2, grain size data indicate a crude upward fining in the deposits below the carbonaceous shale and above the basal contact with the underlying finer-grained sediments (figure 19).

The strata of the interbedded laminated very fine-grained sandstone, siltstone, and claystone facies attain a thickness of about 35 feet at Kalo Bluffs, section 2 (NC, SW 1/4, Sec. 17, T88N, R28W) and grade into, and disconformably overlie and interfinger with, deposits of the laminated siltstone and claystone facies. They are conformably overlain by strata of the laminated fine sandy siltstone, gray claystone, and coal facies, and/or the carbonaceous shale and limestone facies.

Laminated siltstone and gray claystone facies

A thick, although poorly exposed sequence of olive gray (5Y4/1) and light yellowish gray (5Y7/1) to light gray (N7) laminated siltstone and silty claystone comprises the laminated siltstone and gray claystone facies.

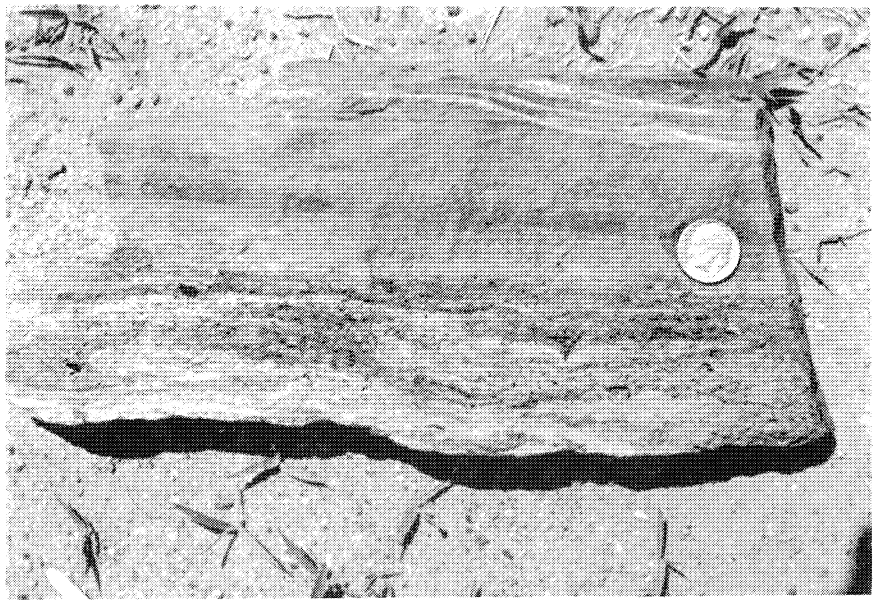


Figure 17. Sandstone bed from the interbedded laminated fine-grained sandstone, siltstone, and claystone facies showing a carbonaceous fragment rich base, laminated silty fine sand, and ripple-bedded fine sandy siltstone.

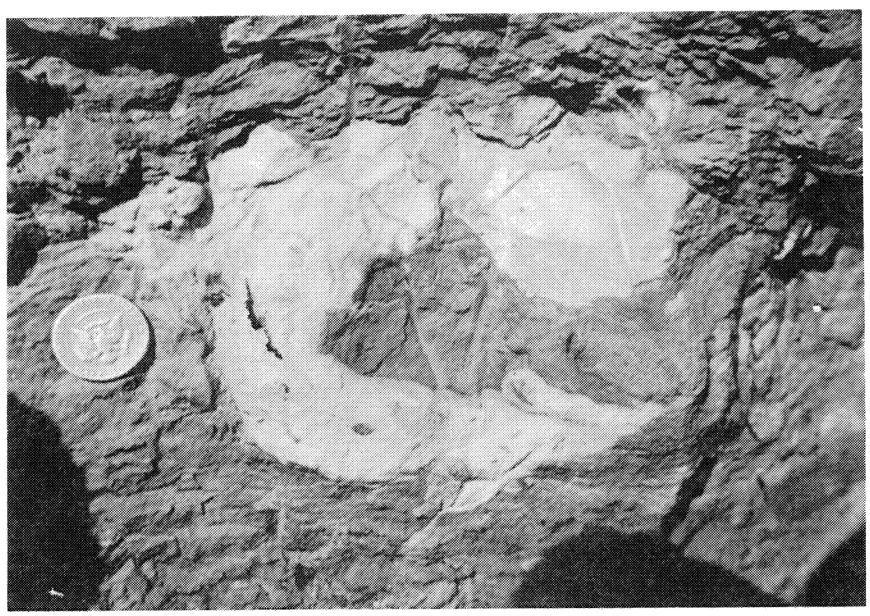


Figure 18. Sandstone deformation structure found in the interbedded laminated fine-grained sandstone, siltstone and claystone facies.

		Mz (ϕ)	σ_I
(Top)	KB-2009	5.98	2.33
	KB-2007	4.34	1.75
	KB-2006	4.29	1.95
	KB-2005	3.57	0.94
	KB-2004	4.04	1.65
	KB-2003B	4.11	1.76
(Base)	KB-2002S	3.78	1.43

Figure 19. Grain size data (Mean [Mz] and Standard Deviation [σ_I])for Kalo Bluffs, section 2.

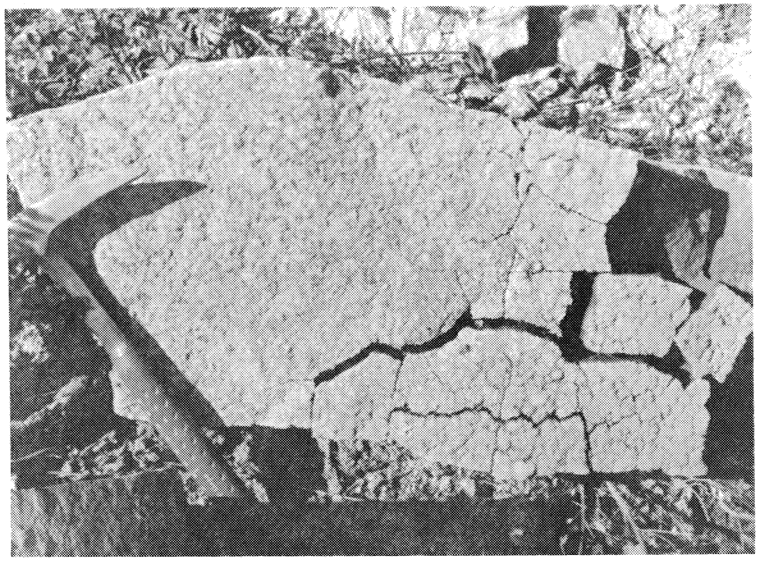
These strata rest with marked disconformity on the underlying marine carbonates of the Mississippian system. They include abundant fragmented carbonaceous debris and may include carbonate concretions of variable size but usually less than 6 inches in diameter. The laminated siltstones (figure 8) are commonly interrupted by thin lentils of fine-grained argillaceous sandstone less than 1/2 inch thick and several inches in width. The gray claystones and silty claystones are occasionally well jointed with dark yellowish orange (10YR6/6) limonitic claystone infilling. Other than for the abundant fragmental carbonaceous debris mentioned above, no other fossils have been observed in this facies.

The laminated siltstone and gray claystone facies is overlain disconformably by the lenticular fine- to medium-grained cross-stratified sandstone facies and interfingers with, or is disconformably overlain by, the interbedded laminated very fine-grained sandstone, siltstone, and claystone facies. It is overlain conformably and interfingers with the carbonaceous shale and limestone facies.

Carbonaceous shale and limestone facies

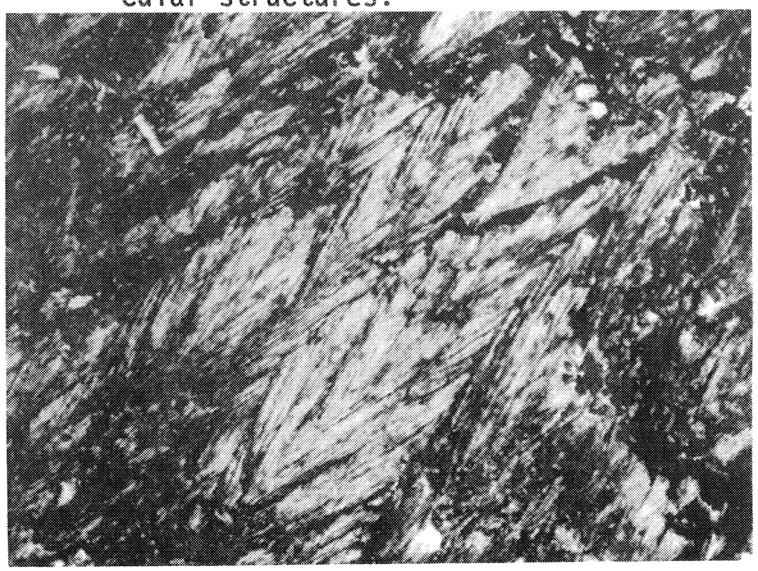
The carbonaceous shale and limestone facies occurs as a northwestwardly thickening wedge of medium dark gray (N4) to gray black (N2) fissile carbonaceous shale with occasional thin lenses of medium gray (N5) argillaceous siltstone, up to 1 inch thick, and dark gray (N3) to dark bluish gray (5B5/1) pyritiferous, fossiliferous limestone. The basal contact of this facies is gradational overlying either the interbedded laminated very fine-grained sandstone, siltstone, and claystone facies or the laminated siltstone and gray claystone facies.

The limestone of this facies occurs as a 14-inch thick arenaceous to argillaceous biomicrite (wackestone of Dunham, 1962). At one locality the limestone includes a 2.5 inch thick cap exhibiting cone-in-cone structure in cross-section and interfering, roughly circular concentric ring structure in plan view (figure 20). The limestone also contains abundant permineralized brachiopod tests, both complete and fragmented. Toward the southeast, this unit thins and interfingers with increasingly carbonaceous shales, which at Kalo Bluffs, section 3, grade into coal.

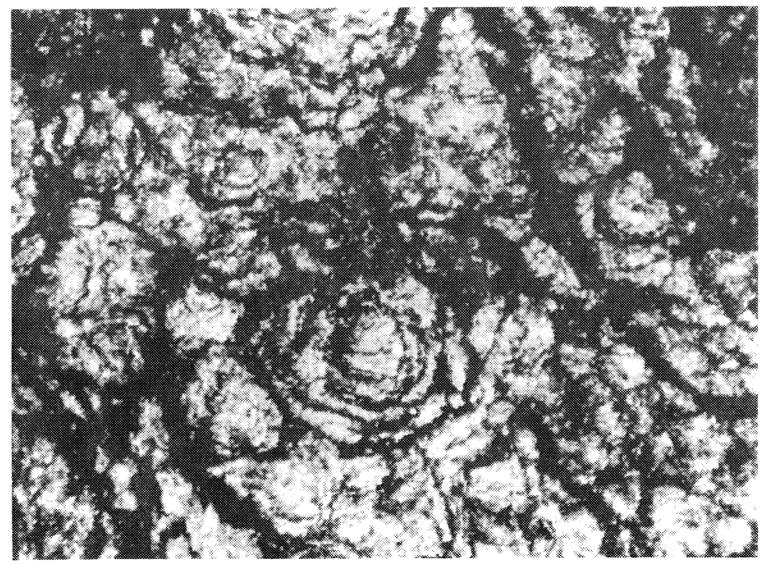


A. Viewed from above; notice irregular circular structures.

B. Viewed from the side



C. Thin section perpendicular to bedding; notice the distinct alignment of carbonate fibers comprising conical structures.



D. Thin section parallel to bedding; notice the fibrous carbonate bundles and the clay concentration surrounding the bundles.

Figure 20. Shallow marine limestone of the carbonaceous shale and limestone facies. Note the thin zone of cone-in-cone structure in the upper 3 inches of the limestone. (Stop 4, Coalville west; NE 1/4, SW 1/4, Sec. 8, T.88N, R.28W).

The carbonaceous shale and limestone facies thickens from less than 4 feet at Kalo Bluffs, section 2, to about 15 feet at Kalo Bluffs, section 3, approximately 1 mile to the northwest. Preliminary petrographic study indicates that the limestone of this facies becomes progressively less arenaceous to the northwest.

DEPOSITIONAL ENVIRONMENT

The complexly interbedded facies described above are interpreted to represent a fluvially-dominated high-constructive delta system which prograded to the southwest as sediment-laden streams flowed into the Forest City Basin from the north and northeast. The respective facies and interpreted depositional environments are listed in figure 21 and illustratively shown in figure 22.

Distributary Channel

The deposits of the lenticular fine- to medium-grained, cross-stratified sandstone facies are interpreted to represent major distributary channels which fed clastic sediments to the prograding delta complex. Stacked sets of large-scale planar cross-stratified sandstone (Alpha and Omikron cross-strata of Allen, 1963) are indicative of large-scale bedforms which have been called megaripples (Reineck and Singh, 1975) or transverse bars (Smith, 1970) in the case of fluvial systems. They are formed in channels of low-sinuosity (Smith, 1970) as bed-load sand is carried downstream forming large sand waves. Individual foreset laminae represent slip-face avalanching of the sand as downstream progradation occurs. Low-angle parallel laminations between successive sets and ripple-bedded fine sands represent stoss-side deposition (Reineck and Singh, 1975). Large-scale trough cross-strata such as that found at the Wildcat Den locality may represent sinuous crested megaripples which formed as part of a lower point-bar in a sinuous reach of the channel similar to models described by Bernard and Major (1963), Allen (1970), and McGowen and Garner (1970). Lenticular concentrations of pebble- to cobble-sized rip-up clasts such as those found at the base of the facies at many localities and particularly well developed at the Copperas Beds of Dolliver Park (SW 1/4, SE 1/4, SE 1/4, Sec. 34, T88N, R28W) are interpreted to represent the cores of channel bars, while the overlying plane-bedded, and lateral lentils of ripple-bedded sandstone, likely represent stoss-side and bar-front deposition analogous to the coarse-grained facies described by Eynon and Walker (1974).

Cumulative grain size frequency distribution curves (arithmetic) for all sand samples analyzed, plus a series of samples from the Kalo Bluffs, section 2, are shown in figure 23. A high degree of sorting predominant in the distributary channel sand samples is shown by the high slope angle of each line within the interval from 15 to about 85 percent. This and the relatively narrow grain size range which accounts for more than 95 percent of each sample are likely an indication of textural maturity reflecting a long transport distance. The largest portion of the finer-than 4ϕ (0.063 mm) sediment was deposited either as overbank silt and clay of the laminated fine sandy siltstone, gray claystone, and coal facies or as delta front

Facies	Depositional Environment
1. Lenticular fine- to medium-grained cross-stratified sandstone	Distributary channel
2. Fine-grained parallel-laminated to ripple-bedded sandstone	Crevasse splay/ crevasse channel
3. Laminated fine sandy siltstone, gray claystone, and coal	Floodbasin and swamp
4. Interbedded laminated very fine sandstone, siltstone, and claystone	Delta front
5. Laminated siltstone and gray claystone	Prodelta
6. Carbonaceous shale and limestone	Shallow marine

Figure 21. Facies and interpreted depositional environments of the lower Cherokee Group in part of southern Webster County, Iowa.

beds of the interbedded laminated very fine sandstone, siltstone, and claystone facies (dotted lines of figure 23).

A plot of the coarsest one percent versus the median for each sample (figure 24) indicates that the principal mode of deposition for the sand samples was by graded suspension (Passega, 1957), while the finer-grained delta front samples were deposited by a combination of graded and suspension sedimentation.

The remarkably uniform paleocurrent trends, lenticular sand body geometries, primary structure sequences, abundance of terrestrial plant remains, and relationships with adjacent facies support the interpretation that the lenticular fine- to medium-grained cross-stratified sandstone facies represents deposition in major distributary channels.

Floodbasin and Swamp

The deposits of the laminated fine sandy siltstone, gray claystone, and coal facies are interpreted to represent floodbasin and swamp depositional environments which developed on a prograding delta platform. Light colored laminated fine sandy siltstones likely represent suspension sedimentation on the delta plain (Coleman and Gagliano, 1965; Fisher et al., 1969; Reineck and Singh, 1975) resulting from overbank flooding during periods of high flow. Strata of this facies likely include natural levee (Coleman and Gagliano, 1965) deposits which occur directly adjacent to the above described distributary channel deposits. However, because of limited exposure it was not feasible to separate natural levee sediments from other deltaic plain deposits. This may also be interpreted to indicate that the natural levee depositional environment is not well developed in Lower Cherokee sediments

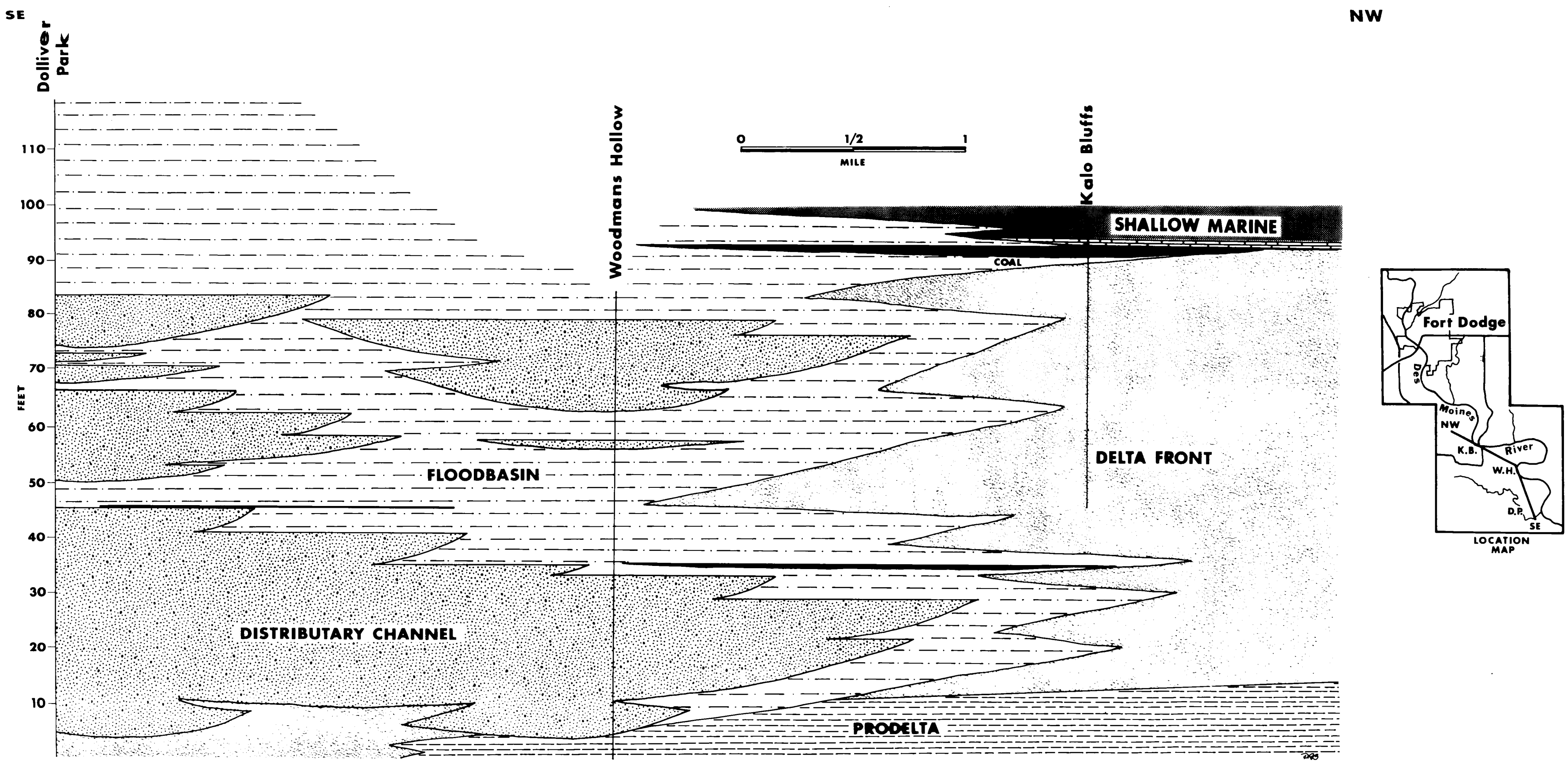


Figure 22. Illustrative diagram of the lower Cherokee facies and lateral relationships.

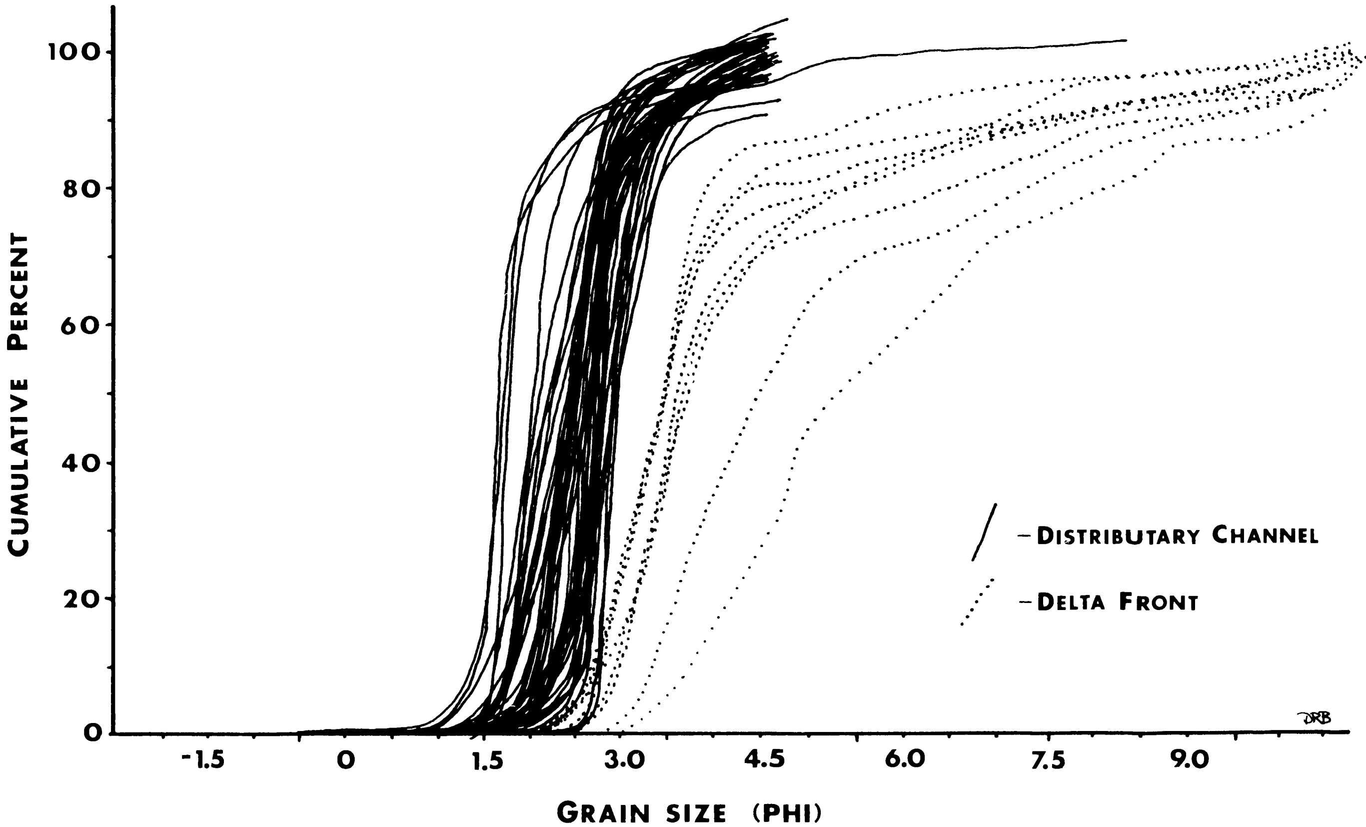


Figure 23. Cumulative weight percent (arithmetic) versus grain size (phi) for 46 samples of lower Cherokee Group samples.

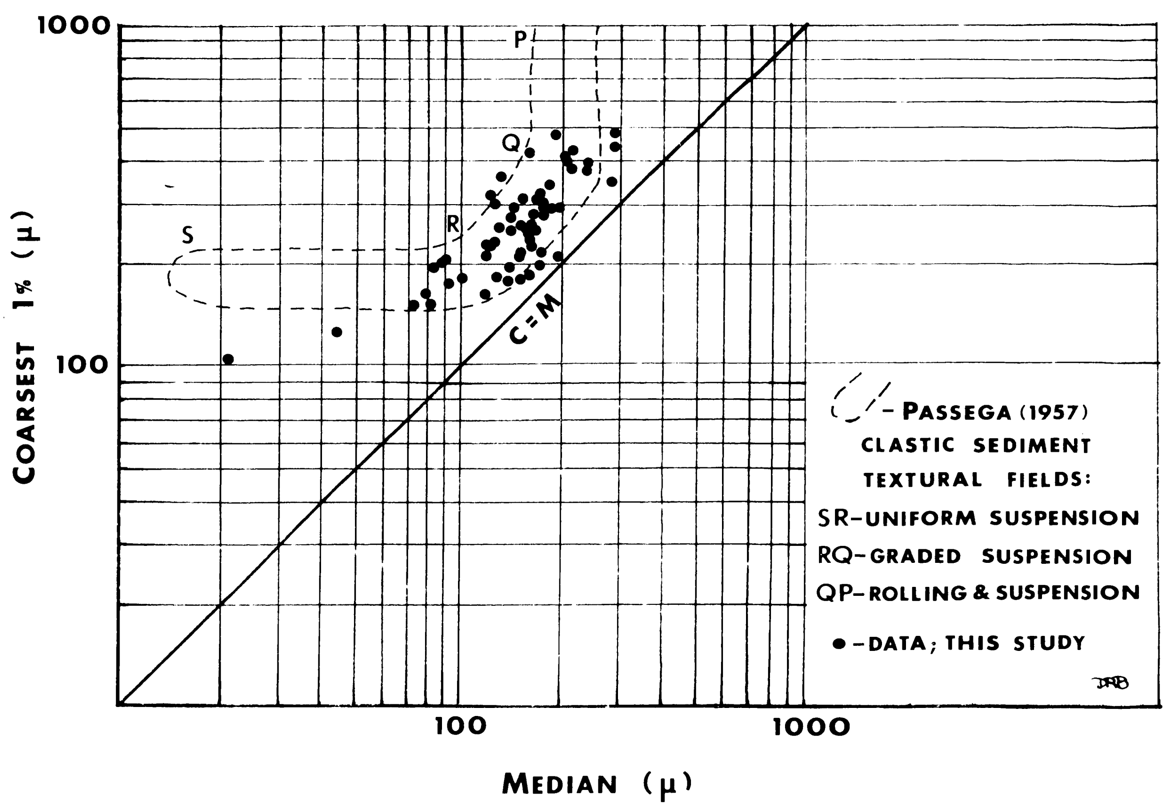


Figure 24. CM diagram for the samples of Figure 23.

in this area. Fisher, et al. (1969) report that in high-constructional delta deposits, the natural levee becomes progressively more poorly developed downstream from the upper delta plain where high-sinuosity channels predominate.

Massive to weakly laminated gray claystones which invariably underlie coal or carbonaceous shale are interpreted to represent suspension sedimentation under poorly drained marsh conditions similar to that described by Coleman (1966) and Gould (1970). These claystones likely provided the medium in which swamp vegetation flourished and accumulated, finally resulting in the development of the Cherokee Group coals. The relationships of these coals to other sediments, and particularly the sandstones, have recently been studied by Mason (1980).

Crevasse Splay/Crevasse Channel

Enclosed either by sediments of the laminated fine sandy siltstone, gray claystone, and coal facies or by the interbedded laminated very fine sandstone, siltstone, and claystone facies are lenticular to tabular sandstones of the fine-grained parallel-laminated to ripple-bedded sandstone facies. These strata most often occur in close proximity to deposits of the distributary channel sands as well and are interpreted to represent crevasse channels and crevasse splays. Crevasse channels cut through sediments of the natural levee and may be several hundred feet in width, although most typically are one to several feet wide (Reineck and Singh, 1975). Upon entering the floodbasin adjacent to the channel and natural levee, the splays spread and thin away from the channel forming lenticular to tabular sand wedges enclosed by finer grained sediments. Parallel-laminated fine-grained sands likely indicate deposition in the upper flow regime, and ripple-bedded fine-grained sands and silts capping the sand bodies reflect decreased energy and deposition in the lower flow regime. Carbonaceous debris included in these sands likely represents local plant life which was incorporated into the sediment during conditions of high flow.

Delta Front

The sediments of the interbedded laminated very fine-grained sandstone, siltstone, and claystone facies occur as a thick sequence lateral to, and underlying, strata of the distributary channel and floodbasin. They are interpreted to represent deposition in the delta front environment reflecting rapid and varied sedimentation (Coleman and Gagliano, 1965). Alternating beds of fine sandy siltstone and claystone represent deposition on the relatively steep delta front toward which much of the channel-derived silts and clays are swept as large turbid plumes (Gould, 1970). Proximity to the plant-rich delta plain is reflected by the abundant fragmented organic debris which is included in both the coarser- and finer-grained strata. The large scour-and-fill features comprising the Kalo Bluffs, section 1, are believed to reflect the erosive abilities of fine-grained sediments in the delta front environment. That no channel lag or other coarser detritus is preserved at the base of the cut suggests that the erosion was largely caused by current supplied fine-grained sediments. Numerous smaller scale truncation features within the fill also attest to this erosive ability of the delta front silts and clays. Lenticular to tabular sand bodies mentioned in the preceding section, but occurring with sediments of the delta front, are believed to be distal portions of distributary channels which were preserved under conditions of low wave energy, low tide range, low littoral drift, and a high fine-grained sediment load similar to that described by Coleman and Wright (1975). Active sedimentation and a relatively high offshore slope are suggested by the lack of faunal remains and by the abundance of small-scale soft-sediment deformational features including contorted and convolute bedding.

Prodelta

The argillaceous siltstones and claystones of the laminated siltstone and gray claystone facies underlying and interfingering with the delta front sediments are interpreted to represent prodelta deposits. These deposits are characterized by a greater degree of homogeneity than any of the other delta facies (Fisher, et al., 1969) and by the abundance of sediment finer than sand in size. Additionally they contain abundant macerated plant debris and lack faunal remains (Fisher, et al., 1969). As is reported for other prodelta deposits (Reineck and Singh, 1975), the prodelta sediments adjacent to strata of the delta front contain more silt and display more parallel- and ripple-lamination.

Shallow Marine

Strata of the carbonaceous shale and limestone facies occur as a northwestwardly thickening wedge overlying and intertonguing with the delta front and prodelta sediments. At Kalo Bluffs, section 3, the limestone includes a rich assemblage of spiriferid brachiopods and a thick black shale, below, which contains small brachiopods tentatively identified as *Lingula*. A thin horizon of cone-in-cone structure at the top of the limestone likely reflects calcite recrystallization under compactive load from the overlying sediments. Because of the lithology, fossil content, and lateral relationship to other facies, beds of the carbonaceous shale and limestone facies are interpreted to represent shallow marine deposition.

PETROGRAPHY

Laboratory analysis of selected samples was undertaken to characterize the texture and mineralogy of the middle Pennsylvanian strata. Thin section description and studies of clay mineralogy and heavy mineral content are included to supplement the field data in this guidebook and to provide insight into the provenance and diagenetic history of the sediments.

Texture

Texturally the sandstones consist of dominantly quartz-supported frameworks, exhibiting no *in situ* grain deformation that may be attributable to post-depositional compaction. Elongate particles show little consistent orientation, except for mica flakes which in hand specimen are oriented parallel to cross laminae.

Visual estimation of detrital grains indicates generally high roundness, especially for coarse-grained quartz (up to 2000 μm), the majority of which is equant and well-rounded. Very fine- to medium-grained (to 500 μm) quartz and feldspar are also largely equant and tend to be angular to subrounded. Feldspar fragments were not observed larger than 500 μm and were usually more angular than quartz. Siltstone rock fragments display consistently high sphericity and roundness within the sand-size range.

Mineralogy

The modal mineralogy of four Dolliver Park sandstones are tabulated in Table 2. Figure 25 includes photomicrographs of the Dolliver Park samples. Terrigenous detritus is dominated by quartz followed by minor feldspar, sedimentary rock fragments, and clay and heavy minerals.

Terrigenous detritus

Monocrystalline quartz exhibits nearly straight to strongly undulose extinction. A small but significant fraction of quartz grains are semi-composite to polycrystalline and occasionally appear as stretched aggregates. A few quartz grains display detrital strain deformation in the form of Boehm lamellae. Equally variable as crystallinity is the abundance of microlites and vacuole trains present. Rutile needles and tourmaline inclusions are common microlitic constituents. The degree of calcite replacement appears to correlate directly with vacuole density. No quartz overgrowths were observed.

Feldspars comprise a minor to trace component of these sands. Orthoclase, microcline, and plagioclase each show kaolinitic alteration and calcite replacement to some degree, but overall untwinned orthoclase grains exhibit the most extensive alteration. Microcline is comparatively unaltered and present in nearly all of the samples. Plagioclase (twinned sodic varieties) exists in variable alteration states, possibly related to compositional variation.

Argillaceous to arenaceous siltstones dominate the sedimentary lithic suite with a minor, although pervasive, chert constituent. Detrital cherts are present throughout the stratigraphic section while siltstone clasts are concentrated within specific beds. As seen from Dolliver Park sample 9b (Table 2; figure 25a), the lithic clasts can comprise 45% of the detrital framework. Virtually every clast is coated by a thin rind of secondary hematite or siderite. It is inferred that, as with the pebble- to cobble-sized siltstone clasts seen along the base of many of the channel sands, the lithics were derived through erosion and transport of older Pennsylvanian units upstream.

Muscovite is the principal mica and occurs in all sandstones analyzed. Biotite is less abundant. Kaolinite and illite with traces of montmorillonite and chlorite comprise the clay mineralogy. For both sandstone matrix and fine-grained sediment, kaolinite is most abundant. Clay minerals form a

Table 2. Mineralogy of Selected Dolliver Park Sandstones.

	DP-9b[a]	DP-9d	DP-11h	DP-CB-A
Quartz				
Monocrystalline	25[b]	77	64	53
Polycrystalline	2	2	5	7
Feldspar				
Orthoclase	--	2	4	T
Microcline	1	--	2	1
Plagioclase	--	2	1	1
Rock Fragments				
Siltstone	23	1	1	--
Chert	1	1	3	2
Mica				
Muscovite	T	1	1	1
Biotite	--	--	2	--
Matrix				
Carbonite				
Calcite	27	12	7	2
Dolomite	--	--	--	22
Clay-Iron Oxides	21	2	10	11
Q:F:R Ratio	53:2:45	94:5:1	86:4:5	94:3:3
Compositional Name	Litharenite (Sedarenite)	Subarkose	Subarkose	Sublitharenite

[a]DP-9b, 9d, and DP-11h: Dolliver Park section and vicinity; DP-CB-A: Copperas Beds.

[b]Based on a number frequency relating to 100. T = trace.

Figure 25. Photomicrographs of Selected Pennsylvanian Strata

Photo

a. Litharenite, DP-9b. Photo displays numerous, well-rounded siltstone clasts in the framework. Note iron oxide rinds coating the quartz and lithics.

b. Subarkose, DP-9d. Typical fine-grained sandstone of the lower Cherokee in Webster County.

c. Subarkose, DP-11h. Similar to photo "b" with predominantly quartz and minor feldspar and lithics.

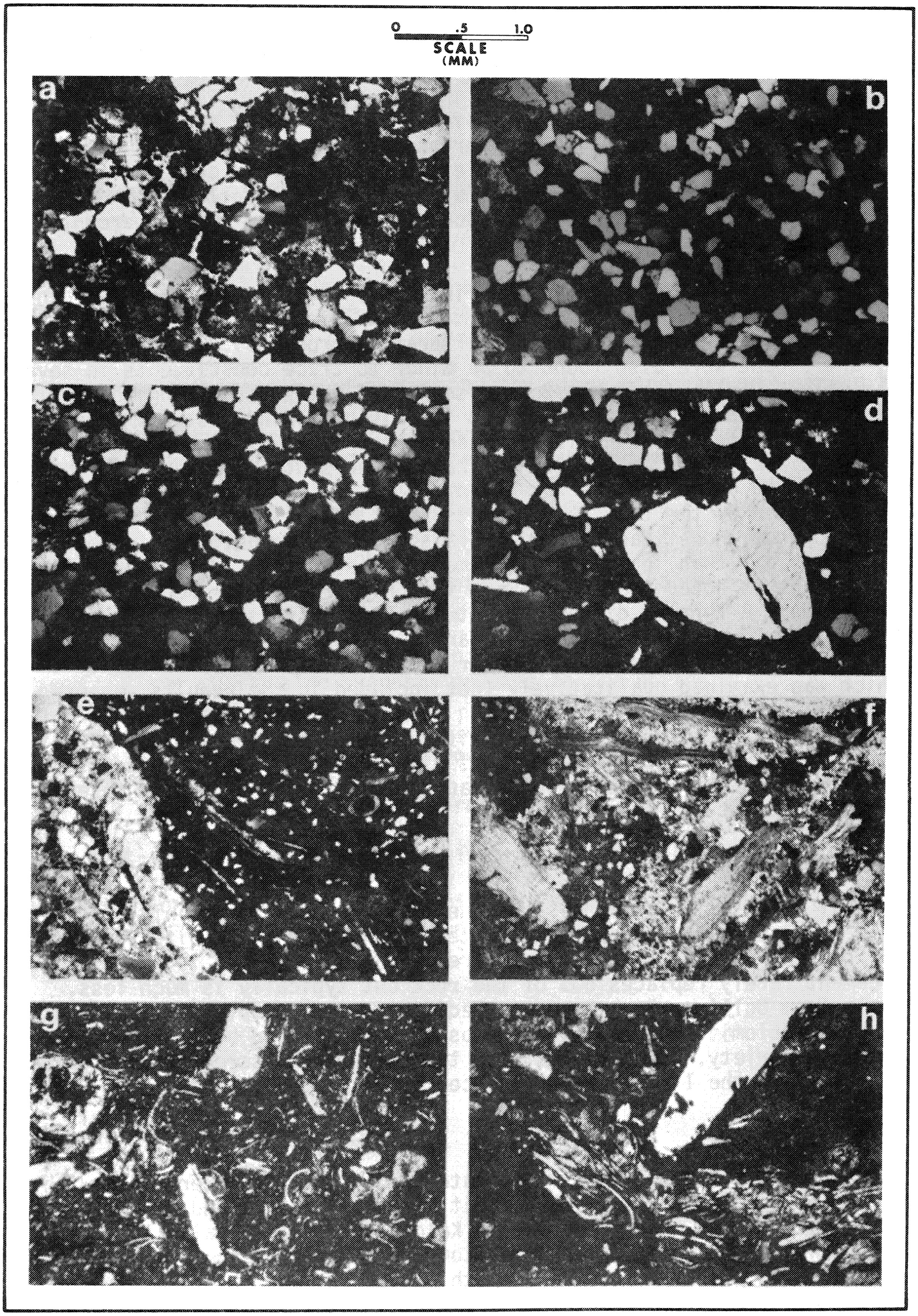
d. Sublitharenite, DP-CB-A, Copperas Beds. Poorly sorted, fine- to coarse-grained sandstone with a dolomitic matrix. Large quartz grain in center of photo.

e. Limestone, arenaceous and pyritic, Kalo Bluffs-3. Abundant very fine sand- and silt-sized quartz floating in a marly, pyritic calcite matrix. Pyrite in black matrix.

f. Limestone, arenaceous, Kalo Bluffs-3. Fossiliferous (brachiopod) equivalent to photo "e." Similar arenaceous concentration as "e."

g. Wackestone, Coalville West. Abundant fossiliferous hash with less abundant quartz detritus than KB-3.

h. Wackestone, Coalville West. Same bed as photo "g" showing accumulated layers of shell material and large calcite fragment, top center.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significant proportion of the binding agent in many sandstones, contributing to the generally moderate induration on outcrop.

The heavy mineral suite of these Pennsylvanian distributary and delta front sandstones was investigated using standard separation, petrographic and x-ray powder camera techniques. Two samples were arbitrarily chosen from each of the four areas, namely, Dolliver State Park, Woodmans Hollow, Wildcat Den, and Kalo Bluffs. Results of the counts, tabulated in number percent, are presented in Table 3.

Examination of Table 3 shows that the principal species encountered, in general order of decreasing frequency, are magnetite/ilmenite, zircon, garnet, and tourmaline (discounting the opaque alteration products). Chloritoid, rutile, and sphene were also found to be minor to trace constituents in several of the samples. Following Table 2 is a series of notes describing the various mineral species and assumptions utilized in this preliminary study. Previous work on the petrology of Pennsylvanian sandstones in Iowa was undertaken by Robey H. Clark (1950) in an area farther to the south. The suite of heavy minerals observed in that study was essentially similar to the one found here. Comparison of the tabulated results shows much higher percentages of the non-opaque, non-titaniferous minerals (zircon, garnet, and tourmaline) in the Clark study than in this one. Some of this apparent discrepancy disappears when it is noted that these were the only grains Clark counted in his tabulation. A further difference between the two sets of results is that Clark also found small amounts of barite and staurolite in his samples; neither was found in this study. Another sample from the Webster County area which was examined qualitatively (not included in the results reported here) showed one grain of a mineral which fit Clark's description of the staurolite grains he observed, but a positive identification was not made. The extremely sporadic occurrence of this mineral in the earlier study suggests that mere chance is possibly the cause of its not having been observed in the Webster County samples.

Secondary components

The chemical constituents of the sandstone framework consist mainly of calcite with local concentrations of dolomite, hematite, and limonite (goethite). Calcite forms an interlocking matrix where pervasive twinning is noted. Carbonate cement rarely replaces 50% of the rock but typically is much less. The sample from Dolliver Park-Copperas Beds (Fig. 25d) displays a prevalent reddish brown dolomite matrix. The rhombs are believed to be iron-rich ferroan dolomite variety. Iron oxides give the sandstone outcrops their typical brownish hue. In the limestone, pyrite concentrations are common.

Limestone petrography

A thin argillaceous to arenaceous carbonate (to 14 in.) is interbedded with the upper coal and carbonaceous shale unit at Kalo Bluffs-2 and is believed to be correlative with that occurring in Kalo-Bluffs-3 and Coalville West. Figure 25, photos "e" and "f," show photomicrographs from the arenaceous carbonate at Kalo Bluffs-3. Compared with photos "g" and "h," the limestone at Coalville West displays a decrease in detrital quartz and an increase in shell fragments. This trend is consistent with the interpretation that these units of KB-3 and Coalville West were deposited progressively more distant from active deposition of the southwesterly trending distributary channels.

Interpretation

The petrography of the middle Pennsylvanian sandstones of Webster County is similar to that of other Pennsylvanian strata elsewhere in the Midwest (e.g., Clark, 1950; Rusnak, 1957) yet reflects probable differences in source lithology. The detrital component, dominated by monocrystalline quartz, is not indicative of any one provenance, although the most likely is that of a plutonic igneous terrain possibly having undergone regional metamorphism. The stable, non-opaque heavy mineral suite identified supports this conclusion. Garnet is a mineral characteristic of metamorphic rocks, as is staurolite. Magnetite and zircon, on the other hand, are widespread accessory minerals in igneous rocks. Tourmaline is most commonly characteristic of granite pegmatites and of the rocks immediately surrounding them, and is also an accessory mineral in other igneous and metamorphic rocks (Hurlbut and Klein, 1977). The presence of this stable heavy mineral association in these sediments suggests that the ultimate source area was an igneous-metamorphic complex. The zircon tourmaline-rutile stability index is high, suggesting a resistant, high maturity, heavy mineral assemblage that possibly survived lengthy transport, sedimentary recycling, and/or intrastratal alteration.

The Canadian Shield to the north and northeast is the most likely source area. Clark (1950) also suggests an area in the northern Appalachian province which has similar characteristics; however, geographic considerations lend little support to this area as a likely source. It is not inconceivable that part of the detritus may be reworked from older Paleozoic strata flanking the crystalline basement. The paucity of feldspar may be the resultant of such recycling and transport abrasion.

The post-depositional diagenetic history appears to be straight-forward; namely, one of calcite cementation concurrent with or followed by local crystallization of dolomite and siderite. Hematite and limonite staining is related to surface oxidation of the sand bodies.

Table 3. Number Frequencies of Heavy Mineral Species

Unit	Dolliver Park E	Dolliver Park G	Woodmans Hollow B	Woodmans Hollow B	Wildcat Den A	Wildcat Den E	Kalo Bluffs C	Kalo Bluffs A
Magnetite/Ilmenite	13	25	34	13	26	47	25	20
Zircon	17	20	40	25	19	38	14	42
Garnet	3	13	7	1	2	4	1	-
Tourmaline	1	7	1	5	4	1	6	7
Chloritoid	1	2	-	-	4	-	-	-
Rutile	-	T	2	1	-	2	T	-
Sphene	-	-	-	-	-	1	T	-
Leucoxene	29	15	13	34	21	6	20	7
Red iron oxides	8	11	1	10	-	1	13	-
Composites	28	7	2	12	24	1	21	24
Totals	100	101	100	100	101	100	100	100

Notes on Heavy Mineralogy:

1. Magnetite and ilmenite are here counted as a single species since microscopic distinction between them is extremely difficult and since they are commonly associated in source area, so that in this study there is little interest in making the distinction. Some of the grains bore a leucoxene coat, indicating that they are more likely ilmenite; also much of the leucoxene showed an unusually high magnetite susceptibility.

2. The garnet is principally the clear variety of grossularite showing a slight pinkish hue. A few grains are without this tint.

3. The tourmaline found in these samples is virtually exclusively the variety schorline, brown in color with a greenish hue, and strongly pleochroic.

4. The entry T in the table indicates that the species was encountered but in recalculation was found to occur less than once per hundred counts.

Table 3 (continued)

5. The designation leucoxene applies to any grain which was entirely composed of leucoxene or was completely coated with that substance. In some cases the grain may have been rutile, anatase, or sphene, but because of the complete coating, the "core" mineral could not be counted. In cases where the grain was partially coated, but the uncoated part could not be accurately identified, the grain was counted as a composite. Thus, could the cores of all coated grains have been identified, the effect would be to increase the relative percentages of these minor to trace nonopaque constituents.

6. All grains having the outward characteristics of rutile were counted as such; no attempt was made here to distinguish between ordinary rutile and its polymorph anatase.

7. The designation "red iron oxides" includes hematite and limonite, as these are frequently indistinguishable optically. The large number of such grains in some samples tends to suggest that they are limonite-coated grains of other materials.

8. The term "composites" comprises grains of various types. One of these was noted in (7) above; a partial alteration coating where the nature of the coated mineral or of the coating itself (or both) was not accurately determinable. Other types of composites are aggregates of two or more species which were also difficult to determine, including a particular gray alteration product similar to that classified by Clark (1950) as a "chloritic."

PART III: ROAD LOG AND STOP DESCRIPTIONS

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ROAD LOG

Mile	(km)	Description
0		Start trip, north side Scheman Continuing Education Center. Proceed south to T intersection; turn left to Elwood Drive.
0.2	(0.32)	At the stop sign, turn right onto Elwood Drive; continue to west.
1.7	(2.72)	Enter new State Route 30, west, just before underpass; continue to west.
6.7	(10.72)	Intersection with old State Route 30. Minor moraines forming a swell-swale topography with a NE trend. Minor moraines (washboard moraines) are low (less than 25 feet, 8 m relief), till-cored ridges which are postulated to have formed along thrust planes at the base of a glacier undergoing compressive flow. They have a mean spacing of 300 feet (100 m) and form the low roadcuts. Transverse, till-cored ridges cross the minor moraines at a 30 to 90 degree angle. These are believed to be crevasse fills along tensional fractures in the glacier. The intervening depressions form swamps; prior to the advent of field tile, this area was known as "wet prairie" and a favorite stopping place for migrating ducks. The minor moraine lineations

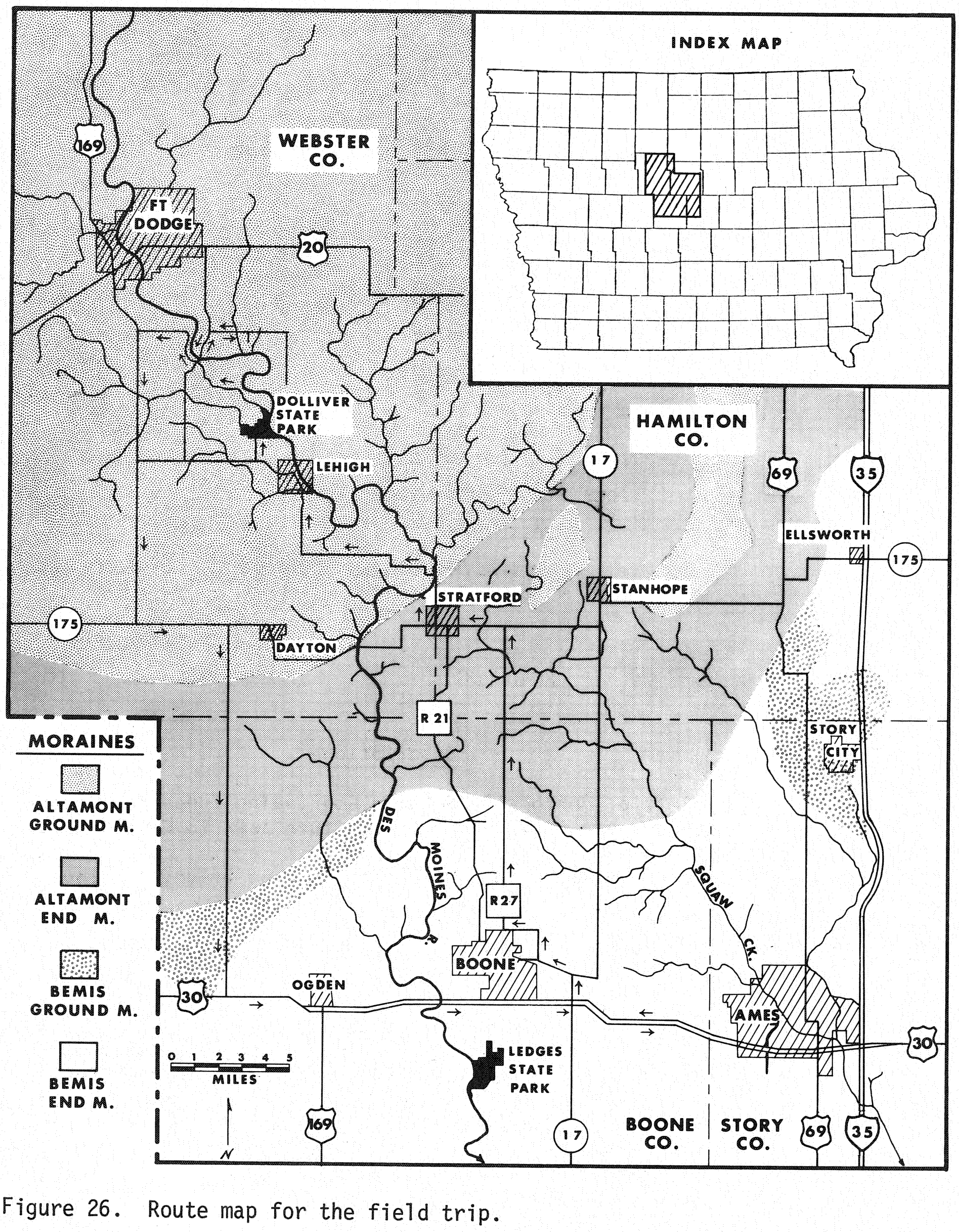


Figure 26. Route map for the field trip.

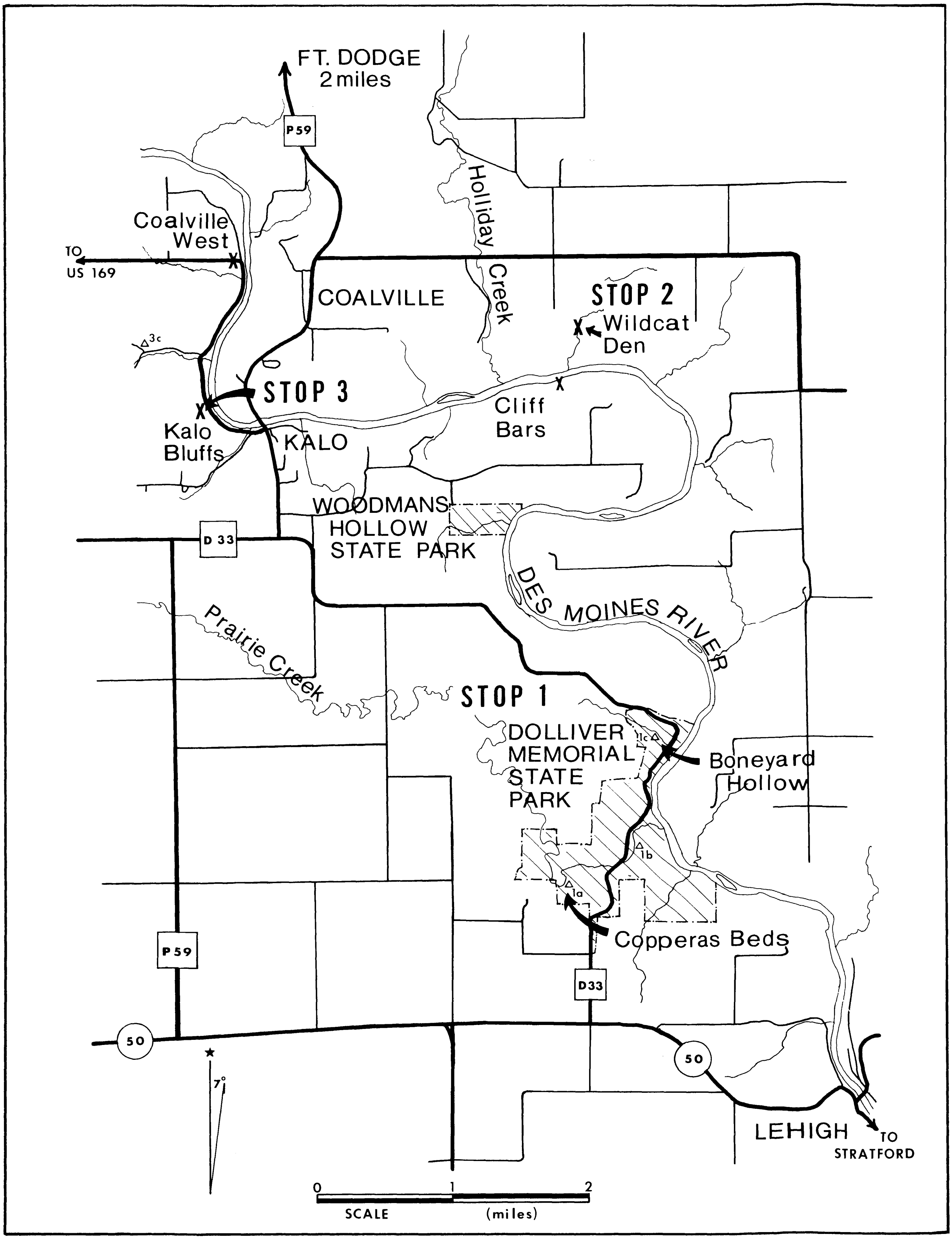


Figure 27. Detailed route map for the field trip stops.

Mile	(km)	Description
		were used by Ruhe (1969) to define the Bemis End Moraine which is the terminal moraine of the 14,000-year-old Des Moines Glacial Lobe. We will be on the Bemis Moraine for the next 18 miles (29 km).
10.3	(16.48)	ISU Experimental Farm to south; United Community High School to north.
11.7	(18.72)	Grain elevators to north are in the town of Jordan. Jordan was destroyed in 1975 by a tornado.
12.4	(19.84)	Right turn on Iowa 17 at cloverleaf intersection. Proceed north on extension of Iowa 17 across railroad tracks.
13.8	(22.1)	Stop sign; turn left (west).
14.9	(23.8)	Railroad underpass.
15.2	(24.3)	Boone Industrial Park; right turn (north) onto paved secondary road.
15.7	(25.1)	Road becomes gravel, continue north.
16.2	(25.9)	Red gravel is gob from coal mines to west of city of Boone. Boone was a coaling stop along the railroads.
16.7	(26.7)	Turn left (west). Low ridge is a northwest trending crevasse fill.
18.1	(28.9)	Right turn (north) onto County Road R27. Low ridges are minor moraines with a NE-SW trend.
19.3	(30.1)	Farmstead on minor moraine; many farmsteads are located at the junction of a minor moraine and a transverse, crevasse fill where soil drainage is better.
21.4	(34.2)	Crossing Prairie Creek a tributary of Squaw Creek which passes through the Iowa State campus. Prairie Creek heads just 2.7 miles (4.3 km) east of the Des Moines River. The Des Moines River between the city of Des Moines and the Boone River to the north lies on a topographic high. The Des Moines River was superimposed from the Des Moines glacier onto a topographic high lying along the axis of the lobe. Within this reach, no major tributary enters the Des Moines River (Lees, 1916; Dekoster, Hussey, Munson, 1959).
22.3	(35.7)	Rise with vista of Bemis End Moraine to east, south, and west. The Altamont End Moraine is 2 miles (3.2 km) to north. The divide between the Des Moines River and Squaw Creek lies just to west.
24.1	(38.6)	Crossing Boone County Road E-18; continue north.

Mile	(km)	Description
24.7	(39.5)	Rising onto Altamont End Moraine; the Altamont End Moraine is the second recessional moraine on the Des Moines lobe. The morainal ridges of the Altamont cross-cut the minor moraine trends of the Bemis Moraine, and this represents a readvance of the glacier which covered 7,030 square miles (18,200 square km) (Ruhe, 1969). the Altamont Moraine in this area has a knobby topography with many of the hills developed upon till-gravel complexes or gravel. The hummocky topography forms two ridges, each about 1 mile (1.5 km) wide, with more than 50 feet (15 m) of local relief (Bohlken, 1980). Many of the conical hills have slight, central depressions; these are known as "ice disintegration ridges" and were developed by stagnant ice with a thick cover of ablation fill. In many places, the Altamont End Morine rests on the crest and fore slopes of bedrock topographic highs (Palmquist and Connor, 1978).
25.9	(41.4)	Depression separating two ridges.
26.2	(41.9)	Numerous kame complexes.
27.0	(43.2)	Leaving Altamont End Moraine and driving across Altamont ground moraine. Crossing line between Boone and Hamilton counties.
29.8	(47.7)	Bridge across Squaw Creek. At this point we are 13.3 miles (21.3 km) east of the Des Moines River. To the north, Squaw Creek extends to within 6.5 miles (10.4 km) of the Des Moines.
30.4	(48.6)	Low relief ground moraine. Although Hamilton County has not been studied, it is probable that this area is an extension of the lacustrine deposits occurring in southern Webster County which we will cross this afternoon.
30.9	(49.4)	Left turn (west) onto Iowa 175 toward Stratford.
31.9	(51.0)	Bridge across Squaw Creek. The channel has been deepened to facilitate the gravity draining of field tiles.
33.4	(53.4)	Enter Stratford; intersection with County Road D-54 (Belleville Road).
34.7	(55.5)	Tributary to the Des Moines River. At this point we are less than 0.6 miles (1 km) from the Des Moines.
35.2	(56.3)	Descend into valley of Des Moines River. The till outcrops on either side of the road are the scarps of small landslides. The landslide susceptibility of the Des Moines River Valley is considered to be moderate by the U.S.G.S.
36.0	(57.6)	Entering Webster County.
36.1	(57.7)	Bridge across Des Moines River.

Mile	(km)	Description
36.6	(58.5)	Low terrace with small alluvial fans. The terrace sequence along the Des Moines River was last studied by Lees (1916) who did not recognize very low terraces.
37.0	(59.2)	Ascend to upland. For the next 8 miles (12.8 km) the road will be on upland remnants between encroaching tributaries of the Des Moines River. This area is an excellent example of late youth in the terminology of W. M. Davis.
37.1	(59.4)	Upland surface. For the next 1.3 miles (2.1 km) the road crosses a very high terrace of the Des Moines river. Sands and gravel occur within 3 feet (1 m) of the surface.
39.4	(63.0)	Crossing large unnamed tributary to Des Moines River which lies 4 miles (6.4 km) south of road.
39.4	(63.0)	Turn right (north) onto Webster County Road P-73.
45.1	(72.2)	Descend into valley of Des Moines River. Note contact between buff-colored oxidized till and gray unoxidized till exposed in borrow pit to west (left).
45.6	(72.9)	Floodplain of Des Moines River. Road to west is along Crooked Creek. Abandoned coal mines along both sides of the valley occur within the lower part of the Cherokee Group. About 3/4 mile (1.2 km) upstream is the clay pit at the Dickey Clay Products Co. Here Pennsylvanian claystones and siltstones are quarried for use in tile making.
46.3	(74.1)	Enter town of Lehigh; continue through town.
46.5	(74.4)	Ascend valley wall of Des Moines River. Outcrops of Pennsylvanian strata on either side.
47.2	(75.5)	West Lawn Cemetery.
48.4	(77.4)	Turn right (north) onto road to Dolliver State Park (figure 28).
48.9	(78.2)	Park entrance.
49.6	(79.4)	Turn left (west) into picnic grounds at Copperas Beds. Park in lot at end of road. Parking lot is on alluvium covered bench over bedrock. Trail to Copperas Beds is along Prairie Creek. Start of trail is on a dissected alluvial fan of Prairie Creek when it flowed at the level of the parking lot terrace.

<u>Stop 1A--Copperas Beds, Dolliver Park</u> (SW 1/4, SE 1/4, SE 1/4, Sec. 34, T88N, R28W; and NW 1/4, NE 1/4, Sec. 3, T87N, R28W). From the north end of the parking lot, follow the trail to the west along Prairie Creek to the wooden foot

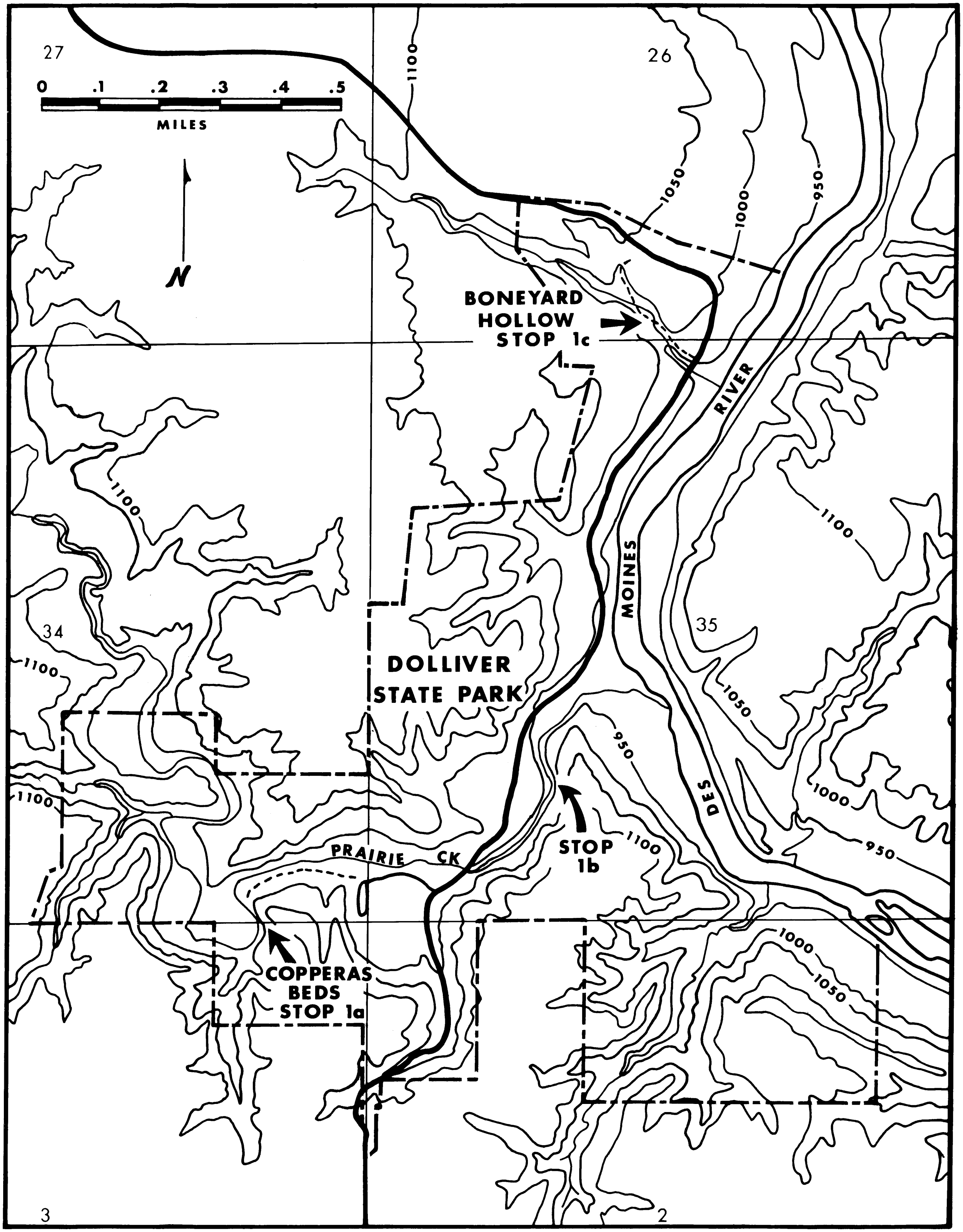


Figure 28. Field trip stops, Dolliver Park.

Mile	(km)	Description
		bridge crossing the creek. (At this point, a short introduction will be given.)

Proceed south, along the eastern bank of Prairie Creek, to view the sandstone outcrop comprising the Copperas Beds. The section (figure 29) includes a series of thin to very thick beds of very fine to conglomeratic sandstones with abundant carbonized, and in some cases permineralized, branches and leaves. Fragmented carbonized and/or pyritized woody material is very common in the lower, coarser-grained deposits which also include abundant subangular to well-rounded discoidal rip-up clasts of fine sandy siltstone. These are usually armored by a 1/8 to 1/4 inch (3-6 mm) thick rind of iron oxide minerals which causes the clasts to stand out from the outcrop face and often to pluck out as a single piece leaving only a partial mold behind. The clasts are rarely imbricated and usually very poorly sorted. They occur in thick lenses or wedges with sharp basal surfaces and sharp to gradational upper contacts; in many cases these bodies are interpreted to represent the cores of channel bars with laterally gradational and interfingering deposits of cross-stratified fine- to medium-grained bar-side sands. The strata of the Copperas Beds represent several cycles of aggradation within a channel and include vertically stacked and interfingering bar forms and overbank fine-grained carbonaceous sand and silt. Of special interest at this locality is the occurrence of sulfate efflorescences along the outcrop face. These were originally identified as ferrous sulfate, or copperas, from which the beds derive their name. Later, analyses by the Iowa Geological Survey identified the hydrated ferrous sulfate melanterite ($FeSO_4.7H_2O$). More recent work by Cody and Biggs (1973) of Iowa State University has shown that the efflorescences, consisting of a layer (3/4 inch thick) of white, fibrous crystals intermixed with equant very fine-grained crystals, include at least 3 mineral species: halotrichite ($FeAL_2(SO_4)_4 \cdot 22H_2O$), szomolnokite ($FeSO_4 \cdot H_2O$), and rozenite ($FeSO_4 \cdot 4H_2O$). All are readily soluble in water and during heavy rainstorms may be completely cleared from the outcrop face. Subsequent periods of low to moderate humidity result in renewed precipitation of the sulfate rind.

Return to the bus.

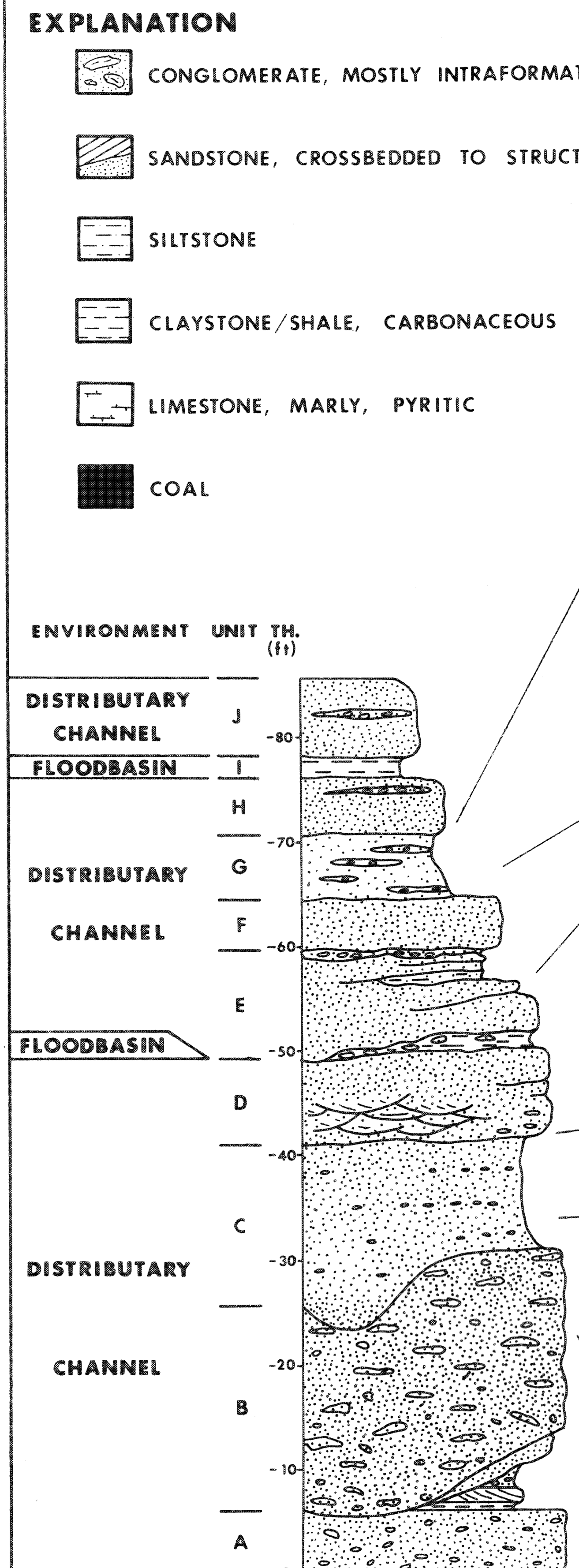
Mile	(km)	Description
50.0	(80.0)	Ford Prairie Creek.
50.1	(80.2)	Outcrop of channel sandstone to left (north); notice large concretion with mammalary morphology.
50.2	(80.3)	Stop 1B--Dolliver Park (SW 1/4, NE 1/4, SW 1/4, Sec. 35, T88N, R28W). From the bus, cross the sand and proceed eastward to the outcrop exposed along the east side of Prairie Creek. Stop before crossing the creek.

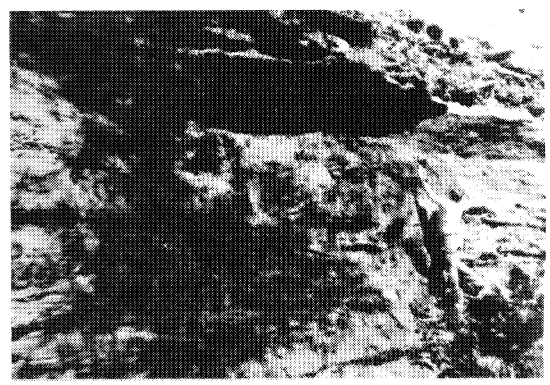
Mile	(km)	Description
		This exposure (figure 30) provides an opportunity to see deposits of the distributary channel and floodbasin depositional environments. At the very base are arenaceous siltstone and laminated silty claystones with small lentils of very fine-grained sandstone and thin sheet sandstone. This interval, carbon-rich and very fine-grained, is interpreted to represent delta front sedimentation. The lenticular sand bodies, horizontally bedded and cross-stratified to ripple bedded, are believed to represent crevasse channels, while the thin sheet sandstone represents a crevasse splay. Overlying the delta front interval is a thick sand sequence, the lower half of which is well exposed in the lower part of the cliff. Notice the sharply erosional basal contact with abundant rip-up clasts and carbonaceous debris, the lenticular body geometry with thinning to the north, and the abundant primary structures exposed in the cliff face. This locality includes abundant large-scale planar cross-bed sets to greater than 2 feet (0.6 m) thick which typically thicken in a downstream direction. Each set includes an erosional base and is overlain either by shallowly dipping stoss-side cross-strata throughout Dolliver Park are overwhelmingly directed to the southwest with a maximum of readings (143 of 249 or 57%) trending between S30°W and S70°W (figure 32). Individual beds commonly exhibit normal grading on outcrops which are strongly iron-stained but poorly indurated. To the north, a wooden footbridge crosses the creek. If the creek level is low enough, walk across the bridge and along the outcrop to observe details of bedding.
		Return to the bus.
		If time permits, walk back (south) to the point where the creek crosses the road. A trail heading east, up the side of the outcrop, leaves the road just south of the ford. This trail can be followed for a distance of about 200 feet (60 m) to a point where it crosses an interval of light colored arenaceous siltsone, gray claystone, and coal/carbonaceous shale. The entire interval is thinly bedded to laminated with shaley parting with abundant organic fragments along the parting planes. This sequence represents flood basin deposition. The coal is apparently of local significance only but occupies a stratigraphic position marked in other localities by carbonaceous shale, siltsone, or very fine-grained sandstone.
50.3	(80.5)	Oxbow lake to right.
50.6	(81.0)	Structural terrace to left with camp ground.
51.0	(81.6)	Stop 1C--Boneyard Hollow, Dolliver Park (park; NW 1/4, NW 1/4, NE 1/4, Sec. 35, T88N, R28W). From the bus proceed across the road along the north bank of the creek draining Boneyard Hollow (figure 31). Looking to the south-southwest,

Figure 29. Graphic Section of Dolliver Park - Copperas Beds

Unit	Description
J.	Sandstone, silty; grayish orange (10YR7/4); very fine grained; indistinct bedding; very friable; 7 ft.
I.	Claystone, silty; light gray (N6); laminated; friable; 2 ft.
H.	Sandstone; similar to unit C; occasional claystone band; 5 ft.
G.	Alternating sandstone and claystone; similar to unit E; 6 ft.
F.	Sandstone; same as unit D; 5 ft.
E.	Sandstone - siltstone; sandstone; same as unit D; siltstone; argillaceous and carbonaceous with clay galls; friable; 8 ft.
D.	Sandstone, similar to unit C; some carbonaceous debris; horizontal laminations to trough crossbedding; lensatic, cobble-clast band at top; 10 ft.
C.	Sandstone, subarkose with thin claystone beds; dusky yellow (5Y6/4); fine-grained; quartz with silt galls, micaceous, clay mineral cement; basal contact sharp, scoured; moderately friable; up to 18 ft.
B.	Conglomerate, intraformational; dark reddish brown (10R3/4) to light brown (5YR5/6); very poorly sorted, pebble to boulder size, moderate sphericity and roundness, quartz and siltstone clasts cemented by ferroan dolomite; basal contact sharp and erosional; thin-bedded with slight imbrication; very well indurated, cliff former; up to 20 ft.
A.	Conglomerate - sandstone: cgl; quartz pebble and sandstone clasts; very dusky red (10R2/2) to moderate reddish brown (10R4/6); pebbles well rounded, poorly sorted; basal contact not exposed; thin bedded; very well indurated with dolomitic cement; sandstone; light brown (5YR5/6); quartzose; fine grained; small scale crossbedding; friable to moderately indurated; unit up to 10 ft.

DOLLIVER PARK - COPPERAS BEDS





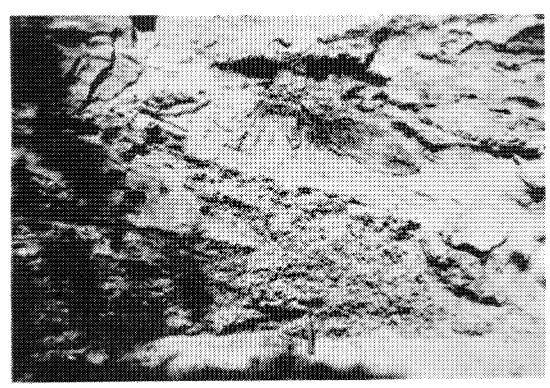


Figure 30. Graphic Section of Dolliver Park

Unit	Description
I.	Sandstone-siltstone repetitions; sandstones, calcareously cemented; similar to unit D below; 23 ft.
H.	Siltstone; sandy at base but very poorly exposed; covered slope; 36 ft.
G.	Sandstone, subarkose, similar to unit E; 9 ft.
F.	Alternating layers of sandstone and siltstone-claystone; as in unit D; 8 ft.
E.	Sandstone; same colors as unit B; fine-grained; indistinct bedding with scour surface and clay galls in lower portion; basal contact sharp; friable; 16 ft.
D.	Sandstone-siltstone; sandstone, carbonaceous with wood fragments; yellowish gray (5Y7/2), fine-grained, horizontal lamination; friable; 4 ft. thick; siltstone, argillaceous to arenaceous and carbonaceous; grayish orange (10YR7/4), to light gray (N7); laminated; friable; 1.5 ft. thick; total thickness 5.5 ft.
C.	Sandstone, abundant claystone bands and rip-up clasts of silt and sand; same colors as unit B; carbonaceous and micaceous; clasts up to 6 in. dia.; sandstone clast conglomerate in upper portion; indistinct bedding; moderately friable; 20 ft.
B.	Sandstone; subarkose; dark yellowish orange (10YR6/6), weathers moderate brown (5YR4/4); fine-grained, moderate sphericity and roundness, well sorted; quartzose with minor feldspar, siltstone rip-up clasts at base; basal contact sharp, irregular with isolated coaly pods; small to large scale trough and planar crossbedding in sets to 2.5 ft. thick; well indurated, cliff former; thins laterally; 22 ft.
A.	Siltstone-sandstone; stilstone, argillaceous and carbonaceous; medium dark gray (N4) to grayish orange (10YR7/4) at the top; thinly laminated to laminated; friable; sandstone; moderate yellowish brown (10YR5/4) to moderate brown (5YR5/5); very fine-grained, well sorted; basal contacts sharp; lenticular; faint cross-bedding, ripple marks on upper surfaces; moderate to well indurated; lenses to 3 ft. thick; basal contact of unit A not exposed; up to 12 ft.

DOLLIVER PARK

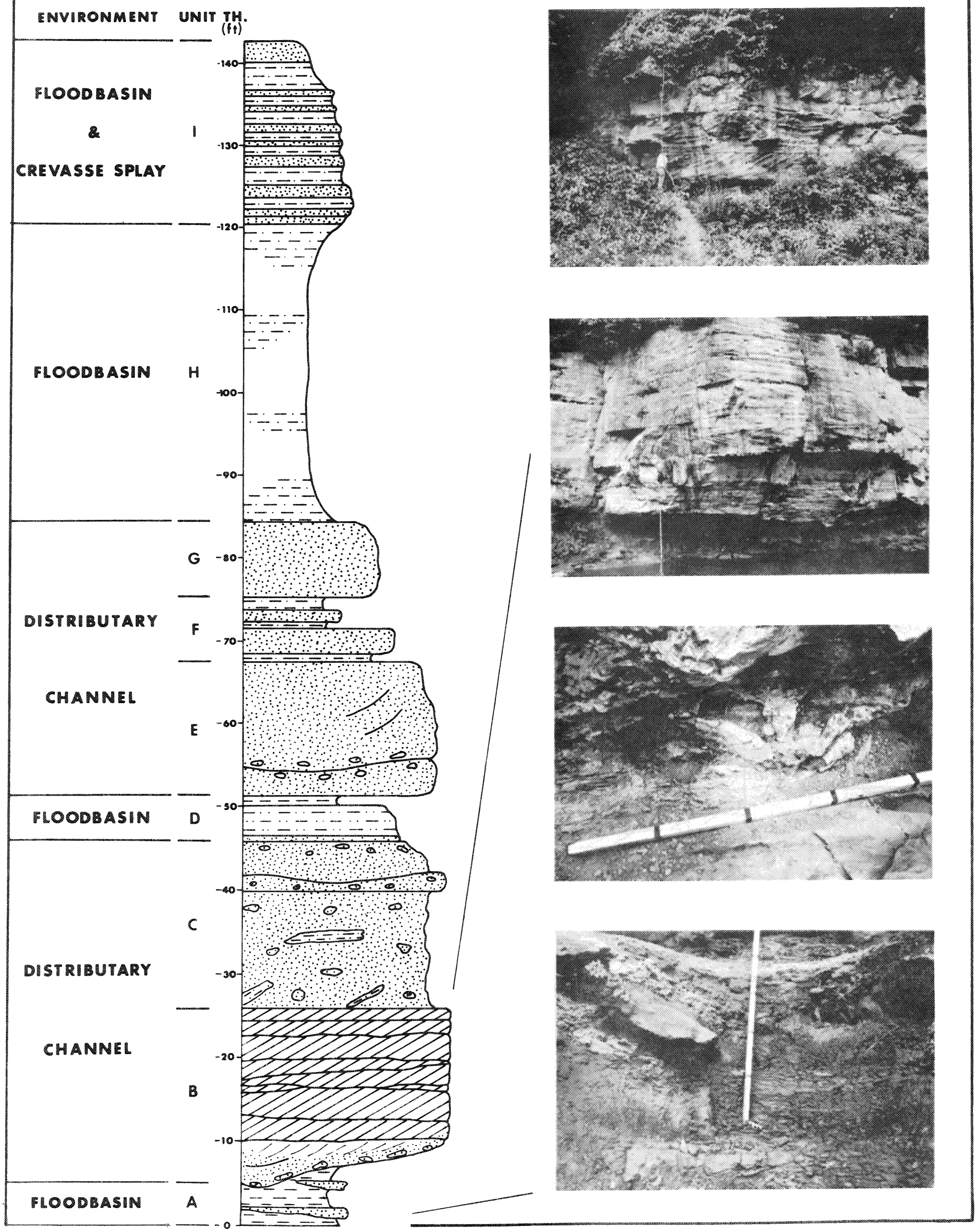
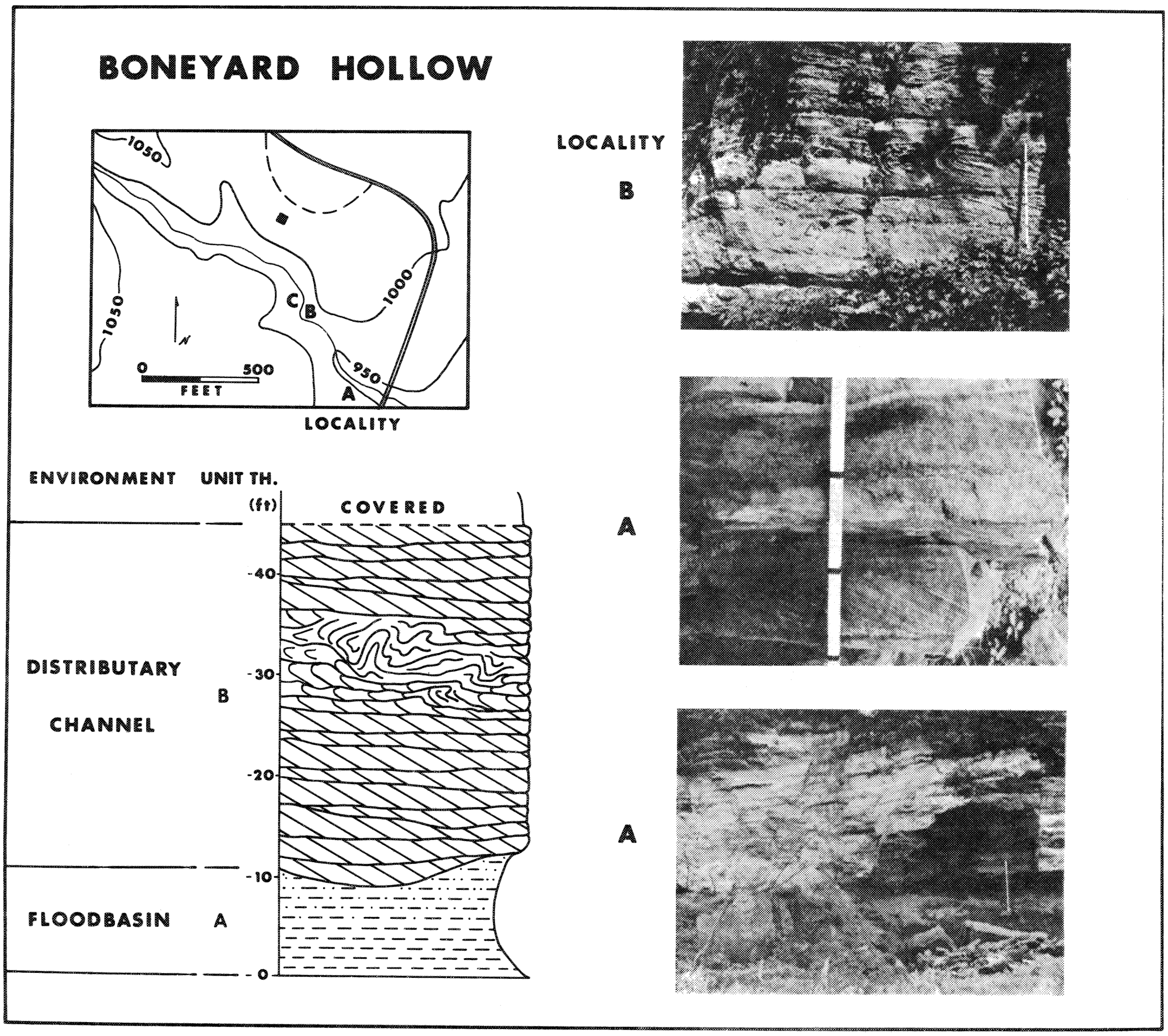


Figure 31. Generalized Graphic Section of Boneyard Hollow

Unit	Description
B.	Sandstone; pale yellowish orange (10YR8/6) to pale brown (5YR5/2); fine- to medium-grained; abundant large-scale planar cross-strata; strongly iron-stained in basal portion; upper contact covered; basal contact sharp, erosional; greater than 35 feet.
A.	Sandy mudstone to claystone; medium gray (N5) to dark yellowish orange (10YR6/6); lower contact covered; basal 4 feet is laminated claystone; gradational upward to sandy mudstone 7 feet thick; highly iron-stained; 11 feet exposed.



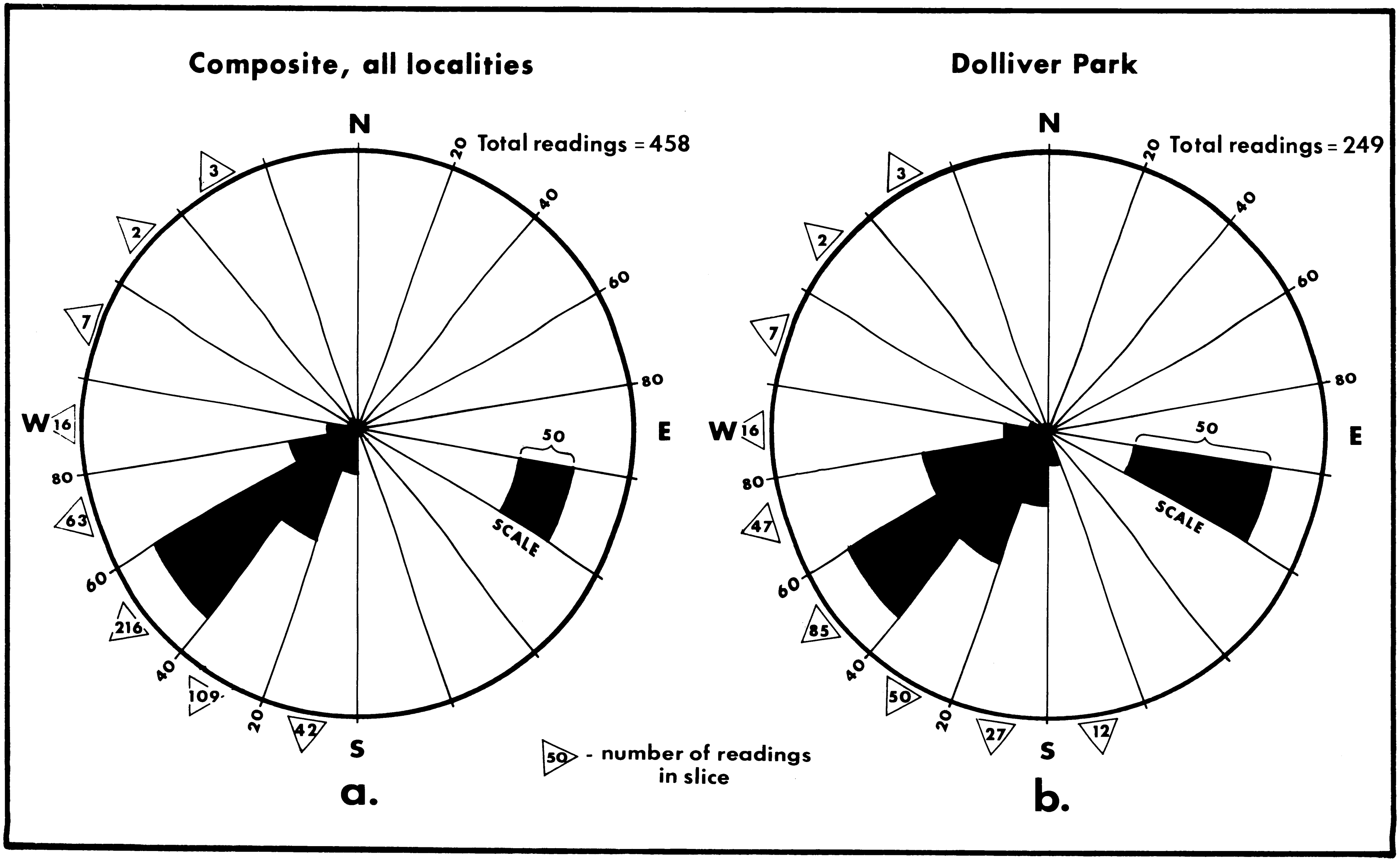


Figure 32. Rose diagram of paleocurrent direction as measured from outcrops in Dolliver Park, Webster County, Iowa, and a composite of all paleocurrent measurements taken in the study area.

Mile	(km)	Description
		notice the sandstone outcrop which comprises the south bank of the drainage way. This distributary channel sand overlies light gray mudstone which is poorly exposed at the cliff base. Notice also the recent rock fall and the abundance of cross-stratification marked by iron-oxide stained foreset laminae. The sandstone/mudstone contact, though indistinctly exposed, is marked by springs which drain the overlying permeable sands. Continuing to the northwest along the trail, cross the creek and observe the vertical cliff faces exposed adjacent to the creek. Approximately 15 feet (4.5 m) above the creek level at outcrops B and C deformed cross-strata are exposed. These deformation features are discussed earlier in the text (figure 15) and have been referred to as intraformational recumbent folding (Reineck and Singh, 1975) or recumbent-folded deformed crossbedding (Allen and Banks, 1972). The over-turning of the foreset laminae and other soft sediment deformation features suggests a saturated condition for the sand beds shortly after deposition and may reflect seismic activity which triggered the deformation. Continue along the creek noting the abundant cross-stratification, both undeformed and deformed. Leave the creek bed, climb out along the north side of the valley to a picnic area and the bus.
		LUNCH.
51.2	(81.9)	Lunch stop. Picnic area to north of Boneyard Hollow. Area is on the second of three outwash terraces. The lower terrace is at the bend in the park road to the east and lies about 65 feet (20 m) above the river. The second level lies 100 feet (30 m) above the river. The highest level is 150 feet (45 m) above the river; we will pass it on the way out. The terraces are preserved on the inside of a bend on the Des Moines River.
51.9	(83.0)	High terrace to right; farmstead is on upland which rises about 25 feet (7 m) above terrace. A large abandoned gravel pit is in scarp to lower terrace.
52.8	(84.5)	Forest to right is on the valley walls of the Des Moines River.
54.2	(86.7)	Intersection, stay on main road which curves to north.
54.5	(87.2)	Intersection, stay on main road which curves to west.
54.7	(87.5)	Stop sign, turn right (north) onto County Road P-59.
55.3	(88.5)	Descend into Des Moines River valley.
55.6	(89.0)	Town of Kalo; continue across Des Moines River.
55.8	(89.3)	Terraces to left lower level, at 80 feet (25 m) above the river, has a small subdivision. A high terrace, at 130 feet (40 m), lies just north of it.

Miles	(km)	Description
56.0	(89.6)	Coalville.
57.0	(91.2)	Right (east) turn onto concrete road.
58.0	(92.8)	Outcrop of till overlying Pennsylvanian.
58.1	(93.0)	Holliday Creek.
58.6	(93.8)	Turn right (south) onto gravel road and continue south 0.4 miles (0.6 km) to Holliday Creek Appaloosa Ranch.
59.0	(94.4)	Stop 2--Wildcat Den (SE 1/4, SE 1/4, SE 1/4, Sec. 10, T88N, R28W). From the Holliday Creek Appaloosa Ranch proceed to the south-southeast across the pasture toward the Des Moines River valley. Enter the wooded drainage south of the ranch, and follow it to the southeast to the valley bottom. Along the western valley wall of this creek, which empties into the Des Moines River approximately 1/4 mile (0.4 km) to the south, are discontinuous exposures of two major sand bodies separated by an interval of siltstone and mudstone (figure 33). Where the trail from the upland reaches the valley bottom, a good exposure of the lower sand body displays several prominent sets of large-scale planar cross-stratification, each marked by an erosional basal contact. These sets, to greater than 2 feet (0.6 m) in thickness, consist of foreset laminae which dip to the southwest as much as 25°. Just upslope and to the northwest of this outcrop, an interval of poorly exposed light brown siltstone and sandy siltstone which overlies the lower sand body can be seen. As with the equivalent fine-grained sediments exposed at the Dolliver Park, Stop 1b, these readily break along shaley partings exposing abundant carbonized organic debris.

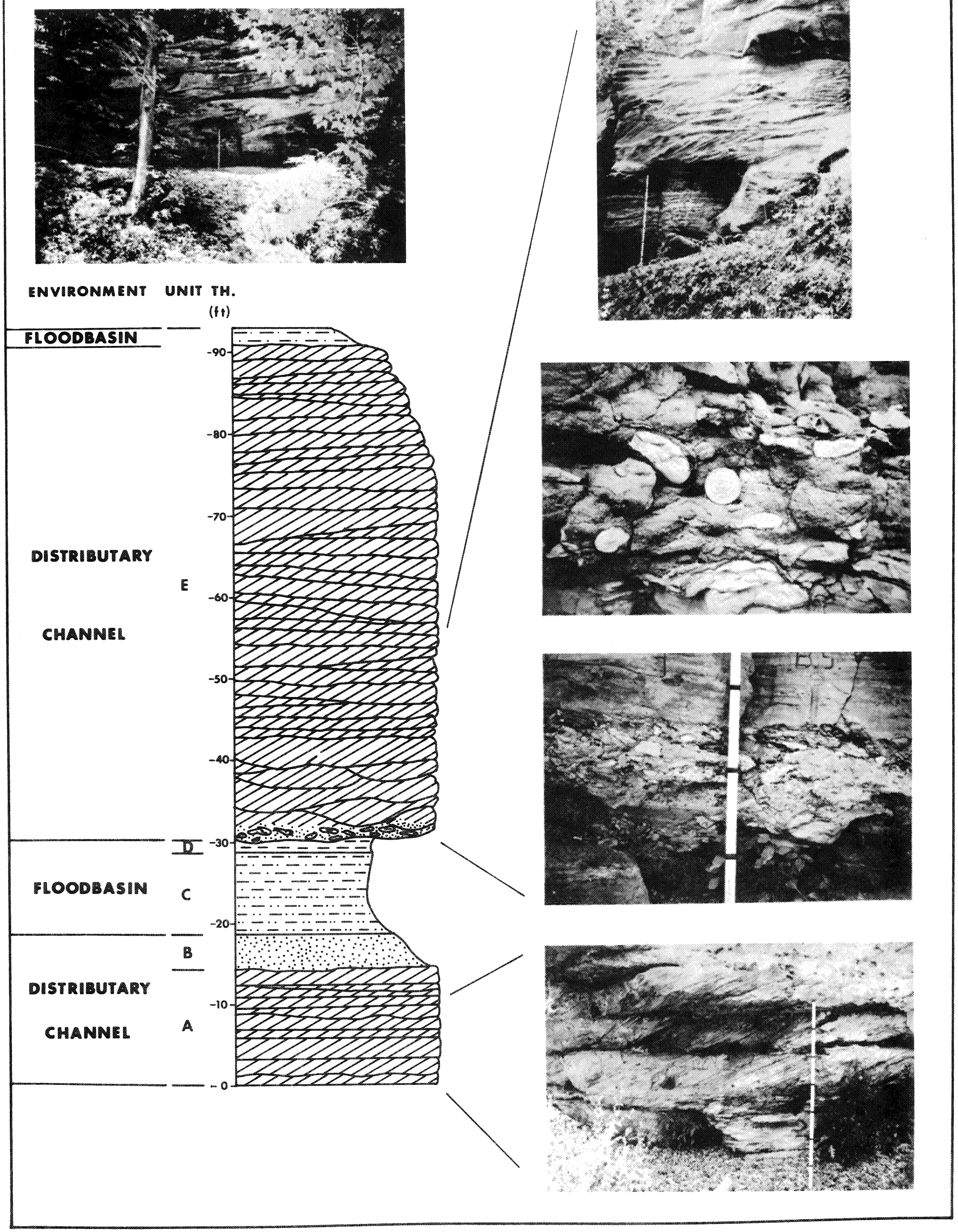
Walking to the north in the valley bottom along the west side of the creek notice the progressively more prominent outcrops of the upper sandstone body. At the foot of the upper sandstone cliff, a crude trail can be followed along much of outcrop extent; however, a word of caution should be taken seriously. At some places the trail is narrow, and loose debris may lead to slippery footing.

Proceeding to the north and east, a large eroded hollow cut into the west wall of the creek valley will be reached. This hollow is informally known as Wildcat Den and is bounded by more than 60 feet (18 m) of partially indurated sandstone (figure 33). The base of the upper sandstone body is exposed discontinuously both south and north of Wildcat Den. It is marked by abundant irregularly shaped clasts of mudrock from the underlying unit. The north wall of Wildcat Den exposes a sequence of low amplitude large-scale trough cross-strata which are overlain by large-scale planar cross-strata. That the cross-stratification type prominent in the lower portion of this sand body is trough rather than

Figure 33. Wildcat Den Graphic Section.

Unit	Description
E.	Sandstone; same colors as unit A; fine-grained, moderate sphericity and roundness, well sorted; dominantly quartz with pebble to cobble size siltstone clasts along base of unit, clay mineral and calcite cement; basal contact sharp and erosional; small- to large-scale trough and planar crossbedding, sets to 4 ft. thick, current direction S40W; well indurated, cliff former; 60 ft.
D.	Clay; medium dark gray (N4); laminated; basal contact gradational but not well exposed; upper 1 in. altered moderate reddish brown (10R4/6) due to groundwater seepage; friable, generally poorly exposed; 2 ft.
C.	Siltstone, sandy at base; yellowish gray (5Y7/2); laminated; not well exposed; 10 ft.
B.	Sandstone; fine-grained; uncemented, very poorly exposed; 4 ft.
A.	Sandstone; yellowish gray (5Y7/2) to dark yellowish orange (10YR6/6); fine- to medium-grained, moderate to high sphericity and roundness, well sorted; predominantly quartz with minor feldspar and lithic siltstone fragments, clay mineral and secondary calcite cementing agents; basal contact covered; large-scale planar crossbedding, sets to 2.5 ft. thick, current direction S40W; well indurated, cliff former; 15 ft. exposed.

WILDCAT DEN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-60
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-40
-30
-20
-10
0

Mile	(km)	Description
		planar probably indicates the transport of sand as sinuous crested megaripples at this point, rather than as straight crested megaripples which predominate at most other locations. Other notable features at this locality include various contorted bedding features and a variety of primary hydrodynamic flow structures.
		Return to bus.
59.8	(95.7)	Return to highway; turn left (west) to return to Kalo.
61.4	(98.2)	Turn left (south) onto P-59.
62.9	(100.6)	Kalo, turn right (west) onto blacktop road along Des Moines River.
63.1	(101.0)	Beginning of Kalo Bluffs.
63.3	(101.3)	Stop 3--Kalo Bluffs (NE 1/4, SE 1/4, Sec. 17, T88N, R28W). At this point several large exposures are visible along the southern and western slope of the Des Moines River valley (figure 34). From the bus walk back toward the southeast to view Kalo Bluffs, section 1 (figure 35). This exposure and Kalo Bluffs, section 2, includes a complex of interbedded laminated very fine-grained sandstone, siltstone, and claystone with abundant laminations to thin beds of carbonaceous debris and occasional lenses of very fine- to fine-grained, moderately indurated sandstone. Both sections are capped by a sequence which includes a lignite or carbonaceous shale, a thin tabular to lenticular arenaceous limestone, and dark gray carbonaceous shale. The thicker sandstones (to about 4 feet) include abundant laminae of carbonaceous material and display gradational to indistinctly erosional basal contacts. Bedding types include parallel lamination and ripple bedding to indistinct large-scale trough cross-stratification. Each bedding type, and the organic laminae mentioned earlier, occur in various states of deformation ranging from simple warping or flexure to complex contortion. The thick sequences of interbedded sandstone, siltstone, and claystone occur as wavy bedding. Individual sandstone beds are rarely thicker than 4 inches (10 cm), and the siltstone beds rarely exceed 2 inches (5 cm). Ripple bedding is common, and the entire sequence includes abundant fragmented organic debris (figure 35).
		A prominent features of the Kalo Bluffs, sections 1 and 2, is the occurrence of arcuate erosion surfaces which separates one sandstone/siltstone complex from another. Section 1 includes a particularly obvious truncation surface with the overlying beds successively decreasing in dip, suggesting a scour and fill origin. In addition, the sequence fines upward and is capped by a gray claystone and coal interval. While the wavy-bedded sandstone/siltstone sequence is

Mile	(km)	Description
		interpreted to represent delta front deposition, it is likely that the upper portion is gradational into the subaerial delta platform or floodbasin represented by the overlying coal and underclay.
		Walk along the road to the northwest; section 2.
		Kalo Bluffs, section 2 This section is essentially the same as section 1 with notable exceptions. The coal bed well exposed in the upper portion of section 1 is represented in section 2 by a carbonaceous shale. Additionally, thin lenses of arenaceous limestone became more prominent from section 1 to section 2 and thicken northwestward into a 14 inch (36 cm) thick bioclastic limestone. Note the many truncation features throughout this outcrop. Close examination of the strata will also reveal many deformed bedding features and abundant fragmented organic matter.
		Return to bus.
63.8	(102.1)	Turn left (west) onto gravel road. Abandoned clay kilns to north.
64.2	(102.7)	Park at intersection.
		Stop 3C--Kalo Bluffs (SW 1/4, NE 1/4, NE 1/4, Sec. 18, T88N, R28W). From the bus, walk up along the gravel road to the northeast. Exposed in the drainage ditch along the north side of the road is a section through delta front deposits similar to those which occur at Kalo Bluffs, sections 1 and 2, although predominantly finer grained. At this locality, the delta front sequence is capped by a thick shallow marine interval (figure 36) consisting of laminated black carbonaceous shale bearing *Lingula* tests, overlain by the 14 inch (36 cm) thick arenaceous bioclastic carbonate referred to at the preceding stop. The limestone includes a lower 3 inch (7 cm) thick interval with shaley lamination and an upper 11 inch interval containing abundant spiriferid brachiopod tests; to the north, the limestone includes lignitic lenses to 5 inches (13 cm) thick in the upper 18 inches (45 cm). No *Lingula* tests have been found in this upper unit, and because of the abundance of organic material, it is therefore, believed to be primarily nonmarine in origin. It is overlain disconformably by a thin distributary channel sand which, in turn, grades upward into floodbasin siltstone.
		Return to bus.
64.6	(103.4)	Return to blacktop road.
65.0	(104.0)	Turn left (north) onto blacktop.

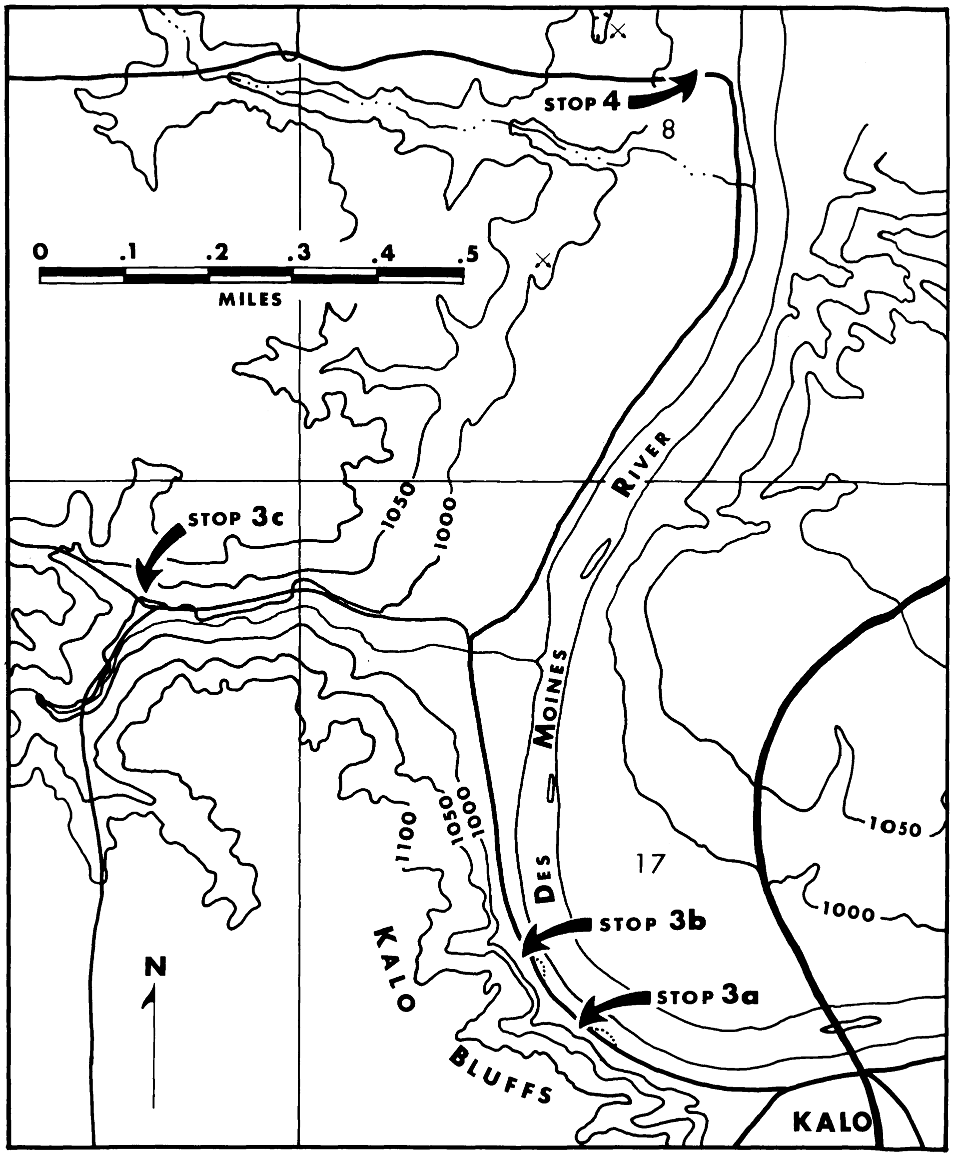


Figure 34. Field trip stops; Kalo Bluffs and Coalville west area.

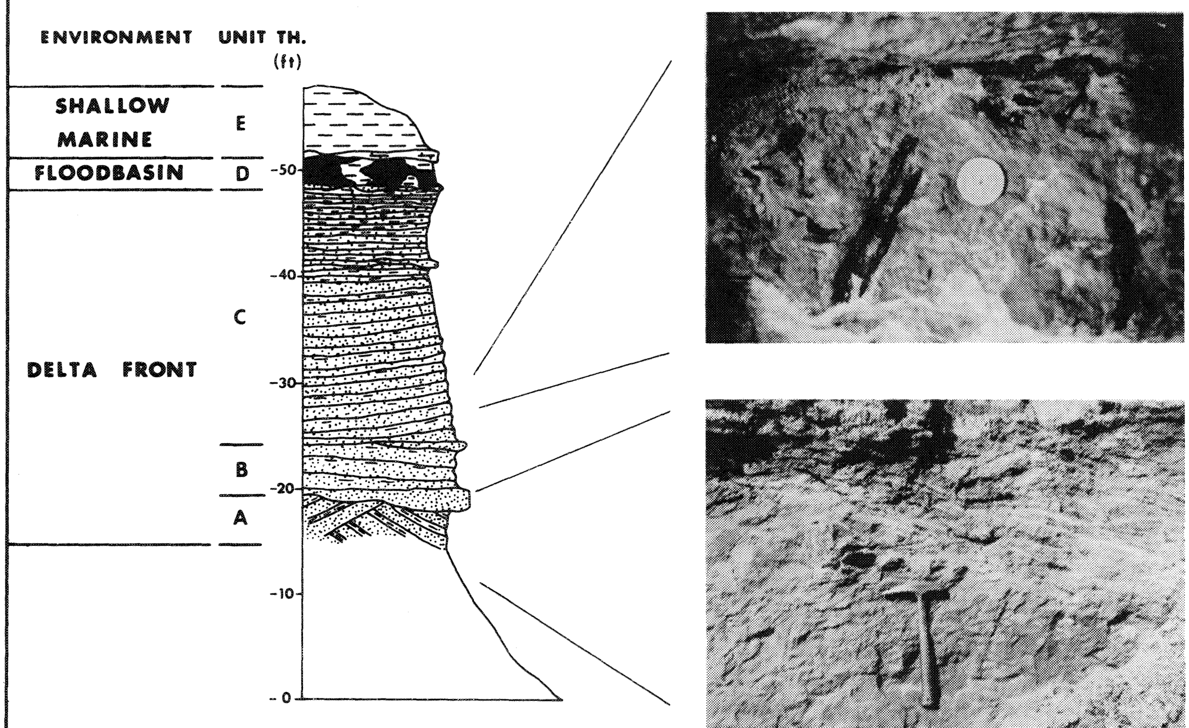
Mile	(km)	Description
65.8	(105.3)	Stop 4--Coalville west (N, NE 1/4, SW 1/4, Sec. 8, T88N, R28W). Proceed to the west along the blacktop road. On both sides of the road, but particularly on the north side, is a series of fissile black carbonaceous shale which is laterally equivalent to that occurring below the limestone at Kalo Bluffs, section 3 (Stop 3C). Here the shale includes abundant sideritic concretions often cored with pyrite and/or marcasite and sometimes including fracture linings of calcite. *Lingula* tests are found here as well. Across the road (on the north side) several blocks of limestone can be seen. These include brachiopod tests, a basal interval of ripple laminated marl, and a cap of algal limestone. This limestone correlates with that at the previous stop and occurs in place in the ditch along the north

Mile	(km)	Description
		side of the blacktop, about 200 feet (60 m) to the west of these limestone blocks. Farther to the west, along the road, a thin coal can be seen. This same coal is exposed around the basal margin of the quarry directly to the north and was likely the reason for the quarrying. The coal is overlain by another sequence of delta front wavy-bedded sandstone and siltstone.
		The strata of this locality have been acted on by local landsliding and perhaps by northeast trending normal faulting associated with the Fort Dodge Fault system. Additional work is required here.
		Continue west on blacktop.
68.1	(109.0)	Intersection with U.S. 169, turn left (south) onto 169. Travel will be on a low relief till plain considered by Ruhe to be part of the Altamont Ground Moraine.
79.4	(127.0)	Beginning an area with silty clay lacustrine sediments about a meter thick mantling an undulating till surface. Mapped as the Marna and Guckeen soil association, it covers about 8 percent of southern Webster County. The undulating lacustrine deposits indicate a stagnant glacier wherein lakes were forming on the ice surface while meltout till was being deposited subglacially by basal melting. The lacustrine clays were eventually superimposed onto the meltout till. Ruhe has included this area in the Altamont End Moraine because of its lineated appearance on aerial photographs. We will be driving across these clays for the next 8 miles (13 km).
80.3	(128.5)	U.S. 169 swings to east at intersection; stay on 169. Town of Harcourt to south.
84.1	(134.6)	U.S. 169 swings south at intersection; stay on 169.
88.1	(141.0)	Boone-Webster county line.
89.4	(143.0)	Leaving the lacustrine mantle on till plain. Over the last 1 mile (1.6 km) knobs of till rising above the lacustrine silts have become more common.
89.9	(143.8)	Boxholm.
		Low relief area, less than 10 feet (<3 m), of minor moraines with a NE-SW trend and of scattered till-gravels complexes. This area is part of the Altamont End Moraine of Ruhe. In the terminology of Clayton and Moran (1974), this is part of the transition suite which has a thin drift, ice stagnation origin. Bohlken (1980) has restricted the Altamont End Moraine to a moderate relief, 10 to 30 feet (<10 m), zone about 1 mile (1.5 km) wide which has numerous till-

Figure 35. Graphic Sections of Kalo Bluffs 1 & 2

Unit	Description
E.	Shale, carbonaceous, locally silty; dark gray (N3); laminated to fissile; basal contact sharp, marked by moderate yellow (5Y7/6) sulfurous alteration; friable; to 12 ft.
D.	Coal; black (N1); basal contact sharp, regular; persistant bed exposed in KB-1, laterally grading to carbonaceous shale (KB-2) overlying a basal, very fine-grained, calcite and pyrite cemented sandstone, 4 in. thick and interbedded with an 8 in. thick argillaceous limestone (wackestone); unit generally very friable; 3 to 7 ft.
C.	Sandstone-claystone repetitions; similar to unit A with sands showing general fining trend to coarse silt size; sand bed thickness decreasing vertically with few beds greater than 6 in. thick; claystone drapes, similar to unit A, cap nearly all sand beds; abundant organic debris along partings; friable; repetitions within unit occur within numerous overlapping wedge-shaped bodies becoming horizontally bedded just beneath the coal; unit thickness up to 25 ft.
B.	Sandstone; pinkish gray (5YR8/1) to grayish orange (10YR7/4) with local iron oxide staining dark yellowish orange (10YR6/6); very fine-grained; abundant fragmented carbonaceous debris throughout but especially toward base; basal contact sharp to gradational, includes silt and clay laminations; lenticular; indistinct small-scale crossbedding; minor ripple lamination; moderately friable to indurated; lenses to 3 ft.
A.	Siltstone-claystone; medium light gray (N6) to light yellowish gray (5Y7/1); basal contact covered; unit includes lenticular laminations of fine sandy siltstone, yellowish gray (5Y8/1) to light gray (N7) and abundant fragmented carbonaceous debris, dark gray (N3); coarsens upward; at the top consists of wedges to 2.5 ft. thick, of fine sandy stiltstone, carbonaceous debris, and silty claystone laminations; very poorly sorted; non-resistant; up to 10 ft. exposed.

KALO BLUFFS - 2



KALO BLUFFS - 1

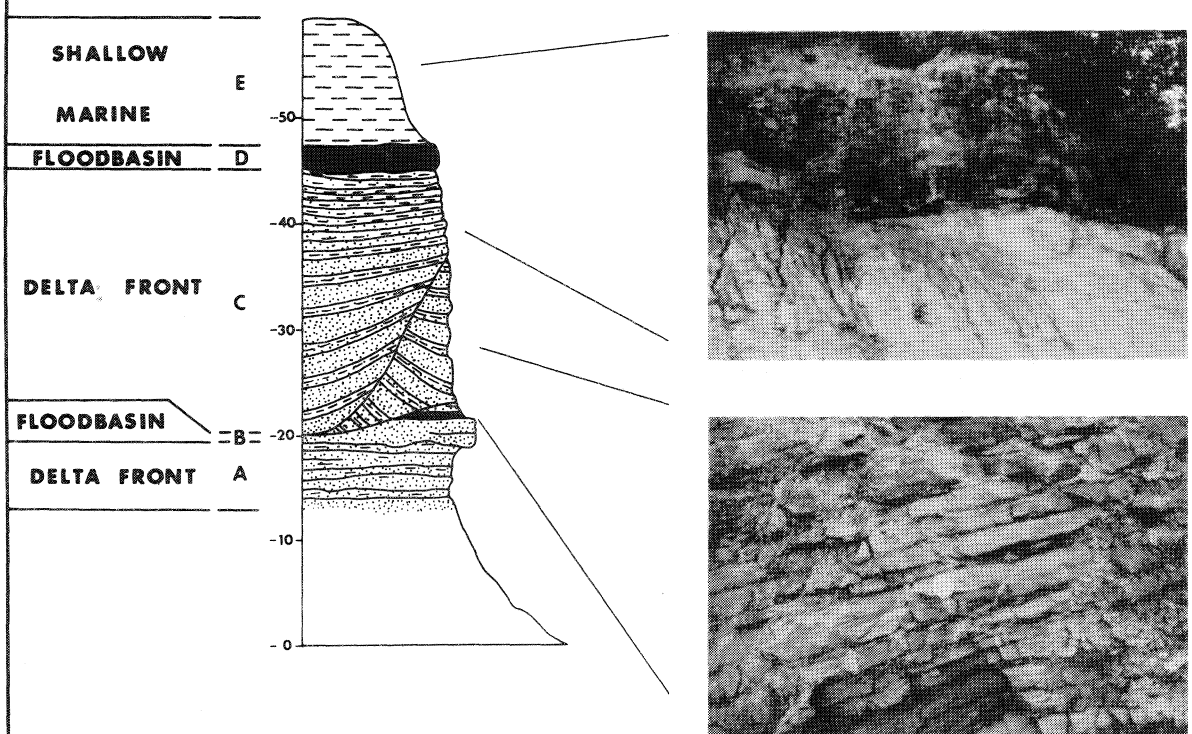
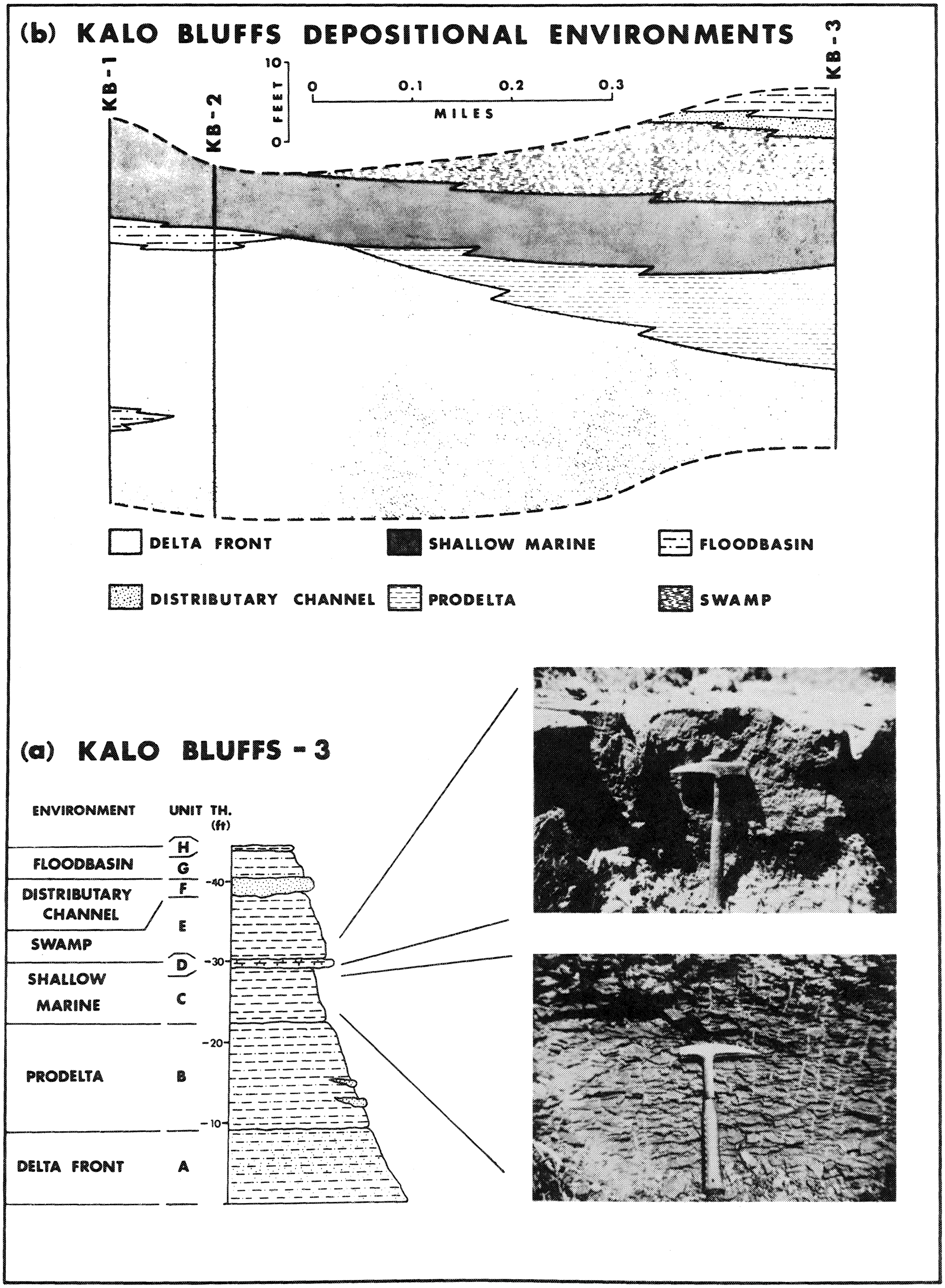


Figure 36. Graphic Section of Kalo Bluffs-3

Unit	Description
H.	Shale; similar to unit G; 8 in.
G.	Mudstone; similar to unit A; 4 ft.
F.	Sandstone; very pale orange (10YR8/2); very fine-grained; tabular to lenticular; ripple laminated, upper 6 in.; basal contact sharp, erosional; 18 in.
E.	Shale, very carbonaceous; gray black (N2); contains coal pods in upper portion; grayish brown (5YR3/2); to 5 in. thick; unit, 8 ft.
D.	Limestone; medium dark gray (N4); abundant recrystallized brachiopod casts, to 1 in. diameter; indistinctly laminated in basal 3 in.; argillaceous at top; basal contact sharp; irregular; 14 in.
C.	Shale, carbonaceous; dark gray (N3); very fissile; minor silt laminae; oxidation layer, dark yellowish orange (10YR6/6), irregular at base; basal contact of unit gradational; 6 ft.
B.	Mudstone; medium dark gray (N4); well laminated; occurs as couplets of lighter, coarser silt and darker, finer silt and clay, averaging 1/4 in. thick; thin sand lenses to 2 in. thick, grayish orange (10YR7/4) to dusky yellow (5Y6/4), becoming less abundant upwards; basal contact of unit gradational; 14 ft.
A.	Siltstone, arenaceous; light brownish gray (5YR6/1) to light olive gray (5Y6/1); abundant dark yellowish orange (10YR6/6), FeO stained fracture fillings; argillaceous siltstone beds to 2 in. thick in upper 7 ft., becoming more abundant upwards; basal contact covered; 9 ft. exposed.


(b) KALO BLUFFS DEPOSITIONAL ENVIRONMENTS
KB-1
KB-2
KB-3
10
0 FEET
0
0.1
0.2
0.3
MILES
DELTA FRONT
SHALLOW MARINE
FLOODBASIN
DISTRIBUTARY CHANNEL
PRODELTA
SWAMP
(a) KALO BLUFFS - 3
ENVIRONMENT
UNIT
TH. (ft)
FLOODBASIN
DISTRIBUTARY CHANNEL
SWAMP
SHALLOW MARINE
PRODELTA
DELTA FRONT
H
G
F
E
D
C
B
A
40
30
20
10

Mile	(km)	Description
		gravel complexes. The restricted Altamont End Moraine belongs to the marginal suite and has a thick drift, ice stagnation origin.
93.5	(149.6)	Altamont End Moraine in the restricted sense of Bohlken. Till-gravel complexes to east. Valley of Beaver Creek to west; its 3 headwater tributaries cross the restricted Altamont End Moraine onto the Bemis Ground Moraine of Ruhe to the south without offset.
94.3	(150.9)	Leave Altamont End Moraine. Area to south is mapped as Bemis Ground Moraine by Ruhe. It has a relief ot 10 to 30 feet (3-6 m) and lacks minor moraine topography. Bohlken has noted that it is composed of 2 to 3 levels which form benches parallel to the Altamont Front. To the south along Beaver Creek the lowest bench abuts a complex of sand-gravel deposits and loams over sand. On aerial photographs an anastomosing pattern can be discerned. This complex is interpreted to be an outwash plain which drained south into Beaver Creek. The outwash plain was active when the glacier stood over the area we are now traversing. We thus have the anomaly of an outwash plain being genetically related to ground moraine. The possibility exists that the outwash is related to the Altamont ice front which stood to the south of us, and the Altamont End Moraine may represent merely a zone of "dirtier" ice within the glacier and not a stable ice front as previously supposed.
98.1	(157.0)	Valley of Middle Beaver Creek. Ahead road will cross Beaver Creek twice. The uplands between the bends in the valley are underlain by sand and gravel deposits of the outwash plain.
98.9	(158.2)	Rise onto Bemis End Moraine as mapped by Ruhe.
99.9	(159.8)	Intersection of U.S. 160 and U.S. 30. Turn left (east) onto U.S. 30.
102.8	(164.5)	Valley of East Beaver Creek. Some 45 miles (70 km) to the south it joins the Des Moines River just north of the city of Des Moines. At this point Beaver Creek is only 4 miles (6.6 km) west of the Des Moines River Valley. As previously mentioned, this pattern has resulted from the superposition of the Des Moines River upon a ridge during deglaciation.
102.9	(164.6)	Town of Ogden to north.
107.1	(171.4)	Descend into valley of Des Moines River. Terraces to north with gravel pits stand at 50 feet (15 m) and 100 feet (30 m) above the river. These two levels have been traced through the Altamont End Moraine and are thus younger.
109.1	(174.6)	Des Moines river.
110.4	(178.2)	Ascend to upland in Bemis End Moraine.

Mile	(km)	Description
111.4	(178.2)	Intersection; Boone to north; continue east on U.S. 30.
125.8	(201.3)	ISU exit onto Elwood Drive; turn left to go toward the north.
127.7	(204.3)	Arrive back at the parking lot of the Scheman Continuing Education Center, Iowa State University, Ames, Iowa.

APPENDIX A:

Woodmans Hollow and Cliff Bars Sections

The sections on the following two pages will not be visited during this field trip. They are included for the interest of the field trip participants and for others who may use this guidebook on their own and may wish to visit additional exposures nearby. Both sections are composed primarily of strata belonging to the lenticular fine- to medium-grained cross-stratified sandstone facies and represent deposition in distributary channels. At both localities, identified on the field trip stop index map, large-scale planar cross-strata dominate the bedding, but additional features to note are the numerous minor scour surfaces, reactivation surfaces, the variety of bedform morphologies, and the uniform paleocurrent direction as revealed by the large-scale planar cross-strata.

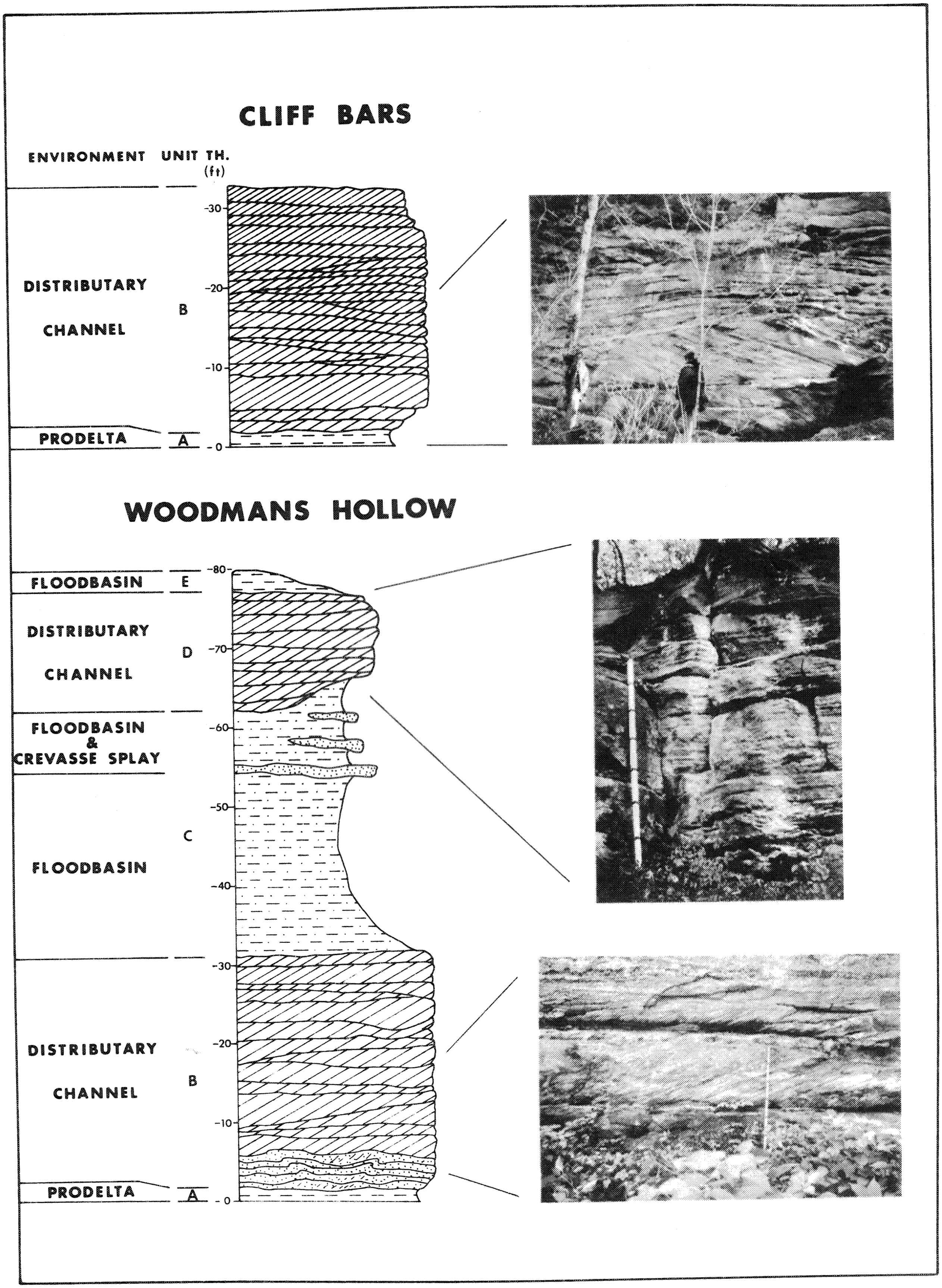
Figure 37. Graphic Section of Cliff Bars and Woodmans Hollow

Cliff Bars

Unit	Description
B.	Sandstone; pale yellowish brown (10YR6/2) to dark yellowish orange (10YR6/6); fine to medium grained, well sorted; quartzose, carbonate and clay mineral cement; basal contact sharp; entire unit large-scale planar crossbedded, sets to 4 ft. thick, with numerous reactivation surfaces, current directions: S45W; well indurated, cliff former; 30 ft.
A.	Claystone; medium gray (N5); laminated; basal contact covered; friable; 6 ft. exposed.

Woodmans Hollow

E.	Siltstone; covered; 3 ft.
D.	Sandstone; similar to unit B below; ripple laminated to large-scale planar crossbedded; moderate induration; up to 15 ft.
C.	Siltstone with thin sandstone beds; siltstone; mostly covered; sandstone; lenticular to laterally persistant; up to 18 in. thick; moderately resistant to friable; unit 32 ft.
B.	Sandstone; pale yellowish orange (10YR8/6) to pale brown (5YR5/2); fine- to medium-grained, very well to well sorted; predominantly quartz with minor silt galls, calcite and clay mineral cemented; basal contact sharp, irregular; large-scale planar crossbedding, sets up to 4 ft. thick, current direction: S45W; moderately well indurated, cliff former; 30 ft.
A.	Claystone; medium gray (N5); laminated; basal contact covered; weathered and largely covered; 3 ft. exposed.


CLIFF BARS
ENVIRONMENT
UNIT
TH. (ft)
DISTRIBUTARY CHANNEL
B
PRODELTA
A
-30
-20
-10
-0
WOODMANS HOLLOW
FLOODBASIN
E
DISTRIBUTARY CHANNEL
D
FLOODBASIN & CREVASSE SPLAY
FLOODBASIN
C
DISTRIBUTARY CHANNEL
B
PRODELTA
A
-80
-70
-60
-50
-40
-30
-20
-10
-0

APPENDIX B:

Glacial Landforms, Des Moines Drift Sheet, Iowa

by Robert C. Palmquist

The landscape of central Iowa is dominated by the Des Moines Drift Sheet of Late Wisconsinan age. The Des Moines glacial lobe extended from central Minnesota 150 mi. southward into central Iowa, and by 14,000 radiocarbon years B.P., it was approaching its southern terminus at the city of Des Moines. Deglaciation apparently was rapid; by 13,000 radiocarbon years B.P., the terminus had retreated into northern Iowa (Wright and Ruhe, 1965, Ruhe, 1969). The depositional topography of the Des Moines Drift Sheet has been only slightly modified by slope and stream erosion during the last 13,000 years.

The landscape of the Des Moines Drift Sheet is dominated by four end moraines (figure 26). Although the four moraines have been recognized for over 50 years, the currently recognized boundaries are the product of studies by Robert Ruhe (1952, 1969). He defines end moraines on the basis of their lineated topography whereas ground moraine lacks lineations (1969, p. 57). These definitions lead to the anomalously wide Bemis Moraine with its paucity of ground moraine. Although Ruhe (1969, p. 58) attributes the end morainal pattern to pauses in the retreat of the ice front during deglaciation, the location of the moraines appears to be controlled by topographic highs on the bedrock surface (Palmquist and Bible, 1974). The landform types also appear to be related to the bedrock topography (Palmquist and Connor, 1978).

Thus the deglaciation of the Des Moines Drift Sheet may have been more complicated than the simple pulsating retreat of the glacial front.

The landform associations on the Des Moines Drift Sheet are best described by the glacial continuum model of Clayton and Moran (1974). They recognize four suites of landforms which are the Fringe Suite composed of outwash; the Marginal Suite which occurs at the glacial margin and consists of rolling to knobby ice stagnation topography developed on till and till-gravel complexes; the Transitional Suite which occurs upglacier from the marginal suite and consists of subglacial landforms such as minor moraines (washboard moraines) and drumlins; and the Inner Suite which is dominated by erosional landforms. The landforms of the field trip area belong to the marginal and transitional suites. They consist of minor moraines, transverse linear ridges, closed disintegration ridges, ice walled lakes, and outwash.

Minor moraines were recognized by Gwynne (1942) in central Iowa. Elsewhere they have been called washboard moraines (Elson, 1957, Gravenor and Kupsch, 1959; Neilson, 1970; Clayton and Moran, 1974) which has become the more popular term. They occur as part of a low, undulating landscape consisting of linear ridges oriented both parallel to and normal to the morainal front. On aerial photographs the swells appear as light-tonal bands with the intervening swales being darker in tone. The minor moraine ridges lie parallel to the ice front, have a mean spacing of 328 ft., and form in sets which are convex down glacier and which are separated by drainageways (Gwynne, 1942; Foster, 1969; Foster and Palmquist, 1969; Palmquist, 1972, 1973). Crossing the minor moraine trends are a series of till-cored ridges which may be large and underlie the minor moraines, for instance, the drumlinoid form described by Thomas, Hussey, and Roy (1955) or about the same size as the moraines and younger. Where the younger, transverse ridges are common, they have a mean spacing of 192 ft. (Palmquist, 1973).

The most commonly accepted origin for the minor moraines postulates the thrusting of basal ice within a compressional zone (Elson, 1957) although numerous other origins have been proposed (Gwynne, 1942; Foster, 1969; Gravenor and Kupsch, 1959). The close spacing of the moraines is difficult to explain by this origin which also postulate that the moraines are annual.

The origin of the transverse ridges has been related to the filling of tensional crevasses within the glacier. Their trend normal to that of the minor moraine places them in a tensional orientation within the glacier. During deglaciation either ablation till slides into the open crevasse (Flint, 1928; Gravenor, 1955; Gravenor and Kupsch, 1959) or perhaps, if the basal till is saturated, it is squeezed and pressed into basal fractures (Hoppe, 1952; Stalker, 1960).

The transitional suite is postulated to have developed under conditions of thin drift ice stagnation (Clayton and Moran, 1974). In this environment, the amount of drift within the glacier is insufficient to form a thick ablation till, and thus the minor moraines and drumlins which are formed at the base of the glacier are not buried. Minor moraines are characteristic of the Bemis Moraine which suggest that it has a thin drift ice stagnation origin (Palmquist and Connor, 1978).

The marginal suite is characterized by high relief, steep sloped, equidimensional hills and ridges. Many of these hills are circular and have a central depression which has given rise to the term closed disintegration ridges. They may be composed of sand, gravel, till, or laminated silt and clay, or any combination (Parizek, 1969). They are postulated to develop by ablation till filling a joint intersection which may contain a pond.

Some ridge complexes undergo several reversals of topography during their development (Gravenor, 1955; Clayton, 1967; Parizek, 1969). Most of the high relief knobs within the field trip area lack a well defined central depression. Marginal suite topography is best developed in the Altamont End Moraine.

The marginal suite is postulted to have a thick drift ice stagnation origin (Clayton and Moran, 1974). A glacier under compression will have upward directed flow and thrusting which carries debris high into the ice. During deglaciation this debris is released to mantle the ice with ablation till. The ablation till slides down the flanks of ice highs to fill local depression. A narrow zone of thick drift ice stagnation gives rise to the typical end moraine; a wide zone gives rise to an "ice stagnation moraine."

Fine-grained, silty clays, 3-7 ft. thick, mantle the flat to rolling till landscape behind the Altamont End Moraine. These clays are interpreted to be lacustrine by Koppen (1975). If so, they represent ice walled lakes which developed upon stagnant ice. The rolling topography suggests that a subglacial depositional topography is mantled by the lacustrine units. A few of the smaller lacustrine deposits are surrounded by till-gravel complexes (Bohlken, 1980), but most lack a well defined margin. Ice walled lakes are typical of the marginal suite and indicate ice stagnation.

Outwash is limited to two localities in the field trip area. It occurs as very high level terraces along the Des Moines River and as a small outwash plain in western Boone County (Bohlken, 1980). Outwash is rare; only in the northern portion of the Drift Sheet, where it is associated with abundant, thick drift ice stagnation topography, does it occupy up to twenty-five percent of a county. The small outwash plain in Boone County occurs at the headwaters of Beaver Creek. It is unusual in that it terminates at a low relief till plain some 2 mi. in front of the Altamont End Moraine. Bohlken (1980) suggests that the Altamont ice front may have stood at this position during deglaciation.

The deglaciation of central Iowa is thus characterized by ice stagnation. The Bemis End Moraine appears to have a thin drift, ice stagnation origin and to belong to the transitional suite. In contrast, the Altamont End Moraine appears to have a thick drift, ice stagnation origin and to belong to the marginal suite. The Altamont ground moraine contains numerous lake deposits which indicate an ice stagnation origin for at least a portion of it. The change in our conceptual model of deglaciation has been large enough during the last decade to necessitate the reevaluation of the deglaciation of the Des Moines Lobe.

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