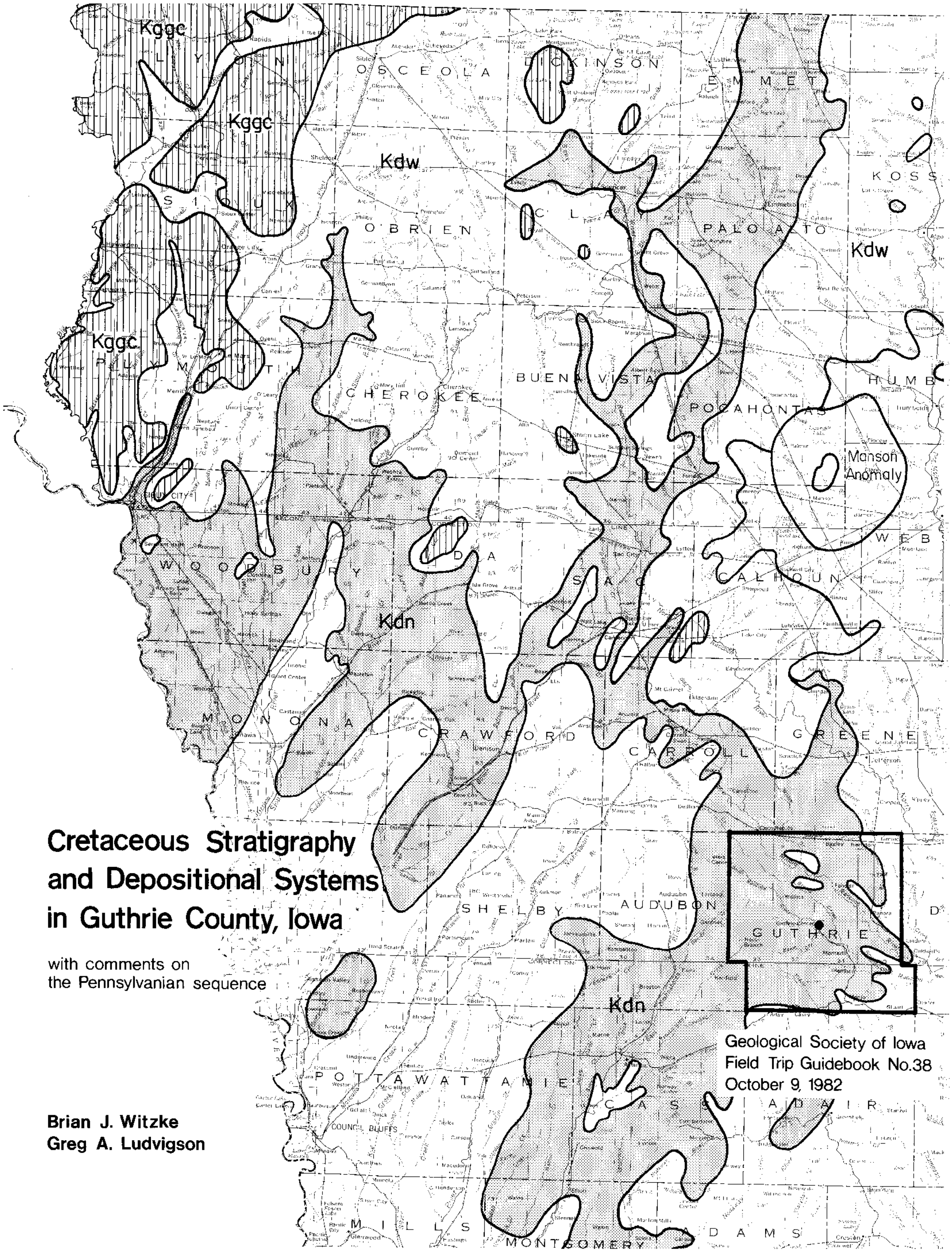

Cretaceous Stratigraphy and Depositional Systems in Guthrie County, Iowa

with comments on the Pennsylvanian sequence

Brian J. Witzke
Greg A. Ludvigson

Geological Society of Iowa
Field Trip Guidebook No. 38
October 9, 1982

CRETACEOUS STRATIGRAPHY AND DEPOSITIONAL SYSTEMS IN GUTHRIE COUNTY, IOWA

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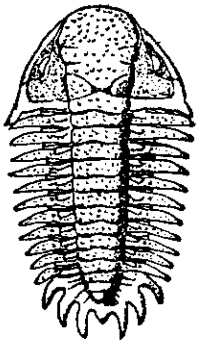
Abstract. The mid-Cretaceous Lower Dakota sequence (Nishnabotna Mbr.) of Guthrie County, Iowa can be roughly divided into two stratigraphic units: 1) a lower fine to coarse-grained sandstone- and gravel-dominated interval displaying horizontal stratification and planar cross-beds, and 2) an upper fine-grained sandstone interval (with some coarse to pebbly beds) displaying abundant trough cross-beds and other sedimentary structures. Both intervals are fluvial deposits. The lower portion displays many characteristics of braided stream deposits, whereas the upper interval was apparently deposited in less competent fluvial systems, perhaps in flow regimes transitional between distal braided and meanderbelt systems. Source areas for the Nishnabotna sediments were the Paleozoic and Precambrian terranes to the east and northeast of Guthrie County, and trough cross-bed orientations and paleogeographic constraints suggest a general southwesterly transport direction. The initiation of Cretaceous fluvial deposition in Iowa may be related to rising base levels accompanying transgression of the Kiowa-Skull Creek marine cyclothem. As transgression of the succeeding marine cycle, the Greenhorn Cyclothem, progressively spread marine environments eastward in the Western Interior region, fluvial systems were modified in western Iowa as base level rose. This resulted in displacement of the braided Nishnabotna fluvial systems (sandstone-dominated) by Woodbury (Upper Dakota) meanderbelt systems (mudstone-dominated) during the early Cenomanian in western Iowa. Field trip participants will examine exposures of the lower and upper Nishnabotna Member as well as portions of the Pennsylvanian sequence (Cherokee and Marmaton groups) in Guthrie County.



TONY THE TRILOBITE SAYS: Remember . . .

1) always drive carefully
2) the first dinosaur bone scrap found wins a case of beer (see p. 13).

Explanation of cover. The guidebook cover illustrates the latest understanding of Cretaceous bedrock geology in western Iowa. Symbols used on this geologic map: Kdn (stippled)--Lower Dakota Fm., Nishnabotna Mbr.; Kdw (unpatterned)--Upper Dakota Fm., Woodbury Mbr.; Kggc (ruled) --Graneros Shale, Greenhorn Formation, Carlile Shale undifferentiated. Manson Anomaly includes Cretaceous undifferentiated.

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> "Guthrie county presents a greater diversity in its geologic structure than any county in" west-central Iowa (St. John _in_ White, 1870, p. 97).
>
> "Although Guthrie county offers exceptional facilities for geological research along certain lines, it has never been studied in great detail" (Bain, 1897, p. 417).

Introduction

Guthrie County presents a great diversity of interesting geologic features, a fact that did not escape the attention of St. John in the first survey of the county (see quote above). However, with a few noteworthy exceptions, Guthrie County geology remains largely unstudied. In general, the quote from Bain given above holds as true today as it did in 1897. The general purpose of this field trip is to acquaint the participant with a portion of the Guthrie County stratigraphic sequence, and to encourage further research on the geology of the county.

This trip will primarily focus on the mid-Cretaceous Lower Dakota sandstone sequence, a sequence whose best exposures in Iowa are located in Guthrie County. The authors of this guidebook first became involved in investigating Iowa's Cretaceous sequence as part of the U.S. and Iowa Geological Survey's Dakota Aquifer study in northwestern Iowa. The accumulation of stratigraphic and geohydrologic data in that portion of the state led to a greater understanding of the Cretaceous stratigraphic sequence and its contained groundwater systems. These studies discovered that the Lower Dakota in the subsurface of northwestern Iowa had the general characteristics of a "sheet sand." Because of its widespread lateral continuity and generally homogeneous character, the Lower Dakota interval was identified as the container for the most significant portion of the Dakota Aquifer (see Munter _et al._, 1982). However, the lower Dakota interval is not exposed in the northwestern Iowa study area, where its characteristics were determined only through subsurface investigations.

The combined efforts of a number of workers who were involved in studies of Cretaceous strata in northwestern Iowa and adjacent areas were organized together into a field trip guidebook and symposium volume for the 1981 North-Central GSA meetings (Brenner _et al._, 1981). Participants in that field trip examined exposures of the Upper Dakota, Graneros, Greenhorn, and Carlile formations in northwestern Iowa. In some respects, this 1982 GSI field trip is designed to supplement the 1981 GSA trip by providing a field trip context to visit exposures of the Lower Dakota interval, the only portion of the Iowa Cretaceous sequence not visited on the 1981 trip. Of all places in Iowa, Guthrie County affords the best opportunity to examine that portion of the section. Upon completion of the Dakota Aquifer study in northwestern Iowa, the U.S. and Iowa Geological Surveys moved their drilling program to investigate groundwater resources in west-central Iowa. As part of that continuing study, the authors of this report renewed their investigation of Cretaceous strata in western Iowa. Although the Lower Dakota is not as widespread in west-central Iowa as it is in the northwestern part of the state, potential exists for local utilization of the Dakota Aquifer as a groundwater source in several west-central Iowa counties. Additional information on the Lower Dakota in the subsurface of west-central Iowa will be available as the drilling program progresses.

Cretaceous rocks in Iowa, Minnesota, and western Wisconsin represent the easternmost occurrences of strata included within the Cretaceous Western Interior Province. Waters of the Western Interior Seaway impinged on this area during the maximum transgressive phases of several Late Cretaceous marine cyclothems. However, the sedimentary record of Cretaceous deposition along the eastern margin of the Western Interior Seaway is, to a large extent, incomplete, primarily due to extensive post-Cretaceous erosion. Nonetheless, portions of this sedimentary record, as preserved in Iowa, Minnesota, and the eastern areas of Nebraska and the Dakotas, provide important insights into Cretaceous sedimentation and paleogeography in the Western Interior Province. The Guthrie County exposures provide a basis for evaluating the initial phases of fluvial deposition in the eastern margin area.

Although the Cretaceous exposures in Guthrie County are among the most instructive found anywhere in Iowa, comparatively few studies have investigated the Cretaceous in the county. White and St. John were the first geologists to identify Cretaceous strata in the county (White, 1869; White,1870, v.2, p. 99-104), and their contributions will be enumerated later in this report. H.F. Bain's field investigations in the county (he was apparently accompanied in the field on occasion by T.C. Chamberlin, A.G. Leonard, S. Calvin, and others) culminated in his report on the geology of Guthrie County, including important observations on the Cretaceous sequence (Bain, 1897, p. 451-459). In subsequent years the Cretaceous of Guthrie County has received only limited attention. Tester (1931, p. 255) apparently visited Cretaceous exposures in the county, but he recorded no information of any kind on its character or stratigraphic significance. The sixth annual Tri-State Field Conference (Cline et al., 1938) visited two exposures of Lower Dakota strata in the southeastern part of the county, and H.G. Hershey briefly described these exposures in the guidebook (p. 21-22). An investigation of the Guthrie County Cretaceous during the 1960s was conducted by several geologists of the Illinois Geological Survey (Frye et al., 1964). They determined the clay mineralogy of mudstone units in the Dakota Formation at four localities in the county in order to make comparisons to mudstones in a probable Cretaceous sandstone formation in western Illinois. Dakota sandstone outcrops in southern Guthrie County were briefly characterized by Richardson (1977, p. 13).

The last two stops on this field trip are included to provide the participants a brief opportunity to see a small portion of the Pennsylvanian sequence exposed in the county. The Dakota Formation disconformably overlies various Pennsylvanian stratigraphic units in Guthrie County. A brief description of Pennsylvanian stratigraphy in the county is included later in this report.

General Geologic Setting of Guthrie County

As noted by Bain (1897, p. 418), "topographically Guthrie county is sharply separated into two portions, the dividing line following, in general, the right bank of the Middle Raccoon river." This dividing line corresponds to the edge of the DesMoines Lobe, the margin of which marks the extent of Wisconsinan glaciation in Iowa (see Fig. 1). The relatively flat surface developed on the DesMoines Lobe in the northeastern part of the county contrasts markedly with the well-developed dissected drainage surface developed over most of the rest of the county. Springbrook State Park lies at the margin of the DesMoines Lobe, where the abrupt contrast between the flat uplands of the Lobe and the dissected bedrock valleys off the Lobe margin is particularly well displayed.

Over portions of the county off the DesMoines Lobe the topography is bedrock controlled, particularly along the valleys of the Middle and South Raccoon Rivers and their tributaries. The bedrock is buried by pre-Illinoian Pleistocene deposits in many areas of the county (pre-Illinoian deposits can be seen at Stop 5 on the field trip). The pre-Illinoian drift is mantled by loess over much of the county. Although the Pleistocene sequence of Guthrie County is not considered in this report, the county is "an exceptionally interesting one to all students of glacial geology" (Bain, 1897, p. 460).

Cretaceous bedrock exposures are abundantly represented in Guthrie County, particularly along the valleys of the Middle and South Raccoon Rivers and some of their tributaries. In some areas of the county, Cretaceous sand and gravel is locally utilized for road aggregate. Underlying the Cretaceous sequence, Pennyslvanian bedrock is encountered along stretches of the same river valleys. The upper Cherokee and Marmaton Groups are the best exposed Pennsylvanian units, although the lowermost portion of the Missourian Series crops out in limited areas of southeastern Guthrie County. Coal mines were developed in Desmoinesian strata at several places in the county, although all coal mines have been inactive for some time. Coal mines were best developed along the Middle Raccoon River between Panora and Springbrook State Park. St. John (in White, 1870) and Bain (1897) described a series of instructive Pennsylvanian and Cretaceous exposures along that stretch of the river, although the construction of the Lake Panorama reservoir has flooded out a large portion of those outcrops.

The structural setting of Guthrie County is both interesting and complex. The county essentially straddles the Midcontinent Geophysical Anomaly (a pronounced gravity high). This region is underlain by Keweenawan (late Precambrian) basalts and mafic intrusives that were deposited within the Central North American Rift system. This ancient rift is fault-bounded, and Keweenawan clastic sediments flank the feature and are locally present in grabens within it. Cambrian strata bury the Keweenawan rocks, in places displaying progressive onlap of Cambrian stratigraphic units onto islands that existed in the area during the Late Cambrian, a time when most of Iowa was under marine waters. These Cambrian topographic-structural highs in the county occur along the southern nose of the Central Iowa Arch, an arch whose influence can be seen throughout much of the Paleozoic (Bunker, 1981). The Paleozoic sequence in the Guthrie County subsurface includes Upper Cambrian, Ordovician, Silurian (southeast portion of county only), Middle and Upper Devonian, Lower and Middle Mississippian, and Middle and Upper Pennsylvanian (known also in outcrop) rock units.

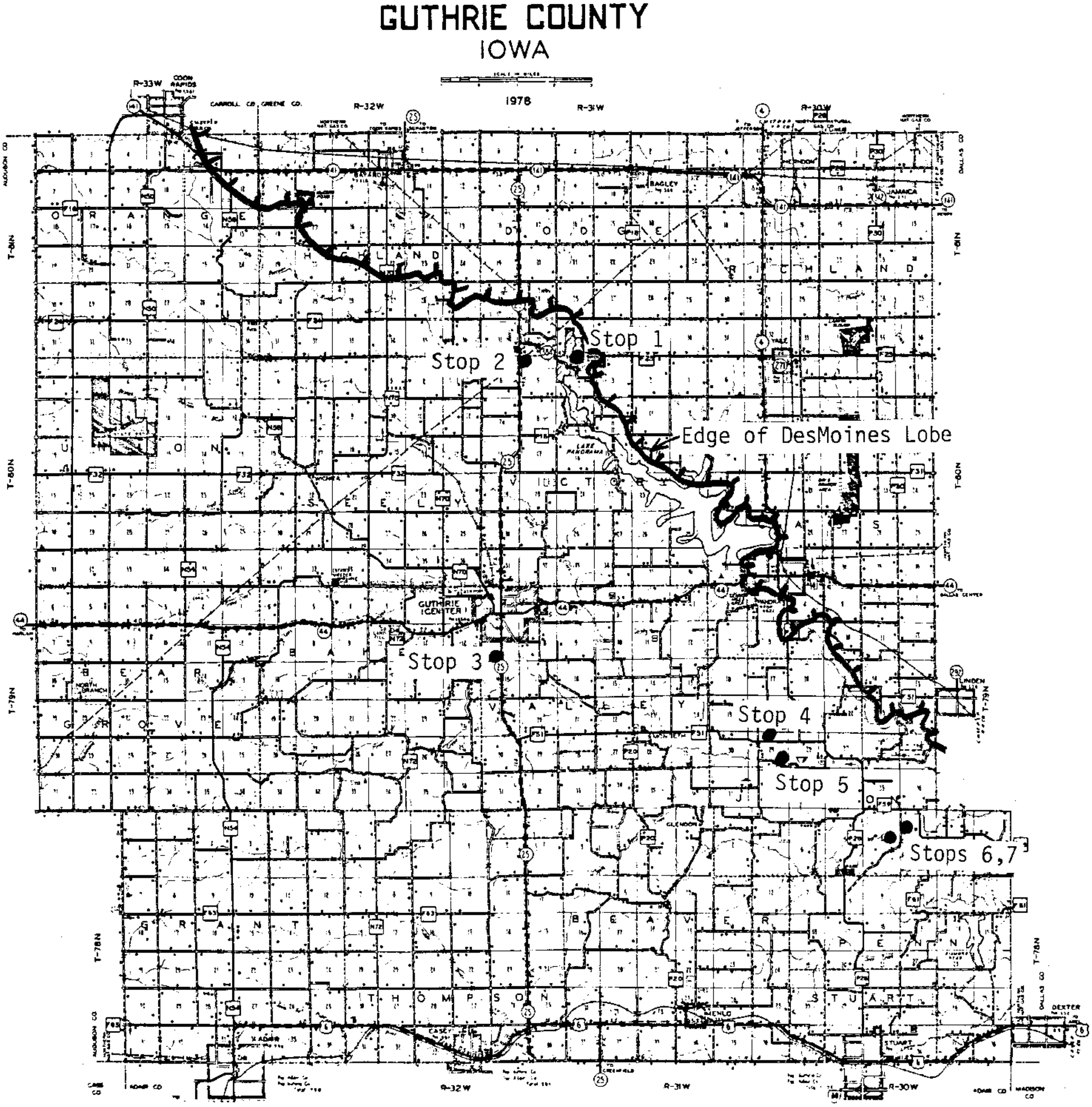

Figure 1. Guthrie County map with location of field trip stops. Edge of Des Moines Lobe from unpublished map of Tim Kemmis.

Paleozoic strata have been structurally deformed in the county. Richardson (1977) documented a series of anticlinal structures in northeastern Guthrie County with vertical closures of up to more than 200 feet (60 m); anticlinal deformation was apparently the result of pre-Middle Pennsylvanian, post-Mississippian structural activity. Pennsylvanian strata in the county are also locally known to display structural warping (e.g. Stop 6). Richardson (1977) also documented Paleozoic faulting in the county, including a series of high-angle reverse faults near Herndon collectively displaying up to 300 feet (90 m) of vertical displacement. Structural deformation and faulting in the county may relate to reactivation of Precambrian basement features within the Central North American Rift. Many structures within the Paleozoic sequence of Guthrie County undoubtedly have not yet been documented. The Thurman-Redfield Structural Zone trends near the southeastern portion of the county, and Redfield Anticline gas storage structure is present a short distance east of the Guthrie County line (see Valentine, 1960). Guthrie County Cretaceous strata are essentially horizontal and display little evidence of local structural deformation, although regional low-amplitude Laramide upwarping of Cretaceous strata is documented in western Iowa (Bunker, 1981).

Development of Cretaceous Stratigraphic Nomenclature in Western Iowa and the Type Dakota Area

The Cretaceous stratigraphic sequence in western Iowa comprises, in ascending order, the Dakota Formation, Graneros Shale, Greenhorn Formation, and Carlile Shale. The Niobrara and Pierre formations were undoubtedly deposited in most or all of western Iowa, but an extensive period of Cenozoic erosion stripped off these units in Iowa. (Niobrara and Pierre strata can be examined a short distance west of the Iowa line in eastern Nebraska and southeastern South Dakota). The Lower Dakota Formation is the only Cretaceous unit present within Guthrie County. The historical development of Dakota stratigraphic nomenclature and a review of certain proposed Dakota correlations in the eastern margin area of the Western Interior are included to acquaint the reader with some of the problems in unravelling the depositional history of the Dakota Formation.

The "Dakota Group" was named by Meek and Hayden (1862) for a sequence of sandstone with interbedded shale and lignite exposed in Dakota County, Nebraska across the Missouri River from the Sioux City, Iowa area. In subsequent years the "Dakota Group" and "Dakota Sandstone" received widespread use as stratigraphic terms for portions of the Cretaceous sequence in Arizona, New Mexico, Utah, Colorado, Wyoming, Kansas, Nebraska, the Dakotas, Minnesota, and Iowa. Unravelling the stratigraphic relations of the various "Dakota" sequences throughout much of the Western Interior to the Dakota sequence in the type area has commonly been frought iwth difficulty and confusion (the "Dakota problem" of McGookey *et al.*, 1972, p. 194). The general imprecision or tentative nature of many of these correlations resulted, in part, from a combination of several factors, the most noteworthy being (1) a poor understanding of the actual Dakota sequence in the type area, (2) the limited scope of subsurface stratigraphic studies in and adjacent to the type Dakota area, and (3) the general scarcity of biostratigraphic studies of Dakota strata.

Shortly after Meek and Hayden's (1862) Cretaceous classification was erected, White (1870) and St. John (*in* White, 1870) made important observations concerning the Cretaceous sequence in western Iowa, including the type area near Sioux City and the Guthrie County area. Many of White's observations have gone relatively unnoticed by many later geologists, in part because he erected a stratigraphic classification largely independent of Meek and Hayden's. White described in ascending order the following sequence: (1) the "Nishnabotany [Nishnabotna] Sandstone," a sandstone-dominated interval best exposed in southwestern Iowa (first named by White, 1867), (2) the "Woodbury Sandstones and Shales" which are well exposed in the Dakota type area near Sioux City, and (3) the "Inoceramus Beds," a thin shaly and chalky limestone interval. As presently understood, the Nishnabotna Sandstone is equivalent to the lower portion of the Dakota Formation in Iowa, whereas White's Woodbury includes the entire interval between the lower Dakota and the Greenhorn Formation. White (1870, p. 269) correctly surmised that a sandstone-dominated Nishnabotna interval occurs in the subsurface beneath the exposures in the type Dakota area. Todd (1892, p. 15) was the first to investigate the subsurface geology in the type Dakota area and noted that a shale-dominated sequence was deposited above a "continuous sandstone which the Iowa geologists have called Nishnabotna sandstone." Gould (1900) and Darton (1905) later noted a unit containing large amounts of coarse sandstone and gravel in lower Dakota outcrops in eastern Nebraska. To summarize, the first geologists to investigate the stratigraphic succession in the Dakota type area and adjacent regions, in general, identified a lower sandstone-dominated interval, generally including coarse sand and gravel, and an upper interval of interbedded sandstone and shale. They also recognized that only the upper Dakota sequence is exposed in the type area.

Condra and Reed (1943, p. 19) selected a specific type locality for the "Dakota Group" in Dakota County, Nebraska for the first time and defined the lithologic character of the complete Dakota sequence, based on surface exposures and well penetrations. They recognized a 392 foot (120 m) thick sequence of Dakota rocks at the type locality resting unconformably on the Paleozoic surface. The lower 170 feet (52 m) of the sequence is a fine to coarse grained sandstone-dominated interval that Condra and Reed labelled the "Lakota Sandstone." They also identified the overlying 75 foot (23 m) shale interval as the "Fuson Shale." The upper portion (147 feet; 45 m) of the Dakota sequence, part of which outcrops at the type locality, was given a new stratigraphic name, the "Omadi sandstone formation." Condra and Reed (1943, p. 18-19) identified the Omadi as an interbedded sequence of sandstone and shale and suggested that it correlates directly to the Newcastle, Skull Creek, and Fall River formations farther west. The Lakota, Fuson, Fall River, and Newcastle formations were originally named for Lower Cretaceous exposures in the Black Hills area.

Schoon (1971) recognized an informal tripartite division of the Dakota section in the type area, where it reaches an aggregate thickness of about 420 feet (128 m), that, in part, paralleled that of Condra and Reed. Schoon's "lower unit," which is not exposed in the type area, is a medium to coarse grained sandstone-dominated interval, apparently equivalent to the Nishnabotna. However, Schoon rejected Condra and Reed's stratigraphic nomenclature and correlations and suggested instead that the type Dakota section includes no rocks equivalent to the Lakota, Fuson, or Fall River formations. In accord with Schoon (1971, p. 8) we have relegated the Dakota to formational status and do not recognize the Inyan Kara Group (i.e., Lakota, Fuson, and Fall River fms.) in the Dakota type area.

Recent outcrop and subsurface studies of the Cretaceous sequence in northwestern Iowa have further clarified the character of the Dakota Formation in the type area (Ludvigson and Bunker, 1979; Whitley, 1980; Whitley and Brenner, 1981). In general, these workers recognized two major Dakota units: a lower sandstone-dominated interval and an upper interval dominated by mudstone/claystone with interbedded sandstone, siltstone, and lignite. The Dakota Formation is known to reach thickness of up to 500 feet (150 m) near the type area in northwestern Iowa (Whitley, 1980, p. 7). Hydrogeologic studies of the Dakota Aquifer in western Iowa have emphasized the utility of a two-part stratigraphic subdivision of the Dakota Formation, and these two units have been accorded member status by the Iowa Geological Survey (Munter et al., 1982). Utilizing the original classification of White (1870), the Dakota Formation in the type area of northwestern Iowa is divided into a lower sandstone-dominated Nishnabotna Member and an upper mudstone/claystone-dominated Woodbury Member (ibid.). Only the Woodbury Member is exposed in the type Dakota area. Although White (1870) logically included strata now assigned to the marine Graneros Shale in his original definition of the Woodbury, the Woodbury Member, as presently used, excludes the Graneros Shale, primarily to maintain a degree of stratigraphic cohesion with adjacent states. Two cored intervals from northwestern Iowa are shown in Figure 2, in order to illustrate the general character of the formation. The Nishnabotna Member essentially filled in the topographically low areas on the Dakota drainage surface, and is locally absent above the paleotopographic highs.

The development of Dakota stratigraphic nomenclature in Kansas has had a significant impact on correlations and nomenclature in the type Dakota area. Plummer and Romary (1942) formally divided the Dakota Formation of Kansas, where it overlies the upper Albian Kiowa Shale, into a lower Terra Cotta clay member and an upper Janssen clay member. While they did not attempt to correlate the Kansas Dakota sequence to the type Dakota area, later workers carried the Kansas classification into the type Dakota area in Nebraska and Iowa (Bowe, 1972; Franks, 1975, 1979). Sandstone exposures of the Nishnabotna Member in southwestern Iowa and adjacent parts of Nebraska have been assigned to the lower Terra Cotta Member of the Dakota Formation by Bowe (1972) and Karl (1976). We, however, do not utilize Kansas Dakota nomenclature in western Iowa for two reasons: 1) the type Terra Cotta Member in Kansas is dominantly a mudstone unit, whereas the southwest Iowa exposures are clearly sandstone-dominated, and 2) we do not believe that the lithostratigraphic correlation of the lower Terra Cotta and Nishnabotna members has been adequately demonstrated.

Franks (1966, 1975, 1979) illustrated a "concept of the stratigraphic relationships seen along the outcrops in Kansas and Nebraska"(1966, p. 40) in which the type Dakota and Kansas Dakota sequences are shown as correlative units with no portion of the Kiowa and type Dakota being laterally equivalent. Franks (1975, p. 511) further suggested that "the pinchout of the Kiowa Formation beneath Dakota rocks in north-central Kansas essentially precludes the presence of Skull Creek and Fall River equivalents in the outcrop of eastern Nebraska and in the type area of the Dakota." This view contradicted the long-standing claim that the Kiowa marine shales were laterally equivalent to a portion of the Dakota Formation (Twenhofel, 1924, p. 41; Tester, 1931, p. 282-283). Franks (1979) recognized a nonmarine to marginal marine facies of the Kiowa in Kansas, the Longford Member, that is lithologically similar to overlying Dakota rocks. He suggested from field evidence that the Longford Member, and the Kiowa Formation in general, pinches out northward in Kansas beneath a disconformity at the base of the Dakota Formation. Franks acknowledged that the Longford Member "could not be distinguished in any practical way from basal Dakota rocks . . . along the pinchout of the Kiowa Formation" (1979, p. 11) and that "apparent local gradation of thick, lenticular, Kiowa

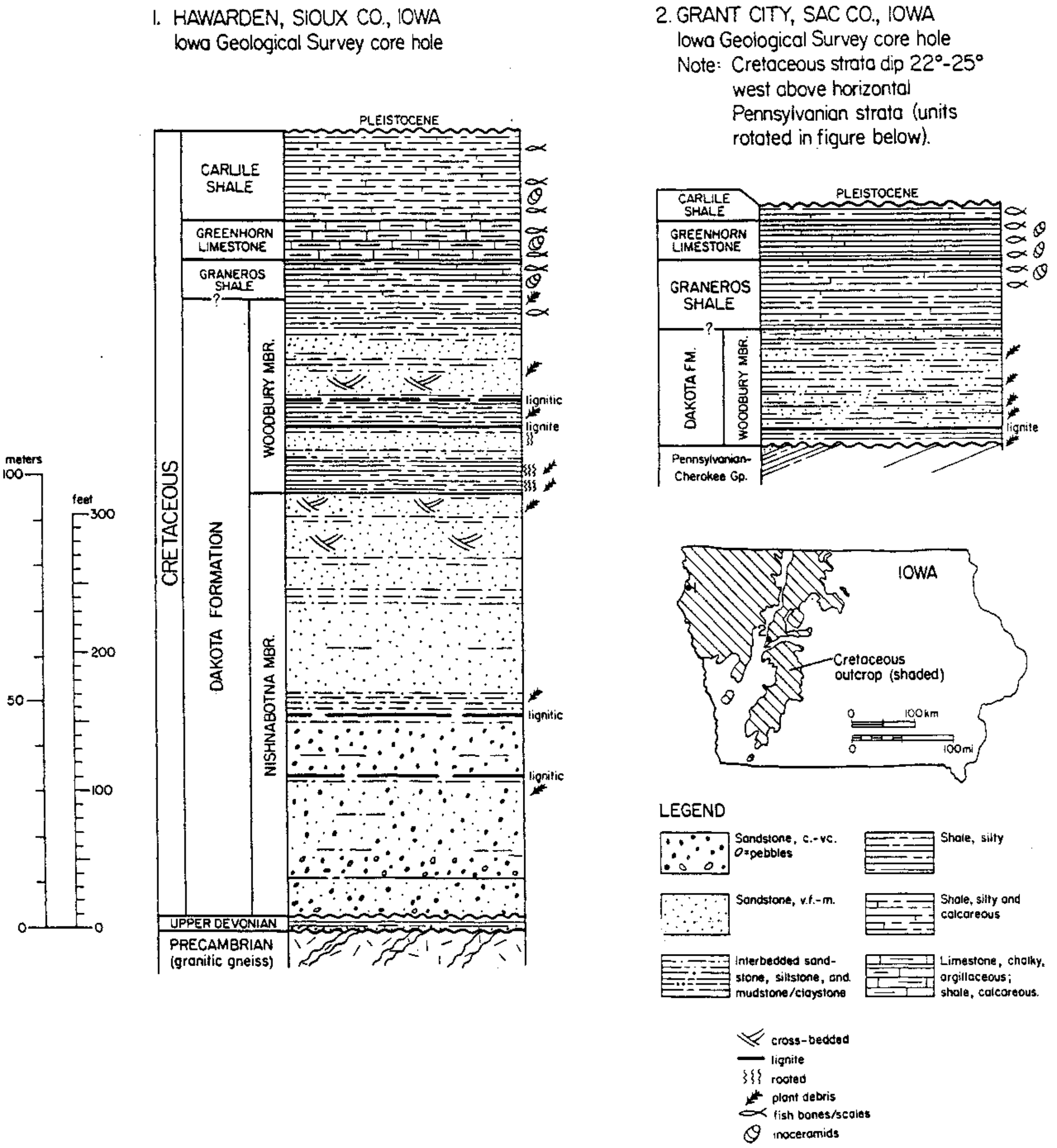

Figure 2. Cretaceous stratigraphic sections in western Iowa.

sandstones into sandy beds in the basal parts of the Dakota in central Kansas poses problems of interpretation" (1975, p. 496).

If the supposed absence of Kiowa or Skull Creek equivalents in the type Dakota area is true, then paleogeographic reconstruction of Dakota sedimentation in the eastern margin area would need to reflect this. As such, some problems relating to Franks' interpretations attracted special attention in our study of the Dakota in western Iowa. 1) Franks (1979, p. 7; 1975, p. 514) suggested that the "Dakota Formation marks the regressive phase of sedimentation" following withdrawl of the Kiowa sea and that earliest Dakota sedimentation in Kansas represents a "progradational shoal-water, deltaic complex." This accords well with the idea that Kiowa-Skull Creek marine deposition represents the maximum transgressive phase of the first widespread transgressive-regressive cycle in the Western Interior (Reeside, 1957; Kauffman, 1977), but also presents a dilemma. In as much as Franks recognized that the lower Dakota is the regressive portion of the Kiowa-Skull Creek marine cyclothem and correlated the base of the Kansas Dakota with the base of the type Dakota section, one can conclude that Dakota sedimentation in the type area was initiated during the regressive phases of this cyclothem. Why would there be no evidence of nonmarine sedimentation during the transgressive or maximum transgressive phases of the Kiowa-Skull Creek Cyclothem in the type Dakota area? This is a particularly vexing question because regional base levels would have been considerably higher during maximum transgression of that cyclothem than during the offlap of that cycle. 2) The Dakota Formation reaches thicknesses of about 500 feet (150 m) in the type area whereas the Dakota is only about 250 feet (75 m) thick above the Kiowa in central Kansas (Franks, 1975). This relationship is especially perplexing in as much as all post-Dakota Cretaceous stratigraphic intervals are known to thicken from the type Dakota area into Kansas. Does the Dakota really thicken towards the type area, or, alternatively, are nonmarine Kiowa equivalents represented in the Dakota type area? Although full resolution of these problems must await further study, two contrasting viewpoints are presented in subsequent sections of this guidebook. A subsurface cross-section was constructed from the Dakota type area to south-central Nebraska in an effort to more accurately define the physical stratigraphy of the Dakota Formation between the areas in question (Fig. 3). Our interpretation of Dakota paleogeography in the study area is an attempt to reconcile regional patterns of sedimentation in the Western Interior with the physical stratigraphy of Dakota rocks in Iowa, Minnesota, Nebraska, and the Dakotas. Additional viewpoints will no doubt be presented by other workers.

The Lower Dakota Formation, Nishnabotna Member, in Western Iowa

The sandstone dominated Nishnabotna Member (Lower Dakota) is distributed over a broad area of western Iowa. It occurs in the subsurface over much of northwestern Iowa, where it ranges from 63 to 365 feet (19-111 m) in thickness. The Nishnabotna Member pinches out northward against the Sioux Ridge and is not recognized east of the western one-third or so of the state (Munter et al., 1982). (The eastern extent of the Nishnabotna is illustrated on the cover of the guidebook). The Upper Dakota Woodbury Member oversteps the Nishnabotna edge in north-central Iowa (see cover map). The contact between the Woodbury and Nishnabotna members in Iowa "varies from sharp to gradational" (ibid.), and portions of the uppermost Nishnabotna and lowermost Woodbury apparently interfinger. The Nishnabotna Member forms the bedrock surface over portions of west-central and southwestern Iowa. The member is known to crop

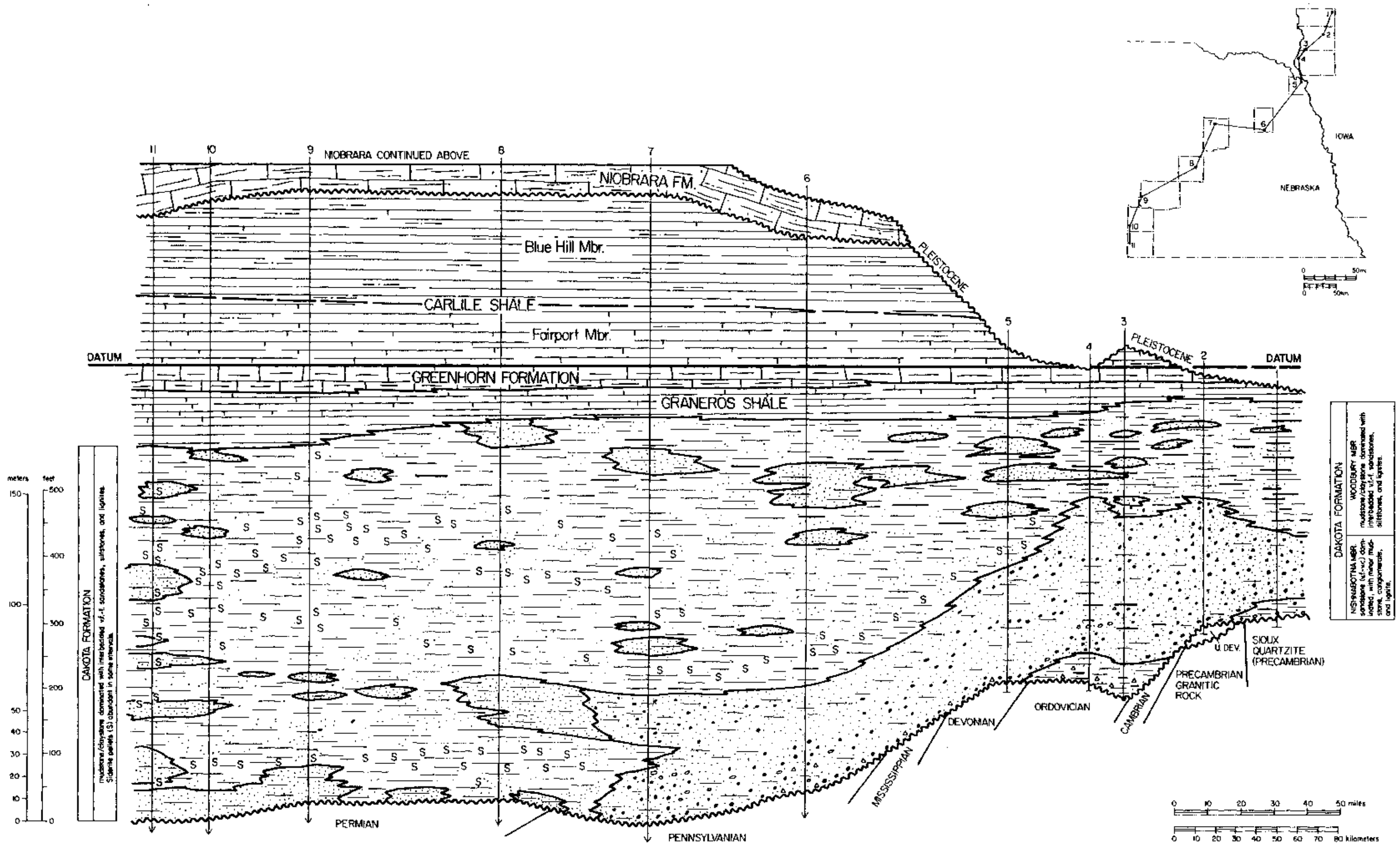

Figure 3. Sub-Niobrara Cretaceous stratigraphic cross-section, northwestern Iowa and eastern Nebraska. Symbols as in Figure 2. Sandstone body geometries are generalized. Localities 1 through 4 are subsurface control points from the U.S.G.S.-Iowa G.S. Dakota Aquifer study; well cuttings and gamma logs on file at the Iowa Geological Survey. The type Dakota sequence at Locality 5 from Condra and Reed (1943, p. 19). Sequences at localities 6-11 are interpreted from well cuttings, gamma logs, and E-logs on file at the Nebraska Geological Survey. Exact locations of all control points are available from the authors. S-abundant siderite pellets.

out in the following Iowa counties: Adams (Wood, 1941; Hershey et al., 1960, p. 45,125,126), Calhoun (St. John in White, 1870, v. 2, p. 149), Carroll (St. John in White, 1870, v. 2, p. 133; Bain, 1899, p. 73-75), Cass (White, 1870, v. 2, p. 373; Tilton, 1917, p. 203-209; Tester, 1931, p. 257-259; Hershey et al., 1960, p. 49,50,128,129), Greene (St. John in White, 1870, v. 2, p. 133), Guthrie, Mills (White, 1870, v. 1, p. 368; Udden, 1903, p. 161-164; Hershey et al., 1960, p. 130), Montgomery (White, 1870, v. 1, p. 363-367; Lonsdale, 1895, p. 412-424,436,438-9; Tester, 1931, p. 257-259; Hershey et al., 1960, p. 71-72,136-138; Bowe, 1972), Page (Lonsdale, 1894, p. 41; Calvin, 1901, p. 439-440; Hershey et al., 1960, p. 81, 143), and Pottawattamie (White, 1870, v. 1, p. 378; Udden, 1901, p. 233-242; Hershey et al., 1960, p. 90-91, 144-145). The Nishnabotna Member reaches maximum thicknesses of about 200 feet (60 m) in west-central Iowa.

Strata that are lithologically and lithostratigraphically equivalent to the Nishnabotna Member are also well-developed in portions of eastern Nebraska. In that region this interval was previously assigned to the "Lakota Sandstone" (Condra and Reed, 1943, p. 19), although more recent workers have assigned it to the "lower Terra Cotta Member" (e.g. Bowe, 1972; Karl, 1976). We suggest abandonment of Kansas nomenclature in those areas of eastern Nebraska for reasons outlined earlier.

The Nishnabotna Member in most of western Iowa is dominantly a fine to coarse grained sandstone, in part pebbly, that is locally interbedded with conglomerates, mudstones, claystones, ironstones, or lignites. The Nishnabotna Member in Iowa averages 83% sandstone by volume (Munter et al., 1982) and forms a continuous sheet-like sandstone body. In Nebraska its stratigraphic equivalents are lithologically similar, although the interval shows a "decrease in mean grain size and coarsest one-percentile towards the south" in eastern Nebraska (Karl, 1976, p. 129). Nishnabotna-like Lower Dakota rocks are not known in central, southern, or far southeastern Nebraska, where instead the interval is apparently replaced laterally by a mudstone-dominated facies containing fine-grained channel sandstones (see Fig. 3). This latter facies is, in turn, apparently replaced westward by facies containing marine shales.

The Nishnabotna Member in western Iowa disconformably overlies various Paleozoic rock units. Across most of Iowa and eastern Nebraska the Cretaceous sequence rests directly on Paleozoic rocks. A series of topographic highs and lows have been delineated in northwestern Iowa that represent an eroded surface of strike-oriented valleys developed on southeasterly dipping Paleozoic strata, with local relief of 200 to 300 feet (60-100 m, Ludvigson and Bunker, 1979). The Nishnabotna Member infills these paleovalleys. In Guthrie County the Nishnabotna rests on various Pennsylvanian units, where elevations at the Pennsylvanian-Cretaceous contact vary from 950 to 1150 feet above sea level. If post-Cretaceous structural movements have been relatively insignificant in the area, then Nishnabotna sedimentation in the county was apparently initiated on an ancient land surface with about 200 feet (60 m) of vertical relief.

Although the Nishnabotna Member is sandstone-dominated, the basal interval locally is mudstone dominated. A regolith of varying thickness was apparently developed on the Paleozoic surface prior to Cretaceous fluvial deposition. The regolith is variably composed of residual Paleozoic carbonate, chert, and/or sands generally in a kaolinitic matrix, and it is, in part, reworked into fluvial sequences at the base of the Dakota Formation. The regolith and associated fluvial mudstones/sandstones in the basal Nishnabotna reach thicknesses of up to about 50 feet (15 m) in northwestern Iowa. In west-central and southwest Iowa the basal mudstone-dominated interval crops out in several areas where it is known to reach thicknesses of up to 36 feet (11 m) (e.g. see Lonsdale, 1895, p. 417). However, this interval is not everywhere present, and Cretaceous sand and gravel beds rest directly on Paleozoic strata in many areas of western Iowa. Where the basal mudstone-dominated unit is present it is highly variable in character; it typically consists of silty micaceous mudstones and is locally interbedded with thin sandstone beds. Lignites and carbonaceous shales are locally present in this sequence, and in some sections it includes relatively pure kaolinitic claystones (usually with trace amounts of silt). These kaolinitic claystones (white to variegated) were previously utilized as a ceramic clay source in portions of southwestern Iowa.

The great bulk of the Nishnabotna Member is sandstone-dominated. The lower 50 to 75 feet (15-23 m) of the Nishnabotna sandstone sequence is characteristically the coarsest grained portion of the member. It includes the greatest percentage of gravelly and conglomeratic beds, and the sandstones vary from fine grained to coarse grained and pebbly. Some thin silty kaolinitic mudstone units are present in the lower Nishnabotna interval (e.g. Stop 5) that are replaced laterally by coarse pebbly sandstones. Imbricated mud clasts are locally noted in these mudstones. Hematite and limonite-cemented sandstones, pebbly sandstones, and conglomerates are a characteristic feature in many exposures of the lower Nishnabotna. These iron-cemented beds typically follow horizontal bedding surfaces and range from about 1 cm to 20 cm in thickness. Some cross-bedded conglomeratic sandstone beds are also partially to completely iron-cemented, locally reaching thicknesses in excess of 1 meter. The hard iron-cemented conglomeratic beds were usually termed "puddingstones" in the older reports (the gravel clasts vaguely resemble raisins in a pudding matrix). These beds have also been termed "peanut conglomerate" (Cline _et al._, 1938, p. 22), and workmen in Guthrie County gravel pits have aptly termed these beds "peanut brittle rock." Partial iron-cementation of some sandstone beds is locally noted, and some mudstones are variegated with iron mottlings. Bizarre swirls of Liesegang iron-cementation within sandstone units are a common feature at many Nishnabotna outcrops. Some calcite-cementation is noted in the Nishnabotna, but is usually proportionately less common than iron-cementation. Although iron-cementation is a prominent feature at many outcrops of the Nishnabotna Member, iron-cemented beds make up only a small percentage of the sequence. For the most part, the lower and upper Nishnabotna sandstones are uncemented and friable.

The upper 100 feet (30 m) or so of the Nishnabotna Member is significantly finer grained than the lower interval and is dominated by fine-grained sandstones. However, the upper Nishnabotna includes fine to coarse grained pebbly sandstone beds, and mudstone units are also commonly seen. Mudstone or claystone clasts are noted in some sandstone and mudstone units as well. Iron-cementation of fine grained to coarse pebbly sandstones, mudstones, and mud-chip conglomerates is commonly noted in the upper Nishnabotna.

Sedimentary structures, primarily cross-stratification, are abundantly represented in the Nishnabotna Member, and their vertical distribution in the sequence has stratigraphic significance. The lower Nishnabotna is primarily characterized by planar cross-beds and horizontal stratification, and trough cross-beds are extremely rare to absent. On the other hand, the upper Nishnabotna is characterized by an abundance of trough cross-beds, and planar cross-beds and horizontal stratification are also noted. These relationships are consistently observed in the Guthrie County outcrops, and the abundance of trough cross-beds can be used to characterize most upper Nishnabotna sequences. The stratigraphic sequence from lower Nishnabotna pebbly sandstones with planar cross-beds to upper Nishnabotna fine-grained sandstones with abundant trough cross-beds is graphically portrayed in Figure 4. Karl (1976, p. 126) and Bowe (1972, p. 70) observed similar relationships in the Lower Dakota sequence of eastern Nebraska. The sedimentologic significance of the vertical changes in sedimentary structures and textures will be discussed in the next section.

The Nishnabotna sandstones consist primarily of rounded to angular quartz grains (monocrystalline to polycrystalline) with lesser quantities of chert, feldspar, muscovite, heavy mineral, and igneous rock grains. The conglomerates consist primarily of well-rounded quartz and chert pebbles with very rare igneous/metamorphic rock pebbles. Silicified Paleozoic fossils are commonly found within the conglomeratic beds. Clays within the Nishnabotna are dominantly kaolinitic with lesser amounts of illite and montmorillonite (Frye et al., 1964). Mudstone units are commonly micaceous (muscovite). The composition of the Nishnabotna provides important evidence for delineating sediment source areas (see later section).

Although the Cretaceous age of the Nishnabotna Member has never been disputed, fossil evidence confirming this age assignment is scant. In general, The Nishnabotna Member is poorly fossiliferous. Fossil angiosperm leaves have been collected in the Nishnabotna Member in the following western Iowa counties, generally confirming the Cretaceous age assignment: Montgomery (White, 1867), Guthrie (Bain, 1897, p. 453), and Pottawattamie (Udden, 1901, p. 234). Unidentified plant fossil debris, including carbonaceous wood fragments, is commonly observed within Nishnabotna mudstone units. Lower Nishnabotna gravels in Guthrie County (Stop 5) have also yielded a petrified wood clast displaying annular rings; this wood piece is almost certainly of Cretaceous age since comparable wood pieces are not known from older stratigraphic units in Iowa.

What about dinosaur fossils in the Lower Dakota sequence? Dinosaur bone scraps and the distal end of an ornithopod dinosaur femus were collected from strata apparently equivalent to the Nishnabotna Member in Burt County, Nebraska, a short distance west of the Iowa state line (Barbour, 1931; Galton and Jensen, 1978). The dinosaur-bearing sandstones also yielded angiosperm leaves at that locality. The ornithopod femur fragment is probably from a hadrosaurian, although possible relationships with Iguanodon could not be ruled out (Galton and Jensen, 1978). This femur fragment is quite large and probably came from an animal whose body length was around 10 m (ibid.). A partial ankylosaur skeleton (Silvisaurus) was collected from the Lower Dakota interval (middle Terra Cotta Mbr.) in north-central Kansas, where it was associated with angiosperm leaf-bearing sandstones (Eaton, 1960). To date, no confirmed dinosaur remains have been found in the Dakota Formation of Iowa, although potential certainly exists in our state for their discovery. The Nishnabotna exposures examined on this field trip are potentially dinosaur-bearing. The discovery of even a small rounded and worn bone scrap in the Cretaceous sandstones and gravels of western Iowa could be potentially important since dinosaur bone can be identified in thin-section. We encourage all trip participants to keep a sharp eye open for bone scraps. The first fossil bone scrap discovered wins a case of beer!

Ongoing palynological studies of the Dakota Formation in northwestern Iowa are providing some important insights into the age of the type Dakota sequence. Diverse palynological assemblages noted in Upper Dakota lignites in the type

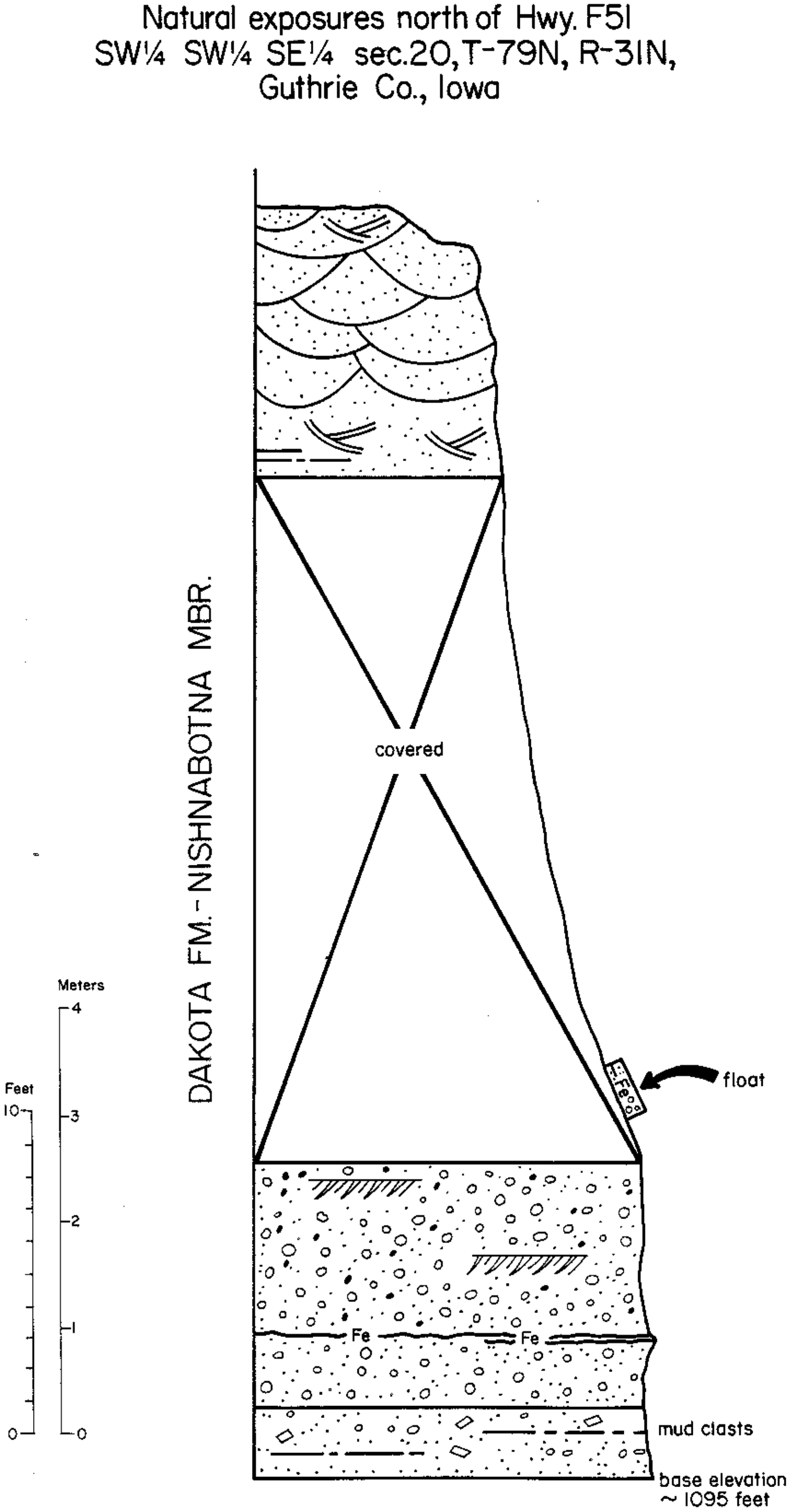

Figure 4. Natural exposure of the Nishnabotna Member in Guthrie County showing fine-grained trough cross-bedded upper Nishnabotna strata in sequence above coarse-grained planar cross-bedded pebbly sandstones of the lower Nishnabotna. Symbols as in Figure 11.

area are probably "lowermost Cenomanian" (earliest Late Cretaceous) in age (Ravn, 1981) suggesting that "significant possibility exists that lower portions of the Dakota may be pre-Cenomanian in age," i.e. Albian (ibid.). Lignites in the upper portions of the Nishnabotna Member in northwestern Iowa have yielded palynological assemblages that do not differ significantly from those recovered in the Upper Dakota (R. Ravn, 1982, pers. comm.), suggesting that the upper Nishnabotna is also lowermost Cenomanian in age. Carbonaceous shales lower in the Nishnabotna sequence in the subsurface of northwestern Iowa have yielded a unique low-diversity palynological assemblage containing the problematical spore-like Petalosporites quadrangularis, "Tasmanites"-like microfossils, and other palynomorphs of uncertain affinities (R. Ravn, 1982, pers. comm.). This unusual assemblage indicates a depositional environment quite different from that of the lignites and spore-rich shales of the Upper Dakota, suggesting that freshwater ponded or lacustrine environments may have existed adjacent to the Nishnabotna fluvial channels. None of the species observed in this impoverished assemblage is of much biostratigraphic significance, however, and lowermost Dakota strata are, in general, largely unfossiliferous.

Although palynological studies suggest that the lower portions of the Dakota Formation in western Iowa may include upper Albian strata, definitive evidence is lacking. Regional stratigraphic evidence also suggests that the lower portion of the Dakota Formation in western Iowa is upper Albian. The stratigraphic continuity of the Newcastle Formation and "J"-sand in the central area of the Western Interior Seaway with Lower Dakota strata in the eastern margin area of the seaway (e.g. western Iowa) has been recognized by previous workers (Gries, 1962; Schoon, 1971). The Newcastle Formation and "J"-sand represent the distal prograding portion of an eastern-derived sandstone wedge that spread from eastern South Dakota and Iowa into eastern Colorado and Wyoming during regression of the Kiowa-Skull Creek marine cyclothem (MacKenzie and Poole, 1962). The Lower Dakota Formation in Iowa apparently represents, in part, the proximal portion of that wedge. The Newcastle Formation in the Western Interior is overlain by upper Albian marine strata of the Mowry Formation (Reeside and Cobban, 1966). The underlying Kiowa-Skull Creek marine shales are also upper Albian in age (Scott and Taylor, 1977). Therefore, regardless of whether or not the Kiowa is equivalent to any portion of the type Dakota section, these observations help bracket the age of the Nishnabotna Member in Iowa, placing the lower limit of its age as probably upper Albian. If the age relations of the Nishnabotna Member in Iowa suggested here are correct (i.e. upper Albian-lowermost Cenomanian), then the Lower-Upper Cretaceous boundary can be correlated somewhere within the Nishnabotna sequence.

Fluvial Deposition of the Nishnabotna Member

Although Nishnabotna outcrops in western Iowa were described by a number of workers in the late 1800s and early 1900s, few attempts were made at interpreting the depositional environments of the sequence. Bain (1897, p. 457) suggested that the Lower Dakota "deposits found in Guthrie County represent shore deposits" of the encroaching Cretaceous seaway. While most modern workers agree that the Lower Dakota was deposited in fluvial environments and not in a shoreline situation, Bain was correct in suggesting that the transgression of the Cretaceous seaway into the eastern margin area of the Western Interior influenced Lower Dakota sedimentation. A fluvial drainage network undoubtedly was developed across Iowa during the earlier Cretaceous, but the absence of pre-Dakota fluvial deposits in Iowa suggests that fluvial downcutting and downstream sediment transport were the dominant processes throughout most of the Early Cretaceous in this area. However, as the Cretaceous seaway encroached eastward into Nebraska in the mid Cretaceous, regional base level was raised in the western Iowa fluvial systems, and stream competency was thereby decreased. The drop in stream competency allowed coarse-grained Nishnabotna fluvial sediments to aggrade in western Iowa.

As interpreted by recent workers (Bowe, 1972; Karl, 1976; Ludvigson and Bunker, 1979; Whitley, 1980; Whitley and Brenner, 1981; Munter et al., 1982), deposition of the Lower Dakota sandstone-dominated interval (Nishnabotna Mbr. in Iowa) probably occurred in braided fluvial channel systems of relatively low sinuosity and possibly in coarse-grained meanderbelt systems. Modern braided fluvial systems, as the name suggests, exhibit multiple anastomosing channels and are characterized by relatively high stream gradients and high sediment bed loads. During low flow stages braided rivers have numerous alluvial islands and exposed braid bars between the channels. The lower Nishnabotna Member exhibits a number of features characteristic of braided fluvial deposition. 1) Sediments in braided fluvial sediments are primarily composed of medium to coarse sand and gravel. The lower Nishnabotna is certainly dominated by sand and gravel. 2) "Relatively poor sorting is characteristic of braided stream sediments" (Ore, 1964, p. 8). The lower Nishnabotna is a poorly sorted deposit, with individual beds commonly including sediments in the fine sand to gravel size range. 3) "Muds or silts are rarely preserved within these systems" (Brown, 1973, p. 13). The lower Nishnabotna is clearly sandstone-dominated, and only minor mudstone units are developed in the unit (excluding the basal regolith). 4) Sedimentary structures in the proximal portions of braided stream systems are dominated by horizontal stratification and planar cross-bedding (Brown, 1973, p. 12; Rust, 1978, p. 613-615). Horizontal stratification is prominent in the lower Nishnabotna, and planar cross-beds are usually well developed within the sequence. Trough cross-beds are also a common feature of many braided stream systems, especially in the distal portions of those systems, although no trough cross-beds have yet been observed in the lower Nishnabotna of Iowa. 5) Planar cross-bed directions in braided fluvial systems typically "show fairly high dispersion" (Ore, 1964, p. 12) and commonly "have paleocurrent directions which are at high angles to the direction of the trough cross-beds" (Cant, 1978, p. 633). Planar cross-bed orientations in the lower Nishnabotna are widely dispersed, often in directions widely divergent from the trough cross-bed orientations noted in the upper Nishnabotna (see later discussion).

Sedimentologic studies of ancient and modern braided fluvial systems, especially those during the last two decades, provide a basis for evaluating lower Nishnabotna depositional environments. In general, the abundance of sand and gravel in the lower Nishnabotna suggests that the ancient fluvial systems carried a mixed sand-pebble bedload. Finer material was carried in suspension in the channels. Deposition within braided channels is commonly marked by the accumulation of sand and gravel into large-scale bedform features termed longitudinal bars (long axes aligned with stream flow). Longitudinal bars are characterized internally by horizontal stratification (Ore, 1964, p. 9). Longitudinal bars accumulate in the higher flow regimes of braided stream systems or during periods of increased discharge. Horizontal stratification in the lower Nishnabotna may have formed during longitudinal bar sedimentation under essentially planar bed flow. Gravel concentrations near the base of some beds in the unit may mark the site of initial longitudinal bar deposition or may represent lag deposits formed when channel flow increased.

Planar cross-beds in the lower Nishnabotna range from small-scale features only a few centimeters high to large-scale features only a few centimeters high. They may occur as solitary planar cross-beds between horizontal beds or as sets of several cross-beds. Planar cross-beds in braided stream systems may form in several ways. Planar cross-bed sets can be deposited by transverse or linguoid bars within the channel systems and are commonly oblique to the main channel trend (Cant, 1978, p. 633). The sediment fronts of these large-scale bedforms are along the downstream edge where planar foresets are actively deposited. However, since the sediment fronts are not necessarily normal to stream flow, the foresets do not always parallel stream flow. Rust (1978, p. 615-616) suggested that planar cross-beds may not necessarily be formed by transverse bar migration within proximal braided stream systems, but may "form as lateral modification of longitudinal bars during falling stage, when flow diverges away from bar axes." Smaller-scale planar cross-bed sets may correspond to deposits of sand waves, common in shallow areas of the river (Cant, 1978, p. 627). Sand flats and braid bars emerge within portions of the braided systems during times of low flow and are internally characterized by stacked sets of planar cross-beds.

Kaolinitic mudstones within the lower Nishnabotna are found interbedded with or laterally equivalent to pebbly sandstone units. Some mudstones fill in shallow channel-shaped geometries, and may represent overbank infilling of abandoned channels. Other mudstone units include beds with imbricated mudstone clasts, and mudstone clasts are also present within some sandstone units. The various mudstone units are best-interpreted as overbank deposits formed during the waning stages of flood deposition. As previously noted, the Nishnabotna also includes carbonaceous mudstones that may have been deposited in backswamp or pond environments. Preservation of overbank deposits is generally unlikely in braided stream systems because they are characteristically deposited in the higher parts of the vertical section, a position that is most vulnerable to erosion by later events. The presence of mud clasts within lower Nishnabotna sandstones indicates that overbank deposits were commonly eroded and coherent pieces of the eroded overbank mudstones subsequently transported as clasts within the braided stream channels. However, because mudstone units are preserved in the lower Nishnabotna, it seems reasonable to suggest that some overbank deposits were apparently buried by aggrading sand bedforms as stream channels shifted. These observations emphasize the warning given by Miall (1978, p. 603) concerning braided fluvial systems: it is generally assumed that overbank deposits are of little importance in braided river sediments. This may not always be the case."

The upper Nishnabotna differs from the lower Nishnabotna in several important aspects: 1) it is generally finer grained, 2) mudstone units are proportionately more common, 3) trough cross-beds are commonly observed (they are absent or very rare in the lower Nishnabotna), and 4) large-scale channel incision and infilling to several meters is noted. These differences clearly suggest that upper Nishnabotna sedimentation occurred in a different type of fluvial system than the lower unit. The first two observations listed above indicate a general decrease in stream competency in the upper Nishnabotna fluvial systems when compared to the lower Nishnabotna systems. The change in the development of cross-strata types upward in the Nishnabotna sequence of Guthrie County has also been noted in the Lower Dakota sequence of eastern Nebraska where the sandstone units "often have tabular cross-bedding in the lower part," but these "change to restricted sand bodies with both trough and tabular cross-bedding" in the upper part (Bowe, 1972, p. 70). Trough cross-beds in the upper Nishnabotna range from small-scale features a decimeter or so high to largerscale troughs up to a meter or more in height. The troughs erosionally truncate underlying sandstone beds. The trough cross-bedded units were probably deposited by migrating dunes within the river channels. As water flow increased, the size of the dunes and the depths of the scour troughs also increased. Planar cross-beds are also common in the upper Nishnabotna and may have been deposited in a variety of ways, some of which were discussed earlier. The possibility that some planar cross-beds in the upper Nishnabotna may have been deposited by lateral accretion of point bars needs to be examined.

Channel incision of up to several meters is evident in some upper Nishnabotna exposures. Such large-scale incision within the upper Nishnabotna may be related to 1) a regional lowering of base level, or 2) the development of meander cut-banks. At Stop 3 a 2.5 meter incision is infilled with mudstone, which contrasts with the smaller-scale sand-filled trough scours commonly seen elsewhere in the member. As active channels shifted or were downcut, older incised channels may have been infilled by overbank mudstones.

What type of fluvial systems were responsible for the deposition of the upper Nishnabotna sequence? At present, sedimentologic evidence in the unit seems equivocal, but analogies can be drawn with the distal reaches of braided stream systems and coarse-grained meanderbelt systems (see Rust, 1978; Brown, 1973). Trough cross-beds are commonly well developed in both types of fluvial systems. In general, "there are no absolute criteria for distinguishing deposits of distal braided and meandering fluvial systems." Because the lower Nishnabotna is best characterized as a braided stream deposit (perhaps proximal braided) and the mudstone-dominated Woodbury Member (Upper Dakota) contains evidence characteristic of fine-grained meanderbelt systems, the intervening upper Nishnabotna sequence may have been deposited in a series of intermediate fluvial environments with characteristics of both types of fluvial systems. Karl (1976, p. 130) suggested that the general change in fluvial deposition upward in the Dakota sequence was due to "eastward transgression of the Cretaceous sea" that "effectively raised base level of Dakota streams, modifying their channels to meandering patterns and reducing their competency in the process." Further studies are needed to clarify the nature of these changes in the upper Nishnabotna fluvial systems.

Trough cross-bed orientation data from the upper Nishnabotna in Guthrie County is presented in Figure 5. In general, trough axes are aligned parallel to stream flow, and, in a general sense, the vector mean of the trough orientations approximates mean flow direction. Our Guthrie County average (northeast-southwest) is similar to that noted by Bowe (1972, p. 53) who gave a vector mean of 244° for all cross-bed data he collected in the Dakota Formation of southwestern Iowa and eastern Nebraska. As will be shown, source beds for the Nishnabotna sediments are generally to the east and northeast of Guthrie County. In addition, regional paleogeographic evidence indicates that a north-south oriented seaway occupied the region west of Iowa during Lower Dakota sedimentation, and river transport from Iowa would thereby be generally east-to-west. These considerations along with the trough cross-bed orientations strongly suggest a general southwesterly transport direction for the Nishnabotna fluvial systems. (Of course, the North American continent was oriented slightly differently with respect to latitude lines during the Cretaceous than it is today, and the directions given are present-day orientation.)

Accurate measurements of planar cross-bed dip azimuths in the Nishnabotna Member of Guthrie County were not as easy to gather as the trough axes mea-

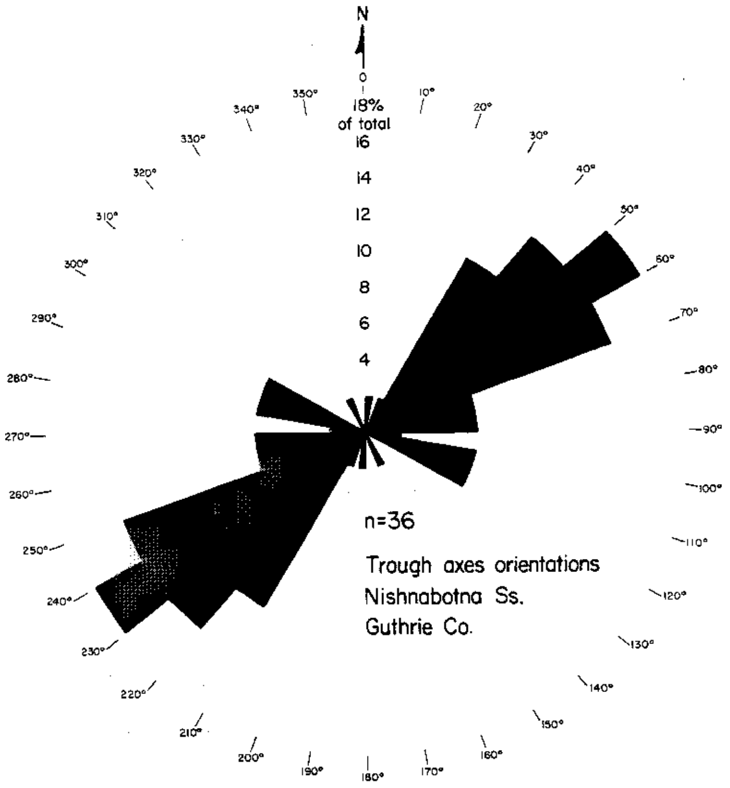

Figure 5. Measurements of trough axes orientations, upper Nishnabotna sandstones of Guthrie County, Iowa.

surements seemed to be. Although planar cross-beds are abundantly seen in the Nishnabotna outcrops of Guthrie County, good three-dimensional surfaces displaying actual orientations are difficult to find. The two-dimensional view seen along most exposure faces is not adequate for detailed analysis, although general observations can be made. On many exposure faces we commonly found planar foresets with southerly and easterly components of dip; this was initially surprising to us. Tester (1931, p. 257-258) made similar observations at a Nishnabotna outcrop in Montgomery County where "practically every possible direction of cross-bedding may be noted." Karl (1976, p. 127) identified "variations in dip direction of as much as 180° between sets" in strata equivalent to the Nishnabotna Member in eastern Nebraska. The data presented in Figure 6 represents only nine measurements of planar foreset directions in the Nishnabotna of Guthrie County, and the sample size is clearly inadequate for detailed analysis. When analizing cross-bed data Ore (1964, p. 12) stressed that "a wrong impression can be gained by considering only a few readings, and it is necessary to use sample sizes proportionate to accuracy." Nevertheless, it is apparent that the planar foreset directions bear no clear relationship to the trough axes orientations in the member (Fig. 5). The widespread deviations of planar foreset directions from mean flow direction provide important insights into flow regimes in the fluvial systems. As noted previously, "localized variations in cross-stratification directions are considered indicative of braided stream deposits" (Bowe, 1972, p. 71), and the "extreme variation in dip directions" noted in the Lower Dakota "is analogous to dispersion of cross-strata observed in some sand deposits of braided and low sinuosity streams." Therefore, planar foreset directions in the Nishnabotna are apparently consistent with braided fluvial deposition. Further cross-bed studies will undoubtedly provide additional information necessary for a more complete understanding of Nishnabotna sedimentation.

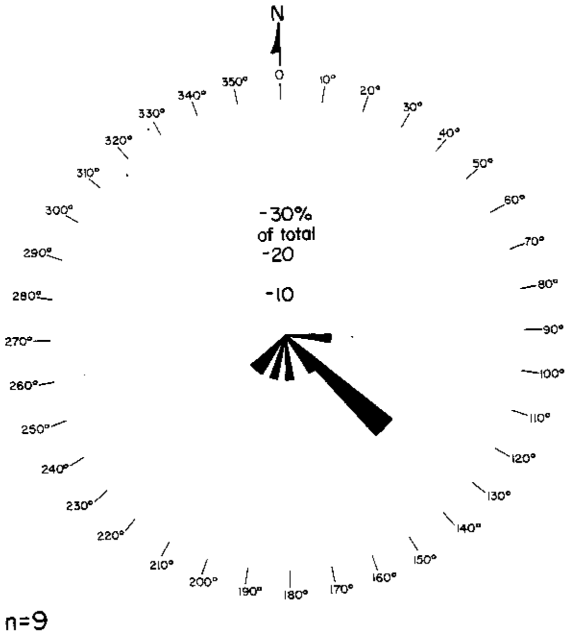

Figure 6. Planar foreset direction measurements, Nishnabotna Member, Guthrie County.

What is the origin of the prominent iron oxide-cementation noted at many exposures of Nishnabotna sandstones in Guthrie County and other areas? Several different iron minerals occur in the Dakota Formation of Iowa. Siderite pellets and nodules are very common in the Woodbury mudstones of northwestern Iowa, but are not known in the Nishnabotna Member. Pyrite-cementation is known from the subsurface of northwestern Iowa in sandstones of the Nishnabotna and Woodbury members, but has not been observed in outcrop. It is possible that some of the iron oxide-cemented zones (hematite, limonite, goethite) in the Dakota may represent oxidized phases of former pyrite cements. Iron oxide deposition is also a common feature of many modern fluvial environments, where iron-bearing pore fluids may precipitate iron oxides within recently deposited mudstone or sandstone units. Iron-cemented beds in the Nishnabotna are best developed within the coarsest-grained units, presumably where iron-bearing solutions could most easily be transported. However, it is not immediately apparent why some mudstone beds have been cemented by iron oxides. Mud clasts in many modern Iowa stream channels are commonly rimmed by iron oxides, indicating that iron oxide deposition is a common feature of many fluvial systems. Similar depositional processes may be responsible for the formation of iron rinds around many mud clasts within the Dakota sandstones. In conclusion, it is probably safe to say that iron oxide-cemented beds in the Nishnabotna probably formed in more than one way and at more than one time. Some, perhaps much, of the iron oxide cementation may have been essentially contemporaneous with fluvial deposition. Other beds may represent oxidized pyrite cements, initially deposited in oxygen-depleted iron-rich environments. Oxygen-depleted solutions may have originated in organic-rich surface or subsurface environments where anaerobic decay predominated. Finally, some, perhaps much, of the iron oxide cements may have been formed during late-stage diagenetic events. Iron is commonly highly mobile in groundwater systems, and, presumably, iron deposition could occur within the friable Nishnabotna sandstones in post-Cretaceous time whenever the physico-chemical conditions were suitable. It is generally more common to find iron oxide-cemented beds in Nishnabotna sandstone outcrops than it is in the subsurface (drilling program in northwest Iowa). This observation suggests that post-Cretaceous exhumation of the sandstone beds may have influenced iron-oxide precipitation.

Sediment Source Areas

The composition of the Nishnabotna sediments, as described in a previous section, forms the basis for evaluating possible source areas. The quartz sand fraction is not particularly instructive because it may have originated in more than one area (reworked Paleozoic or Precambrian sand or from granitic source areas.) Likewise, the minor feldspar content may have equally diverse sources. Chert grains and pebbles form a volumetrically significant portion of the Nishnabotna Member. Chert is abundant in many Paleozoic carbonate units in Iowa, and many source areas are possible on a local or regional scale. Fortunately, the general stratigraphic position in the Paleozoic sequence from which many of the Nishnabotna chert pebbles were derived can be determined by identifying their fossil content. White (1870, p. 290) and Bain (1897, p. 456) identified silicified Silurian and Devonian corals in Nishnabotna chert pebbles in Guthrie County. The authors of this report collected and identified additional silicified fossils in the Nishnabotna conglomerates at Stop 5 in Guthrie County (see Table 1). Silurian corals are the most commonly identified fossils, although Ordovician, Devonian, and possible Pennsylvanian silicified fossils were also collected. In addition, Pennsylvanian fusulinid-bearing chert clasts have been collected by the senior author from Nishnabotna conglomerates in Montgomery County. The fossil-bearing pebbles in the Nishnabotna were clearly derived from terranes exposing Ordovician, Silurian, Devonian, Mississippian (?), and Pennsylvanian rock units. The abundance of silicified Silurian fossils in the gravels is especially instructive since the near-east exposed Silurian terrane, and the only logical source area, was in eastern and northeastern Iowa (and the immediately adjacent areas of Wisconsin and northern Illinois). It can therefore be stated with considerable confidence that the Nishnabotna fluvial systems drained areas in eastern and northeastern Iowa. Even assuming the unlikely possibility that all the Silurian fossils were derived from areas in Wisconsin and Illinois, the Cretaceous drainage network would still have to transect eastern and/or northeastern Iowa in order to reach southwestern Iowa. With these geographic constraints in mind, the occurrence of Ordovician and Devonian fossils in the Nishnabotna gravels can also be readily explained. Pennsylvanian fossils in the gravels were most probably derived from local bedrock exposures in central to western Iowa.

Abundant quartz pebbles in the Nishnabotna gravels were probably not derived from Paleozoic terranes, but most closely resemble "igneous" quartz types commonly associated with fracture and vein fills in Precambrian igneous/metamorphic terranes. The presence of rare igneous rock grains, common muscovite flakes, and jasper and pink quartzite clasts in the Nishnabotna Member also suggests that the Nishnabotna drainage network dissected Precambrian terranes. With the identification of source directions to the east and northeast (Silurian clasts), the most likely source areas for these materials would be the Precambrian terranes in the central area of the Wisconsin Dome and possibly in central Minnesota.

Clay source areas for the Nishnabotna kaolinitic mudstones can also be proposed. Kaolinitic clays are generally rare within the Paleozoic sequence in the Iowa area, although illitic clays may have been derived from Paleozoic shales. A regolith was developed on Precambrian rocks in Wisconsin and Minnesota prior to the onset of Cretaceous fluvial deposition and consists primarily of weathered rock fragments and sand in a dominantly kaolinitic matrix.

TABLE 1. Silicified fossils identified in the lower Nishnabotna gravels at Stop 5, Guthrie County. Number of specimens collected and the known stratigraphic range in the Iowa area of the various fossil types are noted.

CORALS		
Alveolites sp.	1	Sil.-Dev.
cf. *Amplexus* sp.	2	Sil.-Miss.
Arachnophyllum sp	1	Sil.
"*Astrocerium*" sp.	2	Sil.-Dev.
Favosites favosus	4	Sil.
Favosites niagarensis	15	Sil.
Favosites sp. (indet.)	7	Sil.-Dev.
Pleurodictyum sp.	1	Dev.
Streptelasma sp.	2	Ord.-Dev.
Striatopora or *Coenites* (branching)	6	Sil.-Dev.
Syringopora sp.	6	Sil.
Zaphrentis sp.	2	Sil.-Miss.
indet. horn & cup corals*	48	Ord.-Penn.
(*includes forms probably assignable to *Ptychophyllum*, *Enterolasma*, "*Cyathophyllum*", etc.)		
BRACHIOPODS		
Atrypa sp.	1	Sil.-Dev.
Lepidocyclus gigas	1	U. Ord.
indet. rhynchonellid	1	Ord.-Penn.
indet. strophomenid frags.	2	Ord.-Penn.
chert pieces with indet. brachiopod fragments	23	Ord.-Penn.
BRYOZOANS		
?*Rhinidictya* sp.	2	Ord.-Sil.
fenestellid sp.	3	Sil.-Penn.
indet. bryozoan frags.	2	Ord.-Penn.
TRILOBITES		
indet. thoracic segment	1	Paleozoic
ECHINODERMS		
large crinoid stems	2	probably Penn. types
PLANTS		
petrified wood gymnospermous?)	1	probably Cretaceous

Kaolinitic regoliths are noted over much of the Precambrian terrane in Minnesota beneath the Cretaceous cover(Parham and Hogberg, 1964), and similar kaolinitic regoliths (age uncertain) were developed on Precambrian crystalline rocks in northern Wisconsin (Buckley, 1901, p. 233-237). Sloan (1964) and Austin (1970) suggested that these regoliths were formed, in part as pedalfer soils, in a humid warm temperate or subtropical climate during the Cretaceous. Thin kaolinitic regoliths are noted beneath Cretaceous fluvial deposits on Paleozoic carbonate terranes in southeastern Minnesota and Iowa, but the contained kaolinitic clays were probably transported into those areas since *in situ* development of kaolinites from carbonate rock sources is unlikely. The abundance of kaolinitic clays in the Dakota Formation of western Iowa is reasonably explained in terms of the source regions identified in previous paragraphs, and kaolinitic regoliths developed on Precambrian terranes in Wisconsin and Minnesota seem the most likely source. Montmorillinitic clays in the Nishnabotna may be related to eastern Paleozoic or Precambrian sources, although these clays may also have been derived from western volcanic eruptions (bentonites are known in the upper Dakota near Sioux City).

In conclusion, Nishnabotna sediment source areas can be reasonably inferred to lie primarily east and northeast of Guthrie County. Source areas in Wisconsin and eastern Iowa apparently supplied a significant portion of the Dakota sediments. Interestingly, those areas presently lie within the Mississippi River drainage. Because Cretaceous transport directions were primarily to the west and southwest from Wisconsin and eastern Iowa, it is apparent that the Upper Mississippi drainage was not developed at that time.

Mid-Cretaceous Paleogeography along the Eastern Margin of the Western Interior Seaway

Because of previously discussed stratigraphic uncertainties, the paleogeography of Lower Dakota sedimentation along the entire eastern margin area of the Western Interior is not readily apparent. On a broad regional scale, an interpretation of Lower Dakota sedimentation and paleogeography is illustrated in Figure 7A, which depends on the lower Nishnabotna Member and Kiowa-Skull Creek marine units being, in part, contemporaneous. Figure 7A illustrates the Kiowa-Skull Creek seaway near its maximum transgressive stand, with a belt of marginal marine and nonmarine fluvial mudstones/claystones and sandstones developed between the marine facies and the aggrading coarse grained fluvial deposits of the Nishnabotna. A narrow belt of nonmarine "lower Dakota" and Skull Creek equivalents in eastern South Dakota is schematically illustrated to reflect the steeply sloping margin of the adjacent Precambrian uplands. Alternatively, if no part of the Nishnabotna is equivalent to any portion of the Kiowa or Skull Creek formations, the lower Dakota paleogeographic reconstruction would consist of an eastern coarse-grained alluvial plain (Nishnabotna) with a western prograding sheet of Newcastle or lower Dakota sandstones and mudstones. In either case, the offlap of Kiowa-Skull Creek marine units would have created a situation similar to that just described, making the Nishnabotna, partially or wholly, a regressive prograding sequence.

As previously discussed, lower Dakota sedimentation in the type Dakota area may have been initiated concurrent with rising base levels during transgression of the Kiowa-Skull Creek Cyclothem. The eastward migration of the Lakota Formation in South Dakota may also be related to rising base levels during the earlier phases of this cyclothem (Schoon, 1971). Although the Lakota Formation is not present in the type Dakota area, gross lithologic similarities suggest similar depositional environments and source areas for the

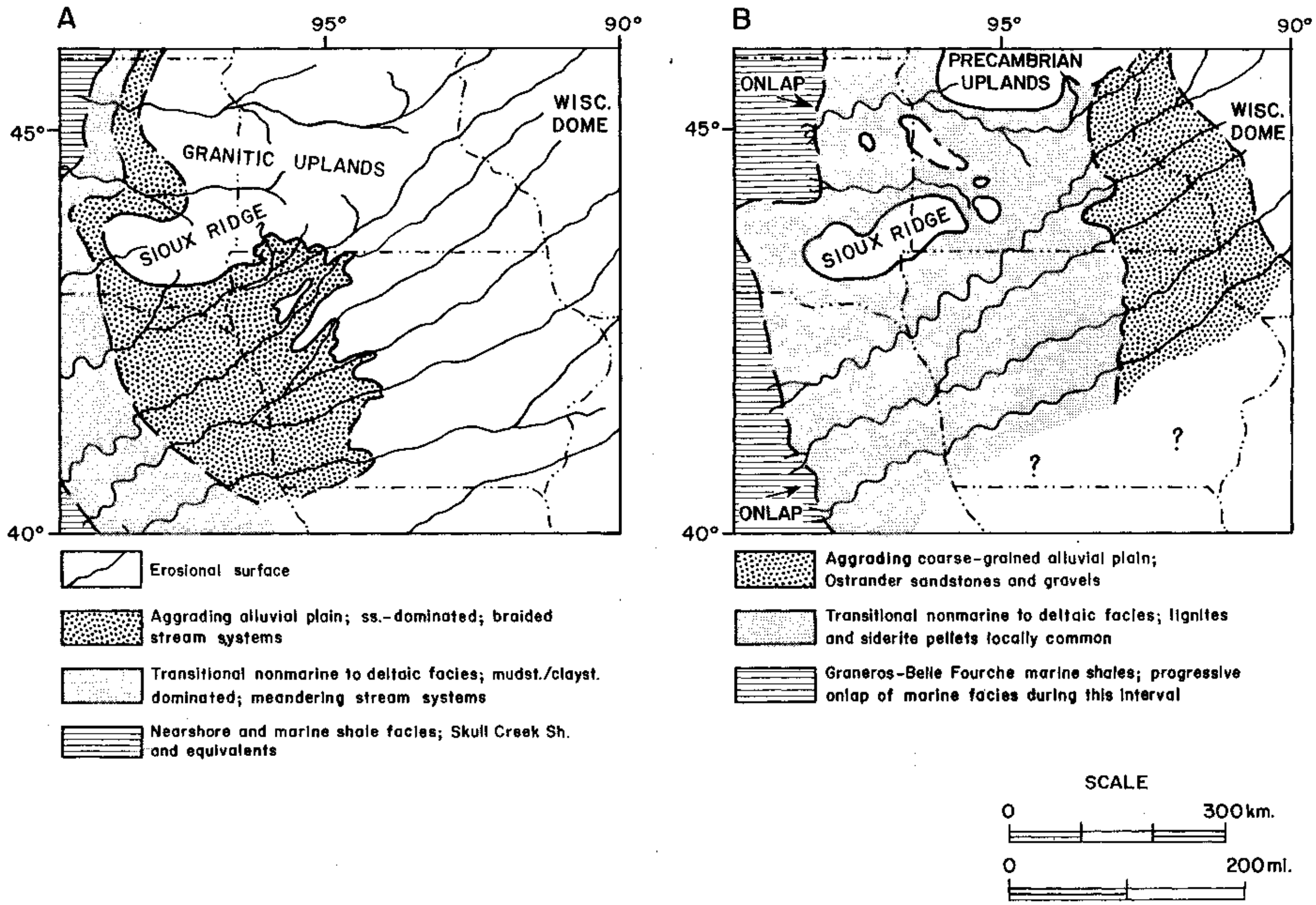

Figure 7. Schematic paleogeography of Dakota sedimentation in the eastern margin area of the Western Interior. Newcastle regressive phase not illustrated. A. Generalized interpretive map-view of Lower Dakota sedimentation. Aggrading coarse-grained fluvial deposition (lower Nishnabotna) is hypothetically depicted as concurrent with rising base levels during maximum transgressive phase of Kiowa-Skull Creek Cyclothem. B. Generalized map-view of Upper Dakota sedimentation. Eastward displacement of mudstone-dominated fluvial facies (Woodbury Mbr.) by Graneros marine shales; aggrading coarse-grained fluvial facies (Windrow Fm.) marginal to Wisconsin Dome.

Lower Dakota and the easternmost occurrences of the Lakota. Kiowa-Skull Creek shale deposition apparently overstepped the Lakota edge in portions of the study area, generally precluding any physical continuity between the Lakota and the type Dakota sequence. However, in a general sense the Lakota Formation of central South Dakota and the Lower Dakota of the type area may represent physically and temporally separated portions of the same general transgressive package of coarse clastics (see Fig. 8).

The regressive phase of the Kiowa-Skull Creek Cyclothem (Newcastle Regression) resulted in widespread westward progradation of eastern clastics (Fig. 8). If lower Nishnabotna deposition is, in part, equivalent in time to marine Kiowa-Skull Creek deposition in Kansas-Nebraska, then evidence of declining base levels, corresponding to the Newcastle Regression, might be expected in the middle or upper Nishnabotna sequence of western Iowa (schematically shown in Fig. 8). However, evidence for declining base levels within a portion of the Nishnabotna sequence is, at present, not particularly convincing. One might expect to see evidence of incision in the Nishnabotna sequence corresponding to declining base levels, and some evidence of incision is seen in the upper portions of the sequence in Guthrie County. One might also expect to see aggrading coarse-grained fluvial deposits similar to those in the lower Nishnabotna repeated higher in the sequence above the level of incision as base levels once again began to rise following the Newcastle Regression. However, this latter prediction does not apparently hold true in the western Iowa sequence. This leads us to conclude that either 1) the Newcastle Regression did not produce any significant alteration of fluvial depositional processes in western Iowa, or 2) no portion of the Lower Dakota in Iowa is the lithostratigraphic of time equivalent of either the Kiowa-Skull Creek marine shales or the Newcastle Formation. As shown in Figure 8, we favor the first option, although additional studies are clearly needed to verify which choice is "more correct."

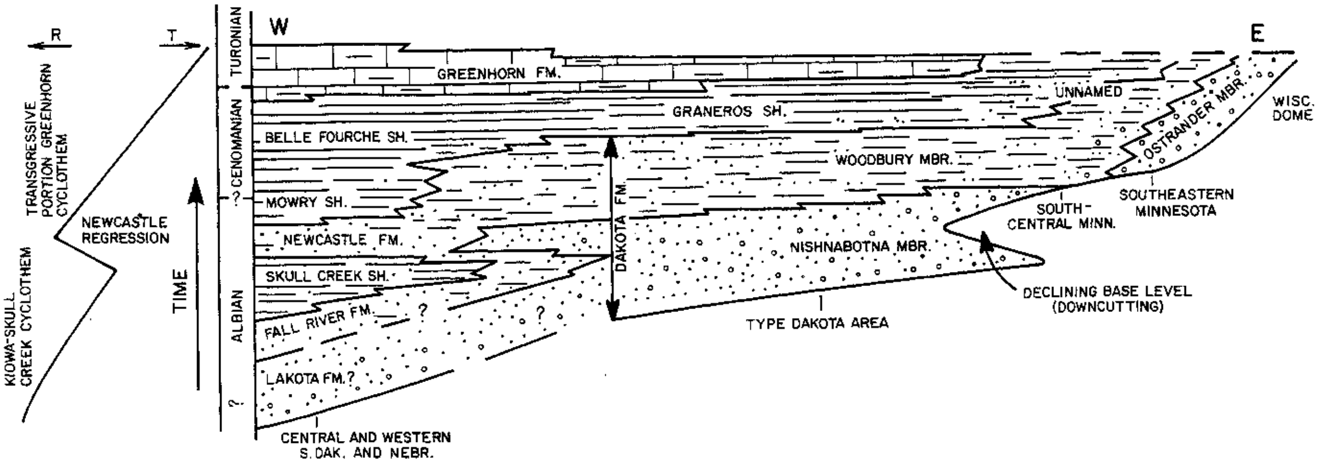

Figure 8. Hypothetical schematic cross-section of sub-Carlile Cretaceous sequence in eastern margin area. Vertical axis is time (not thickness). Lakota Fm. and Lower Dakota sequence in type Dakota area are not physically continguous (relationships queried). R-regressive; T-transgressive. Lithologic symbols as in Fig. 2.

Transgression of the next marine cycle, the Greenhorn Cyclothem, followed the regressive Newcastle episode. A decrease in stream competency accompanying this transgression resulted in the displacement of coarse-grained Nishnabotna fluvial deposition in western Iowa by Woodbury (Upper Dakota) meanderbelt fine-grained sandstone and floodbasin mudstone deposition (Whitley and Brenner, 1981). Coarse-grained fluvial facies shifted eastward into eastern Iowa, southeastern Minnesota, and western Wisconsin as base levels changed, resulting in the deposition of the Windrow Formation (Ostrander Mbr.) clastic sequence (Fig. 7B). Progressive eastward displacement of Dakota and Windrow fluvial-deltaic systems by marine shale deposition proceeded during the Cenomanian to middle Turonian interval (Fig. 8). Marine transgression into the eastern margin area during this interval was far from being "instantaneous," and approximately 6 to 10 million years (Kauffman, 1977 time scale) was required for marine deposition to spread from western South Dakota into eastern Minnesota. Coincident with rising base levels during the transgressive phase of the Greenhorn Cyclothem, fluvial systems aggraded eastward (Fig. 8). By the Turonian, Greenhorn carbonate deposition had spread throughout much of the eastern margin area, reflecting a significant decrease in eastern clastic influx in the offshore areas as shorelines spread eastward to the Wisconsin Dome area. However, "Greenhorn" marine shale deposition apparently occurred in central and southeastern Minnesota closer to the eastern shoreline, in a situation analogous to earlier Graneros depositon farther west. In general, the eastward progression of marine depositional environments during the Cenomanian-mid Turonian interval in the eastern margin area closely parallels the transgressive portion of Kauffman's (1969) ideal Cretaceous marine cycle.

The preceding paragraphs have outlined a generalized and highly interpretive framework of mid-Cretaceous deposition along the eastern margin of the Western Interior Seaway. A more detailed synthesis of Cretaceous paleogeography in this area by B. Witzke, G. Ludvigson, J. Poppe, and R. Ravn is presently in review for possible inclusion in the upcoming SEPM (Rocky Mtn. Section) volume entitled "Mesozoic Paleogeography of the West-Central United States." Review copies of that manuscript can be accessed at the Iowa Geological Survey from the authors.

Summary of Pennsylvanian Stratigraphy in Guthrie County

Pennsylvanian strata are well exposed in portions of Guthrie County, and descriptions of many outcrops are given in St. John (in White, 1870, v. 2, p. 104-128) and Bain (1897, p. 428-451). The 1938 Tri-State field trip also visited Pennsylvanian exposures in the county (Cline et al., 1938). The unpublished field notes of L.M. Cline (1936, Iowa Geol. Survey) are the single most valuable source of information on the Guthrie County Pennsylvanian exposures. Cline's notes and our own field observations form the basis for a brief resumé of Pennsylvanian stratigraphy in the county.

The Cherokee Group disconformably overlies an eroded Mississippian surface and reaches thicknesses of about 325 feet (100 m). Only the upper portion of the Cherokee Group is exposed in Guthrie County, primarily in the southeastern portion of the county. One of the thickest known natural outcrops of the Cherokee Group known anywhere in Iowa can be found in southeastern Guthrie County along the Middle Raccoon River (Fig. 9). The Dakota Formation overlies uppermost Cherokee strata in the vicinity of Stops 4 and 5, and we will examine the top-most portion of the group at Stop 6. Swade et al. (1981) proposed that the Cherokee Group be subdivided into four formations whose bound-

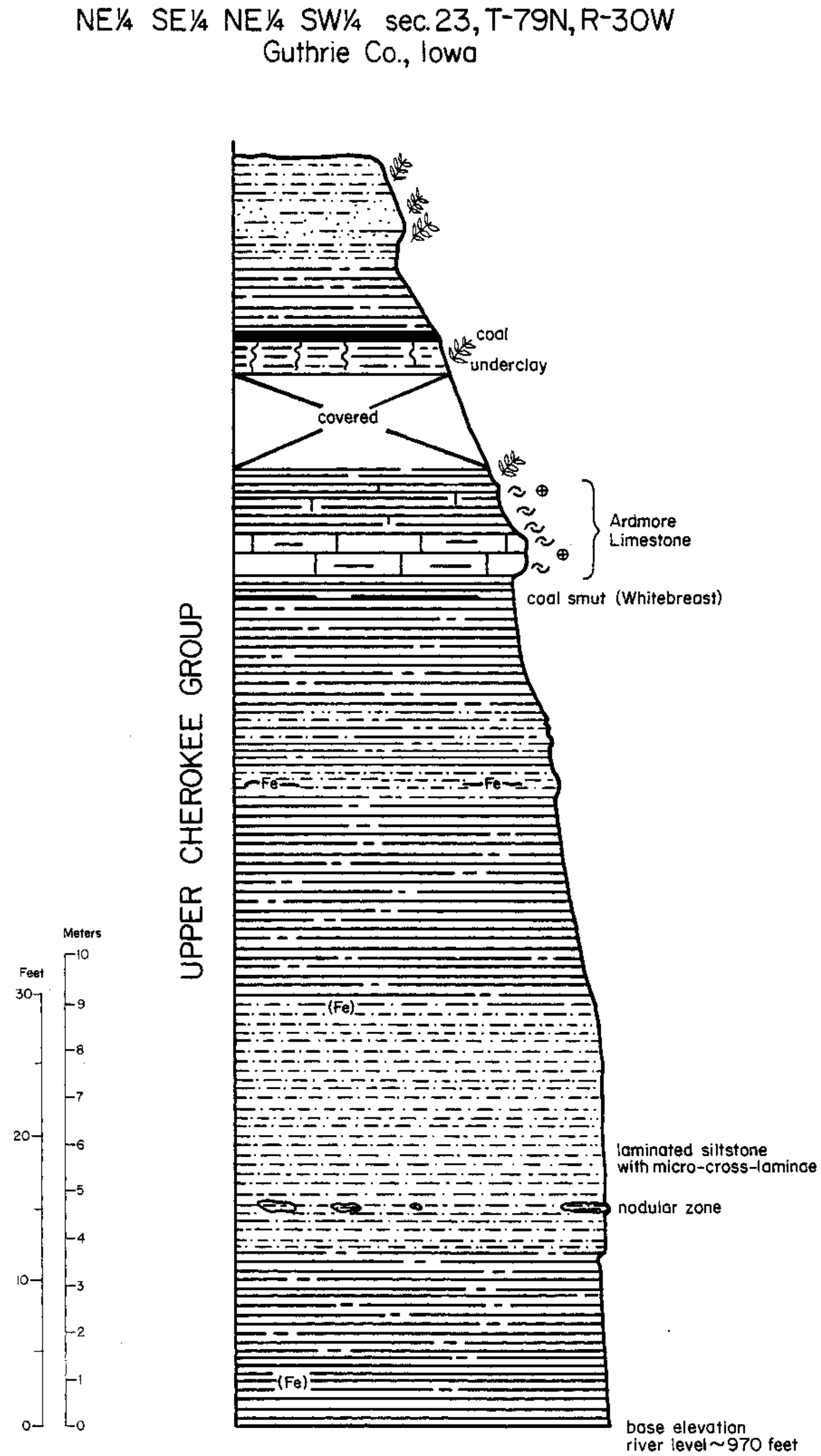

Figure 9. Upper Cherokee stratigraphic sequence exposed at a natural outcrop along the Middle Raccoon River. This is one of the thickest known exposures of Cherokee strata in Iowa. Symbols as in Figs. 10 and 17.

aries are defined at the base of widely traceable coals. Formational names have not yet been formally introduced, although a formal description of these units is forthcoming (R. Ravn and others, Iowa Geol. Survey). The upper two formations of the Cherokee Group are represented in the Guthrie County outcrop (Fig. 10). The top of the Excello Shale Member was commonly used in earlier studies to mark the top of the Cherokee Group. However, following Swade et al. (1981), the top of the Cherokee is drawn at the base of the Excello and the top of the Mulky Coal to parallel other cyclic units in the Marmaton Group.

Several Cherokee Group coals are present in the county, and the exposed Cherokee Group sequence is, in general, dominated by nonmarine detrital sediments. However, one widely traceable marine interval, the Ardmore Limestone Member, is present in the upper part of the Cherokee Group. The Ardmore is an interbedded limestone and shale sequence. It is commonly divided into an upper limestone unit, a middle shale, and a lower limestone and has been informally termed the "two-layer limestone." However, the three-part subdivision of the Ardmore is a generalized scheme and is locally modified where interbedded shales occur in the limestone units (especially upper limestone).

Every formation within the Marmaton Group can be studied in outcrop within Guthrie County (Fig. 10). The Marmaton Group includes a series of nonmarine detrital formations alternating with marine limestone and/or shale formations. The repetition of marine and nonmarine units in the sequence identifies the cyclic nature of Marmaton deposition. The lower interval of the Marmaton has been termed the Fort Scott Formation in earlier studies of Midcontinent Pennsylvanian stratigraphy. However, "because the Fort Scott contains portions of two depositional cycles," Swade et al. (1981) proposed three new formational subdivisions "to replace the Fort Scott Formation in Iowa." Formal definition of these formations is forthcoming, and on Figure 10 the lower formation is termed the "Lower Fort Scott" while the upper two formations are lumped as the "Upper Fort Scott." We will see the lower portion of the "Fort Scott" at Stop 6. The Labette, Bandera, and Nowata shales in the Marmaton Group are primarily nonmarine detrital units that, in general, mark the regressive portions of major marine cyclothems. The Pawnee Formation characteristically includes marine limestone members at most localities in Iowa and adjacent areas. However, the Pawnee limestone members have not yet been recognized in Guthrie County, although the Anna marine black shale member is apparently present. Price (1981) documented a northward increase in clastic content in the Pawnee of Iowa, probably derived from source areas on the Transcontinental Arch. The possibility exists that the Pawnee limestones may be absent in Guthrie County, being replaced by shale units.

The Altamont and "Lenapah" formations represent the upper two prominent marine units in the Marmaton Group of Guthrie County. The Cooper Creek Limestone Member in Iowa was included within the Lenapah Formation by some previous workers. However, as summarized by Swade (1982, p. 71), recent work at the University of Iowa "has revealed a long-standing miscorrelation" between the type Lenapah Formation in Oklahoma and the Cooper Creek Limestone Member in Iowa. "A minor marine incursion in the Nowata" in south-central Iowa "occurs at approximately the same horizon as the Lenapah Formation in northern Oklahoma" (ibid.). The Cooper Creek Limestone should, therefore, not be included within the Lenapah. "This widespread limestone formation actually remains unnamed, pending a proposal by P.H. Heckel" (ibid. p. 72). It is informally referred to as the "Lenapah" formation on Figure 10. We will examine strata tentatively referred to the Cooper Creek Limestone at Stop 7.

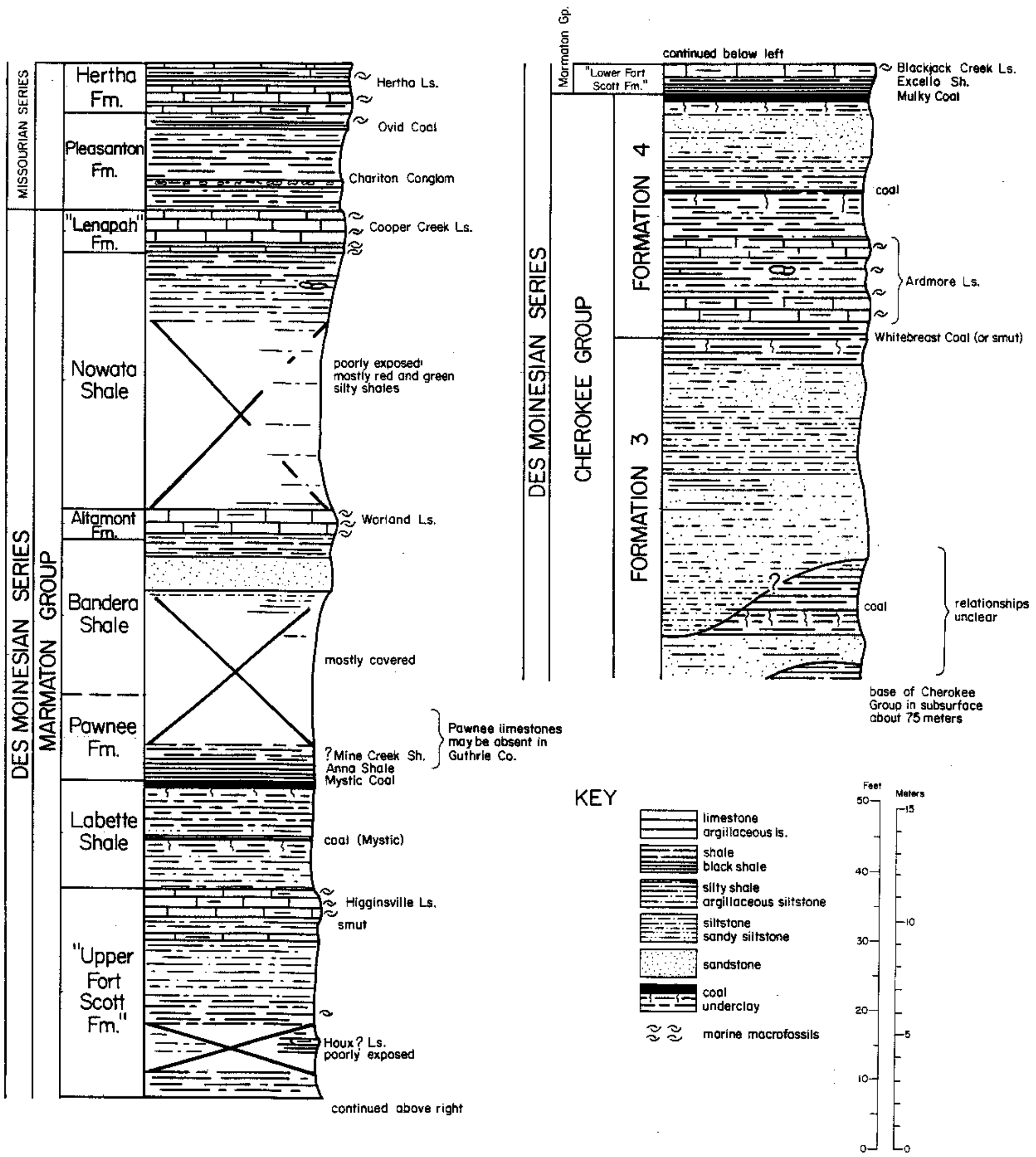

Figure 10. Generalized composite stratigraphic section of Pennsylvanian rock units exposed in southeastern Guthrie County. Based, in part, on unpublished field notes of L.M. Cline (1936) and recent field observations.

The top of the Marmaton Group (and the Desmoinesian Series) is drawn at the top of the Cooper Creek Limestone in Guthrie County, where it is overlain by the Pleasanton Formation. In other areas of the Midcontinent the Pleasanton is accorded group status. The Pleasanton "represents a single depositional phase analogous to other Missourian detrital formations," and, "accordingly, the Pleasanton is reduced to formational status" in Iowa (Swade et al., 1981). The Pleasanton is a relatively thin unit in Guthrie County, as it is over much of Iowa, and its former recognition as a group in our state seems disproportionate to its thickness. "Several thin layers of a real honest-to-goodness conglomerate of limestone pebbles" (Cline, 1936, unpubl. field notes) within the Pleasanton of Guthrie County are assigned to the Chariton Conglomerate Member. The Pleasanton is, in turn, overlain by the Hertha Formation, the youngest Pennsylvanian unit exposed in the county.

Acknowledgments

First, we want to gratefully acknowledge the hard work and assistance of Liz Conley (Lincoln, Neb.) in collating Cretaceous subsurface information in eastern Nebraska for this project. Information and assistance provided by personnel of the Nebraska Geological Survey (Marv Carlson, Roger Pabian, Hal DeGraw) has been of considerable importance in our synthesis of Dakota sedimentation. Dan Burggraf (Kent State) kindly reviewed some Guthrie County Cretaceous exposures with us, and his interest and observations are appreciated. Donna Runkle's (U.S.G.S.) primary involvement in the west-central Iowa water resources project and her field reconnaissance of the Guthrie County area have been of considerable value in our investigations. Darwin Evans, driller for the Iowa Geological Survey, deserves special mention for his expert drilling and logging of Cretaceous strata in western Iowa, most recently in Guthrie County. Jim Munter (now of the Alaska Geol. Survey) also provided us with Cretaceous outcrop information for Guthrie County. Mark Underwood and Bob McKay accompanied us on a canoe reconnaissance of Cretaceous exposures along the Middle Raccoon River in the county, and we appreciate their logistical support.

Phil Heckel and John Swade (Univ. Iowa) kindly reviewed some of our Pennsylvanian stratigraphic interpretations. Continuing studies of Dakota palynology in Iowa by Bob Ravn (Amoco) are gratefully acknowledged. Jim Poppe (Minn. Geol. Surv.), Rich Bretz (S.Dak. Geol. Surv.), and George Shurr (St. Cloud State) provided valuable review comments on portions of the manuscript. Tim Kemmis (Iowa Geol. Survey) provided information on the Des Moines Lobe. Melanie Sherwood did most of the illustrating for the guidebook, and Pat Lohman and Donna McGuire also contributed illustrations; their efforts are especially appreciated.

Several Guthrie County residents deserve special mention for their cooperation in providing access to property for this field trip. These include Luckinbill's Bar-L Ranch, Mrs. J. Heiland, Steve Akes (County Engineer), Floyd Meacham, and Lawrence Raber. Finally, we wish to thank the officers and members of the Geological Society of Iowa for ultimately making this trip possible.

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Road Log and Stop Descriptions

For logistical reasons we want to minimize the number of vehicles on the trip. If there are less than four people in a vehicle, please-double up and share the ride (4 or more people per vehicle, if possible). The car caravan will be stopping along the road edge at several points; please be cautious of traffic.

Mileage

0.0 Springbrook State Park

STOP 1. Natural exposures of Dakota Formation in Springbrook State Park.

Springbrook State Park straddles the terminal moraine of the Des Moines Lobe, and is bordered on the east by comparatively low-relief uplands which are underlain by Wisconsinan deposits. The park itself is located along the confluence of two steep-walled stream valleys which drained glacial meltwaters from the Des Moines Lobe into the Middle Raccoon River. The southward draining valley has been dammed to create a small recreational lake, but the westward draining valley of Springbrook Creek has been largely left in its natural condition. Two natural exposures of the Nishnabotna Member of the Dakota Formation can be accessed in the valley of Springbrook Creek. These two exposures differ in several important respects, and constitute a prelude to several important themes which will be elaborated further as we look at more of the Dakota Formation.

The Campground exposure (Fig. 11) is located on an east-facing cutbank of Springbrook Creek at the far eastern end of the campground. It is found about 100 feet to the north of the footbridge over the creek. The 3 meter exposure consists of sandy conglomerates and pebbly fine to coarse grained sandstones. Planar cross-beds, mudstone clasts, and liesegang iron cementation are noted. At the top of the exposure is a thin weathered mudstone that is overlain by Holocene (?) colluvial deposits. Notice that conglomerates form the stream floor of Springbrook Creek along this exposure.

The Trail Overlook exposure (Fig. 11) can be reached by walking upstream from the Campground exposure about one-quarter mile, or by trail from the Springbrook Conservation Education Center. It forms a prominent 10 meter high north-facing escarpment along the south valley wall. The grain size distribution and primary sedimentary structures in this exposure differ markedly from those observed at the campground. Here we find fine to medium grained sandstones displaying trough cross-bedding (cross-bedding is partly obscured by weathering and vegetation. Except for mudstone clasts, coarser material is absent.

What is the relationship between these exposures? Their elevations do not overlap (Fig. 11), and the stratigraphic relationships and depositional significance of these two contrasting sequences will be examined further as our field trip continues. We will return to the campgrounds and drive up the valley of the Middle Raccoon River. Look for natural exposures of Dakota Formation sandstones and mudstones along both valley walls.

0.0 Leave campground area; head towards park entrance.

0.35 Park entrance; turn right (west) on Hwy 384; notice exposures of Nishnabotna sandstones and mudstones along both valley walls.

2.0 Turn south (left) on Hwy 25.

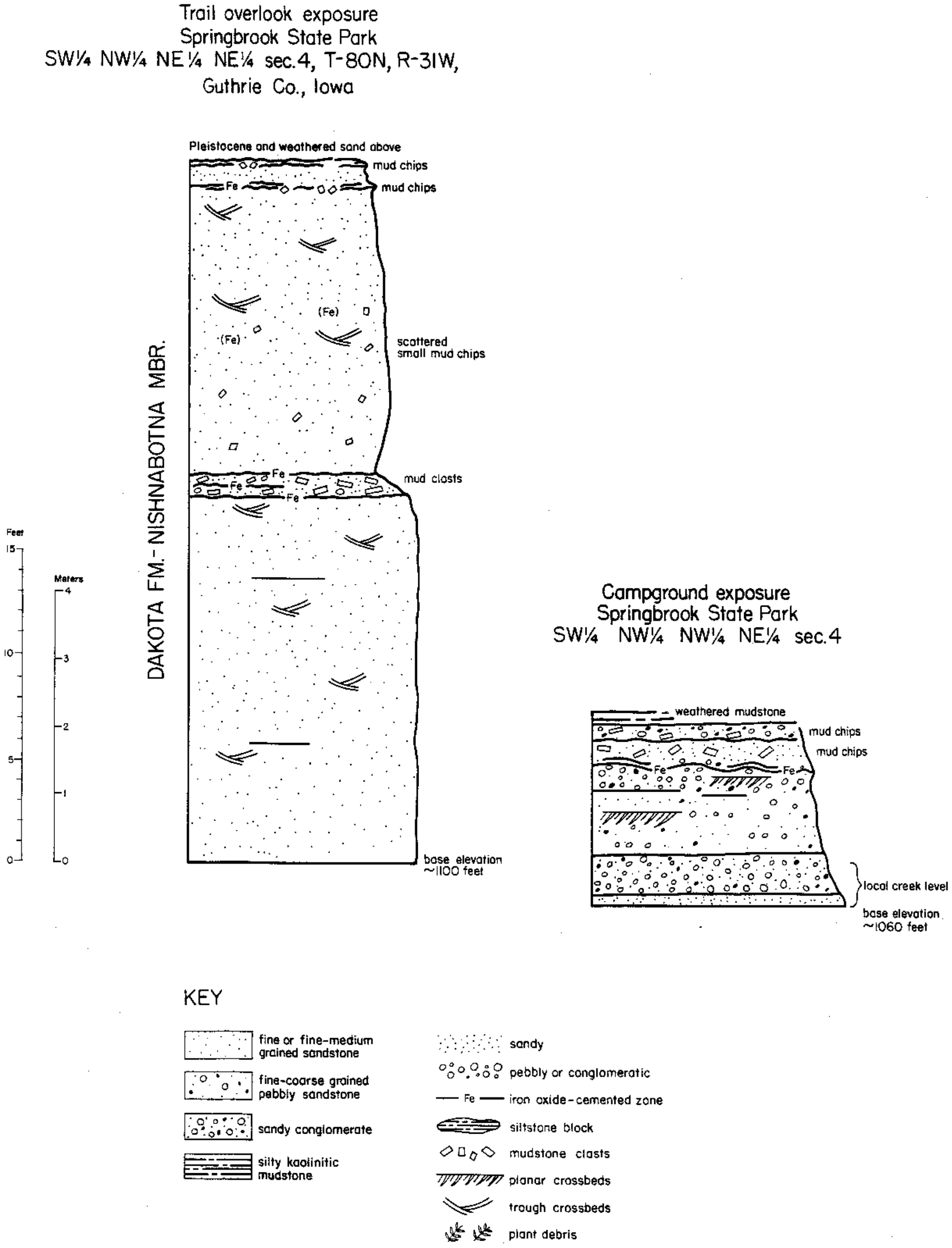


Figure 11. Exposures of the Dakota Formation in Springbrook State Park.

2.15 Bridge over the Middle Raccoon River.

2.4 STOP 2. Pull off on right shoulder of Highway 25. Be cautious crossing highway to access Dakota exposures.

STOP 2. Highway 25 Roadcut Exposure.

An approximately 10 meter thick sequence of the Nishnabotna Member is exposed along a roadcut on the east side of Highway 25 on the southern bluff of the Middle Raccoon River valley (Fig. 12). This sequence is reminiscent of the Trail overlook exposure, except for the prominent planar cross-beds in the lower part of the section. Note the prominent iron-cemented large-scale troughs at the top of the exposure.

How does this section compare with the other Dakota exposures in this vicinity? In order to better understand these stratigraphic relationships, and outline hydraulic relationships between the alluvial and bedrock aquifers, a transect across the Middle Raccoon River valley was drilled late this summer. An initial interpretation of this transect, including the roadcut section (Fig. 12) is shown in Figure 13. Attempts at bed-by-bed correlation would be a fruitless exercise. Nevertheless, the Nishnabotna Member appears to be separable into a lower coarse grained conglomeratic sandstone unit, and an upper fine to medium grained sandstone unit, each with interbedded mudstones. When compared by elevation, all the exposures we examined in the Springbrook Park area appear to fit nicely into this two-fold division. The Highway 25 roadbut (Figs. 12 and 13) is contained within the upper fine-grained unit. Likewise, the Trail overlook exposure (Fig. 11, elev. base 1100 ft.) appears to fit well in the upper fine-grained unit. The Campground exposure (Fig. 11, elev. base 1060 feet) appears to fit well within the lower coarse-grained unit.

Research drilling and additional natural exposures in Guthrie County (Fig. 4, p. 14) have supported the recognition of these two distinct units within the Nishnabotna Member of the Dakota Formation. As our trip continues, we will examine exposures of both of these units, and have a chance to compare the suites of sedimentary structures and clastic materials contained within them.

2.4 Continue south on Highway 25

8.6 Entering Guthrie Center.

9.4 Intersection with Highway 44; continue south on Highway 25.

9.75 Bridge over South Raccoon River.

10.5 STOP 3. Turn in to Bar-L Ranch parking area. There may not be enough room for all vehicles to park in the Bar-L property; additional cars may have to park on the shoulder of Hwy. 25.

STOP 3. Bar-L Ranch Exposure.

This interesting section (Fig. 14) of the Nishnabotna Member is exposed on a prominent north-trending ridge along the south bluff line of the South Raccoon River. It forms an aesthetically pleasing setting for the Luckinbill's Bar-L Ranch, whose permission for access is gratefully acknowledged. This stop provides an opportunity to examine a succession of several distinctive sedimentation sequences in the upper Nishnabotna, which record a variety of fluvial processes.

The lowermost unit is a 2.5 meter thick fine to medium grained sandstone with small-scale (10-40 cm amplitude) trough cross-beds (Fig. 14). Scattered

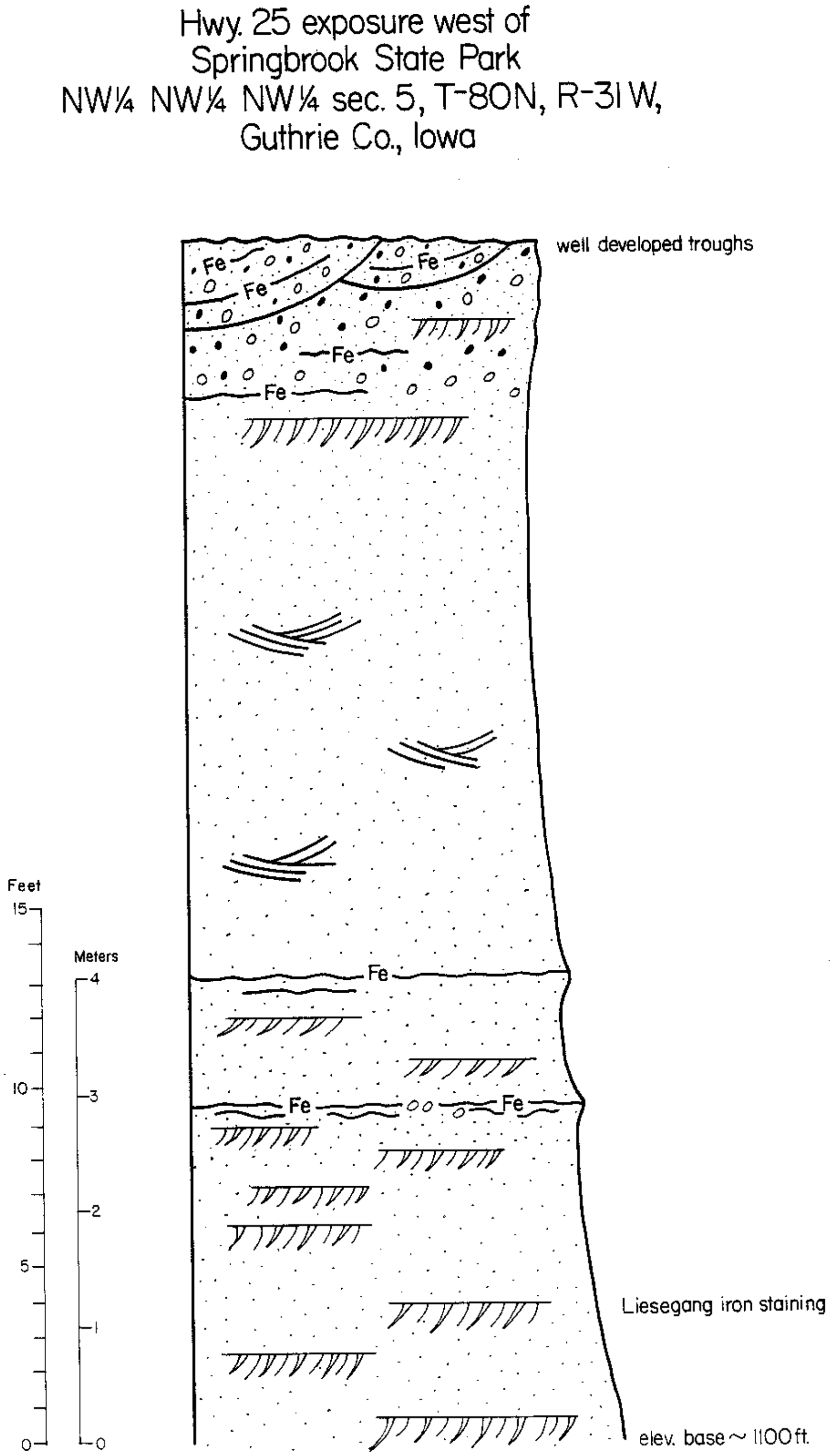


Figure 12. Exposure of upper Nishnabotna sandstone along Hwy. 25.

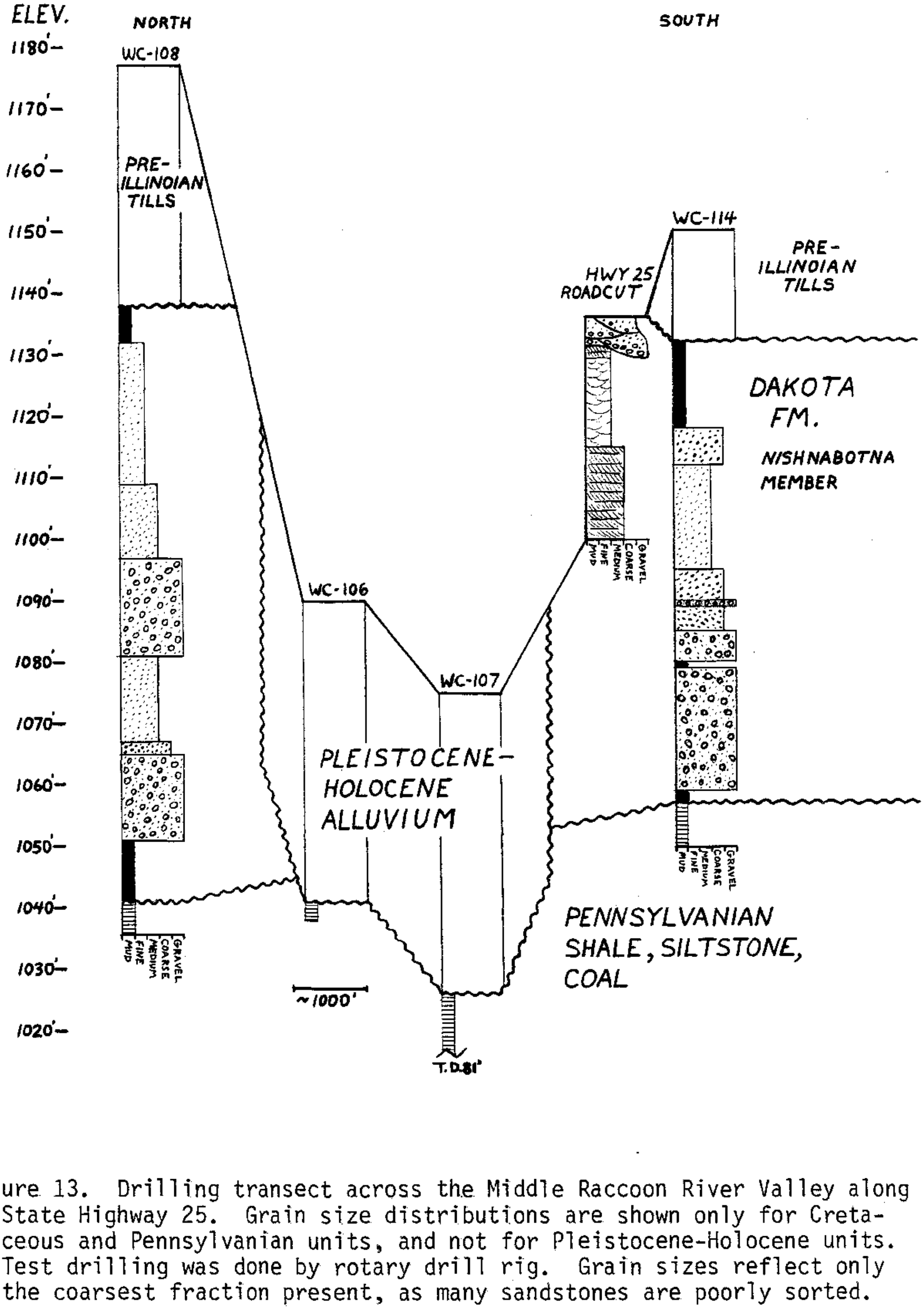
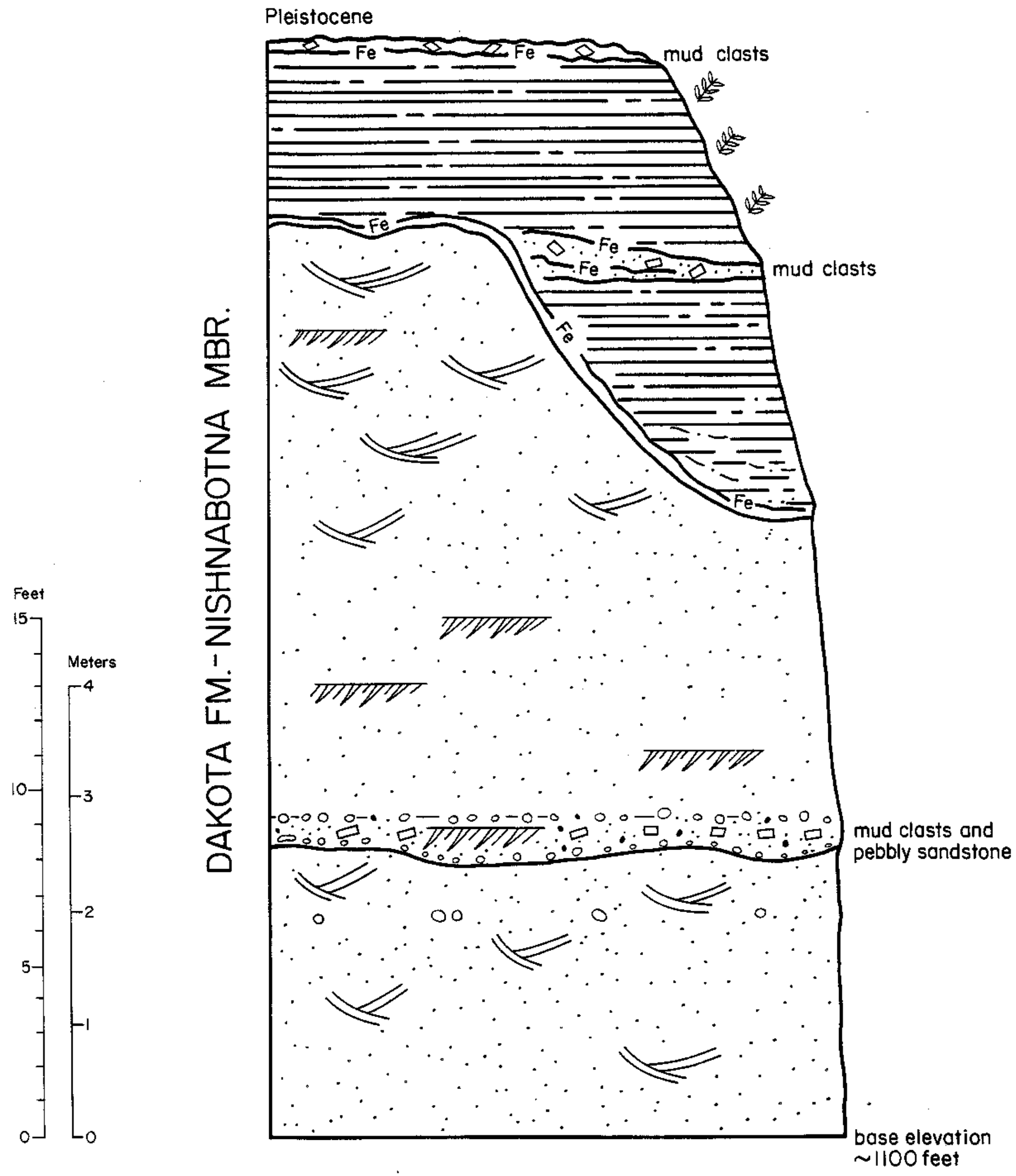


Figure 13. Drilling transect across the Middle Raccoon River Valley along State Highway 25. Grain size distributions are shown only for Cretaceous and Pennsylvanian units, and not for Pleistocene-Holocene units. Test drilling was done by rotary drill rig. Grain sizes reflect only the coarsest fraction present, as many sandstones are poorly sorted.



Bar-L Ranch exposure
W½ SE¼ SE¼ SW¼ sec.7, T-79N, R-31W,
Guthrie Co., Iowa

Figure 14. Upper Nishnabotna exposure, Bar-L Ranch near Guthrie Center.

rare pebbles are present near the top of this unit, which otherwise is well-sorted. Some troughs up to 3 meters wide are observed near the top of the unit, which is truncated by the overlying unit with up to 20 cm of relief.

Overlying this truncation surface is a 3 to 11 cm thick sandy chert and quartz pebble conglomerate, with clasts up to 3 cm in diameter (Fig. 14). The conglomerate grades upward into medium to coarse grained sandstone to fine to medium grained sandstones which are prominently planar cross-bedded. Southerly components of dip are evident on these planar foresets. These sandstones are overlain by up to 2.7 meters of fine grained sandstone with prominent trough cross-bed festoons. Some planar cross-beds with southerly components of dip are noted. This unit is truncated by an erosion surface with up to 2.6 meters of relief over a horizontal distance of 15 meters.

The erosion surface is overlain by a light gray silty kaolinitic mudstone unit up to 4 meters thick (Fig. 14). Note the hard iron-cemented ledge along the erosion surface and the abundance of plant debris within the mudstones. These mudstones are classical fluvial overbank deposits, and their relationship to the erosion surface is intriguing. A period of fluvial incision is recorded in this sequence, with active channel deposits being eroded and then buried by floodbasin deposits. The floodbasin mudstones must have been deposited some distance away from active channel aggradation. One can only speculate on what the total depth of incision might have been along the active fluvial channels. Could this possibly relate to a period of downcutting along the eastern margin of the Western Interior as base levels dropped during the Newcastle Regression (see discussion on paleogeography, p. 25)? What do you think?

We now have had a chance to observe some of the field relationships in the upper fine-grained portion of the Nishnabotna Member in Guthrie County. After our lunch stop in Guthrie Center, we will continue farther south down the valley of the South Raccoon River to look at the lower coarse-grained portion of the Nishnabotna Member, and the underlying Pennsylvanian rocks.

LUNCH STOP. Field trip participants may wish to return to Guthrie Center for lunch. Some of us will eat our picnic lunches at Mitchell Park on the west edge of town. Mitchell Park is located west of Hwy. 25 0.4 miles on Hwy. 44.

10.5	Leave Bar-L Ranch. Continue south on Hwy. 25.
13.0	Turn left (east) on County Road F-31 toward Monteith.
13.7	North-facing outcrop of trough cross-bedded sandstone immediately to north (left) of road; this section is represented in Fig. 4.
16.4	Town of Monteith; continue east on County Road F-31.
16.9	Bridge over South Raccoon River; continue east on F-31.
18.2	Turn left (north) on gravel county road.
18.6	Abandoned gravel pit in lower Nishnabotna Mbr. on right side (east) of road.
18.95	Turn right (east) on gravel county road.
20.3	Turn right (south) on gravel county road.

21.2 STOP 4. Heiland pit; pull off along edge of road. Do not block roadway.

STOP 4. Heiland Sand and Gravel Pit. (Figure 15)

To the east of Monteith, along the north bluff line of the South Raccoon River, are a series of sand and gravel quarries in the lower Nishnabotna Member of the Dakota Formation. The most spectacular of these is the Heiland pit, and we gratefully acknowledge the permission for access of Mrs. Jerry Heiland. The sequence exposed in this pit is undoubtedly the most spectacular clastic interval that the authors have seen in the state of Iowa, particularly when one remembers the immense area covered by this deposit.

Approximately 12 meters of interbedded very coarse grained sandstones and chert and quartz pebble conglomerates can be seen along the south-facing high wall. Please be careful around the high wall, as some large blocks are unstable. Horizontal bedding and large-scale planar foreset cross-beds are the prominent primary structures. Easterly components of dip are noteworthy (see discussion on paleocurrent data). Iron-cemented ledges control much of the relief on the quarry face. Note the erosional expression of these deposits on the natural exposure across the ravine to the east of the quarry workings.

Looking south into the valley of the South Raccoon River, note the scattered outcrops of Pennsylvanian shales, mudstones, and limestones in the lower landscape positions. We are only a short distance above one of the major interregional unconformities of the North American Interior. Toward the northwest heading in the direction of the Transcontinental Arch, the Nishnabotna Member truncates successively older Paleozoic strata, and rests on the Precambrian surface in northwesternmost Iowa. As we proceed to the next stop, watch the valley walls carefully and you will see evidence of large-scale erosional relief on this unconformity.

21.2 Leave Heiland pit. Continue straight ahead.

21.3 Intersection with County Road F-31. Continue straight ahead.

21.9 Turn left (east) on gravel county road.

22.0 Cretaceous-Pennsylvanian contact exposed to left (north) of road. A "two-layer limestone" (Ardmore?) can be seen in the Pennsylvanian exposure at this point. A thin coal bed is present a short distance below the Pennsylvanian-Cretaceous contact.

22.7 Outcrop of Dakota conglomerate and sandstone to left (north of road). Prickly pear cactus inhabit this slope.

23.0 STOP 5. County pit. Drive in entrance to pit and park. The gate should be open; if not, park along edge of county roadway.

STOP 5. County Sand and Gravel Pit.

The county sand and gravel pit provides an opportunity to examine lateral variations within the lower Nishnabotna Member. A pre-Illinoian Pleistocene sequence can be seen above the Cretaceous exposures. The lower Nishnabotna exposures in the pit are dominantly pebbly coarse grained sandstones and conglomerates. Some conglomeratic beds are cemented by iron oxides and have been called "peanut brittle rock" by workmen in the pit. Wild swirled liesegang iron cementation can also be observed in some sandstone units. Planar cross-beds are abundantly represented along the pit faces, and measurements of foreset directions range from southeast to southwest. These planar cross-beds

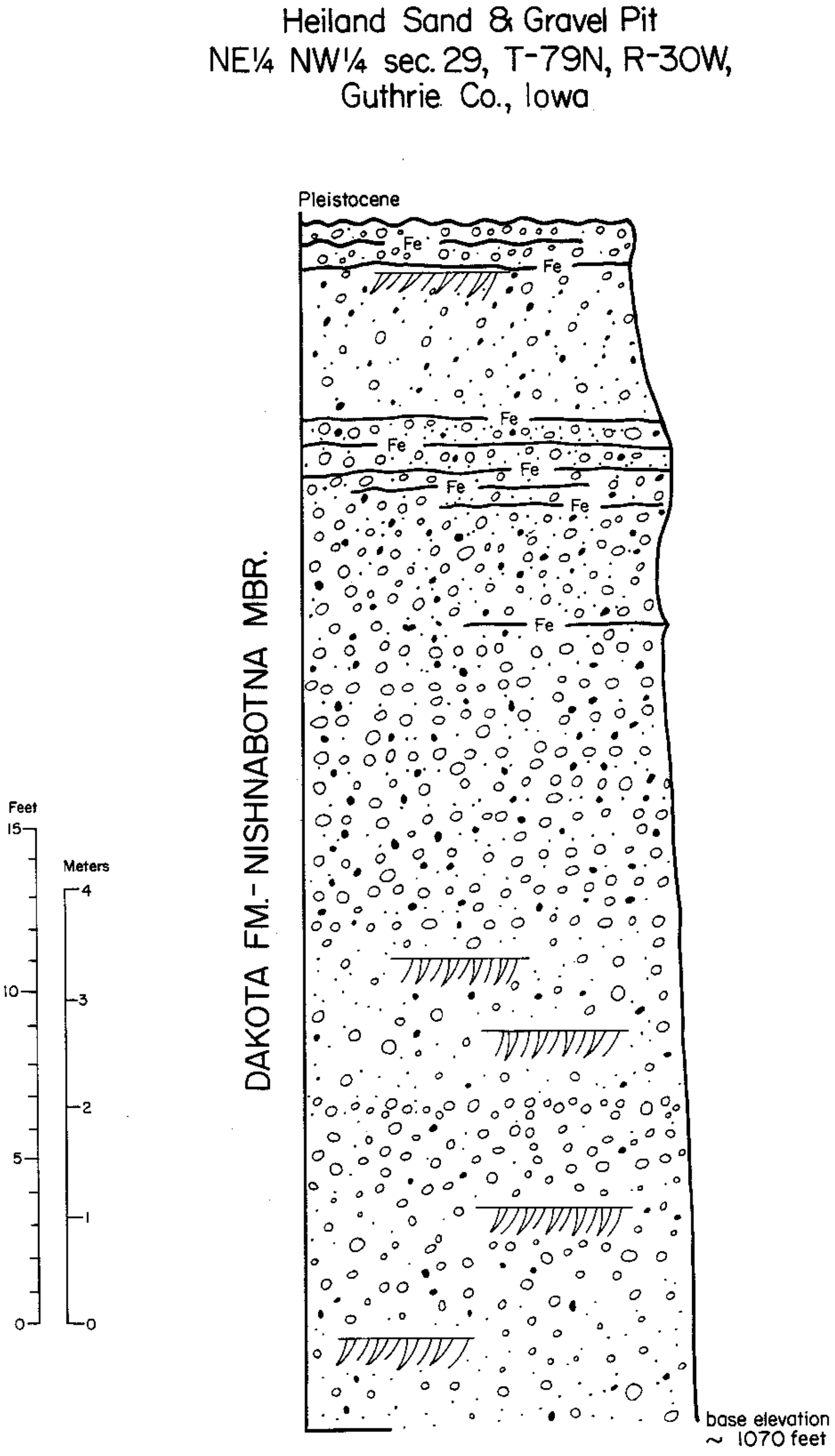


Figure 15. Exposure of lower Nishnabotna Member, Stop 4.

are interspersed within a sequence displaying horizontally-stratified coarse-grained units. A thick conglomeratic unit truncates underlying pebbly sandstones in the southeast area of the pit (Fig. 16), and a large silty to sandy mudstone clast (70 cm wide) can be seen along the truncation surface.

We encourage the trip participants to closely examine the composition of the gravel clasts in the lower Nishnabotna sequence. A variety of silicified Paleozoic fossils have been identified in these gravels (see p. 22), providing important evidence on source areas. Cretaceous petrified wood has also been found in the pit. Maybe someone will get lucky and find a dinosaur bone scrap.

The north wall of the pit displays a series of kaolinitic mudstones within the coarse-grained Nishnabotna sequence (Fig. 16). These mudstone units apparently represent slack-water overbank deposits that were subsequently buried by coarse-grained braided fluvial deposits. A thicker mudstone unit is exposed east of the pit area, where it is interbedded with sandstone and mud-chip-bearing intervals (Fig. 16).

Trip participants may wish to examine some of the following features displayed in the pit area: 1) cross-beds and other sedimentary features, 2) lateral stratigraphic relations of the various sandstone, conglomerate, and mudstone units, 3) patterns of iron oxide cementation, 4) composition of the gravel clasts, and 5) sorting within individual beds. How would you interpret the environment of deposition?

23.0	Return to pit entrance and turn left on gravel county road.
24.0	Turn left (north) on gravel county road.
24.4	Turn right (east) on County Road P-28.
28.5	Bridge over South Raccoon River; county park to right (west) of county road.
29.2	Turn left (northeast) on gravel county road.
31.1	Bridge over South Raccoon River; STOP 6, pull off along edge of county road. Do not block roadway.

STOP 6. Middle Pennsylvanian exposure along South Raccoon River

We will walk for about 15 minutes along the east bank of the South Raccoon to reach this outcrop. We will be on the property of Floyd Meacham and Lawrence Raber, whose cooperation is acknowledged. The Pennsylvanian exposure displays a westward-plunging syncline with 1.5 meters of relief along the south edge of the outcrop. What does this structure tell us about the tectonic history of southeastern Guthrie County?

The stratigraphic sequence begins at river level with a 1.1 meter-thick siltstone to very fine grained horizontally-laminated sandstone unit; small-scale troughs are also noted. The overlying 80 cm-thick very fine to fine grained sandstone contains some small-scale troughs, and a prominent 3.2 m long Lepidodendron trunk impression is exposed near the top of the sandstone ledge (Fig. 17). Abundant plant debris and lepidodendron leaves are also noted. This sandstone is overlain by a 75 cm sequence, in ascending order 1) thin-bedded siltstone with coaly plant debris, 2) silty claystone with leafy plant debris, and 3) underclay with abundant plant debris. This is, in turn, overlain by a 20-25 cm-thick coal unit; it becomes clayey in the top 5-10 cm.

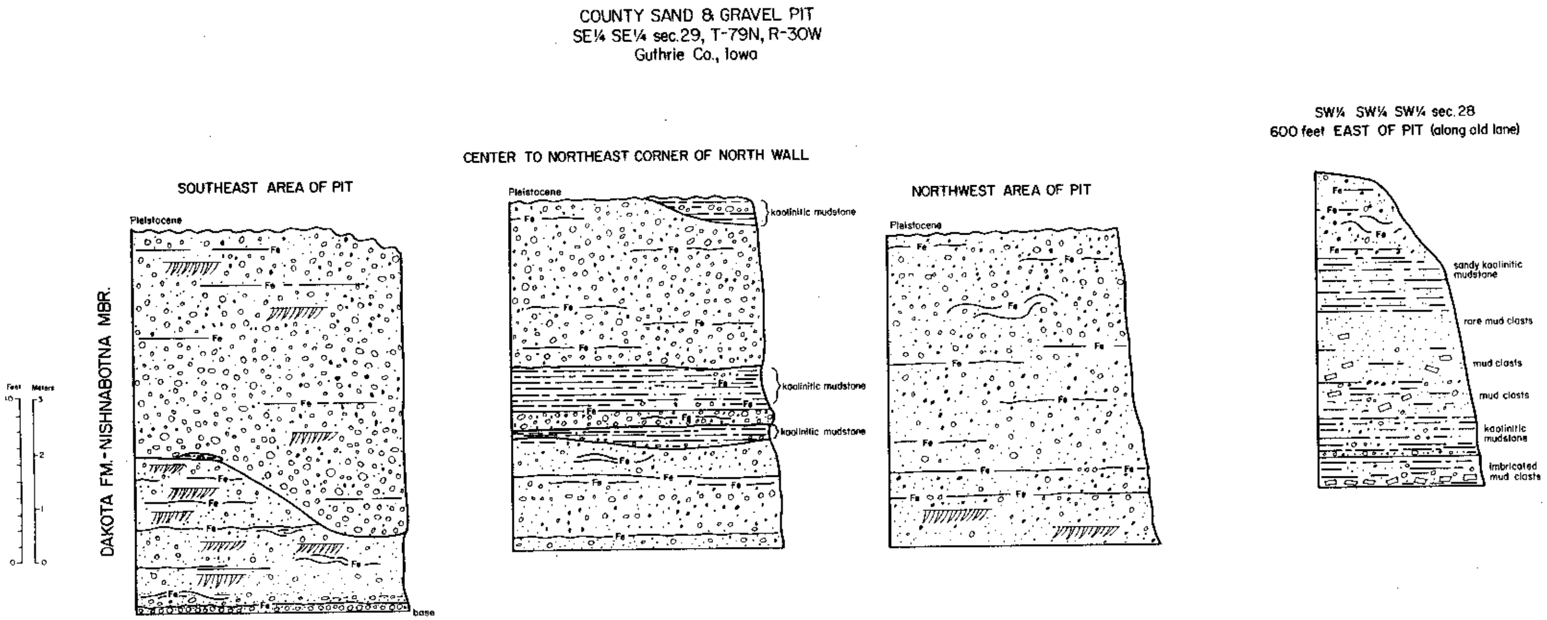


Figure 16. Lower Nishnabotna sections in the area of the county sand and gravel pit. Symbols as in Fig. 11.

The coal unit is overlain by a dark gray to black shale; the basal 7 cm is a hard platy black shale (phosphatic?). The unit becomes lighter colored and softer above, and is overlain by a light gray to orange-mottled slightly silty claystone. Above this, a 36-45 cm-thick light gray, argillaceous limestone unit forms a prominent ledge on outcrop. Brachiopods (productids, Composita, Mesolobus?, small spiriferids) and scattered echinoderm debris can be seen. The limestone is overlain by a 1.15 m-thick mudstone to silty claystone sequence with abundant plant debris in the lower portion.

The sequence exposed at Stop 6 is a cyclic deposits, and records a single marine transgression between two nonmarine units. The lower sequence records a fluvial and nonmarine depositional episode that culminated in the development of a widespread coal swamp. The coal is directly overlain by a black shale unit; the absence of a limestone between the coal and black shale categorizes this as an example of an "Illinois-type cyclothem" (see Heckel, 1977). Many recent workers in Iowa interpret these black shale units as representing the maximum transgressive phase of marine deposition (Heckel, 1977). Where are the intervening transgressive deposits? As suggested by Heckel (1977, p. 1061), there may have been "a time of slow or no deposition while the coal swamp was transgressed by the sea, after detrital influx had been diverted elsewhere and little or no carbonate was being generated on the sediment surface of decaying vegetation (future coal)." The limestone unit and overlying nonmarine shale sequence records the regressive portion of the cyclothem.

Although paleontologic work remains to be done on the Stop 6 sequence to verify correlation, the stratigraphic units are tentatively assigned to the uppermost Cherokee Group and lowermost Marmaton Group on lithostratigraphic grounds. The sequence seems most consistent with this assignment, although it may correlate to one of the higher Marmaton cycles. We encourage trip participants to sample portions of the sequence for palynomorphs or conodonts.

31.1 Leave Stop 6; continue ahead on road.

31.8 Park along edge of county road; Stop 7. Do not block roadway.

STOP 7. Roadside exposure of a Pennsylvanian limestone.

A thick light green-gray silty shale sequence is poorly exposed in the ditch and along a drainage to the north of this locality. The shale becomes red near the top of the sequence, and silty argillaceous limestone nodules are also noted. The shale sequence is overlain by a 9 cm-thick skeletal limestone bed containing crinoid and brachiopod debris and abundant fusulinids. This thin limestone bed is overlain by an 11 cm-thick calcareous light green-gray shale. Above this a 1 meter-thick limestone sequence is well exposed and contains abundant crinoidal debris and brachiopods (especially Composita) and rarer bryozoans. Fusulinids occur in the lower portion of the upper limestone.

Although biostratigraphic studies are needed to confirm the stratigraphic assignments, the lithostratigraphic sequence most closely resembles the Nowata Shale-"Lenapah" formation interval. The upper limestone is tentatively labelled the Cooper Creek Limestone. We encourage trip participants to sample the sequence for conodonts, especially the thin shale interval sandwiched between the limestones.

END OF TRIP. The route to Panora is as follows:

31.8 Leave Stop 7. Continue ahead on gravel road.
32.4 Turn left (west) on County Road F-59.
33.4 Turn right (north) on County Road P-28 into Panora.

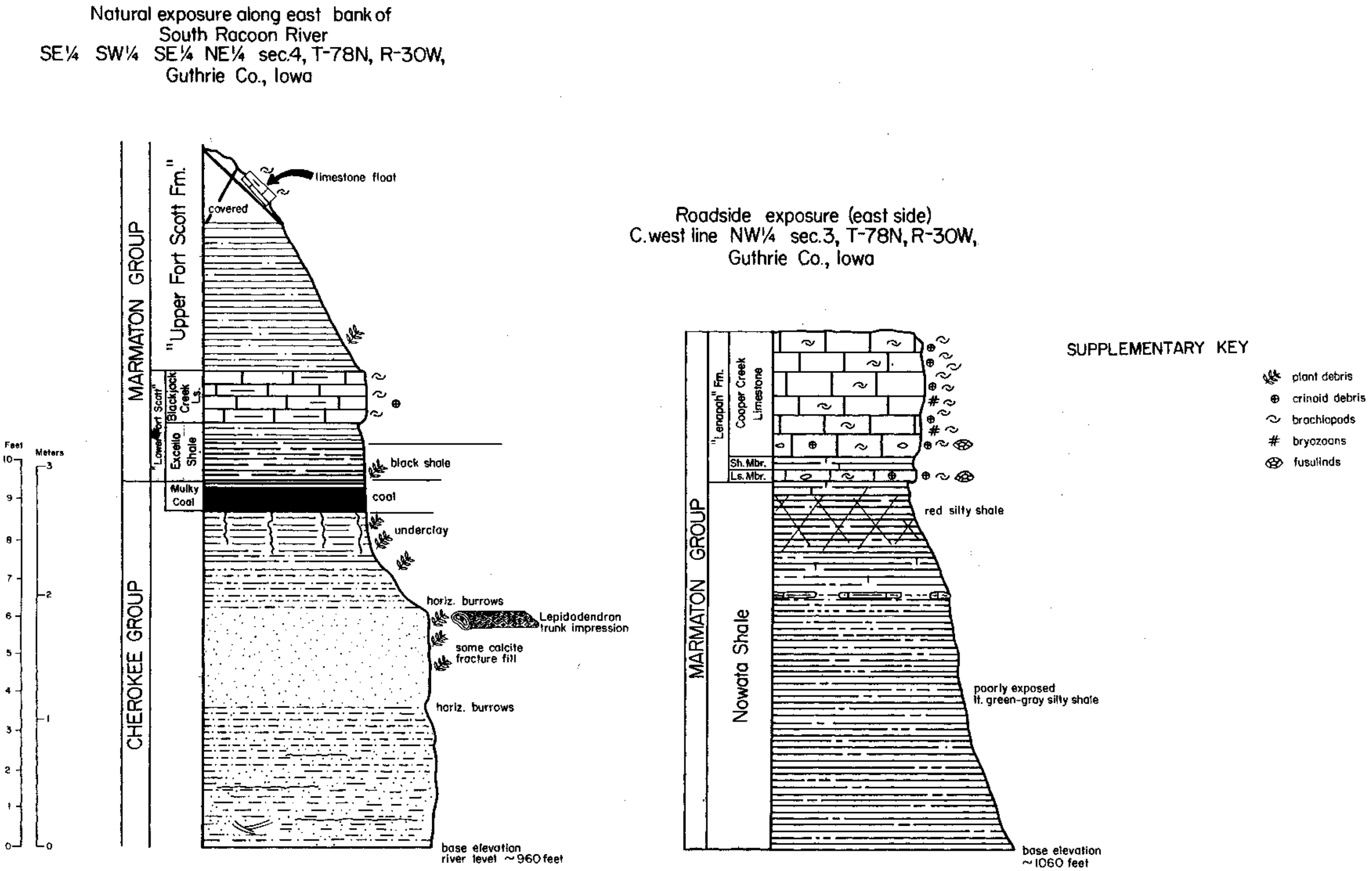


Figure 17. Pennsylvanian exposures in southeastern Guthrie County seen at Stops 6 and 7. Stratigraphic nomenclature is tentative pending further studies. Symbols as in Figure 10.