# Lost Branch Formation and revision of upper Desmoinesian stratigraphy along midcontinent Pennsylvanian outcrop belt

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Editor's note—The stratigraphic nomenclature used in this report is a revised classification for the Desmoinesian through Virgilian strata of the midcontinent. This classification will be outlined in more detail in subsequent reports. The revised classification formalizes and makes consistent most stratigraphic names across the midcontinent states. Other units are still in a state of flux (e.g., Critzer limestone, Exline limestone, Hepler sandstone, South Mound shale, Sasakwa limestone, Eleventh Street limestone) and are treated as informal units.

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# Abstract

The name Lost Branch Formation is proposed for a thin but widespread sequence of gray to black marine shales with thin limestones that lies upon a subaerial exposure surface developed upon terrestrial deposits and lies beneath another sequence of terrestrial deposits. The name Memorial Shale is revised to apply to the underlying sequence of blocky mudstone, shale, sandstone, and coal (Dawson coal) that overlies (and partly interfingers with) the marine Lenapah Limestone. The Lost Branch Formation can be traced in both cores and wire-line logs for several hundred miles along the midcontinent Pennsylvanian outcrop belt and into the subsurface. It ranges from a few feet thick in Iowa and Nebraska through 15 ft (4.5 m) thick in Missouri and Kansas to at least 65 ft (20 m) thick in east-central Oklahoma. It includes the following previously named units: Cooper Creek Limestone Member, named in Iowa; Sni Mills Limestone Member, named in Missouri; and Homer School limestone bed, Nuyaka Creek black shale bed, and Glenpool limestone bed, all named in Oklahoma. Recognition of the Lost Branch Formation as a single widespread marine horizon helps to correct long-standing miscorrelations of strata across the Desmoinesian–Missourian Stage boundary, as it includes strata of Desmoinesian age previously assigned to the Desmoinesian Lenapah Limestone and Holdenville Shale and the Missourian Seminole Formation and Hertha Limestone. A distinctive fauna of conodonts and ammonoids allows biostratigraphic correlation of the Lost Branch Formation along the entire midcontinent outcrop belt into the upper part of the type Holdenville Shale of east-central Oklahoma. The conodonts also allow correlation with the Lonsdale and West Franklin Limestone Members of Illinois. The highest occurrences in the Lost Branch Formation of certain genera and species of conodonts, ammonoids, brachiopods, and fusulinids, which are characteristic of underlying Desmoinesian rocks, in conjunction with the highest occurrences of characteristically Desmoinesian lycospore-dominated palynomorph floras in the underlying coals strongly suggest that the best current placement of the Desmoinesian–Missourian Stage boundary (and thus the Middle Pennsylvanian–Upper Pennsylvanian Series boundary) is at (or above) the top of the Lost Branch Formation. This boundary, which is at its traditional position in Kansas, Missouri, and Iowa, is marked by an upward transition from marine to terrestrial deposits with widespread subaerial exposure. Although it may thus be disconformable in places, it is not an unconformity of the stratigraphic magnitude previously believed, which was based on the miscorrelations. Depositionally, the Lost Branch Formation represents a single widespread inundation and withdrawal of the sea over the broad northern midcontinent shelf following the upper Memorial regression, which terminated the earlier, less widespread Lenapah inundations. The Lost Branch differs from the other widespread but limestone-dominated marine formations in the midcontinent Pennsylvanian by having only thin local developments of limestone. This difference probably resulted from a greater rate of transgression and regression for the Lost Branch inundation and consequent shorter periods of time during which the sea bottom remained within the appropriately shallow sunlit water depths favorable for carbonate production. The greater than usual marine withdrawal from the shelf that terminated Lost Branch deposition may have been responsible for the post-Desmoinesian extinctions in both biotic realms, both by crowding the marine organisms into small cratonic basins and by eliminating the broad freshwater swamp environments of the arborescent lycopods from the emergent shelves.


# Introduction

Most of the upper Desmoinesian, Missourian, and lower Virgilian sequence of the midcontinent Middle–Upper Pennsylvanian outcrop belt has been subdivided into an alternation of dominantly marine limestone formations with thin shale members and dominantly terrestrial to nearshore-marine shale formations with coal beds and local sandstone members (fig. 1). This system of subdivision was established by Moore (1936) for the Bronson, Kansas City, and Lansing groups of the Missourian Stage and the Shawnee Group of the Virgilian Stage and was applied by Jewett (1941, 1945) to the Marmaton Group, which forms the top of the Desmoinesian Stage. It has proved to be quite successful in delineating the stratigraphy of those parts of the midcontinent Pennsylvanian because it has been adopted with only minor modifications of nomenclature and correlation over the years by the state geological surveys of Kansas, Missouri, Iowa, and Nebraska [e.g., Moore (1948), Condra (1949), Burchett and Reed (1967), Hershey et al. (1960), Searight and Howe (1961), and Zeller (1968)].

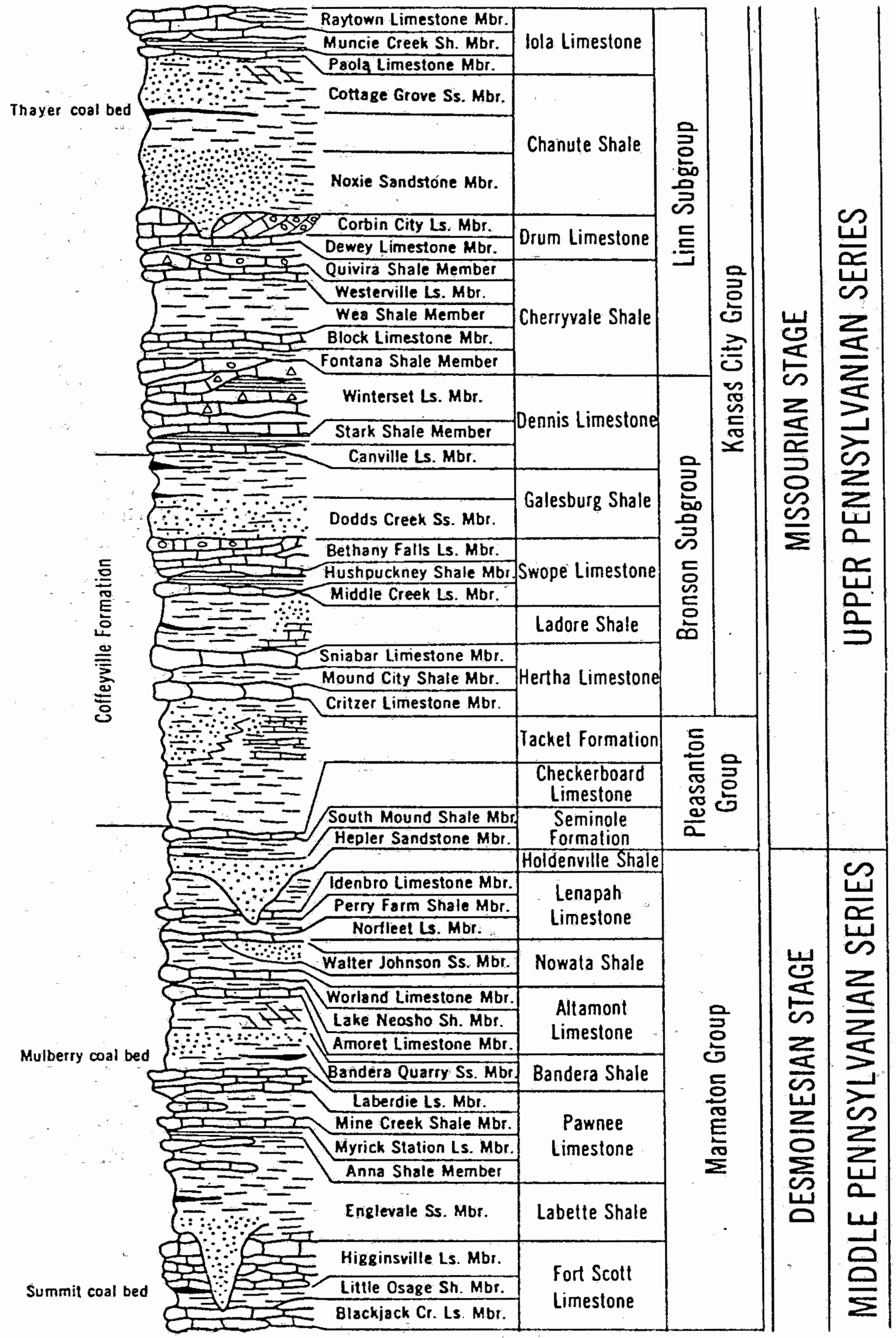



FIGURE 1—STRATIGRAPHIC COLUMN OF PART OF MIDDLE AND UPPER PENNSYLVANIAN SEQUENCE in Kansas showing subdivision of most of sequence into alternation of dominantly marine limestone formations with limestone and thin shale members (e.g., Pawnee, Altamont, Swope, Dennis, and Iola Limestones) and dominantly terrestrial to nearshore shale formations with coal beds and sandstone members (e.g., Labette, Bandera, Nowata, Galesburg, and Chanute shales). Subdivision of the Pleasanton Group is currently undergoing revision (Heckel, unpublished), and the Lenapah Limestone does not show the stratigraphic pattern common to most other limestone formations; thus the entire shale-dominated sequence between the Altamont and Hertha Limestones appears anomalous to the general pattern. The Lost Branch Formation and the revised Memorial Shale proposed herein occupy the position of the Holdenville Shale in this column, which shows the previous formal nomenclature for this part of the sequence in Kansas. [Adapted slightly from Zeller (1968, Plate 1).]

## Depositional controls

This system of subdivision also has been useful as a stratigraphic framework within which the long-recognized cyclic repetitions of rock units (cyclothems) constituting the formations have been interpreted in terms of an actualistic depositional model [e.g., by Schenk (1967) and Heckel (1977, 1980, 1983, 1984, 1986)]. This model (fig. 2) recognizes cycles of marine inundations, which correspond closely to deposition of the limestone formations, and withdrawals, which correspond closely to deposition of the intervening shale formations.

The intervening shale formations consist of a variety of rock types deposited at low stands of sea level. Gray to reddish blocky mudstones represent paleosols (Schutter and Heckel, 1985; Goebel et al., 1989; Joeckel, 1989), which are locally overlain by coals. Unfossiliferous sandy shales with local sandstones represent alluvial to deltaic deposits, and sparsely fossiliferous, typically thick and monotonous, silty to sandy shales represent prodeltaic to aggradational muddy shoreline deposits.

Overlying the variable nearshore to terrestrial shale formations is the lowest member of the limestone formations, the transgressive limestone. It is characteristically a thin, dense, dark, skeletal calcilutite with local calcarenitic horizons at the base and represents deposition in deepening marine water.

Above the transgressive limestone is a thin, widespread, sparsely to abundantly fossiliferous, nonsandy, gray to black shale member at the "core" of the limestone formation. This shale typically contains phosphorite nodules and laminae. It also carries an abundant and distinctive fauna of conodonts, dominated by the genera *Idiognathodus*, *Idioprioniodus*, *Gondolella* (in most formations), and *Neognathodus* (in Desmoinesian formations). This shale represents an offshore-marine shelf environment with very slow sedimentation that resulted in the concentration of the conodonts. It developed at the highest stand of sea level, when the water column became stratified over a large area and inhibited replenishment of bottom oxygen. This stratification led to deposition of the black shale facies and promoted upwelling, which led to deposition of the phosphorite (Heckel, 1977; Kidder, 1985).

The offshore shale is overlain by the thicker upper member of the limestone formation. This unit displays a classic shallowing-upward lithic sequence, ranging from skeletal calcilutite at the base through skeletal calcarenite to locally oolitic and muddy shoreline facies at the top, often with subaerial exposure. This member represents regression of the sea.

Thus each named member recognized by Moore (1936) and later researchers represents a particular phase of deposition corresponding largely to a position of sea-level stand (high or low) or a trend in sea-level change (deepening = transgressive; shallowing = regressive). Heckel (1984) related variations in this basic sequence of members to variation in the extent and rates of transgression or regression of the sea and consequent differences in water depth during highstands, in the position of the shoreline during lowstands, in the encroachment of detrital clastics during regression, and in thickness of the limestone facies formed at intermediate stands. The alternating rises and falls in sea level responsible for this stratigraphic pattern in the midcontinent have been increasingly recognized as eustatic, resulting from periodic waxing and waning of Gondwanan glaciation (Wanless and Shepard, 1936; Heckel, 1984, 1986; Veevers and Powell, 1987), although with autocyclic sedimentary mechanisms, such as delta shifting, which operated wherever the shoreline stood for a sufficient period of time (Wanless, 1967; Heckel, 1980).

## Purpose

The only portion of the midcontinent Pennsylvanian succession from the upper Desmoinesian Marmaton Group through the upper Missourian Lansing Group that has not been stratigraphically subdivided in this fashion is the thick shale-dominated sequence that spans the Desmoinesian–Missourian boundary. This includes the Pleasanton Group of Kansas, Missouri, and northward and the Seminole Formation of Oklahoma at the base of the Missourian, and the Holdenville Shale, Lenapah Limestone, and Nowata Shale as currently recognized throughout most of the area at the top of the Desmoinesian Marmaton Group (fig. 1).

Convergence of recent research activities of a number of geologists has contributed greatly to sorting out the detailed stratigraphy of this portion of the sequence. A. P. Bennison of Tulsa, Oklahoma, is working out field relations of lithic units in eastern Oklahoma and adjacent Kansas. W. B. Howe, of the Missouri Geological Survey, is placing in the public domain [e.g., Howe (1982)] the results of his extensive field studies in Missouri, which had been only partly published [e.g., Howe (1953)]. L. R. Wilson, of the Oklahoma Geological Survey, and R. A. Peppers, of the Illinois Geological Survey, are making available the results of their ongoing independent palynologic studies of the coals. D. R. Boardman, currently at Texas Tech University, R. H. Mapes, of Ohio University, and D. M. Work, of the Missouri Geological Survey, are working out the ammonoid sequence, which is represented particularly well in Oklahoma. J. W. Swade (1982, 1985) determined the conodont biostratigraphy of most upper Desmoinesian cycles from two cores in Iowa. Parkinson (1982) and Greenberg (1986) described the stratigraphy and petrology of the Lenapah Limestone from northeastern Oklahoma to northern Missouri and provided details of its conodont fauna that Swade (1982) did not detect in Iowa. My work has involved applying the conodont zonation of Swade (1982, 1985) and more recent findings of other students and colleagues, as well as my own, to the lithic tracing of units along the entire midcontinent outcrop belt. In this work I have

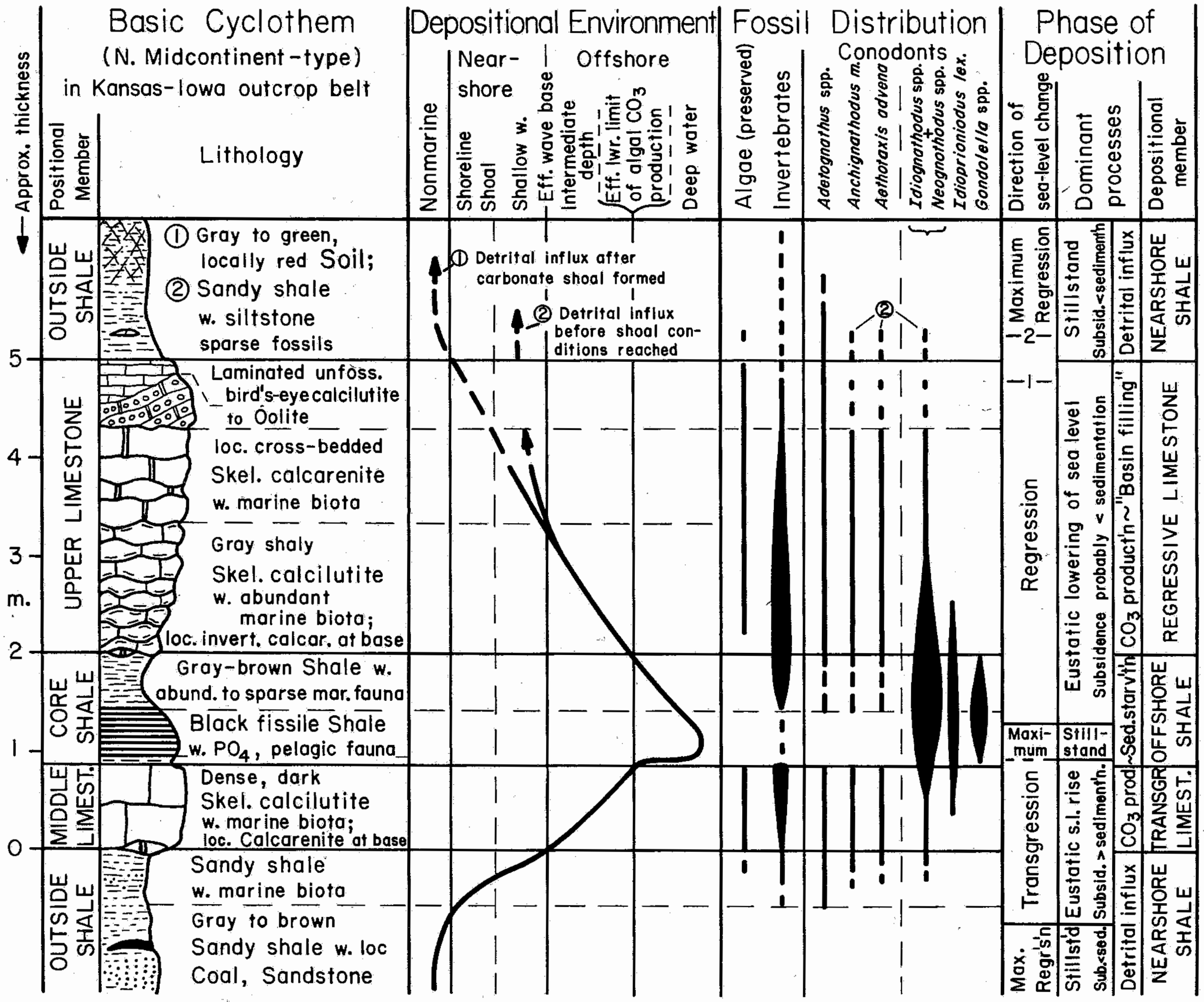



FIGURE 2—BASIC DEPOSITIONAL MODEL for vertical sequence of members within limestone formations (middle limestone–core shale–upper limestone) and adjacent parts of shale formations (outside shales). This figure shows the relations between the members of the limestone and shale formations mentioned in fig. 1 and the phase of deposition during one cycle of marine inundation and withdrawal over the northern midcontinent shelf. Note the high abundance of certain conodont genera, concentrated in offshore (core) shale by sediment starvation during maximum transgression, compared with the sparse conodont faunas dominated by other genera during shallower-water phases of deposition.

utilized cores made available by the Iowa, Nebraska, Missouri, Kansas, Oklahoma, and Illinois geological surveys and studied the field localities either discovered by Howe and Bennison or described in the older literature.

These combined efforts have identified miscorrelations and misuse of names that are not adequately rectified by the currently used stratigraphic nomenclature. The purpose of this report is to begin the more accurate characterization of the stratigraphy of the interval from the top of the Altamont Limestone up into the Missourian Stage along the midcontinent outcrop belt and in the near subsurface, particularly the Forest City basin. This analysis is facilitated by the recognition and the lithic and biostratigraphic correlation of a continuous, distinctive marine horizon at the top of the Marmaton Group and the Desmoinesian Stage, which I propose to call the Lost Branch Formation.

# Origin and evolution of previous nomenclature

## Earliest work

The names Wewoka Formation, Holdenville Shale, and Seminole Formation (fig. 3) were originally applied in ascending order by Taff (1901) to a thick sequence of shale and sandstone with conglomerate and thin limestone beds in what is now recognized as a Middle–Upper Pennsylvanian basinal facies in the east-central Oklahoma counties of Hughes and Seminole (for geographic localities, refer to fig. 7). The names Nowata Shale, Lenapah Limestone, and Curl (now Coffeyville) Formation were originally applied in ascending order by Ohern (1910) to a shale–limestone–shale-with-sandstone sequence in what is now recognized as the equivalent shelf facies 120 mi (193 km) northward, in Nowata County, northeastern Oklahoma. Ohern (1918) later erroneously correlated the Lenapah Limestone with the Dawson coal of the Tulsa region to the south, a region now recognized as near the shelf edge along the north side of the basin. Thus the Nowata Shale was regarded as extending upward to the base of the Dawson coal around Tulsa.

## Revised correlations

Later work [reported by Dott (1941)] determined that the stratigraphically lower, informally named Eleventh Street limestone of the Tulsa region, rather than the Dawson coal, is equivalent to the Lenapah Limestone. Then, when Moore et al. (1937) delimited the base of the Coffeyville Formation at the Checkerboard Limestone [named from Okmulgee County just to the south; see Oakes (1940, p. 27)] and extended the Seminole Formation below it northward into the Tulsa region as the lowest Missourian formation in that area, they also included the Dawson coal in the middle shaly part of the Seminole (fig. 3). This revision of correlation caused D. J. Jones to change the unit names in his long-term study of the conodont fauna of the black shale that overlies the Dawson coal at Collinsville, 20 mi (32 km) northeast of Tulsa, from "Nowata Shale" in his Master's thesis (1935) to "Seminole Formation" in his doctoral dissertation (1941).

Dott (1941) applied the name Memorial Shale to a sequence previously regarded as part of the Nowata Shale. This sequence extends upward from the Eleventh Street limestone to the base of the lower sandstone of the Seminole Formation, which lies below the Dawson coal. Along with Moore et al. (1937), Dott (1941) indicated that the Memorial Shale is Desmoinesian in age, equivalent to the upper part of the Holdenville Shale to the south, and that the regionally unconformable contact supposedly existing between the Memorial Shale and the overlying Seminole Formation is the Desmoinesian–Missourian boundary. Oakes and Jewett (1943) discussed and illustrated the nature of this unconformable contact in the two counties (Nowata and Labette) on either side of the Kansas–Oklahoma border. Their placement of the contact depended on the assumption that the Dawson coal was Missourian and that the brachiopod *Mesolobus* was a Desmoinesian index fossil. These assumptions effectively classified any coal lying upon the Lenapah Limestone and above which no *Mesolobus* was found (as in most of Nowata County, Oklahoma) as Missourian Dawson coal and any coal lying upon the Lenapah Limestone but above which *Mesolobus* was found (as around Mound Valley in Labette County, Kansas) as Desmoinesian and thus not Dawson coal (Oakes and Jewett, 1943, fig. 1).

Oakes (1952, p. 41) decided that in Tulsa County and southward the Lenapah (Eleventh Street) Limestone is equivalent to the uppermost sandstone beds of the Wewoka Formation (fig. 3). On the basis of this assumed correlation, the Memorial Shale, which extended from the top of the Lenapah to the base of the Seminole Formation, would occupy the same stratigraphic interval as the earlier named Holdenville Shale to the south, and thus the prior name, Holdenville, should take precedence. This change was subsequently accepted by the Missouri and Kansas geological surveys [e.g., Howe (1953), Searight and Howe (1961), and Zeller (1968)], which now utilize the name Holdenville Shale or Formation for the shale interval between the top of the Lenapah and the Desmoinesian–Missourian unconformity (fig. 3). This boundary is marked by a basal Missourian sandstone along much of the outcrop in Kansas and Missouri.

## Hepler sandstone

Based on a type section in southern Bourbon County, Kansas, Jewett (1940) originally applied the name Hepler to the basal Missourian sandstone that he assumed was a persistent key marker horizon for surface mapping. (Current problems with this assumption involve recognition of sandstones at three distinctly different stratigraphic horizons, all of which had been identified as Hepler sandstone in the older literature, a point that is discussed later.) The Hepler sandstone was considered to overlie the Memorial (=Holdenville) Shale in Kansas and to form the base of the Bourbon group (now called the Pleasanton Group) (fig. 3). Although Jewett (1940) thought that the Hepler was equivalent to the lower part of the Seminole Formation in Oklahoma, Oakes and Jewett (1943) stated that it is equivalent to only the upper part, because the middle part of the Seminole, which contains the Dawson coal, supposedly had overlapped the lower part northward from Tulsa. More recently, Jewett et al. (1965) classified the Hepler sandstone as the lower member of the Seminole

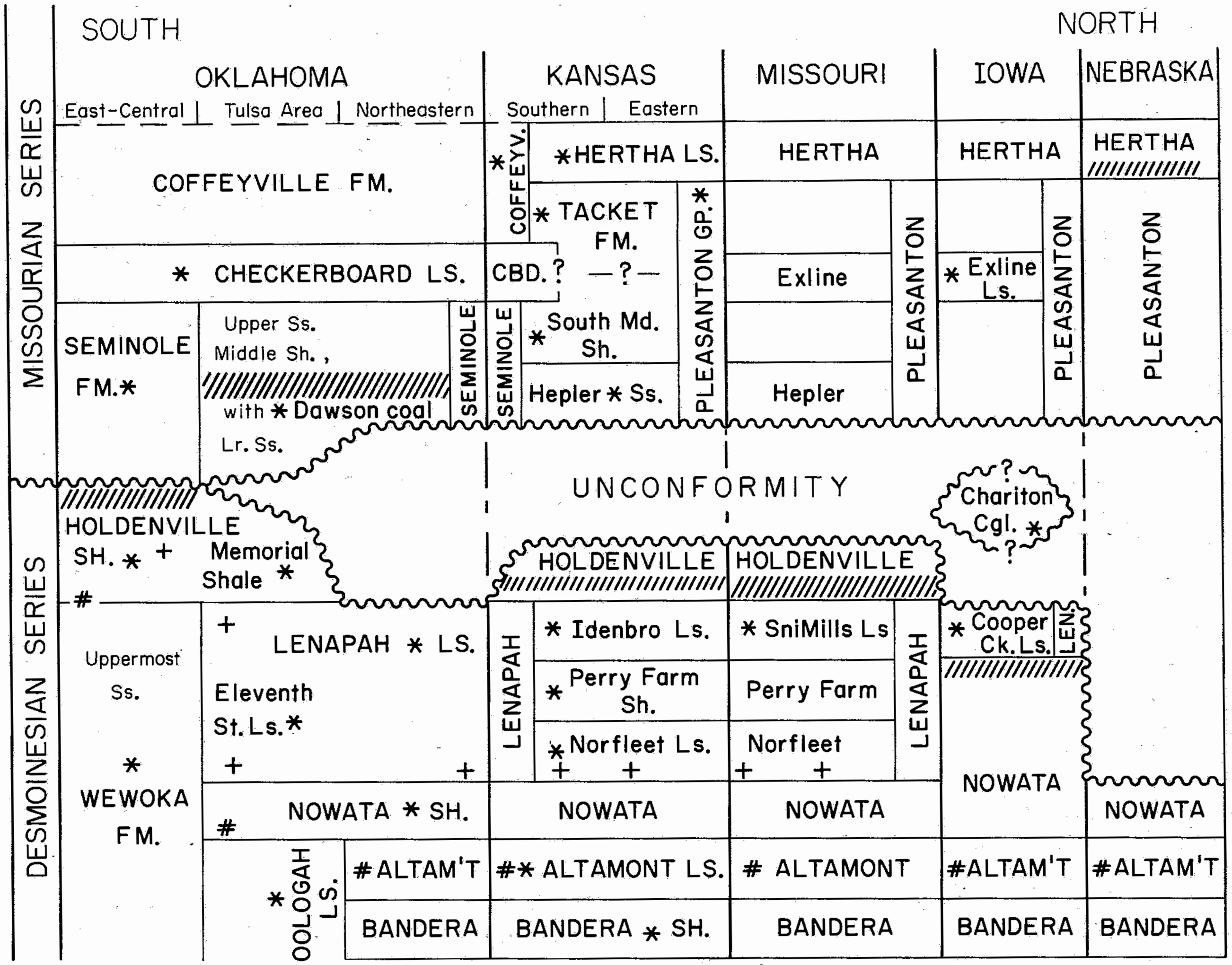



FIGURE 3—Previous nomenclature and correlation of Desmoinesian–Missourian boundary interval from Bandera Shale to Hertha Limestone along the midcontinent outcrop belt [compiled from references discussed in text and from Fay et al. (1979) for Oklahoma]. Asterisks (*) denote geographic locations of type sections of each named unit. Formation and group names are printed in capital letters; member and other names are printed in lowercase letters. Hatch marks (///) show previously correlated positions of strata now recognized as correlative with the uppermost Desmoinesian marine horizon described in the text on the basis of distinctive conodont fauna (Swade, 1985; my work) and ammonoid fauna (Boardman and Mapes, 1984). Plus signs (+) denote previous correlated positions of strata correlative with the lower Lenapah Limestone (Norfleet Limestone Member) based on distinctive conodont fauna (Parkinson, 1982; Greenberg, 1986; my work). Scratch marks (#) denote previous positions of strata correlative with the Altamont Limestone based on distinctive conodont fauna (Swade, 1985; my work) and ammonoid fauna (D. R. Boardman, personal communication, 1984). Hatch marks drawn in the Hertha Limestone in Nebraska are based on conodont analysis of shale within the limestone in the Amerada core (NAC) that was correlated with the Hertha by Condra (1939) and to my knowledge has not been revised since.

Formation in Kansas and proposed the name South Mound for the overlying shale member of the Seminole, which is overlain by the Checkerboard Limestone, the same unit that caps the Seminole in Oklahoma (fig. 3).

## Lenapah Limestone

Jewett (1941, 1945) subdivided the Lenapah Limestone in Kansas into three members, all named from central or western Labette County. In ascending order they are the Norfleet Limestone Member, the Perry Farm Shale Member, and the Idenbro Limestone Member (fig. 3). Jewett (1941, p. 337) recognized the Idenbro as the limestone bed at the top of the type Lenapah Limestone in northern Oklahoma and concluded (Jewett, 1945) that the Perry Farm, which contains limestone nodules in Kansas, grades southward into the nodular limestone that constitutes the main part of the type Lenapah, with only a thin green shale at the top representing the shale facies. Jewett (1941, 1945) recognized the Norfleet Limestone Member as discontinuous and thin, except where it forms the sandy base of the lower limestone ledge just south of the Lenapah type section in Oklahoma (Jewett, 1945, plate 4). Oakes (1952) neither recognized nor traced these members of the Lenapah Limestone as separate lithic units southward to Tulsa.

The tripartite subdivision of the Lenapah Limestone was soon recognized in Missouri [see Howe (1953, p. 10)], but the name Idenbro was dropped in favor of Sni Mills Limestone Member, named by F. C. Greene [in Moore et al. (1936)] from the Kansas City area, because Cline and Greene (1950) believed that the two limestones were equivalent (fig. 3). Howe (1953) noted that the base of the Holdenville Shale just above the Sni Mills is a black fissile phosphatic shale in many places, that it extends laterally beyond the pinch-out of the Sni Mills, and that it had been called the "Dawson coal horizon" by earlier workers.

After correlations by Weller et al. (1942) and despite mild reservations expressed by Cline and Greene (1950), the Iowa Geological Survey recognized the Cooper Creek Limestone, named by Cline (1941, p. 65) from Appanoose County on the Missouri border, as the only member of the Lenapah Limestone in that state (Hershey et al., 1960). The Cooper Creek Limestone had been correlated with the Sni Mills Limestone Member of Missouri by Howe (1953) and also with the Lonsdale Limestone Member of Illinois by Weller et al. (1942). The Iowa Geological Survey did not recognize the Holdenville Shale, instead considering the Cooper Creek Limestone to be overlain by the Pleasanton Group of Missourian age (Hershey et al., 1960). In Iowa the Pleasanton lacks the Hepler sandstone but contains a thin limestone, named the Exline limestone by Cline (1941, p. 65) from Appanoose County, not far from the type Cooper Creek. Cline (1941, p. 70) suggested that the position of the Desmoinesian–Missourian series (now stage) boundary was marked by the "Chariton conglomerate," a lenticular unit that Cline (1941) thought lay above the Exline limestone but that Landis and Van Eck (1965) thought lay below the Exline (fig. 3). The Iowa Geological Survey has placed this series/stage boundary at the top of the Cooper Creek limestone (Hershey et al., 1960; Landis and Van Eck, 1965). Although Howe (1982, p. 34) believes that the "Chariton" overlies the Exline limestone member in Missouri, the stratigraphic relations of the "Chariton conglomerate" in its type area in Iowa remain uncertain (Ravn et al., 1984).

Neither the Lenapah Limestone nor the Holdenville Shale has been officially recognized in Nebraska (Condra, 1949), where the Missourian Pleasanton Group is considered to rest disconformably upon the Nowata Shale (fig. 3), with the uppermost Marmaton beds removed by erosion (Burchett, 1979).

# New findings

## Age of the Dawson coal

The old scheme of classification and correlation (fig. 3) began to come apart when Wilson (1972) noted that fossil plants in the Seminole Formation in Tulsa County have Desmoinesian affinities and when Pearson (1975) and Wilson (1979, 1984) reported that the Dawson coal in Tulsa County, its type area, contains Desmoinesian palynomorphs. Moreover, both Wilson (1979) and Bennison (1979, p. 289) reported that the Dawson coal is overlain in Tulsa County by shale that contains *Mesolobus*, the supposed absence of which had helped previous workers place the coal in the Missourian. Also in 1979, I collected conodonts from the black shale above the Dawson coal at Collinsville (just north of Tulsa) to corroborate the fauna reported by Jones (1935, 1941). This fauna closely resembles the Desmoinesian fauna found by Swade (1982, 1985) in a thin shale below the Cooper Creek Limestone in Iowa. Shortly thereafter, D. R. Boardman discovered ammonoids in the upper part of the type Holdenville Shale that are identical with those reported by Miller and Owen (1937) from the black shale above the Dawson coal at Collinsville (Boardman and Mapes, 1984). Although Miller and Owen (1937) had noted that the Collinsville ammonoids include many characteristic Desmoinesian forms, they regarded them as Missourian because the beds had been mapped as Missourian. The new findings now necessitate the removal of the Dawson coal and the overlying black shale from the Seminole Formation and the Missourian Stage (fig. 4). Detailed subsurface correlations by Krumme (1981) and extensive field mapping by Bennison (1981, 1984) southward into the basinal type areas of the Holdenville Shale and Seminole Formation have revealed enough uncertainty in definition and miscorrelations by previous workers between there and Tulsa to question the use of these names in the Tulsa area and northward until the northern equivalents can be adequately ascertained.

## Relations of the Lenapah Limestone

Bennison's field mapping north of Tulsa revealed that the Lenapah Limestone is traceable south of Lenapah as two distinct limestone beds diverging from one another, and he rediscovered the observation of Moore et al. (1937, p. 41) that the upper limestone at the Lenapah type section is overlain by the Dawson coal and its overlying black shale. Recognition of this relation strongly aided Parkinson's (1982) study of the Lenapah Limestone in its type area, which turned up a distinctive *Neognathodus*-dominated conodont fauna [plus signs (+) in figs. 3 and 4] at the base of the lower limestone bed, a fauna that was not detected by Swade (1982) in the Iowa cores. Greenberg (1986) and I have since recovered this fauna from the entire thickness of the Eleventh Street limestone in the Tulsa region, from the type Norfleet Limestone Member of Labette County, Kansas, and from numerous places in eastern Kansas and western to north-central Missouri in limestones that Howe (1953) had correlated mostly with the Norfleet. Greenberg (1986) noted that this fauna is replaced progressively by a nearshore *Adetognathus*-dominated fauna in the Norfleet Member in north-central Missouri.

Thus the Eleventh Street limestone is equivalent to only the Norfleet Limestone Member at the base of the type Lenapah Limestone (fig. 4) rather than to the entire Lenapah Limestone, as assumed by previous workers (fig. 3). Furthermore, because the lower Seminole sandstone, which defines the top of the original Memorial Shale, extends northward only through T. 23 N. (Oakes, 1952, p. 54) just south of Talala in northeastern Oklahoma (see fig. 8) and because A. P. Bennison has traced the upper Lenapah Limestone (Idenbro Member), which always lies a few feet below the Dawson coal, from the Lenapah type section southward to Talala, it follows that the type Memorial Shale of Dott (1941) is largely equivalent to the Perry Farm Shale Member in the middle of the Lenapah, which Parkinson (1982) found to thicken southward near Nowata. Consequently, the type Holdenville Shale is equivalent to at least the middle and upper Lenapah Limestone in addition to what had been called the Holdenville Shale to the north, and Krumme (1981) suggested that it might include most of the Nowata Shale as well. In this light, the Memorial Shale can be viewed as a valid subdivision of the Holdenville Shale, rather than as a junior synonym.

Moreover, D. R. Boardman's latest ammonoid information and my latest conodont information strongly suggest that the lowest marine horizon currently assigned to the Holdenville Shale in its type region, informally named Tuckabatchee shale by Bennison (1984), actually correlates with the Altamont Limestone below the Nowata Shale and one marine cycle below the Lenapah Limestone (fig. 4). If this is the case, then the type Holdenville Shale is equivalent to the entire upper (post–Bandera Shale) part of the Marmaton Group of the northern shelf. Nevertheless, uncertainty still exists as to whether the Tuckabatchee shale properly belongs in the Holdenville, where it was mapped by Weaver (1954) in northern Hughes County, or in the Wewoka Formation, where its supposed southern extent was mapped by Taff (1901) in southern Hughes County. Either alternative reinforces the case that the name Holdenville Shale (Formation) as currently utilized by the Kansas and Missouri geological surveys (fig. 3), should be abandoned because it is equivalent to only the top of the type Holdenville Shale in Oklahoma.

## Recorrelation of northern "Lenapah" limestones

Parkinson (1982) also found in the black shale above the Dawson coal, where it lies above the upper Lenapah Limestone, the same conodont fauna that Jones (1935, 1941) found at Collinsville and later that I found both at Collinsville and in samples from the upper part of the type Holdenville Shale that D. R. Boardman sent to me. Swade (1982, 1985) found this fauna below the Cooper Creek Limestone in Iowa, and I collected it from the dark phosphatic shale in the base of the "Holdenville Formation" in west-central Missouri, where it directly overlies the Sni Mills Limestone Member in its type area (fig. 3). The occurrences of this distinctive conodont fauna [hatch marks (///) in figs. 3 and 4] point to several conclusions: (1) This offshore-marine, conodont-rich, black to gray, phosphatic, shale-dominated horizon seems to be continuous along the midcontinent outcrop. (2) This horizon overlies the type Lenapah Limestone but is separated from it by the terrestrial Dawson coal and its underclay. (3) Therefore this marine horizon and its northern associated marine strata, the Sni Mills Limestone Member and the Cooper Creek Limestone, formed during a marine inundation that was younger and more widespread than that forming the Lenapah Limestone, and this inundation followed a marine withdrawal to at least the southern extent of the Dawson coal some distance south of Tulsa. [The importance of the lateral extent of the terrestrial horizon below the Sni Mills Member in Missouri was recognized earlier by Greene and Howe (1952) and Howe (1953).] (4) Consequently, the Sni Mills Member and Cooper Creek Limestone must be removed from the Lenapah Limestone (fig. 4).

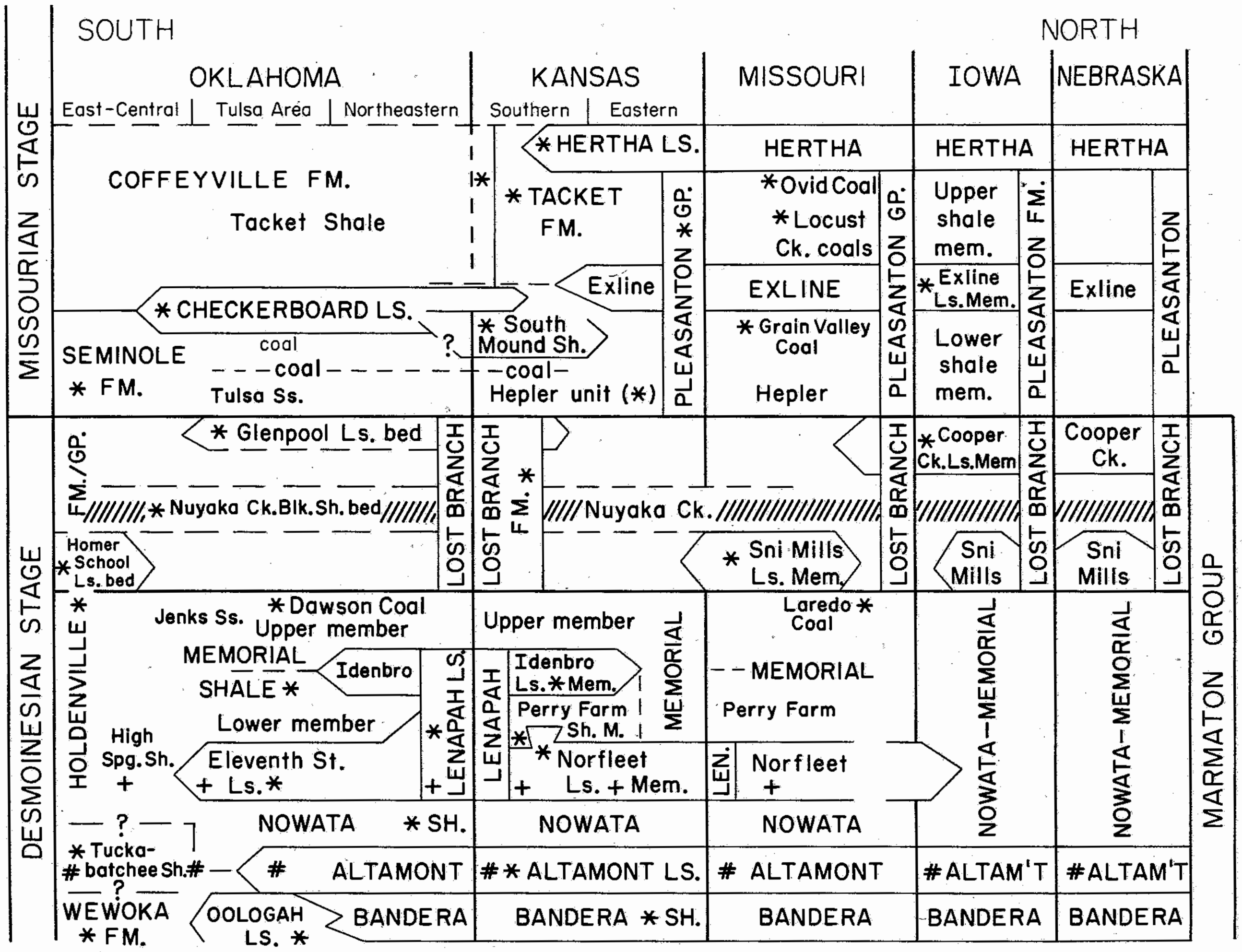



FIGURE 4—REVISED CORRELATION AND NEW NOMENCLATURE of uppermost Desmoinesian and adjacent strata shown in fig. 3 along the midcontinent outcrop belt, based on lithic relations in outcrop exposures and cores and correlated by means of conodonts (Swade, 1985; Parkinson, 1982; Pavlicek, 1986; Greenberg, 1986; my work), ammonoids (Boardman and Mapes, 1984; D. R. Boardman, personal communications, 1982–1986), and palynomorphs (R. A. Peppers, personal communications, 1981–1984). As in fig. 3, hatch marks (///) show the correlation of the Lost Branch horizon, plus signs (+) show the correlation of the lower Lenapah horizon, scratch marks (#) show the correlation of the Altamont horizon, and asterisks (*) show the geographic location of the type sections of all named units. Formation and group names are printed in capital letters; member and other names are printed in lowercase letters. Bandera Shale–Oologah Limestone relations were worked out by Price (1984). The nomenclature of Missourian strata is still in flux. Krumme (1981, p. 20–32) and Bennison (1984, p. 120–122) summarized problems of miscorrelation of the Seminole Formation and Checkerboard Limestone in Oklahoma. An understanding of Hertha Limestone–Tacket Formation–Pleasanton Group relations has evolved through the work of Ravn (1981), Bennison (1984, pp. 122–123), Underwood (1984), and Pavlicek (1986) and is currently being summarized by Heckel (unpublished). Pleasanton nomenclature in Iowa is based on Ravn et al. (1984), and in Missouri it is currently under revision by W. B. Howe.

## Desirability of a new named formation

The higher marine horizon is significant because it contains the youngest known midcontinent occurrences of the conodont *Neognathodus*, the brachiopod *Mesolobus*, and several typically Desmoinesian ammonoid taxa (Boardman and Mapes, 1984). Moreover, it overlies the Dawson coal, which contains the youngest known occurrence of a typical Desmoinesian miospore flora rich in *Lycospora* (R. A. Peppers, personal communications, 1982, 1983). Thus the regional correlation of this interval is of paramount importance for the exact delineation of the Desmoinesian–Missourian boundary in the type area of both stages in the midcontinent outcrop belt. Because the names previously applied to different parts of this horizon are overly inclusive names (Holdenville Shale), miscorrelations (Seminole Formation, Lenapah Limestone), or just local facies [Cooper Creek Limestone, Sni Mills Limestone Member; also Homer School limestone bed, Nuyaka Creek black shale bed, and Glenpool limestone bed of Bennison (1981, 1984)], I propose to name the entire marine horizon as a new formation (fig. 4).

# Lost Branch Formation

The name Lost Branch Formation is proposed for the sequence of gray to black marine shales and thin, pure to impure limestones that extends from the top of the Dawson coal bed and its equivalent strata upward to the base of the terrestrial strata that include the unfossiliferous sandstone that accords with the traditional concept of the Hepler sandstone (fig. 4). As defined, the Lost Branch Formation includes shale formerly encompassed by the Holdenville Shale or Formation as recognized in Kansas and Missouri and shale formerly included in the middle shaly zone of the Seminole Formation as recognized in northeastern Oklahoma. Northward it includes, as named members, the Sni Mills Limestone Member of Missouri at its base and the Cooper Creek Limestone of Iowa, recently correlated into Nebraska using cores, at its top; it also includes the dark shale beneath the Cooper Creek. Southward the Lost Branch Formation encompasses as informally named beds the Nuyaka Creek black shale bed of Bennison (1981), the Glenpool limestone bed of Bennison (1984) at its top, and the Homer School limestone bed of Bennison [1981; emended from Morgan (1924)] at its base; it also includes the associated shaly strata in the upper part of the type Holdenville Shale in east-central Oklahoma and its now-recognized northward extension in northeastern Oklahoma. The Lost Branch is 15 ft (4.6 m) thick in southern Kansas, increasing southward to as much as 65 ft (20 m) in east-central Oklahoma and thinning northward to as little as 4 ft (1.2 m) in the subsurface of southeastern Nebraska.

The Watkins shale member of the Holdenville Shale, informally proposed by Bennison (1984, p. 119) for what was previously regarded as the middle shaly zone of the Seminole Formation by Oakes (1952) in the Tulsa region, includes the Dawson coal and its underlying strata as well as strata above the Glenpool limestone bed and below the Tulsa sandstone. Thus it encompasses more of the sequence than that included in the Lost Branch Formation and therefore does not offer as much stratigraphic differentiation. Furthermore, the name Watkins is preoccupied by a Quaternary unit that is recognized by the U.S. Geological Survey in southwestern Iowa (Keroher, 1970, p. 812).

If the Lost Branch Formation is extended southward as the upper part of the type Holdenville Shale in east-central Oklahoma, then the Holdenville there could be raised to the rank of group and the component beds of the Lost Branch could be raised in rank to member. If the Holdenville is retained as a formation, then the Lost Branch can be recognized as its upper member in that part of Oklahoma, retaining its component beds as currently ranked. If the name Holdenville is retained in the states to the north, then it may be appropriate as a subgroup at the top of the Marmaton Group, composed of, in descending order, the Lost Branch Formation, the Memorial Shale, the Lenapah Limestone, the Nowata Shale, and possibly the Altamont Limestone (after its position in the type area of the Holdenville Shale is resolved).

## Type locality and stratotype

The type locality of the Lost Branch Formation is an excellent exposure in a cutbank on the west side of Lost Branch, near center NE-NE-NE sec. 10, T. 33 S., R. 18 E., just southwest of Mound Valley, Labette County, Kansas (fig. 5). The stratotype of the Lost Branch (fig. 6) is nearly 15 ft (4.5 m) thick and consists of, in ascending order, (1) 0.3 ft (0.1 m) of slightly micaceous, sandy, soft dark-gray shale (unit 4 in fig. 6) that contains abundant megaspores, carbonized wood fragments, weathered invertebrate skeletal debris, including a small gastropod, and sparse conodonts; (2) 1.3 ft (0.4 m) of fissile black shale (unit 5) with phosphorite laminae and nodules and an abundant and diverse fauna of conodonts; (3) 12 ft (3.6 m) of gray shale (unit 6) that becomes micaceous and silty upward and carries an abundant and diverse invertebrate fauna, particularly in the lower part, including crinoid debris, brachiopods, bryozoans, gastropods, ostracodes, foraminifers, pelecypods, and scattered conodonts; and (4) 1 ft (0.3 m) of hard, calcareous, fossiliferous, very fine grained quartz sandstone to sandy skeletal calcarenite (unit 7) containing brachiopods, crinoid debris, foraminifers, and sparse conodonts.

The fissile, phosphatic black shale (unit 5 in fig. 6) is the Nuyaka Creek black shale bed of Bennison (1981). It carries the same distinctive abundant conodont fauna as that described by Jones (1935, 1941) from the black shale above the Dawson coal at Collinsville, Oklahoma, and that described by Swade (1982, 1985) from the thin shale below the Cooper Creek Limestone in Iowa. The lateral persistence of this conodont-rich horizon of sediment starvation provides the basis for internal stratigraphic differentiation of the Lost Branch Formation, and the distinctive nature of its conodont fauna allows lithic and faunal correlation of the Lost Branch along the midcontinent outcrop belt (figs. 7 and 8), and among cores across the subsurface of the Forest City basin (fig. 9).

The overlying fossiliferous gray shale (unit 6) at the type section carries a diverse macrofauna, including the brachiopod *Mesolobus*, which facilitated the shale's classification as Desmoinesian by Moore (1937, p. 34) and by Oakes and Jewett (1943) in nearby outcrops (Oakes and Jewett, 1943, sections 18, 21, and 22) in the Mound Valley area. It is possible that this horizon also is the fossiliferous shale collected about 3 mi (5 km) to the northeast as "Perry Farm" by Spencer (1978, p. 1360, locality 11).

The capping calcareous, fossiliferous sandstone horizon (unit 7 in fig. 6) was classified by Moore (1937, p. 34) as the base of the Missourian Series. It was regarded by Oakes and Jewett (1943, section 22) as the Hepler sandstone, which had been believed by Jewett (1940, p. 8) in his original description of the Hepler to grade laterally in central Labette County into a sandy limestone containing marine fossils. In a gully just to the southwest of the type section (location 3 in fig. 5), this fossiliferous sandstone is overlain by an underclay and a coal, which is overlain by a dark carbonaceous shale and a more friable sandstone (units 8–11 in fig. 6). Because the marine sandy limestone–calcareous sandstone (unit 7) is merely an upward continuation of the marine strata forming the main part of the Lost Branch Formation (units 4–6) and because the unit is overlain by a nonmarine coal with underclay and an associated sandstone (unit 11) that could be considered the Hepler sandstone, this marine sandstone is included as the top of the Lost Branch Formation. It is considered a probable northern time equivalent of the Glenpool limestone bed of Bennison (1984) in northeastern Oklahoma, rather than the lower bed of the Hepler as illustrated by Bennison et al. (1984, p. 25).

# Component units

Several previously named lithic units are recognized as components of the Lost Branch Formation along parts of the outcrop belt. Because not all units are present in the stratotype for the formation, they are briefly described with information appropriate to their definition and recognition.

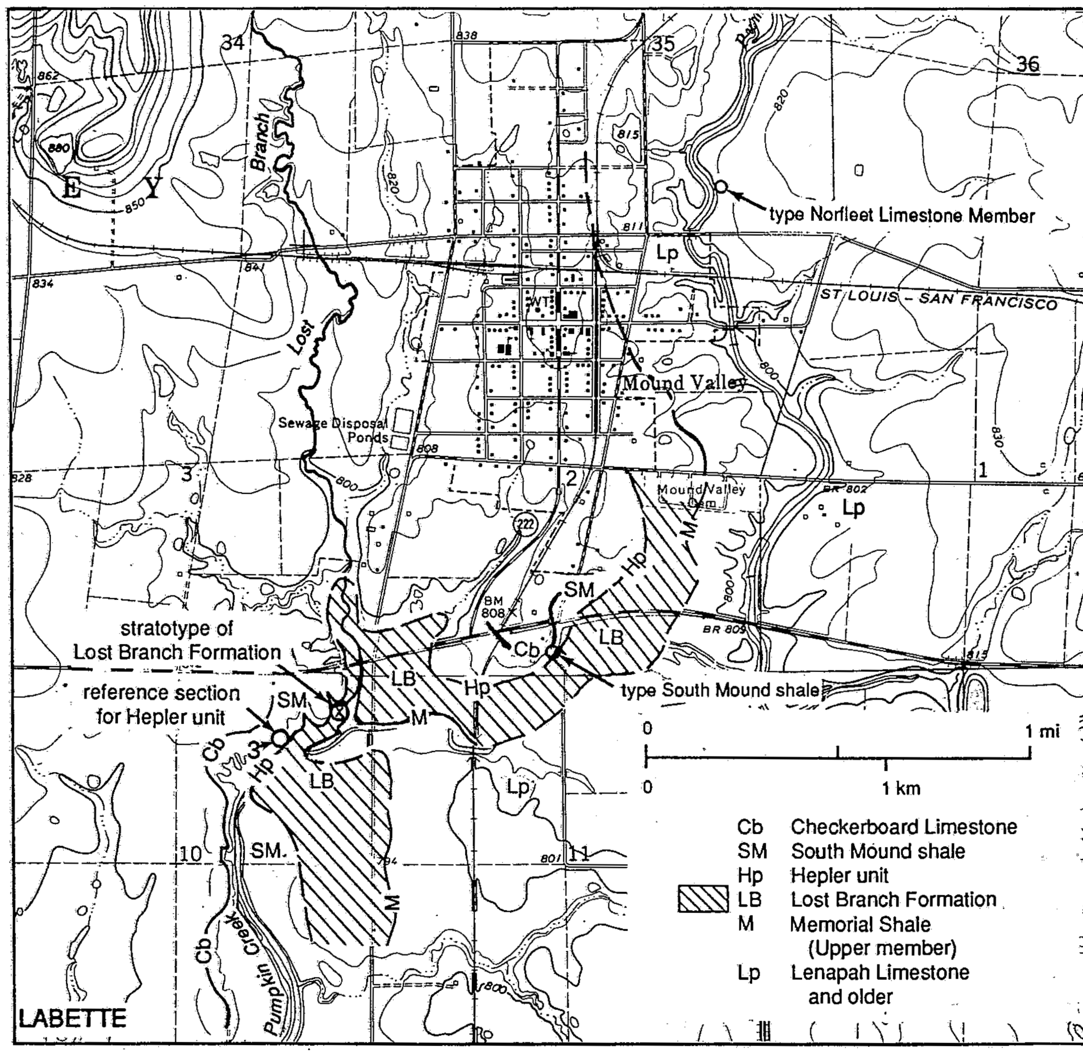
## Sni Mills Limestone Member

The Sni Mills Limestone Member was named by F. C. Greene (Moore et al., 1936, pp.18–20) from a creek bed exposure in NW sec. 28, T. 48 N., R. 29 W., at Sni Mills in Jackson County, east of Kansas City, Missouri (outcrop 7 in figs. 7 and 8). It was considered the upper member of the Lenapah Formation by Greene and Searight (1949) and was recognized as having priority over Jewett's (1941) name, Idenbro, for the upper member of the Lenapah Limestone in Kansas by Cline and Greene (1950), who suggested suppression of the name Idenbro. The Idenbro Limestone Member lies at the top of the Lenapah Limestone and below the Dawson coal in their type areas, whereas the Sni Mills Limestone Member lies above the horizon of the Dawson coal and is not part of the Lenapah but rather the basal bed of the Lost Branch Formation (fig. 8). Consequently, the Sni Mills and Idenbro Members are not correlative, and both names are retained as valid.

The Sni Mills Limestone Member is characteristically a single ledge of dense skeletal calcilutite like most other Pennsylvanian transgressive limestones, and it lies everywhere beneath a conodont-rich, gray to black phosphatic shale (fig. 8). Its field appearance was thoroughly described by Howe (1953). The Sni Mills Member ranges in thickness on outcrop from 1 ft (0.3 m) near the Kansas–Missouri border, thinning generally northward through 0.4 ft (0.1 m) in Missouri, to only 0.1 ft (0.03 m) in those cores in Iowa and southeastern Nebraska where it is still present (fig. 9). Southward, for example, at Trading Post, Kansas, it is developed as lenses up to 1 ft (0.3 m) thick that extend for several feet along the outcrop. The limestone grades laterally both northward and southward into the base of the overlying marine shale or into a diastemic surface between the overlying shale and the underlying terrestrial rocks. The Sni Mills Member carries an open-marine biota consisting largely of brachiopods, crinoid material, bryozoans, foraminifers, gastropods, and phylloid algal blades. A good principal reference section is a creek bank exposure 2 mi (3 km) south of the type section (outcrop 8 in figs. 7 and 8); other good exposures are in the bank of the Marais des Cygnes River at Trading Post, Linn County, Kansas (outcrop 11), and high in the railroad cut just northwest of Richmond, Missouri (outcrop 6).

## Cooper Creek Limestone Member

The Cooper Creek Limestone was named by Cline (1941, p. 65) from outcrops along tributaries to Cooper Creek in SE sec. 26, T. 69 N., R. 18 W., on the west side of Centerville, Appanoose County, Iowa (fig. 7). The principal reference section is an outcrop in the northwest corner of the old quarry


34
35
36
Branch
Lost
E
Y
type Norfleet Limestone Member
T.
32
S.
T.
33
S.
ST LOUIS - SAN FRANCISCO
Mound Valley
Sewage Disposal Ponds
Mound Valley Cem.
Lp
1
2
3
10
11
SM
Hp
LB
Cb
M
stratotype of
Lost Branch Formation
reference section
for Hepler unit
type South Mound shale
0
1 mi
0
1 km
Cb Checkerboard Limestone
SM South Mound shale
Hp Hepler unit
LB Lost Branch Formation
M Memorial Shale
(Upper member)
Lp Lenapah Limestone
and older
Pumpkin Creek
LABETTE

a

R. 18 E.

b

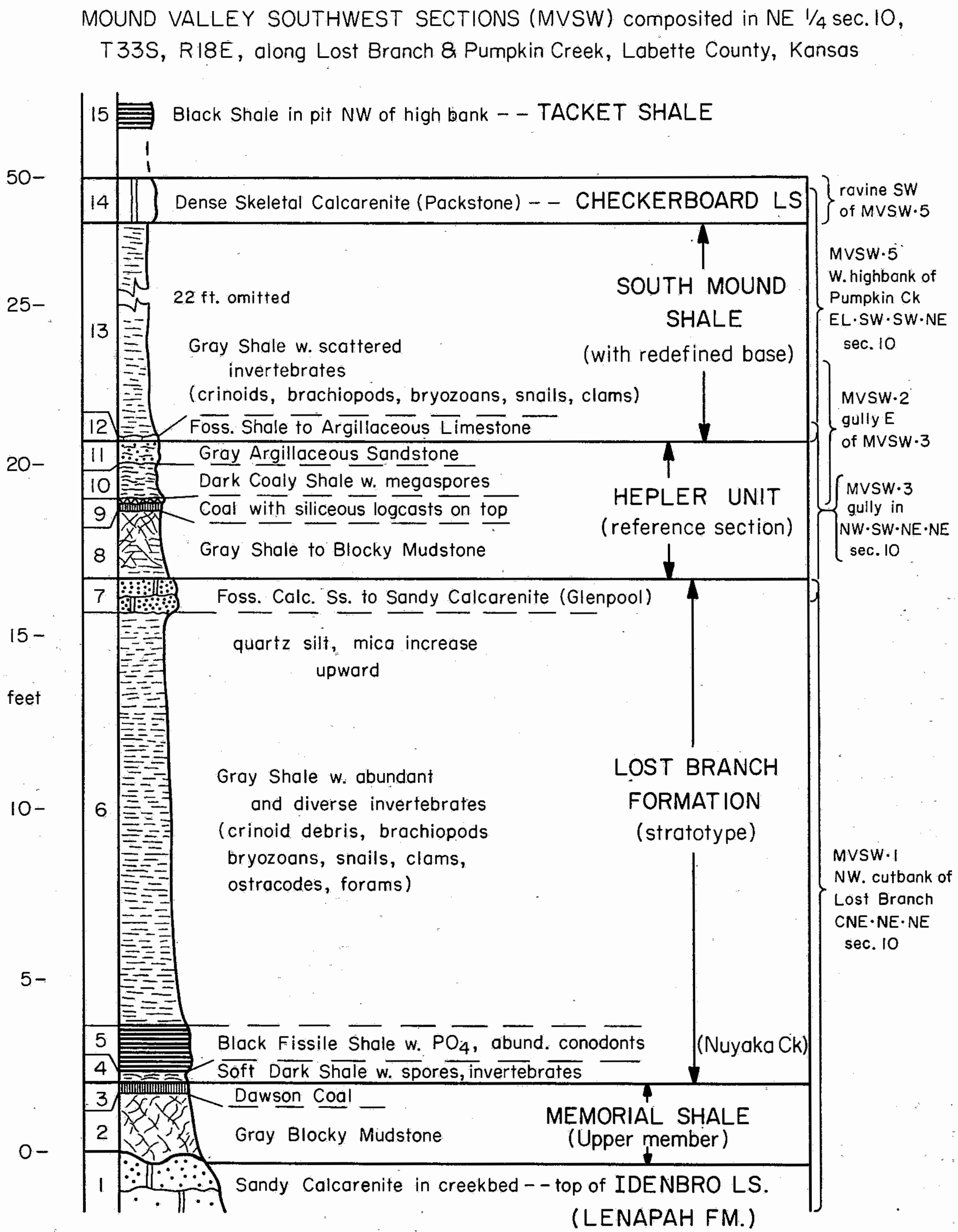



FIGURE 6—MEASURED SECTION OF STRATOTYPE of the Lost Branch Formation along Lost Branch. This figure is a composite with sections of higher strata exposed to the southwest in gullies and highbanks of Pumpkin Creek, all in NE sec. 10, T. 33 S., R. 18 E., 1 mi (1.6 km) southwest of Mound Valley, Labette County, Kansas. The exact locations of individual sections that form the composite are indicated on the right-hand side. The formal rank for the Hepler unit and the classification of it and higher units have not yet been decided. This section (outcrop 19 in figs. 7 and 8) is the same as that illustrated by Moore (1937, p. 34) and by Bennison et al. (1984, p. 25), both of whom identified unit 7, now defined as the top of the Lost Branch Formation, as all or part of the Hepler sandstone.

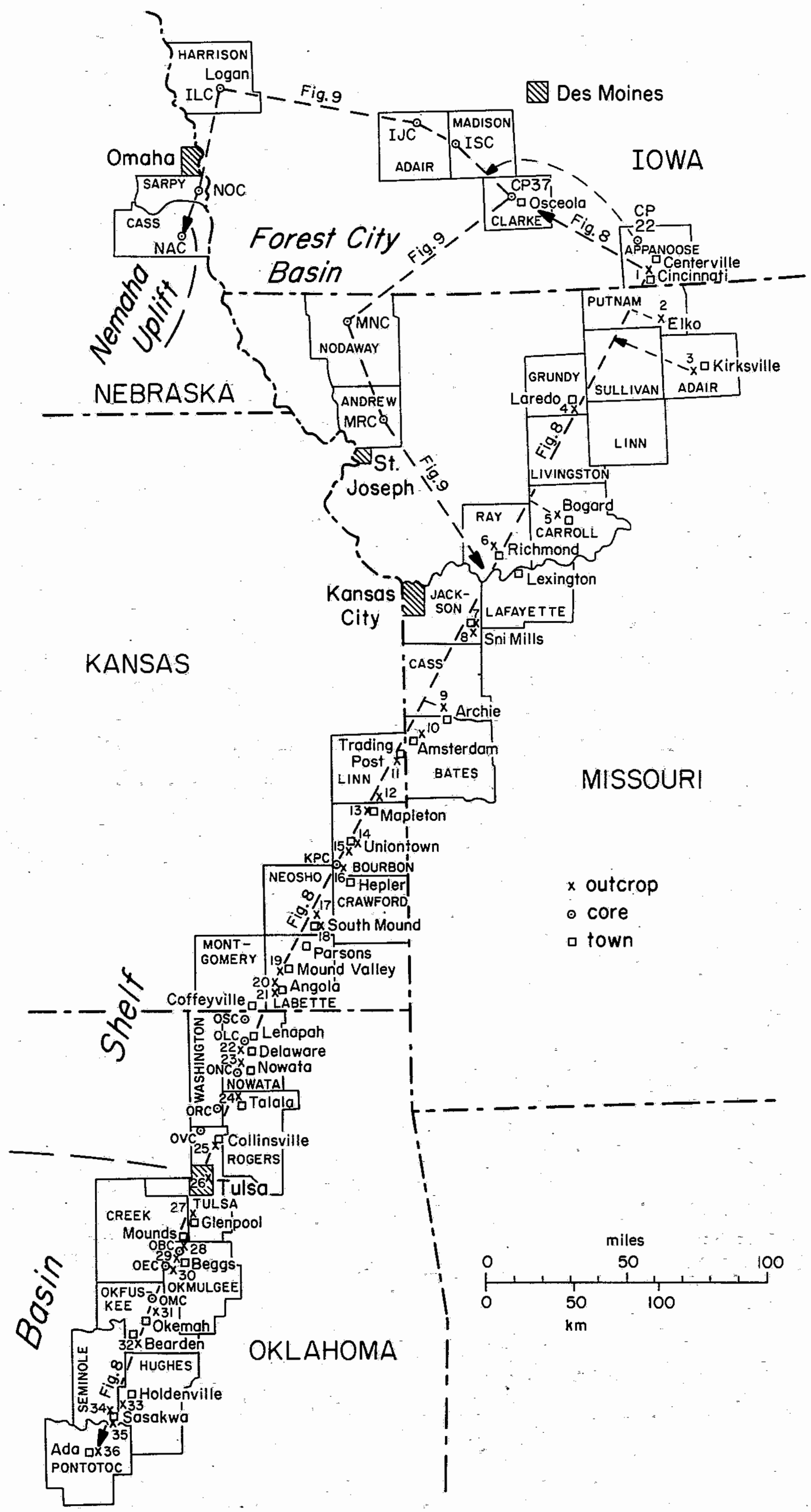
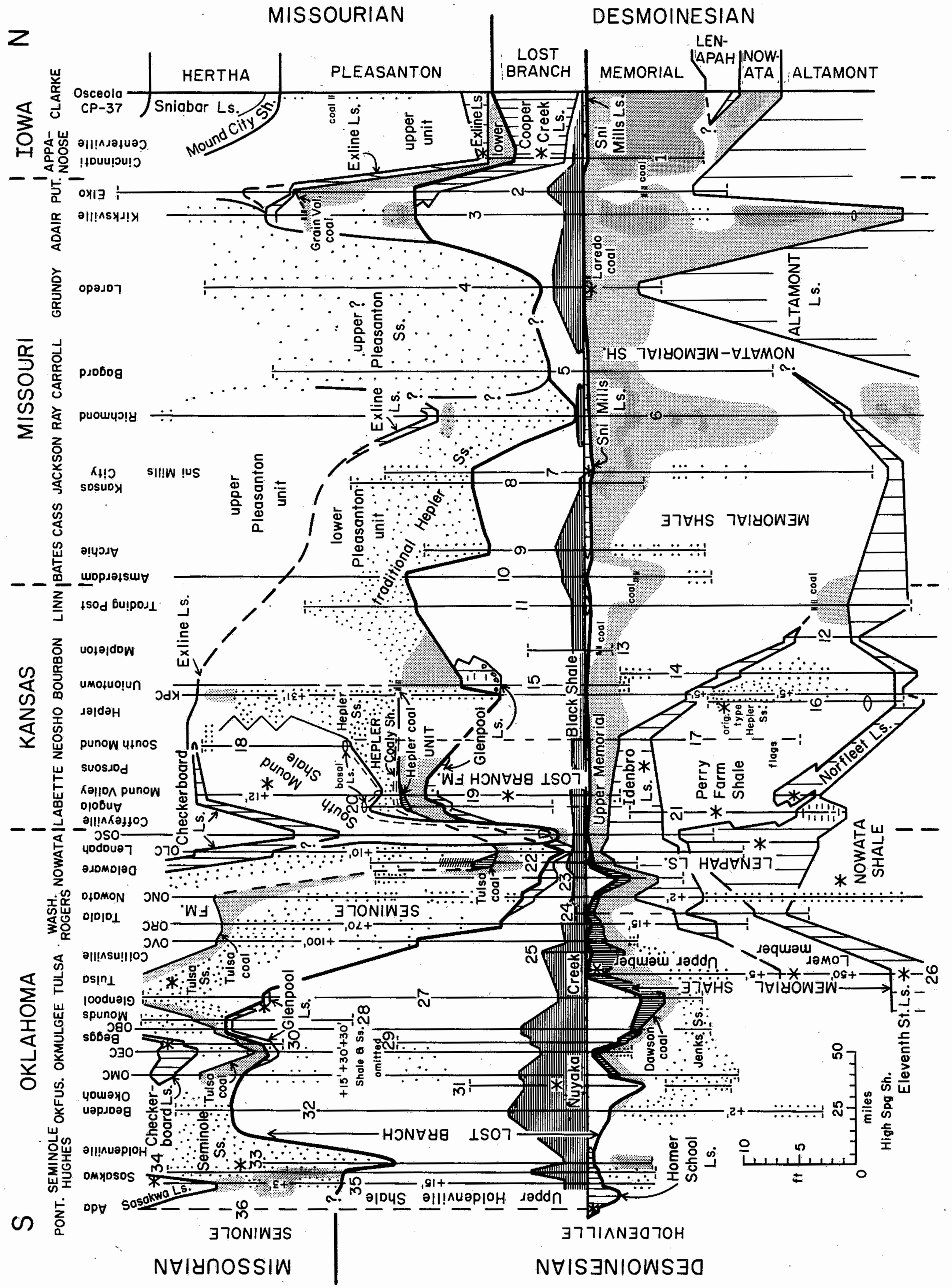



FIGURE 7—LOCATIONS OF EXPOSURES (×) of Lost Branch Formation and associated units along outcrop belt, locations of cores (lettered circle with dot) that contain Lost Branch strata, and lines of cross sections illustrated in figs. 8 and 9. Exact locations of all exposures and cores are given in the appendix.


MISSOURIAN
DESMOINESIAN
HERTHA
PLEASANTON
LOST BRANCH
MEMORIAL
LEN-APAH
NOW-ATA
ALTAMONT
N
S
IOWA
MISSOURI
KANSAS
OKLAHOMA
CLARKE
APPA-NOOSE
PUT.
ADAIR
GRUNDY
CARROLL
RAY
JACKSON
CASS
BATES
LINN
BOURBON
NEOSHO
LABETTE
NOWATA
WASH.
ROGERS
TULSA
OKMULGEE
OKFUS.
SEMINOLE
HUGHES
PONT.
Osceola CP-37
Centerville
Cincinnati
Elko
Kirksville
Laredo
Bogard
Richmond
Kansas City
Archie
Amsterdam
Trading Post
Mapleton
Uniontown
KPC
Hepler
South Mound
Parsons
Mound Valley
Angola
Coffeyville
OSC
OLC
Lenapah
Delaware
ONC
Nowata
ORC
Talala
OVC
Collinsville
Tulsa
Glenpool
Mounds
OBC
Beggs
OEC
OMC
Okemah
Bearden
Holdenville
Sasakwa
Ada
Sniabar Ls.
Mound City Sh.
Exline Ls.
upper unit
lower
Cooper Creek Ls.
Sni Mills Ls.
Grain Val coal
Laredo coal
ALTAMONT Ls.
upper ? Pleasanton Ss.
NOWATA-MEMORIAL SH.
upper Pleasanton unit
lower Pleasanton unit
traditional Hepler Ss.
MEMORIAL SHALE
Checkerboard Ls.
Mound Shale
Hepler Ss.
Coaly Sh.
Hepler coal
HEPLER UNIT
Glenpool Ls.
LOST BRANCH FM.
Black Shale
Upper Memorial
Idenbro Ls.
Perry Farm Shale
orig. type Hepler Ss.
flags
Norfleet Ls.
South Mound
LENAPAH LS.
NOWATA SHALE
Tulsa coal
SEMINOLE FM.
Upper member
Lower member
MEMORIAL SHALE
Tulsa Ss.
Creek
Nuyaka
Dawson coal
Jenks Ss.
Seminole Ss.
Checker-board Ls.
Sasakwa Ls.
LOST BRANCH
Upper Holdenville Shale
Homer School Ls.
Eleventh St. Ls.
High Spg Sh.
miles
ft
SEMINOLE
HOLDENVILLE
MISSOURIAN
DESMOINESIAN

the banks of Nuyaka Creek. The type section is just west of the O–56 bridge near the center east line of NE sec. 32, T. 12 N., R. 10 E. [emended from Bennison (1981)], 3 mi (5 km) northeast of Okemah, Okfuskee County, Oklahoma (outcrop 31 in figs. 7 and 8). Because of incomplete exposure at the type section, the principal reference section is chosen 12 mi (19 km) to the southwest in the ravine 2 mi (3 km) southeast of Bearden (outcrop 32), where a complete vertical sequence is exposed. The Nuyaka Creek black shale bed is traced southward through Hughes and Seminole counties, where it and adjacent lighter shales occupy the upper part of the Holdenville Shale, above the Homer School limestone bed and below the irregular basal sandstone of the Seminole Formation. The Nuyaka Creek black shale is typically hard and fissile as it is traced northward through numerous localities, including Beggs, Tulsa, Collinsville, and Nowata in Oklahoma [where it thins to about 1 ft (0.3 m)], Mound Valley, South Mound, Uniontown, Mapleton, and Trading Post in Kansas, and Amsterdam, Archie, Sni Mills, Richmond, Laredo, and Kirksville in Missouri (figs. 7 and 8). In north-central Missouri the black fissile shale facies grades laterally into a soft black clayey facies [e.g., near Kirksville (outcrop 3)] and into a dark-green-gray clayey but still phosphatic, conodont-rich shale facies along the Iowa outcrop belt and in most of the cores from the Forest City basin (fig. 9).

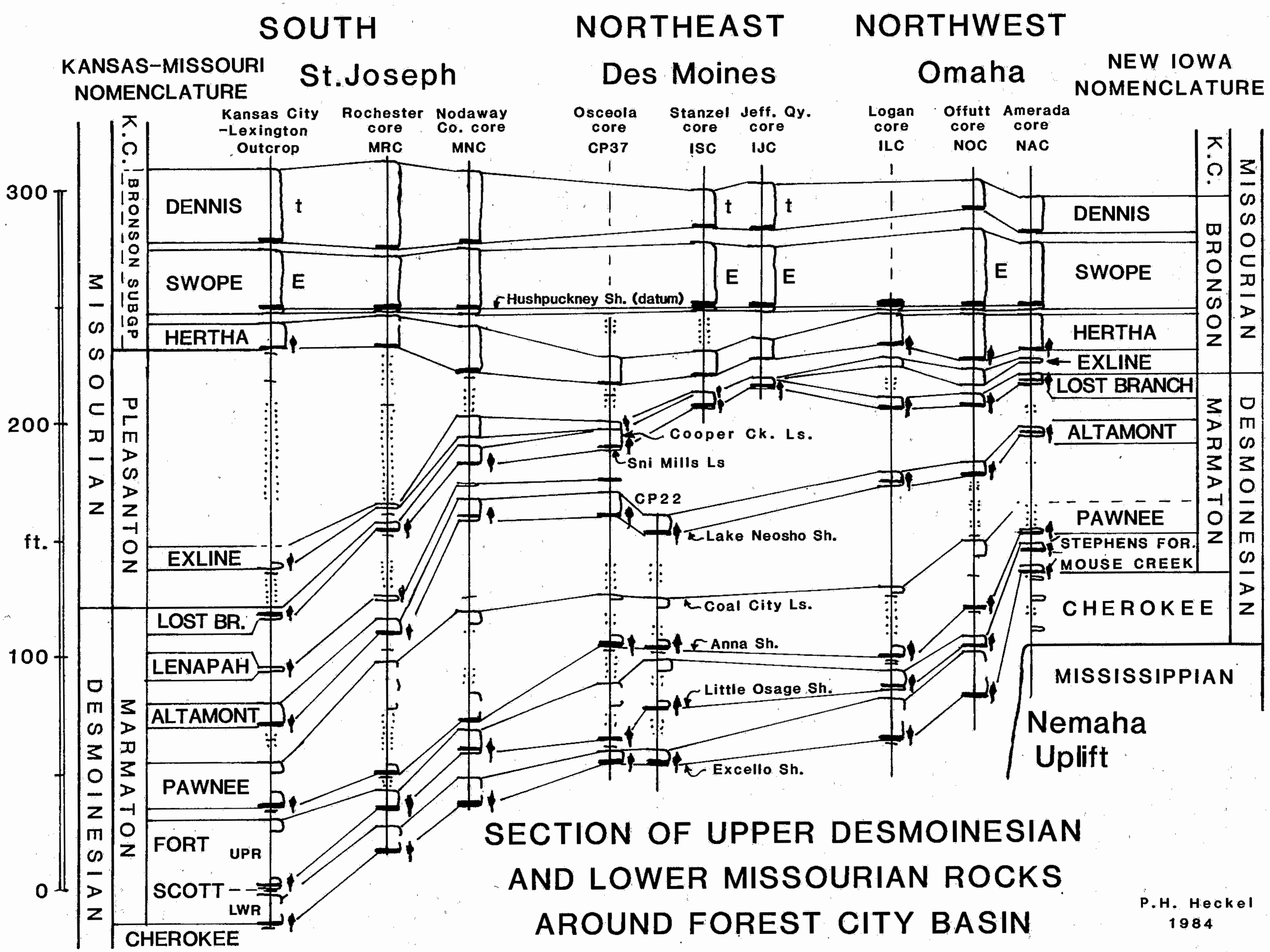
At present, it seems preferable to retain the name Nuyaka Creek for only the distinctive black shale bed as originally named, rather than to expand it to include all the gray marine shale within the Lost Branch Formation. The black shale facies is easily identified on gamma-ray logs in the subsurface of eastern Oklahoma (Bennison, 1981) and east-central Kansas (Sutton, 1985) (fig. 10). Throughout much of eastern Kansas the high gamma-ray peak of the Nuyaka Creek black shale readily marks the position of the Lost Branch Formation, 30–50 ft (9–15 m) above the black Lake Neosho Shale Member in the Altamont Limestone. This position also ranges from 50 ft (15 m) below the two black shales in the Tacket Formation in the south to 100 ft (30 m) or more below the lower Tacket (Mound City) black shale (classified in the Hertha Limestone) toward the north (fig. 10).

The fauna of the Nuyaka Creek black shale bed and its northern lateral equivalent is strongly dominated by a distinctive assemblage of conodonts, which are extremely abundant (10,000/kg) where the horizon is thinnest in the north. Limestone nodules in the black shale at Collinsville, Oklahoma, and Archie, Missouri, yield ammonoids (Miller and Owen, 1937; Boardman and Mapes, 1984).

The underlying thin gray shale (unit 4 of the stratotype; fig. 6) thickens southward at places to 3 ft (0.9 m) near Nowata and to 7 ft (2.1 m) locally near Glenpool, south of Tulsa, where it contains limestone concretions. This shale ranges from at least 5 ft (1.5 m) to less than 1 ft (0.3 m) farther southward, where its contact with the black shale becomes more transitional. The gray shale is at least in part the lateral equivalent of both the Sni Mills Limestone Member and the Homer School limestone bed (fig. 8). It contains a fauna of brachiopods, crinoid debris, and snails adjacent to the lens of Sni Mills limestone at Trading Post, Kansas.

The overlying gray shale unit ranges from 7 ft to 14 ft (2.1–4.3 m) in thickness in most of Kansas and Missouri down to a few inches beneath the Cooper Creek Limestone Member in Iowa. From 12 ft (3.7 m) at the Lost Branch type section (unit 6 in fig. 6) it thins southward to 1–2 ft (0.3–0.6 m) in Nowata County, Oklahoma, and thickens to 25 ft (7.6 m) near Glenpool, Tulsa County, all beneath the Glenpool limestone bed. Farther southward it ranges from 15 ft (4.6 m) to 55 ft (17 m) in east-central Oklahoma, where it grades upward into thin-bedded sandstones (as seen in the Oklahoma Geological Survey cores from Beggs to Okemah) and into red shales farther south (Dott and Bennison, 1981, pp. 18, 20). The gray shale is conspicuously fossiliferous in several places, such as around Mound Valley, Kansas, and Glenpool, Oklahoma, where brachiopods, crinoids, and bryozoans dominate the fauna, which also includes ostracodes, clams, and snails. At places southward, near Holdenville, mollusks of all types (Malinky, 1984) predominate in the lower part, along with ammonoids (Boardman et al., 1984). The fauna at the top near Sasakwa is dominated by brachiopods, especially chonetids, and includes bryozoans and crinoid debris. At least the upper part of this gray shale unit is the southern lateral equivalent

FIGURE 8 (opposite)—Cross section along outcrop of Lost Branch Formation (delimited by thickest lines) and adjacent strata, based on measured sections (numbered or lettered vertical lines) located in fig. 7 and described in the appendix. Horizontal scale is approximate. Vertical exaggeration is roughly 26,000 times. Where a thick unit would cause excessive vertical distortion, the amount of footage that is indicated by a plus sign is omitted. The main datum is the base of the black fissile, phosphatic shale horizon (Nuyaka Creek black shale bed) and the equivalent conodont-rich gray shale. Lithic symbols are standard or labeled, with carbonate widely vertically lined, coal closely vertically lined, blocky mudstone ("clay") lightly shaded, red mudstone more darkly shaded, and gray shale left blank or marked by dashes within limestone unit. Type sections or type areas of named units are marked with asterisks. See fig. 9 for relations in Iowa, Nebraska, and northwestern Missouri. Sources of measured sections and other stratigraphic information are given in the appendix.




SECTION OF UPPER DESMOINESIAN AND LOWER MISSOURIAN ROCKS AROUND FOREST CITY BASIN

P.H. Heckel
1984

of the Cooper Creek Limestone Member from Missouri southward, and the top of this shale in places is the lateral equivalent of the lenticular Glenpool limestone bed.

The best exposed and most easily accessible reference sections of the Nuyaka Creek black shale bed are found in the river bank at Trading Post, Kansas (outcrop 11 in fig. 8), in the railroad cut north of Richmond, Missouri (outcrop 6), in the creek bed at Walley Mound near Amsterdam, Missouri (outcrop 10), in the Lost Branch stratotype near Mound Valley, Kansas (outcrop 19), in the stream bank at the tank farm north of Glenpool, Oklahoma (outcrop 27), and at the principal reference section in the ravine near Bearden, Oklahoma (outcrop 32). The adjacent shales are best exposed near Sni Mills (outcrop 8), Trading Post (outcrop 11), Lost Branch (outcrop 19), Glenpool (outcrop 27), Bearden (outcrop 32), and Sasakwa (outcrop 35, especially the upper part).

## Glenpool limestone bed

The Glenpool limestone bed was named informally by Bennison (1984, p. 118) from an outcrop on US–75, along the west line of SW-NW-NW sec. 23, T. 17 N., R. 12 E., just south of Glenpool, Tulsa County, Oklahoma. The principal reference section showing the bed's relationship to the rest of the Lost Branch Formation is found northward 3 mi (5 km) along US–75 (west line of NW-NW-SW sec. 2, T. 17 N., R. 12 E.; outcrop 27 in figs. 7 and 8). The Glenpool bed is nearly everywhere 1 ft (0.3 m) or less of orange- to yellow-weathering, impure limestone to dolomite and ranges from sandy to shaly skeletal calcarenite to calcilutite. It can be traced from the type section northward about 3 mi (5 km), where it becomes lenticular and eventually disappears in the Tulsa–Collinsville region. Southward the Glenpool can be traced past Beggs in Okmulgee County, where it becomes quite sandy. It reappears northward in Nowata County and again around Mound Valley in Labette County, Kansas, where it is unit 7 in the Lost Branch stratotype (fig. 6); here the Glenpool is again sandy enough in places to have been misidentified as the Hepler sandstone. Northward, near Uniontown (outcrop 15) in Bourbon County, the Glenpool limestone bed is composed of a conglomeratic limestone overlain by fossiliferous shale and shaly limestone that aggregate a sequence 4 ft (1.2 m) thick. Where contacts are observed, the Glenpool limestone bed is underlain by gray fossiliferous marine shale of the upper Lost Branch Formation and overlain by underclay and coal or sandy shale and sandstone of the overlying formation (fig. 8).

The Glenpool limestone bed contains an abundant and diverse marine biota dominated in most places by brachiopods, bryozoans, and crinoid debris but locally by phylloid algae (northwest of Nowata, outcrop 23). The biota also includes snails, clams, foraminifers, ostracodes, and coaly plant fragments. The Glenpool is laterally equivalent to the top of the gray fossiliferous shale that overlies the Nuyaka Creek black shale bed, and the lateral transition is displayed locally by the extremely shaly sequence near Uniontown. Because it is regressive and more basinal, the Glenpool is probably slightly younger than the top of the Cooper Creek Limestone Member of Iowa. Other reference sections include the ravine exposure near Uniontown (outcrop 15 in figs. 7 and 8); the Lost Branch Formation stratotype (outcrop 19); a creek bank near the KGGF radio tower (outcrop 20) about 4 mi (6.4 km)

FIGURE 9 (opposite)—Cross section of upper Desmoinesian (Marmaton Group) and lower Missourian (Pleasanton Group and Bronson subgroup) strata around the Forest City basin based on cores (located in fig. 7) and on outcrops in the Kansas City–Lexington area of Missouri [compiled from Cline (1941), Howe (1953, 1982), and Parizek and Gentile (1965, p. 16)]. The names shown are mainly those of marine, dominantly limestone formations. The new Iowa nomenclature is that of Ravn et al. (1984). Correlations are based on characteristic conodont faunas for those units marked with "tailed-diamond" symbols, after the zonation of Swade (1985; based on faunas in cores CP–37 and CP–22) and supplemented by later work and on fusulinid faunas for those units marked with "E" (*Eowaeringella ultimata*) and "t" (lowest triticitids), based on identifications by J. R. Meacham, as reported by Heckel and Meacham (1981). Units in the Amerada core (NAC) were correlated by Condra (1939) as follows: Altamont Limestone with Pawnee Limestone (questioned); Lost Branch Formation with Hertha Limestone; Exline limestone with Middle Creek Limestone Member (lower Swope Limestone); Hertha Limestone with Bethany Falls Limestone Member (upper Swope Limestone); Swope Limestone with Dennis Limestone (Winterset Limestone Member); and Dennis Limestone with parts of Westerville Limestone Member and Cherryvale Formation. The Dennis Limestone later was termed the Sarpy Formation in Nebraska (Condra, 1949, p. 37) and correlated with the three middle members (Block, Wea, and Westerville) of the Cherryvale Shale of Kansas; according to correlations established by conodonts and fusulinids shown here, "Sarpy" is a junior synonym for the Dennis Limestone. Locations of all cores and brief descriptions of the Lost Branch Formation and adjacent strata in them are given in the appendix.

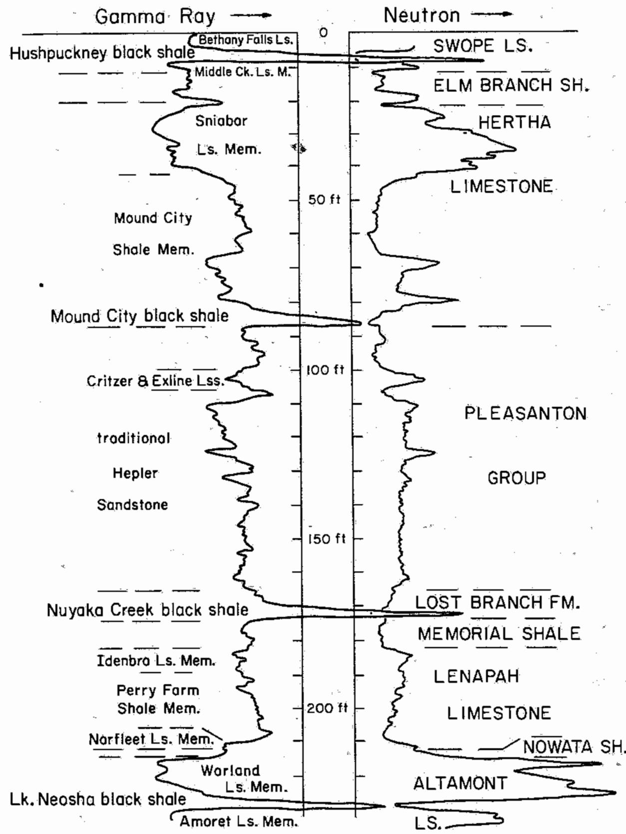



FIGURE 10—GAMMA-RAY AND NEUTRON LOGS of cored well drilled west of Prong Creek (KPC in fig. 7) in southwestern Bourbon County, 9 mi (15 km) south-southwest of Uniontown. The logs show the characteristic signatures of stratigraphic units recognized in this core and described in the appendix. Note the distinctive high gamma-ray ("hot") signature of the Nuyaka Creek black shale bed of the Lost Branch Formation in its typical position low in the thick sequence of shale with scattered sandstone and thin limestones that lies above the distinctive Altamont Limestone with its medial "hot" shale (black Lake Neosho Shale Member) and below the three characteristic thick limestones (Hertha, Swope, and Dennis) of the lower Kansas City Group (Bronson subgroup). The next "hot" shale upward (basal black shale bed of the Mound City Shale Member of the Hertha Limestone, just above the top of the Pleasanton Group) converges northward with the Sniabar Limestone Member of the Hertha Limestone; southward it becomes the lower black shale in the Tacket Formation as it converges with the higher "hot" black Hushpuckney Shale Member, which becomes the upper Tacket black shale south of the pinchout of the Sniabar Limestone Member. Note that without conspicuous sandstone at the base of the Pleasanton in the traditional Hepler interval, the top of the Lost Branch Formation (hence the Desmoinesian–Missourian boundary as currently identified) is difficult to determine on geophysical well logs. Note also that without conspicuous limestone in the Lenapah interval, the entire interval from the Altamont Limestone to the Lost Branch Formation becomes undifferentiated Nowata–Memorial Shale. Kansas Geological Survey, Troike #1, SE-SE-NE-SE sec. 5, T. 27 S., R. 22 E., Bourbon County, Kansas.

southwest of the Lost Branch type section; in Wolf Creek west of Delaware, Oklahoma (outcrop 22); along Mormon Creek northwest of Nowata (outcrop 23); along South Duck Creek west of Alt. US–75, south of Mounds (outcrop 28); and in the creek bed near Dentonville, southwest of Beggs in Okmulgee County (outcrop 30).

# Contacts

The lower contact of the Lost Branch Formation at the type section is the contact between the base of the lower dark-gray shale (unit 4 in fig. 6) and the top of the Dawson coal (unit 3). The Dawson coal is traceable southward through the Tulsa region into Okfuskee County and therefore provides a good marker horizon below the base of the Lost Branch throughout the area (fig. 8). Northward the Dawson coal thins and becomes discontinuous where the Lost Branch is seen in Kansas and most of Missouri, but the gray blocky mudstone (unit 2 in fig. 6) that underlies the Dawson coal as its seat earth extends far beyond the extent of the coal and serves as an excellent marker horizon below the base of the Lost Branch, whether the coal is present or not. Similar blocky mudstones that locally are seat earths are paleosols that represent widespread emergence and subaerial weathering for some period of time (Schutter and Heckel, 1985; Goebel et al., 1989). Consequently, the lower contact of the marine Lost Branch Formation is a terrestrial surface upon which marine transgression took place. Therefore the contact is a disconformity, and there may be slight angular discordance near Laredo, Missouri, where the Lenapah Limestone is absent (outcrop 4 in fig. 8). Thus recognition of the surface that separates marine deposits above from terrestrial deposits below helps to determine the basal contact of the Lost Branch Formation in areas where lithologies are different from those at the type section. For example, the Sni Mills Limestone Member, which forms the base of the Lost Branch Formation in much of Missouri, typically overlies blocky mudstones, called "clays" or shale with "conchoidal fracture" by Howe (1953), as well as local sandstone, sandy shale, and coal. The Homer School limestone bed, at the base of the Lost Branch Formation in east-central Oklahoma, typically overlies gray to reddish silty shale to sandstone, considered fluvial in origin by Dott and Bennison (1981).

The upper contact of the Lost Branch Formation is not well exposed in the stratotype, where the capping fossiliferous calcareous sandstone (unit 7 in fig. 6) forms the top of the exposure. However, in a small gully just to the southwest (location 3 in fig. 5a) the overlying strata exhibit a sharp contact with the calcareous sandstone. These overlying beds are termed the Hepler unit (see the later discussion on this unit) and consist of an ascending sequence of blocky mudstone (unit 8 in fig. 6), which probably is a paleosol, overlain by a coal informally called the "Hepler" coal (unit 9); this is overlain in turn by a dark coaly shale that contains only megaspores (unit 10) and a friable sandstone considered the traditional Hepler sandstone (unit 11), both representing alluvial deposits. Thus the strata overlying the type Lost Branch Formation also are terrestrial, with a paleosol representing subaerial exposure at the upper contact of the Lost Branch. This is the general situation seen along much of the outcrop belt, except where later channeling has removed the higher strata, as in the South Coffeyville Core (OSC) taken just south of the Kansas–Oklahoma border (fig. 8). Where the upper limestones (Cooper Creek, Glenpool) exist in the Lost Branch Formation, each stands out conspicuously as a marine bed belonging to the Lost Branch, and the upper formational contact is placed at its top. The Cooper Creek and Glenpool limestones are overlain in most places by blocky mudstone. Where the top of the Lost Branch is shale, any noticeable upward change from fossiliferous marine shale to unfossiliferous terrestrial shale or sandstone is chosen as the contact. Where Lost Branch shale is overlain by unfossiliferous sandstone that is not definitely part of the continuous marine sequence (as unit 7 is at the type section), the contact is placed at the lowest conspicuous, laterally persistent sandstone bed (fig. 8); this type of contact is also seen along much of the outcrop, and it may mark either an upward transition into a shoreline distributary mouth bar or terrestrial deposit, or a minor erosional disconformity below a later alluvial channel.

# Basis for correlation

The main basis for chronostratigraphic correlation of the Lost Branch Formation along the midcontinent outcrop belt and into the subsurface is the upper Desmoinesian conodont biostratigraphy established in Iowa by Swade (1982, 1985). Other biostratigraphic investigations currently underway by D. R. Boardman, R. H. Mapes, and D. M. Work on ammonoids and by R. A. Peppers on palynomorphs will be published in detail elsewhere. Their findings so far are in accord with the conodont information with respect to vertical and lateral extent and correlation of the Lost Branch Formation.

## Conodonts

Swade (1985) established a biostratigraphic zonation for six major upper Desmoinesian marine horizons in two overlapping cores from south-central Iowa (CP–22 and CP–37 in figs. 7 and 9). Swade characterized the conodont faunas from the Oakley Shale Member [lower Swede Hollow (=Verdigris) Formation], the Excello Shale Member (lower Fort Scott Limestone), the Little Osage Shale Member (upper Fort Scott Limestone), the Anna Shale Member (Pawnee Limestone), the Lake Neosho Shale Member (Altamont Limestone), and the shale below the Cooper Creek Limestone Member, now recognized as part of the Lost Branch Formation (figs. 8 and 9). As a result of Swade's tutelage before his untimely death in March 1983, my students and I have been able to supplement this zonation above and below the Lost Branch Formation for the underlying Lenapah Limestone (Parkinson, 1982; Greenberg, 1986) and for the overlying Tacket Formation in southern Kansas and Oklahoma (Pavlicek, 1986) and the Exline limestone in Missouri and Iowa (Nielsen, 1987). The horizon of the Lenapah Limestone in the Iowa core (CP–37) that Swade (1982) studied is occupied by a nondiagnostic nearshore *Adetognathus* fauna [D. Lipsius–Swade, in Swade (1985)], and Greenberg (1986) showed that the diagnostic forms of *Neognathodus* appear in this horizon only as far north as north-central Missouri.

A brief résumé of the conodont faunas of the Altamont, Lenapah, Lost Branch, and Exline horizons is presented next to establish the uniqueness of the fauna characterizing the Lost Branch Formation.

The Lake Neosho Shale Member, which is the medial phosphatic shale of the Altamont Limestone, carries a distinctive fauna [scratch marks (#) in figs. 3 and 4] dominated by many species of *Neognathodus* and by *Idiognathodus* sp. 5 of Swade (1985), a distinctly troughed form that appears to be nearly confined to this horizon. *Idioprioniodus* is also present, but *Gondolella* is absent. This fauna has been recovered from the Altamont in other cores from Iowa, Nebraska, and Missouri (fig. 9), from the type section of the Lake Neosho Shale Member in Neosho County, Kansas, and from localities that had been regarded as the base of the Nowata Shale (fig. 3) in the Tulsa area. It also has been found in samples of the Tuckabatchee shale of Bennison (1984) and the underlying limestone [Yeager limestone of Bennison (1981)] from several localities in east-central Oklahoma.

The basal beds of the Lenapah Limestone carry an extremely distinctive fauna [plus signs (+) in figs. 3 and 4] dominated by a small species of *Neognathodus*, described as new by Parkinson (1982, pp. 86–87) after consultation with J. W. Swade; it is illustrated by Greenberg (1986, fig. 28). This fauna includes other species of the same genus [described by Merrill (1975)] and contains a small number of *Adetognathus*. However, unlike any other fairly widespread marine horizon in the midcontinent Desmoinesian–Missourian marine sequence, this fauna contains only a small number of *Idiognathodus*, many of which are juvenile. Both *Idioprioniodus* and *Gondolella* are absent. This fauna has been found in the Eleventh Street limestone at several localities from a new exposure south of Tulsa to the Lenapah type area, in the basal bed of the Norfleet Limestone Member at its type section at Mound Valley, and in other shale and limestone beds assignable to the Norfleet at several localities in southeastern Kansas and northwestern Missouri (including core MRC in fig. 9); *Adetognathus* progressively increases in proportion northward (Greenberg, 1986). A similar fauna consisting entirely of several species of *Neognathodus* was recovered from a shale sample collected by A. P. Bennison, 70 ft (21 m) below the Nuyaka Creek black shale bed (Lost Branch Formation) and 20 ft (6.1 m) above the lower Holdenville sandstone south of Okemah and southeast of Bearden (near outcrop 32 in figs. 7 and 8) in Okfuskee County near the type area of the Holdenville Shale; this is a horizon that Bennison (1984, p. 115) has designated informally as the High Spring shale (figs. 4 and 8).

The thin shale below the Cooper Creek Limestone Member (Lost Branch Formation) in the Iowa core studied by Swade (1982, 1985) carries a distinctive conodont fauna dominated by *Idiognathodus* sp. 6 of Swade (1985), which is another distinctively troughed form and one that appears nearly confined to this horizon. *Idiognathodus* sp. 1 of Swade (1985), *Gondolella* sp. 3 of Swade (1985), *Idioprioniodus*, and several species of *Neognathodus* are also present. All these forms were illustrated by Jones (1935) from the black shale above the Dawson coal at Collinsville, Oklahoma (outcrop 25 in fig. 8), where they have been confirmed by re-collection. I have recovered this fauna from a single horizon in several cores in Iowa, Nebraska, and Missouri (fig. 9) and from many outcrops of the black shale at the base of the Holdenville Shale as previously recognized in Missouri and Kansas, from the black shale above the type Laredo coal near Laredo, Missouri (Howe, 1953, p. 26), which had been referred to the Nowata formation, from the black shale above the Dawson coal at many localities extending from southern Kansas to well south of Tulsa, and from the upper Holdenville Shale in its type area in east-central Oklahoma [all indicated by hatch marks (///) in figs. 3 and 4]. It also has been recovered from a green-gray shale in the lower part of the Lonsdale Limestone Member at a locality between Galesburg and Peoria, Illinois (which was studied by J. W. Swade for his Senior Honors thesis project at Knox College), and from a gray shale in the West Franklin Limestone Member in a core taken at Charleston in east-central Illinois. This widespread distinctive fauna allows correlation of the Lost Branch Formation not only all along the midcontinent outcrop belt and into the near subsurface but also into the Illinois basin, where it confirms Weller et al.'s (1942) correlation of the Lonsdale Member with the Cooper Creek Limestone Member of Iowa.

The fauna of the Exline limestone, which lies with apparent disconformity on top of the Cooper Creek in Iowa core CP–37 studied by Swade (1985), is strongly dominated by a species of *Idiognathodus* that has a relatively narrow, flat to slightly troughed platform marked by distinct transverse ridges. This species was included within *Idiognathodus* sp. 1 by Swade (1985) and Pavlicek (1986). Small numbers of *Adetognathus*, *Anchignathodus*, and *Idioprioniodus* are also present. *Neognathodus* and *Gondolella* are absent. This fauna has been recovered from both limestone and shale at several Exline localities throughout north-central and western Missouri and in eastern Kansas and eastern Oklahoma, where Pavlicek (1986) found it in the base of the Tacket Formation (fig. 4). Northwestward in cores from western Iowa and Nebraska, *Adetognathus* increases in abundance to dominate the fauna in the Exline limestone (Nielsen, 1987).

## Ammonoids

Boardman et al. (1984) briefly summarized the current knowledge of ammonoid generic occurrences in the midcontinent. Boardman and Mapes (1984) discussed the changeover in ammonoid species at the Desmoinesian–Missourian boundary and explicitly corrected the miscorrelation of the Collinsville locality and the resulting confusion that arose when Miller and Owen (1937) regarded the ammonoid fauna there as early Missourian. Boardman and Mapes (1984) showed that the Collinsville fauna is equivalent to faunas from the upper Holdenville Shale in its type area and from the base of the Holdenville Formation as previously recognized in Missouri. Chatelain (1984) described a number of new ammonoid species from Oklahoma, including the Collinsville locality. Most recently, Boardman et al. (in press) have updated the ammonoid biostratigraphy for the Desmoinesian–Virgilian sequence in the midcontinent.

## Palynomorphs

Pearson (1975) and Wilson (1979, 1984) first reported the strong Desmoinesian affinities of the flora in the Dawson coal in northeastern Oklahoma and removed it from the Missourian Stage, where it had been placed by Moore et al. (1937). Wilson (1979, 1984) also suggested placing the next higher coal, which he termed "Seminole," in the Desmoinesian as well. From work on the palynomorph floras from a number of midcontinent coal samples spanning the Desmoinesian–Missourian boundary that I provided, R. A. Peppers (personal communications, 1981–1984) has emphatically confirmed the Desmoinesian age of the Dawson coal at several localities in Oklahoma and Kansas and of the Laredo coal from its type section in Missouri. Both of these coals underlie the Lost Branch Formation.

The coals in the Hepler unit overlying the Lost Branch [called "Hepler coal" in Kansas and "Tulsa" (instead of "Seminole") coal in Oklahoma by Bennison (1984)], however, show a great reduction in the diversity of palynomorphs and a reduction in dominant Desmoinesian forms, such as *Lycospora* and *Thymospora*, to less than 1% of the flora, along with the loss of *Cappasporites* (R. A. Peppers, personal communication, 1984). This is sufficient evidence to regard these coals as Missourian, as all Missourian coals are characterized by low-diversity palynomorph floras dominated by fern spores and containing abundant sphenopsid spores, even though a few forms of Desmoinesian affinity, especially *Lycospora*, are found in places. All other coals in the Pleasanton Group, including the Grain Valley coal, the

Locust Creek coals, and the Ovid coal (fig. 4), have palynomorph floras of definite Missourian age (R. A. Peppers, personal communication, 1984).

### Fusulinids

Although fusulinids have been the fossil on which much Pennsylvanian biostratigraphy has been based [e.g., Thompson et al. (1956) and Thompson (1957)], this group is reduced greatly in abundance in most horizons close to the Desmoinesian–Missourian boundary (Boardman and Mapes, 1984). Fusulinids have not been reported from the Exline limestone (G. J. Verville, personal communication, 1983) and were not found in a recent petrographic study by Nielsen (1987). Fusulinids are common in the Cooper Creek and Lonsdale Limestone Members and have been reported from the Homer School limestone bed by Morgan (1924, p. 104). Fusulinids from the Cooper Creek Limestone Member belong to the genus *Fusulina* (*Beedeina*), which dominates the Desmoinesian sequence (Thompson et al., 1956), and thus confirm the Desmoinesian age of the Lost Branch Formation.

### Desmoinesian–Missourian boundary

Based on the foregoing discussion and more recent findings, the boundary between the Desmoinesian and Missourian stages (and thus also between the Middle and Upper Pennsylvanian series as recognized in Kansas) is recognized biostratigraphically in the midcontinent, the type area for both stages, on the basis of changeovers in a number of different groups. The highest occurrences of the following taxa mark the top of the Desmoinesian: the conodont genus *Neognathodus* and *Idiognathodus* sp. 6 of Swade (1985), the ammonoid genus *Gonioglyphioceras*, the fusulinid genus *Beedeina*, the brachiopod genus *Mesolobus*, and the palynomorph genus *Cappasporites*. All the foregoing invertebrates are found in the Lost Branch Formation but not in the overlying marine beds, and the palynomorph is found in the Dawson coal but not in the overlying coals. The lowest occurrences of the ammonoid *Pennoceras* are in shale associated with the horizon of the Exline limestone near Uniontown, Kansas, and in equivalent shale near Sasakwa, Oklahoma (Boardman et al., 1989). Morphotypes of *Idiognathodus* sp. 1 of Swade (1985) in the South Mound shale and Exline limestone (fig. 4) in Kansas may be distinct enough from those in the Lost Branch Formation to set them off as a different species that first appears in the base of the Missourian. Further considerations with respect to the Desmoinesian–Missourian boundary are summarized by Boardman et al. (1989), who point out that the exact ranges of the critical taxa need to be documented in more detail from continuously exposed sequences across the boundary before a boundary stratotype can be chosen. As an aid in this undertaking, the appendix gives the highest occurrence of the conodont *Neognathodus* in all sections in which I found it above the Nuyaka Creek black shale bed, where it is typically quite common. In the meantime, the Lost Branch Formation–Hepler unit contact is regarded as the Desmoinesian–Missourian boundary for the present purposes, although this contact is slightly diachronous from place to place because of its lithic definition.

## Memorial Shale (revised)

The name Memorial Shale is revived and revised herein to apply to the largely terrestrial formation that underlies the Lost Branch Formation. The name Memorial was originally applied to shale extending upward from the top of the Eleventh Street limestone to the "base of the Seminole Formation" in the Tulsa area by Dott (1941). It is revised herein to extend farther upward to include the Dawson coal bed and its seat earth and their lateral equivalents, which underlie the Lost Branch Formation along the entire outcrop belt. The type section is that originally selected by Dott (1941), with the higher beds added from nearby (outcrop 26 in fig. 8). This upward extension of the Memorial Shale is a reasonable consequence of the more recent discoveries (explained previously) that the Dawson coal, the overlying marine strata (Lost Branch Formation), and the underlying sandy beds ("lower Seminole sandstone") are Desmoinesian in age, equivalent to the upper part of the type Holdenville Shale and therefore not part of the Seminole Formation. Thus the former upper contact of the Memorial Shale at the base of the "lower Seminole sandstone," which was believed to be the Desmoinesian–Missourian unconformity, loses its stratigraphic significance. This loss of significance and the general observation that most sandstones by their depositional nature are notoriously lenticular within more widespread shale-dominated horizons of terrestrial to deltaic strata render basal sandstone contacts far less desirable as formation boundaries than the widespread regressive exposure surfaces upon which marine transgression took place. Such an exposure surface now forms the revised upper boundary of the Memorial Shale at the base of the Lost Branch Formation.

The informal name Jenks sandstone has been used by Bennison (1984) for the sandstones that lie below the Dawson coal horizon and that previously were incorrectly considered the "lower Seminole sandstone." Because this zone of sandstones is sufficiently persistent through Tulsa County and southward to warrant a name, the term Jenks sandstone is herein regarded as a useful but informal subdivision of the Memorial Shale where the sandstone facies is present.

Because the Memorial Shale, as redefined, extends from the top of the Eleventh Street limestone, which is equivalent to only the Norfleet Limestone Member (the lower member of the Lenapah Limestone), up to the base of the Lost Branch Formation, the revised Memorial Shale is equivalent to the medial Perry Farm Shale Member and the upper Idenbro Limestone Member of the Lenapah Limestone and to the strata lying above the Idenbro and below the Lost Branch (figs. 4 and 8). Furthermore, because a marine horizon recognized below the Jenks sandstone at several places in the Tulsa region is the probable southern equivalent of the Idenbro Limestone Member (Bennison, 1984), the revised type Memorial Shale (outcrop 26 in fig. 8) can be subdivided into three informal members (lower, middle, and upper) with known northern equivalents.

The lower member is a 60-ft (18-m) thick sequence of silty shale with thin-bedded sandstone above the middle at the Memorial Shale type section along East Eleventh Street in Tulsa [units 7, 8, and 9 of Dott (1941, p. 1,595)]. It includes all but the top of the originally defined Memorial Shale and is equivalent to the Perry Farm Shale Member of the Lenapah Limestone.

The middle member is 0.2 ft (0.06 m) of brown crinoidal limestone at the Memorial Shale type section [unit 10 of Dott (1941)] and includes the sandy, fossiliferous limestones reported by Bennison (1984, p. 117) along 71st Street west of the Arkansas River (along center of north line of NW sec. 12, T. 18 N., R. 12 E.) and noted elsewhere in the Tulsa region [e.g., by Oakes (1952, measured sections 33, 39, and 75)]. On the basis of its stratigraphic position, this marine horizon is considered the southward equivalent of the Idenbro Limestone Member of the Lenapah Limestone, which can be traced readily in both outcrops and cores (fig. 8) from its type area in southern Kansas southward to the vicinity of Talala (outcrop 24) and Ramona (core ORC) in northern Rogers and southern Washington counties.

The upper member of the revised Memorial Shale includes the upper several feet of silty shale of the original Memorial Shale type section [unit 11 of Dott (1941)] and the entire "lower sandy zone" (="lower Seminole sandstone") and the lower part of the "middle shaly zone" of the Seminole Formation of Oakes (1952), which consists of the Dawson coal, its underclay, and the underlying sandy shale. This member includes the informal Jenks sandstone of Bennison (1984) as a local facies in the Tulsa region and southward. Northward, where the Idenbro Member is thick, the upper Memorial Shale consists of only the Dawson coal and its underclay (fig. 8). Both the section below the Lost Branch Formation stratotype near Mound Valley in Labette County, Kansas (outcrop 19 in fig. 8), and the section on Wolf Creek west of Delaware in Nowata County, Oklahoma (outcrop 22), serve as reference sections for this member. Although these beds had been referred to as the Dawson coal horizon in Missouri, the name Dawson has been preoccupied by a Cretaceous–Paleocene formation in Colorado since 1912 (Keroher, 1966, p. 1,052); therefore, although the name Dawson can be retained informally for the coal bed, it cannot be applied formally to a new member. I believe that a new formal name is unnecessary, as the informal term "upper Memorial Shale" suffices for these strata.

Southward, the Memorial Shale is defined at the top by the base of the Lost Branch Formation, which is at or just below the base of the Nuyaka Creek black shale bed or the underlying Homer School limestone bed. It is not known whether the marine sandy horizon near the top of the Memorial Shale at the Bearden section (outcrop 32) in Okfuskee County is equivalent to the Idenbro Limestone Member or is a younger marine horizon in the Jenks interval, which might be expected in this more basinal region. Southward, in Seminole County, the top of the Memorial Shale consists of green to red shale and pebbly sandstone, noted by Dott and Bennison (1981, pp. 16–17) below the Homer School limestone bed. The base of the Memorial Shale is defined as far south as the underlying Eleventh Street limestone is definitely recognized (currently, southern Tulsa County). The lower Memorial Shale is poorly known southward except for two exposures south of Okemah in Okfuskee County, where gray shale with a sparse *Neognathodus*-dominated conodont fauna overlies a dark-red limestone that may be equivalent to the Eleventh Street limestone at the High Spring locality of Bennison (1984). Farther southward, gray shale with a similar but more abundant fauna lies 70 ft (21 m) below the Lost Branch Formation, exposed in the ravine southeast of Bearden (see appendix, outcrop 32 for details), suggesting that it is the southward equivalent of the Eleventh Street limestone.

Northward, where the Lenapah Limestone is thick in its type area in Nowata and Labette counties along the Oklahoma–Kansas border, all members of the Memorial Shale can be delineated, but the lower and middle members are the Perry Farm Shale Member and the Idenbro Limestone Member, respectively, which are included as the upper two members of the Lenapah Limestone because the Perry Farm Shale Member is only 1 ft (0.3 m) thick and the entire Lenapah Limestone forms a more natural lithic grouping (figs. 4 and 8). In this area only the upper member would be readily classified in the Memorial Shale. Northward beyond the northern limit of definite Idenbro limestone (currently at Elk Creek, in Linn County, Kansas; outcrop 12 in fig. 8) or its probably equivalent coal at Trading Post just to the north (outcrop 11), the Memorial Shale extends as a coherent lithic unit from the top of the Norfleet Limestone Member to the base of the Lost Branch Formation throughout Missouri and parts of Iowa. It is mainly a gray to reddish blocky mudstone and gray shale with thin local sandstones in this region. If the Idenbro horizon can be identified in this sequence in Missouri, then the Perry Farm Shale Member can be delineated, although lithically it is more appropriately included in the Memorial Shale throughout the entire region from east-central Kansas to Missouri. Where the Norfleet Limestone Member is missing, the term Nowata–Memorial Shale is appropriate for strata from the top of the Altamont Limestone to the base of the Lost Branch Formation (figs. 4 and 8).

The extension of members from one formation (Memorial Shale) laterally into another (Lenapah Limestone) is consistent with the 1983 North American Stratigraphic Code, Article 24d. Deciding which formation name to use for these members at a particular locality in Kansas depends on either traditional usage or the relative prominence of limestone (Idenbro, Lenapah) or shale (Perry Farm, Memorial) and probably is best left to the user's judgment.

The name "Mound Valley formation" had been used tentatively in a redefined sense for strata now included within the Memorial Shale in Kansas, Missouri, and Iowa [e.g., by Swade (1985) and Greenberg (1986)]. Recent recorrelation of overlying lower Missourian strata has revived the original designation of Mound Valley (Adams, 1896; Haworth, 1898) as a valid name for a Missourian limestone in Labette and adjacent counties in Kansas that had been lithically miscorrelated with the Swope Limestone for many years.

# Overlying strata

## Hepler unit

The name Hepler was applied originally by Jewett (1940) to a sandstone and generally has been used in that way since [e.g., by Searight and Howe (1961) and Zeller (1968)]. Nevertheless, current workers [e.g., Bennison et al. (1984, p. 25)] and I have been informally using it for the entire sequence that directly overlies the Lost Branch Formation, even though sandstone may be subordinate in most sections and absent locally. Just southwest of the stratotype of the Lost Branch Formation (at location 3 in fig. 5a and outcrop 19 in fig. 8), this sequence consists of, in ascending order, units 8, 9, 10, and 11 in fig. 6. Unit 8 is a 2-ft (0.6-m) thick blocky mudstone overlying with abrupt contact the capping calcareous sandstone bed (Glenpool limestone bed) of the Lost Branch Formation. Unit 9 is 0.3 ft (0.09 m) of coal capped by a distinctive bed of silicified log casts; this unit has been referred to informally as the "Hepler" coal. Unit 10 is a dark-gray to black coaly shale [1 ft (0.3 m) thick] that contains megaspores but no conodonts. At the top is unit 11, 0.7 ft (0.2 m) of friable shaly sandstone that is in the position traditionally recognized as the Hepler sandstone in Kansas and Missouri (fig. 8).

The underclay–coal–coaly shale sequence (units 8–10) has also been found at several localities from just southwest of Parsons (west line of NW-SW-NW sec. 26, T. 31 S., R. 19 E.) through the Mound Valley area to the KGGF radio tower section north of Angola in Labette County, Kansas (outcrop 20, fig. 8). This sequence is found again at Wolf Creek (outcrop 22), west of Delaware in Nowata County, Oklahoma, where the coal is referred to as "Tulsa" coal. This coal was positionally correlated southward into the Tulsa region by A. P. Bennison, where it was called "Seminole" coal by Wilson (1979, 1984). The palynomorph flora recovered from this coal at several localities, from Parsons to South Duck Creek (outcrop 28) south of Tulsa, is considered of Missourian age by R. A. Peppers.

At the top of the sequence, the Hepler sandstone (unit 11) ranges locally at the KGGF tower section (outcrop 20) from 1 ft (0.3 m) thick (center west half of SE-SE sec. 19, T. 33 S., R. 18 E.) to 15 ft (4.6 m) thick only 0.2 mi (0.3 km) away (southeast corner of sec. 19, T. 33 S., R. 18 E.). Although it seems to be absent at Parsons, the sandstone appears again northward at scattered localities from South Mound (outcrop 17), where it overlies a black coaly shale containing only megaspores, to Uniontown (outcrop 15), where it overlies the northernmost known exposure of "Hepler" coal. The "Tulsa sandstone" of Bennison (1984, pp. 119–120) lies below the "Tulsa" coal horizon (considered equivalent to the "Hepler" coal, unit 9); thus it would be below the Hepler but would also belong to this terrestrial unit because it lies above the Glenpool limestone bed in the type area for both the Glenpool limestone and the Tulsa sandstone (Bennison, 1984, p. 118).

The sequence of units 8–11 (fig. 6) at location 3 in fig. 5a near the stratotype for the Lost Branch Formation near Mound Valley is sufficiently well exposed to be designated as an important reference section for the redefinition of the Hepler sandstone as a more useful stratigraphic unit, either at member or formation rank. However, there are several problems with the definition and past application of the name Hepler that need to be resolved before considering its formal application to the terrestrial sequence above the Lost Branch Formation.

The name Hepler originally was applied by Jewett (1940) to a sandstone with a supposed disconformable base and generally has been considered since then to apply only to sandstone in both Kansas (Jewett et al., 1965; Zeller, 1968) and Missouri (Searight and Howe, 1961). In fact, at the type section of the overlying South Mound shale designated by Jewett et al. (1965, p. 6) in the southern part of sec. 2, T. 33 S., R. 18 E., less than 1 mi (1.6 km) east of the Lost Branch Formation stratotype, Jewett et al. specifically excluded the coal and underclay with silicified wood (units 8 and 9 at Lost Branch) from the Hepler sandstone. They included these units instead in the type section of the South Mound shale, presumably because the overlying sandstone, currently regarded as Hepler at Lost Branch, apparently is absent. What Jewett et al. (1965) called Hepler sandstone at the South

Mound type section is sandy limestone and calcareous sandstone with brachiopods, that is, unit 7 (fig. 6) at Lost Branch, which I include in the Lost Branch Formation as an upward continuation of the underlying marine shale (unit 6) with no disconformity between them. This older correlation by Jewett et al. (1965) would have the effect of eliminating the Hepler sandstone in the Mound Valley area because the sandstone (unit 11 in fig. 6) appearing above the coal at Lost Branch would be included in the South Mound shale. Consequently, I propose redefining the base of the South Mound shale as the base of the fossiliferous marine shaly limestone and shale sequence (units 12 and 13 in fig. 6). This horizon is shown at the top of the coal at the type section of the South Mound shale, but it is at the top of the overlying sandstone near the type section of the Lost Branch Formation (outcrop 19 in fig. 8). This redefinition keeps all the terrestrial deposits in the same unit, designated as the Hepler unit in figs. 4 and 8.

The original type section of the Hepler sandstone in the center of sec. 14, T. 27 S., R. 22 E., Bourbon County, along K–7, 2 mi (3.2 km) north of Hepler, is currently poorly exposed, but Jewett (1940) placed its base 16 ft (4.9 m) above the Lenapah Limestone. Two miles (3.2 km) to the northwest, in a stream cut on Prong Creek along K–39 (outcrop 16 in fig. 8), what appears from regional dip to be the same sandstone horizon lies with gradational contact upon 11 ft (3.4 m) of sandy shale containing two thin, fossiliferous shaly limestones (see appendix, outcrop 16 for detail). This sequence rests upon limestone that is now known to be the Norfleet Limestone Member, the lower member of the Lenapah Limestone, and the sandstone appears to be overlain by Idenbro limestone float [since confirmed by the Prong Creek core (KPC)]. This places the type Hepler sandstone within the Perry Farm Shale Member of the Lenapah Limestone. Furthermore, a similar sequence (appendix, outcrop 14) exposed just east of Uniontown, 9 mi (14.5 km) to the north, displays 6 ft (2 m) of sandstone called Hepler sandstone by Jewett (1945, stratigraphic section 51; see the appendix for details) 6 ft (2 m) above the Norfleet Member and just below the Idenbro Member in place and therefore unquestionably within the Perry Farm Shale Member of the Lenapah Limestone. The Nuyaka Creek black shale bed of the Lost Branch Formation is exposed less than 1 mi (1.6 km) northwest of this Lenapah–"Hepler" section (outcrop 14) at Uniontown. The Prong Creek core (KPC in fig. 8) shows that the Lost Branch Formation also lies within the 50-ft (15-m) covered interval above the type Hepler equivalent at Prong Creek (outcrop 16); this means that the higher sandstone that crops out above this covered interval 0.5 mi (0.8 km) westward along K–39 (in the southeast corner of sec. 4 and the northwest corner of sec. 10, T. 27 S., R. 22 E.) lies in the position traditionally accorded the name Hepler. This upper sandstone horizon was found by Sutton (1985, who termed it Hepler–C) to be the only one of the three she identified in outcrops as having been called Hepler that was thick enough in the subsurface to be identified as a distinct sandstone horizon on well logs in eastern Kansas.

It seems that almost any sandstone exposed between the lower Lenapah and Hertha Limestones in Kansas was identified by earlier workers as Hepler sandstone and assumed to represent the same stratigraphic horizon, presumably eroding in places into underlying beds because of the supposed unconformity at its base. I currently recognize three different stratigraphic horizons of sandstone that were or might have been identified in the field as Hepler (fig. 8): (1) within the Lenapah Limestone [Hepler–A of Sutton (1985)], (2) between the Lenapah Limestone and the Lost Branch Formation [Hepler–B of Sutton (1985) but only at Uniontown (outcrop 14), where Jewett (1945) considered it higher in the Pleasanton Group], and (3) above the Lost Branch Formation [Hepler–C of Sutton (1985)]. The two lower horizons of Hepler sandstone (A and B) are of Desmoinesian age; they do not seem to be developed outside of Bourbon County and probably Linn County, Kansas (and locally northward in Missouri, for horizon B), and are not thick or widespread enough to be detected in the subsurface. Consequently, even though its original type locality would no longer be called Hepler, it seems reasonable to retain the name Hepler for the well-developed sandy horizon called Hepler–C by Sutton (1985) because this horizon is the position traditionally regarded as Hepler by the Kansas and Missouri geological surveys (fig. 8) and because it is the position of apparently all the sandstones identified as the Hepler sandstone in Missouri. However, because of problems that usually arise with formally naming just a lenticular sandstone facies, I propose that the name Hepler be applied to the entire terrestrial unit above the Lost Branch Formation at either member or formation rank with revised boundaries and redefined lithic content and carefully selected reference sections (Heckel, unpublished).

## South Mound shale

Above the Hepler sandstone (as traditionally recognized) lies the South Mound shale (fig. 4), for which the type section was designated by Jewett et al. (1965) in sec. 2, T. 33 S., R. 18 E., less than 1 mi (1.6 km) northeast of Lost Branch on the south side of Mound Valley, Kansas. Both units have been grouped as the component members of the Seminole Formation in Kansas (fig. 3). Because the description of the South Mound type section by Jewett et al. (1965, p. 6) raises the problems that were elaborated earlier, I now regard the South Mound shale at the Lost Branch Formation type section (outcrop 19 in fig. 8) to comprise just units 12 and 13 in fig. 6 (Heckel, unpublished). There the South Mound shale contains a distinctly marine horizon in its lower part, consisting of a thin argillaceous limestone (unit 12) at the base with abundant invertebrates extending up into the overlying shale (unit 13), which forms the bulk of the unit. The South Mound shale is overlain by a limestone (unit 14) that appears to correlate with perhaps the upper part of the Checkerboard Limestone of Oklahoma.

In Kansas the South Mound shale is well exposed mainly in the Mound Valley region of Labette County and just east of South Mound in Neosho County, Kansas, where it is 12 ft (3.7 m) thick at a well-exposed road cut (outcrop 18 in fig. 8). This exposure was apparently misinterpreted by Jewett et al. (1965) when they chose a type section (see appendix). I propose that this exposure near South Mound (outcrop 18) be designated the principal reference section of the South Mound shale. The South Mound contains a coal at the top at Tacket Mound between Parsons and Mound Valley. The South Mound appears to grade northward, with an increasing amount of sandstone, into the top of the Hepler unit, as seen in the partly exposed section along the tributary to West Bachelor Creek 3 mi (4.8 km) north of South Mound and in the well-exposed stream bank 3.3 mi (5.4 km) east of Kimball in northeastern Neosho County (Heckel, unpublished).

In Oklahoma the South Mound shale is recognizable only in the northernmost core (OSC), 3 mi (4.8 km) south of the Kansas border, where it is a 19.1-ft (5.8-m) thick, sparsely fossiliferous shale with argillaceous limestone at the base, resting with a thin [0.2 ft (0.06 m)] intervening sandstone directly upon weathered shale of the Lost Branch Formation. Another 9 mi (14.5 km) to the south, in core OLC and in all other cores southward toward Tulsa, the entire sequence between the Checkerboard Limestone and the Tulsa coal is dominantly sandstone that has been classified as Seminole Formation (fig. 8). Whether the South Mound grades laterally into this sandstone or thins and grades laterally into the lower part of the shaly Checkerboard Limestone of the more southern cores remains an open question (fig. 4). The apparent truncation of the Hepler unit (including the "Tulsa–Hepler" coal) and of the Glenpool limestone bed in the top of the Lost Branch by the South Mound shale in the South Coffeyville core (OSC), as illustrated in fig. 8, suggests that the marine South Mound shale here fills an erosional channel cut during deposition of the Hepler unit elsewhere; but the channel was not filled until after the minor South Mound marine transgression, except for the thin [0.2 ft (0.06 m)] sandy bed at the base classified as Hepler (see appendix). Its marine character suggests that the South Mound is more related depositionally to the marine Checkerboard Limestone than to the terrestrial Seminole Formation.

The Exline limestone of Missouri and Iowa is correlated with the basal part of the lower Tacket shale sequence above the Checkerboard Limestone (fig. 4), based on Pavlicek's (1986) and my conodont data. If the limestone identified as Checkerboard in the section above the Lost Branch Formation stratotype (unit 14 in fig. 6) is at the same horizon as the type Checkerboard Limestone in the area south of Tulsa, then the Hepler unit and the South Mound unit together constitute the Seminole Formation as the term is currently used by the Oklahoma Geological Survey in the Tulsa area (revised to exclude the Lost Branch and upper Memorial strata) and could be used as currently recognized in Kansas. However, if the limestone called Checkerboard near Lost Branch (outcrop 19 in fig. 8) is largely stratigraphically higher than type Checkerboard, a possibility suggested by Pavlicek (1986) and discussed further in the commentary on the Wolf Creek section (outcrop 22) in the appendix, then the type Checkerboard Limestone may be equivalent mainly to the thin limestone at the base of the South Mound shale, and the Seminole Formation would be equivalent to the Hepler unit alone.

More work is being done on the rocks overlying the Lost Branch Formation, but further subdivision has not yet been formalized. In the meantime, the more general designation "lower Pleasanton," similar to that used in Iowa (fig. 4) for the Lost Branch–Exline interval, is available to include both the Hepler unit and the South Mound shale.

# Depositional history

Having correlated the marine horizons represented by the Lenapah Limestone and the Lost Branch Formation, I present a brief outline of the depositional history of this part of the sequence based on the phases of deposition outlined by Heckel (1980).

## Lenapah transgressions

The marine transgression that produced the lower, most widely traceable part of the Lenapah Limestone (Eleventh Street and Norfleet limestones) inundated only the lower to intermediate parts of the broad northern shelf and extended only a short distance into Iowa (Greenberg, 1986). The coal near the middle of the Nowata–Memorial sequence at the Elko section (outcrop 2 in fig. 8) in Putnam County, Missouri, may represent a swamp just landward of the extent of this transgression. Even over the lowest parts of the shelf, the water was not deep enough to lose vertical circulation and produce a black shale facies. Among the conodonts, no *Gondolella*, *Idioprioniodus*, or many species of *Idiognathodus* found this shallower water favorable. Species of *Neognathodus* dominated the faunas of the deeper offshore parts of the lower Lenapah sea, and *Adetognathus* dominated the faunas of the shallower nearshore parts, which included northern Missouri and parts of Iowa.

After a minor regression exposed Iowa, Missouri, and parts of Kansas to subaerial soil-forming processes and brought Perry Farm sands into transitional environments in east-central Kansas, Perry Farm mud to the Oklahoma border, and lower Memorial mud into the Tulsa area, a minor transgression established Idenbro carbonate production from northern Oklahoma to southern Linn County, Kansas (Greenberg, 1986). A local swamp that developed just shoreward of the maximum extent of this transgression allowed coal to form at the Idenbro horizon in the Trading Post section (outcrop 11) in eastern Linn County.

# Upper Memorial regression

During the regression that closed Lenapah deposition, the sea withdrew into the Arkoma–Anadarko basin of east-central Oklahoma and the shales and thin sandstones that form the upper Memorial Shale were deposited in alluvial environments across Missouri into Kansas. The Jenks sandstone and associated shales were deposited in alluvial to deltaic environments in the Tulsa region while their southern lithic equivalent, the upper Holdenville sandstone interval of Dott and Bennison (1981, p. 17), accumulated in fluvial environments along the southern shoreline. During the low sea-level stand at maximum regression, most of the present outcrop belt and the Forest City basin were exposed. Intense soil-forming processes, which had continued uninterrupted since the Altamont inundation beyond the extent of the Lenapah transgression in western Iowa and Nebraska, turned much of the earlier alluvial deposits and perhaps some of the highest Idenbro carbonates into the blocky mudstone that characterizes most of the upper Memorial Shale [see Schutter and Heckel (1985)]. Across parts of Nebraska, Iowa, and Missouri and along the alluvial southern shoreline in Oklahoma, the soils were drained well enough for iron to oxidize and dehydrate to produce a red color.

# Early Lost Branch transgression

The earliest phase of the Lost Branch transgression raised sea level at a rate that was sufficiently balanced by freshwater inflow to form a great swamp on lower areas of the broad northern shelf. This swamp migrated toward higher areas to form the Dawson coal in northeastern Oklahoma and adjacent Kansas. The Laredo coal may have formed at this time in a poorly drained area between the Saline County arch and the Kirksville–Mendota anticline [see Price (1981, p. 30)] in north-central Missouri. The rate of transgression then probably increased and inundated the originally better drained, higher areas of the shelf too rapidly for swamp or peat formation.

# Late Lost Branch transgression

During the later stages of the Lost Branch transgression, an area from western to north-central Missouri and adjacent parts of west-central Iowa and eastern Nebraska and an area in southern east-central Oklahoma remained in the photic zone over a peat-free bottom long enough for predominantly algal carbonate muds to produce the thin Sni Mills and Homer School limestones. Elsewhere invertebrates flourished locally in a generally thin layer of argillaceous mud that settled slowly onto the old soil and alluvial surface. Eventually the water became too deep for algal muds to be produced, and the shoreline lay far away from the midcontinent. Thus little detrital material was transported onto the shelf, where conditions of sediment starvation produced a diastem.

# Maximum Lost Branch transgression

Finally, during the higher sea-level stands through maximum transgression, the water was deep enough to establish a thermocline that cut off vertical circulation and oxygen replenishment to the sea bottom across the lower to intermediate parts of the shelf. There, a large amount of incompletely decomposed organic matter accumulated under anoxic conditions to form the black fissile Nuyaka Creek black shale bed from the basinal areas of east-central Oklahoma across Kansas into west-central Missouri and over the Laredo coal in north-central Missouri. Around the edges of these lower areas, in most of the remainder of Missouri and parts of Oklahoma and Iowa, the organic content was still high enough to color the shale black to dark-gray but apparently not high enough to bind the clay particles into the fissile shale that is difficult to disaggregate. Farther away, in Iowa and Nebraska, organic matter was sparse enough to color the shale only green-gray. Throughout the entire area, however, upwelling, engendered at times by quasi-estuarine circulation of the two-layer stratified water mass, produced conspicuous amounts of nonskeletal phosphorite within the sediment as nodules toward the south and peloidal laminae toward the north [see Kidder (1985)].

During the higher stands of sea level, *Idiognathodus* and *Neognathodus* swarmed in the surface water, feeding on the plentiful organisms nourished by the upwelling. As the cooler, deeper water spread over the shelf, *Idioprioniodus* returned and *Gondolella* made its first appearance since the Excello shale was deposited, after missing several cycles of inundation. *Adetognathus*, which had lived across the shelf in shallower water during earlier stages of transgression, was confined to similar nearshore environments away from the presently preserved limits of this horizon. Sedimentation at this time virtually ceased in the northern midcontinent, where an inch or two of sediment yields thousands of conodonts per kilogram. In contrast, sedimentation remained sufficient in the basinal area nearer the southern Oklahoma detrital source to produce up to 8 ft (2.4 m) of this facies with the same conodont fauna but in a much lesser concentration.

# Early Lost Branch regression

After sea level started to drop, the thermocline disappeared from the shelf, oxygen returned to the sediment-water interface, and benthic invertebrates returned in great number. These invertebrates are particularly well represented in southern Kansas and Oklahoma, where the greater rate of sedimentation ensured preservation through rapid burial [see Boardman et al. (1984)]. To the north, however, even where the bottom had been oxygenated throughout maximum transgression, sedimentation was so slow in water deep enough to be below the aragonite compensation depth and within the calcite lysocline (of this Pennsylvanian sea) that all the mollusks and perhaps many thin-shelled calcitic organisms were dissolved before burial (Malinky, 1984).

# Late Lost Branch regression

Soon sea level dropped to a point at which much of the northern shelf in Iowa, Nebraska, and northwesternmost Missouri was brought back into the effective photic zone for carbonate-mud-producing algae, and deposition of the Cooper Creek Limestone Member ensued across that area. Southward, closer to the detrital sources in Missouri, Kansas, and Oklahoma, prograding detrital sediments, locally in the form of small deltas, reached the area, clouded the water, and destabilized the substrate before carbonates had a chance to form. These sediments produced some sandstone facies of the Hepler unit in Missouri, the marine to transitional shales in Kansas, and the thin-bedded sandstones below the Glenpool limestone bed south of Tulsa. Later, after the sea had withdrawn from the surface of the Cooper Creek Limestone Member, the water became shallow enough in parts of Oklahoma and southern Kansas that sufficient invertebrates and locally algae proliferated (although in places with quartz sand) to produce the thin, discontinuous, locally sandy Glenpool limestone bed. The conglomeratic limestone at the base of the Glenpool near Uniontown in Bourbon County, Kansas, indicates local erosion before Glenpool deposition and suggests the possibility that the Glenpool might represent a minor transgression (during this generally regressive phase) that stymied the coarse clastic influx in east-central Oklahoma and established marine deposition above an erosion surface in east-central Kansas.

# Maximum Hepler regression

Shortly after the Lost Branch regression, the sea withdrew completely from the shelf and from the part of the basin exposed along the outcrop. Sand moved in alluvial channels across parts of Missouri and Kansas to produce channel sandstone facies of the Hepler unit; intense soil formation altered the top of the Cooper Creek Limestone Member and any overlying alluvial deposits to a blocky mudstone that extended downward into fissures and vugs in the limestone that were left unfilled by sparry calcite. This process accounts for the fragmental, shale-penetrated appearance of Cooper Creek limestone, in which the floating nodules in the green shale at the top are part of the C horizon of the soil profile. Similar soil-forming processes affected the Glenpool limestone bed and overlying material, but the Glenpool was less intensely weathered because it was lower on the shelf and therefore exposed only later during the regression, leaving less time to develop conspicuous weathering features. There was sufficient time, however, for the top of the thick gray shale sequence around Sasakwa, Oklahoma, to be oxidized and dehydrated to a red color and for channel sands and gravels of the type Seminole Formation to cut deeply into the sequence in places.

# Possible cause of terminal Desmoinesian extinctions

The maximum regression of the sea that closed the Lost Branch marine cycle coincides with the changeover from Desmoinesian to Missourian biota in both the terrestrial and marine regimes and so marks the Desmoinesian–Missourian Stage boundary. The changeover involved mainly extinctions of Desmoinesian forms, at least in the midcontinent, for example, the conodont *Neognathodus*, the brachiopod *Mesolobus*, several ammonoid taxa, and the fusulinid *Fusulina* (*Beedeina*) *eximia* (Thompson et al., 1956) in the marine regime and the swamp-dwelling arborescent lycopods in the terrestrial regime. Consequently, Schutter and Heckel (1985) reasoned that this sea-level drop may have been sufficiently greater and longer than those that closed previous marine cycles to have actually caused the extinctions. It can be readily seen that a greater than usual drop of sea level would crowd both the shelf-dwelling and deeper-living marine forms into less living space for a longer time so that, as the shallow shelf area shrank and the basins shallowed, more organisms than usual would not survive. The same principle also applies to the terrestrial extinctions, because they were mainly among the swamp-dwelling arborescent lycopods (Phillips and Peppers, 1984), which required freshwater for reproduction (Phillips, 1979). Thus, if a sea-level drop greater than usual brought the shoreline off the broad, gently sloping shelf everywhere onto the steeper slopes of the basins, it would greatly reduce the areas of freshwater swamps that could form. If sea level remained this low long enough for the reproduction of these lycopods to be severely inhibited, it would have caused their extinction.

## Comparison of the Lost Branch Formation with other marine formations

The Lost Branch inundation was much more widespread than those of the previous Lenapah transgressions. It reached depths great enough to produce over most of the seafloor the anoxic black fissile facies that is similar to those in other black-shale-bearing but much more limestone-rich marine formations. Only in those cores from Iowa and Nebraska where both the Sni Mills and Cooper Creek Limestone Members are present with an intervening thin shale does the Lost Branch Formation display the same transgressive limestone–offshore shale–regressive limestone sequence that characterizes the more limestone-rich marine formations along most of the outcrop belt. In contrast, the Lost Branch Formation almost everywhere is dominated by shale and has much thinner carbonate members than nearly all other widespread cycles. This explains why it had long been overlooked or at least not well understood in Pennsylvanian stratigraphic work. Heckel (1984) explained this different nature of the Lost Branch by greater rates of both transgression and particularly regression. The more rapid regression allowed much less time for the sea bottom to remain in the shallow sunlit depths optimal for carbonate production before the bottom was exposed or before shoreline detrital material moved in and swamped the carbonate-producing organisms.

# Conclusions

1. The long-standing miscorrelations within the Seminole Formation and Lenapah Limestone and the misapplication of the name Holdenville Shale that have recently been discovered in the upper Desmoinesian and lower Missourian shale-dominated sequence along the midcontinent outcrop belt are most reasonably resolved by recognizing and tracing the newly proposed Lost Branch Formation (figs. 3 and 4). Its stratotype is in a nearly completely exposed sequence that extends from the top of the Lenapah Limestone to the top of the South Mound shale (fig. 6). The Lost Branch Formation is distinctive enough both lithostratigraphically and biostratigraphically that it can be traced along the entire midcontinent outcrop belt (fig. 7). It extends from Iowa, where it includes the Cooper Creek Limestone Member, through Missouri, where it includes the Sni Mills Limestone Member, through Kansas into Oklahoma, where it lies above the type Lenapah Limestone and correlates with the upper part of the type Holdenville Shale, and includes the more recently named Homer School limestone, Nuyaka Creek black shale, and Glenpool limestone beds (fig. 8). It also correlates with the Lonsdale and West Franklin Limestone Members of the Illinois basin. Recognition of the Lost Branch Formation corrects previous miscorrelations of the Cooper Creek and Sni Mills limestones with the Lenapah Limestone and of the black shale above the Dawson coal in northeastern Oklahoma with the Seminole Formation. It also corrects the mistaken impression that what has been called the Holdenville Shale in Kansas and the Holdenville Formation in Missouri is equivalent to the entire type Holdenville Shale in Oklahoma.

2. Slight revision of the type Memorial Shale in the Tulsa region, based on the addition of higher strata through the Dawson coal (which are removed from the Seminole Formation), provides an appropriate name for the underlying terrestrial formation that includes the Dawson coal and separates the marine Lost Branch Formation from the underlying marine Lenapah Limestone. The revised Memorial Shale is readily subdivided in its type area into three informal members, which can be traced northward at least to the Kansas–Missouri border. The lower two members, in ascending order, are a thick shale and a thin limestone, which are equivalent to the Perry Farm Shale Member and the Idenbro Limestone Member, respectively, of the Lenapah Limestone of northern Oklahoma and adjacent Kansas, where they are part of the type Lenapah. The upper member of the Memorial Shale includes the Dawson coal, its underclay, and the underlying Jenks sandstone around Tulsa and consists mainly of thin, blocky mudstone paleosol and terrestrial detrital strata to the north.

3. The outcrop sequence that includes the Lost Branch stratotype also provides a good reference section for the redefined Hepler unit, which comprises the terrestrial strata overlying the Lost Branch Formation.

4. The best placement of the Desmoinesian–Missourian (=Middle–Upper Pennsylvanian) boundary is at the top of the Lost Branch Formation (fig. 4) because (a) the Lost Branch carries the highest occurrences of several genera and species of conodonts, ammonoids, fusulinids, and brachiopods that are either common in underlying strata or confined to the Lost Branch and (b) the underlying Dawson coal carries the

highest occurrence of the diverse *Lycospora*-dominated palynomorph flora characteristic of Desmoinesian coals, whereas the overlying "Hepler" and "Tulsa" coals carry a much less diverse flora, which is characteristic of higher Missourian coals. Because of slight diachroneity of the lithically defined upper contact of the Lost Branch Formation (e.g., the base of the lowest sandstone, whether of deltaic or fluvial channel origin), a single boundary stratotype will have to be chosen after well-exposed sequences are described paleontologically.

5. The proposed placement of the Desmoinesian–Missourian boundary fortunately is close to its traditional placement at the supposedly unconformable base of the Hepler sandstone, because the Hepler traditionally has been considered to occupy a position just above the Lost Branch Formation. The contact, however, is often conformable upward from marine to terrestrial deposits. It is disconformable only locally, where Hepler channel sands cut through the alluvial deposits into the Lost Branch. Misidentification of sandstones at lower stratigraphic horizons (e.g., in the Lenapah Limestone) as Hepler helped to perpetuate the assumption of a major unconformity at the boundary (fig. 3). Miscorrelation of the Dawson coal and the overlying black shale with the Missourian Seminole (then called Coffeyville) Formation by Oklahoma geologists, as reported by Miller and Owen (1937), even though the shale contained an ammonoid fauna of strong Desmoinesian affinities, aggravated the problem of identifying the boundary. The apparent lack of a major unconformity on the shelf corroborates the observations of Krumme (1981, p. 26), who could find no evidence of an unconformity in the basin of central Oklahoma.

6. The depositional history of the marine shale-dominated Lost Branch Formation is analogous to that of both older and younger limestone-dominated marine formations. The only substantive difference is the much lesser proportion and thickness of limestone units in the Lost Branch Formation. This difference may be related to a greater rate of sea-level changes and thus more rapid passage of the sea bottom through carbonate-producing depths during the Lost Branch marine inundation. Although several other limestone-rich cycles have little or no transgressive carbonates, suggesting that rapid transgression was common among Pennsylvanian marine inundations, the Lost Branch inundation is one of the few inundations that was followed by relatively rapid regression.

7. Because the well-defined lithic and faunal nature of such a thin, widespread marine horizon extends for hundreds of miles across five states, sandwiched between two well-defined, widespread terrestrial units with coals and paleosols (figs. 4 and 8), it seems inconceivable that the controlling mechanism for this stratigraphic pattern could be anything other than relatively short-term (i.e., glacial) eustatic change. Whatever deltas are associated with the Lost Branch marine horizon are small and local, mainly regressive, and nonexistent north of Missouri. In fact, the correlation of several distinctive marine horizons across the area of the Forest City basin (fig. 9) shows the potential for determining the different extents of successive transgressions [see Heckel (1986)]. Knowledge of certain characteristics of the rock sequence, such as carbonate thickness and development and extent of soil profiles, should shed light on the speed of sea-level changes and duration of inundations and withdrawals. Thus it appears that analysis of the Pennsylvanian cyclic sequence will greatly aid in deciphering the nature and tempo of Gondwanan glaciations.

# Appendix

The location and description of measured outcrop sections and cores used in constructing figs. 8 and 9 are given in this appendix. The sections are listed in order from north (or northwest) to south, that is, from right to left, on each figure in succession. The depth intervals (in parentheses after the unit name) are given only in feet because they are marked only in feet on the cores.

## Sections for figure 8

**OSCEOLA CORE (CP–37)**—3 mi (4.8 km) northwest of Osceola, Clarke County, Iowa (NE-SE-NE sec. 2, T. 72 N., R. 26 W.; reposited at the Iowa Geological Survey, Iowa City, Iowa). Description modified from Swade (1985) and O'Brien (1977) by P. H. Heckel.

| | Thickness ft | Thickness m |
|---|---|---|
| HERTHA LIMESTONE (41.5–53.2 ft) | 11.7 | 3.6 |
| Sniabar Limestone Member (41.5–52.0 ft) | | |
| **Calcilutite**, skeletal, with fossiliferous **shale** in lower middle | 10.5 | 3.2 |
| Mound City Shale Member (52.0–53.2 ft) | | |
| **Shale**, black, phosphatic, with gray fossiliferous **shale** at top and base | 1.2 | 0.4 |
| UPPER PLEASANTON UNIT | | |
| **Shale**, sandy, with **sandstone** in middle and at top and **coal** at 58 ft | 16.7 | 5.1 |
| EXLINE LIMESTONE (69.9–72.3 ft) | | |
| **Calcilutite**, skeletal, with shale partings increasing upward, and small phosphatic internal molds of fossils | 2.4 | 0.7 |
| LOWER PLEASANTON UNIT (72.3–72.6 ft) | | |
| **Shale**, fossiliferous | 0.3 | 0.1 |
| LOST BRANCH FORMATION (72.6–80.9 ft) | 8.3 | 2.5 |
| Cooper Creek Limestone Member (72.6–80.6 ft) | | |
| **Calcilutite**, skeletal, mottled, becoming nodular toward top and with shale partings toward base; conodont fauna includes common *Diplognathodus* and highest occurrence of *Neognathodus* [about 1 ft (0.3 m) below top (Swade, 1985)] | 8.0 | 2.4 |
| Phosphatic shale unit (80.6–80.7 ft) | | |
| **Shale**, green, fossiliferous, with laminar and granular phosphorite and abundant conodont fauna [described by Swade (1985)], which is also characteristic of the Nuyaka Creek black shale bed in more southern localities | 0.1 | 0.03 |
| Sni Mills Limestone Member (80.7–80.9 ft) | | |
| **Calcilutite**, skeletal | 0.2 | 0.06 |
| MEMORIAL SHALE (80.9–91.7 ft) | | |
| **Mudstone**, red, silty, barren, with irregular carbonate nodules | 10.8 | 3.3 |
| LENAPAH LIMESTONE, Norfleet Limestone Member (91.7–94.9 ft) | | |
| **Shale**, gray calcareous, with scattered fossils, and 0.2-ft (0.06-m) layer of argillaceous skeletal **calcilutite** at base | 3.2 | 1.0 |
| NOWATA SHALE (94.9–98.9 ft) | | |
| **Mudstone**, barren, blocky, green at base and red to mottled red and gray upward, with irregular carbonate nodules in upper part | 4.0 | 1.2 |
| ALTAMONT LIMESTONE (98.9–110.3 ft) | 11.4 | 3.5 |
| Worland Limestone Member (98.9–108.9 ft) | | |
| **Calcilutite**, skeletal; grades upward to shaly, barren calcilutite | 10.0 | 3.0 |
| Lake Neosho Shale Member (108.9–109.9 ft) | | |
| **Shale**, green-gray, phosphatic, fossiliferous, with dark zone in middle and abundant conodont fauna [described by Swade (1985)] | 1.0 | 0.3 |
| Amoret Limestone Member (109.9–110.3 ft) | | |
| **Calcilutite**, skeletal | 0.4 | 0.1 |

**OUTCROP 1**—2 mi (3.2 km) north of Cincinnati, Iowa, near Appanoose County dump (in northwest corner of old quarry, southeast of dump entrance; east of center of SW-NW sec. 27, T. 68 N., R. 18 W.; Centerville West Quadrangle). Discovered from old literature by D. E. O'Brien; measured and described by P. H. Heckel, 1984. This exposure is within 6 mi (9.7 km) of the type area of the Cooper Creek Limestone Member and therefore serves as the principal reference section for this member.

| | Thickness ft | m |
|---|---|---|
| EXLINE LIMESTONE | | |
| **Calcilutite**, skeletal, dense, brownish, now mostly slumped | 1.0 | 0.3 |
| LOWER PLEASANTON UNIT | | |
| **Mudstone**, gray, blocky | 2.5 | 0.8 |
| LOST BRANCH FORMATION | 6.5 | 2.0 |
| Cooper Creek Limestone Member | 4.5 | 1.4 |
| **Calcilutite**, skeletal, gray, medium-bedded, with spar-filled voids and fractures. Biota includes crinoid debris, foraminifers, brachiopods, bryozoans, snails, fragments of phylloid algae, and sparse conodonts, including the highest occurrence of *Neognathodus* (in sample from middle). | | |
| Shale unit | 2.0 | 0.6 |
| **Shale**, green-gray, with brachiopods, fusulinids, and crinoid debris | 0.5 | 0.2 |
| **Shale**, dark-gray, with phosphorite laminae and abundant conodont fauna like that described by Swade (1985) from shale below the Cooper Creek Limestone Member in the Osceola core (CP–37) and that characteristic of Nuyaka Creek black shale bed to the south | 0.8 | 0.2 |
| **Shale**, gray, with brachiopods, ostracodes, and sparse bryozoans | 0.5 | 0.2 |
| **Shale**, slightly darker gray, with coaly fragments and scattered brachiopods and bryozoans | 0.2 | 0.06 |
| MEMORIAL SHALE | 10.8+ | 3.2+ |
| **Shale**, gray, blocky, unfossiliferous | 0.8 | 0.2 |
| **Mudstone**, red, blocky, unfossiliferous | 10.0+ | 3.0+ |

**OUTCROP 2**—Near Elko, Putnam County, Missouri (along road on east line of NE sec. 25, T. 65 N., R. 18 W.; Graysville Quadrangle). This is Stratigraphic Section 37 of Howe (1982), condensed and reclassified for the present purposes. Only his unit 8, the black shale (at center east line of NE-NE sec. 25), and unit l, the top of the Altamont Limestone, were exposed in the spring of 1983.

| | ft | m |
|---|---|---|
| UPPER PLEASANTON UNIT | | |
| **Shale**, with molluskan fauna like that often found in the Exline limestone near middle (units 15–18) | 16 | 4.9 |
| EXLINE LIMESTONE (unit 14) | 0.3 | 0.09 |
| LOWER PLEASANTON UNIT | 11.1 | 3.4 |
| Grain Valley **coal** (unit 13) | 0.1 | 0.03 |
| **Clay** above **shale** (units 11 and 12) | 11 | 3.4 |
| LOST BRANCH FORMATION | 15 | 4.6 |
| Cooper Creek Limestone Member | | |
| **Limestone**, rubbly, argillaceous (unit 10) | 2 | 0.6 |
| Shale unit | 13 | 4.0 |
| **Shale**, gray (unit 9) | 10 | 3.0 |
| **Shale**, black to dark-gray (Nuyaka Creek black shale bed), with abundant characteristic conodonts (unit 8) | 3 | 0.9 |
| NOWATA–MEMORIAL SHALE | 10 | 3.0 |
| **Shale**, with **clay** at top (units 5–7) | 5 | 1.5 |
| **Coal** (unit 4), possibly landward equivalent of Norfleet Limestone Member | 1.0 | 0.3 |
| **Clay** and covered interval (units 2 and 3) | 4 | 1.2 |
| ALTAMONT LIMESTONE (unit 1) | | |

**OUTCROP 3**—Near spillway of lake in Thousand Hills State Park, west of Kirksville, Adair County, Missouri (mainly in spillway and hill on south side, NE-NE-NW sec. 23, T. 62 N., R. 16 W.; Novinger Quadrangle). This combines Stratigraphic Section 39 of Howe (1982) and Stratigraphic Section 13 of Howe (1953), condensed and reclassified for the present purposes. Only Upper Pleasanton sandstone, black and gray shales of the Lost Branch Formation, and the top of the Altamont Limestone were observed in 1982–1985.

| | Thickness ft | m |
|---|---|---|
| UPPER PLEASANTON UNIT (strat. sec. 39, unit 6) | | |
| **Sandstone** resting unconformably on beds as low as the Lost Branch Formation | 60 | 18 |
| EXLINE LIMESTONE (strat. sec. 39, unit 5) | | |
| **Calcilutite**, skeletal, with conspicuous phylloid algae, small mollusks, etc. | 0.7 | 0.2 |
| LOWER PLEASANTON UNIT | 12.5 | 3.8 |
| **Shale**, dark-gray, flaky (strat. sec. 39, unit 4) | 2.5 | 0.8 |
| **Coal** (Grain Valley) (strat. sec. 39, unit 3) | 0–0.15 | 0–0.05 |
| **Mudstone** to **sandstone**, brown, reddish at base, leached as underclay at top; thickness varies from 5 ft to 15 ft (1.5–4.6 m) (strat. sec. 39, unit 2) | 10 | 3.0 |
| LOST BRANCH FORMATION | 15 | 4.6 |
| **Shale**, gray to tan, micaceous, silty upward with clay-ironstone concretions in upper part (strat. sec. 13, unit 14) | 13.5 | 4.1 |
| **Shale** (strat. sec. 13, unit 13), dark-gray to black (Nuyaka Creek black shale bed), clayey, with phosphate laminae to nodules and abundant conodont fauna like that described by Swade (1985) from shale below the Cooper Creek Limestone Member in Iowa core CP–37 and that found in the equivalent Nuyaka Creek black shale bed to the south. Collected at spillway by M. A. Nielsen and in gully north of dam by P. H. Heckel in NW-SE-NE-SW sec. 14, T. 62 N., R. 16 W. | 1.5 | 0.5 |
| MEMORIAL SHALE | 25 | 7.6 |
| **Mudstone**, light-gray (strat. sec. 13, unit 12) | 1 | 0.3 |
| **Mudstone**, reddish, with gray zone at base (strat. sec. 13, units 10 and 11) | 9 | 2.7 |
| **Sandstone**, micaceous (strat. sec. 13, unit 9) | 1 | 0.3 |
| **Shale**, tan, micaceous (strat. sec. 13, unit 8) | 3 | 0.9 |
| **Underclay**, with plant roots and a coal streak at top (strat. sec. 13, units 6 and 7) | 1 | 0.3 |
| **Mudstone**, gray to reddish (strat. sec. 13, units 4 and 5) | 10 | 3.0 |
| ?LENAPAH LIMESTONE, Norfleet Limestone Member [compare to sequence in core CP–37 taken at Osceola, Iowa, 90 mi (145 km) to northwest] | | |
| **Limestone**, light-gray (strat. sec. 13, unit 3) | 0.1 | 0.03 |
| NOWATA SHALE | | |
| **Mudstone**, gray (strat. sec. 13, unit 2) | 4 | 1.2 |
| ALTAMONT LIMESTONE, Worland Limestone Member | | |
| **Calcilutite**, skeletal, gray; forms floor of top of spillway (strat. sec. 13, unit 1) | 5 | 1.5 |

**OUTCROP 4**—In creek bed south of Laredo, Grundy County, Missouri (east side of creek reached by tributary ravine across north end of hog farm east of road, near center of south half of NW-SW-SW sec. 24, T. 60 N., R. 23 W.; Chula Quadrangle). This is Stratigraphic Section 11 of Howe (1953), condensed and reclassified for the present purposes. Most units were fairly well exposed in the autumn of 1982.

| | ft | m |
|---|---|---|
| UPPER PLEASANTON UNIT | | |
| **Sandstone** forming banks along upper reaches of creek (unit 7); base is disconformable and contains conglomerate in places | 3.0 | 9.1 |
| LOST BRANCH FORMATION | 4 | 1.2 |
| **Shale**, gray (unit 6) | 1 | 0.3 |
| **Shale**, black, fissile (Nuyaka Creek black shale bed), with abundant characteristic conodonts (unit 5) | 2.8 | 0.9 |
| Zone of limestone concretions (unit 4, not seen) | 0.2 | 0.06 |

| Outcrop 4 (continued) | Thickness ft | m |
|---|---|---|
| NOWATA–MEMORIAL SHALE | 4.5 | 1.4 |
| **Coal** [type Laredo, as designated by Howe (1953, outcrop 11)] (unit 3) | 0.5 | 0.2 |
| **Mudstone**, light-gray, silty, fairly slumped (unit 2) | 4.0 | 1.2 |
| ALTAMONT LIMESTONE, Worland Limestone Member (unit 1) | | |
| **Calcilutite**, skeletal, rubbly weathering, mottled, in bed of creek; contains conodonts more characteristic of Worland Limestone Member than of Lenapah Limestone | 2.0+ | 0.6+ |

Compared to the Kirksville area, this area must have undergone either little deposition or much erosion as well as leaching during the time between the end of Worland deposition and the Lost Branch marine inundation.

**OUTCROP 5**—Along railroad northwest of Bogard, Carroll County, Missouri (exposed in small rill on south side of railroad cut, west of drainage west of section-line road crossing, in SW-SE-SE-SE sec. 14, T. 54 N., R. 24 W.; Bogard Quadrangle). This is Stratigraphic Section 10 of Howe (1953), condensed and reclassified for the present purposes. The Sni Mills Limestone Member was seen only in the small rill in 1981.

| | ft | m |
|---|---|---|
| UPPER PLEASANTON UNIT | | |
| **Sandstone**, massive, medium-grained; rests unconformably on lower beds (unit 5) | 5–25 | 1.5–7.6 |
| LOST BRANCH FORMATION | 3.4 | 1.0 |
| **Shale**, gray to tan; contains at base small phosphate nodules and conodonts characteristic of the Nuyaka Creek black shale bed | 3.0 | 0.9 |
| Sni Mills Limestone Member | | |
| **Calcilutite**, skeletal (unit 3) | 0.4 | 0.1 |
| MEMORIAL SHALE | 16+ | 4.9+ |
| **Clay**, gray to reddish (unit 2) | 3–4 | 0.9–1.2 |
| **Shale**, gray, micaceous, silty, with clay-ironstone concretions (unit 1) | 13+ | 4.0+ |

**OUTCROP 6**—Along railroad northwest of Richmond, Ray County, Missouri (exposed on cutbank on southeast side of railroad near center of east half of NW-SW sec. 24, T. 52 N., R. 28 W.; Richmond Quadrangle). This combines Stratigraphic Section 14 of Howe (1982) and Stratigraphic Section 9 of Howe (1953), condensed and reclassified for the present purposes. The Hepler sandstone, Lost Branch Formation, and Memorial Shale were still relatively well exposed in 1981; the Norfleet Limestone Member can be dug out.

| | ft | m |
|---|---|---|
| UPPER PLEASANTON UNIT | 51+ | 15.5+ |
| **Sandstone**, micaceous, thin-bedded to massive, with crossbeds; detrital coaly zone at base (strat. sec. 14, units 5 and 6) | 28 | 8.5 |
| **Shale**, gray, with clay-ironstone concretions and scattered molluskan fauna (strat. sec. 14, unit 4) | 23 | 7.0 |
| EXLINE LIMESTONE | | |
| **Calcilutite**, skeletal, impure, argillaceous (strat. sec. 14, unit 3) | 1 | 0.3 |
| LOWER PLEASANTON UNIT | 12.5 | 3.9 |
| Covered (strat. sec. 14, unit 2) | 0.5 | 0.2 |
| **Sandstone** (Hepler), massive to medium- to thin-bedded, rippled, with mica and carbonaceous material on bedding planes; the upper few feet are calcareous (35–60% acid-soluble), concentrated in irregular nodular to linear patches (rhizolithic?) (strat. sec. 14, unit 1, and strat. sec. 9, unit 15) | 12 | 3.7 |
| LOST BRANCH FORMATION | 1 | 0.3 |
| **Shale**, black (Nuyaka Creek black shale bed), with phosphate laminae, abundant characteristic conodonts, and scattered brachiopods (*Crurithyris*) (strat. sec. 9, unit 14) | 0.5 | 0.15 |

| | Thickness ft | m |
|---|---|---|
| Sni Mills Limestone Member | | |
| **Calcilutite**, skeletal, dense, weathering nodular, with brachiopods, bryozoans, crinoids, foraminifers, and snails (strat. sec. 9, unit 13) | 0.5 | 0.15 |
| MEMORIAL SHALE | 23 | 7.0 |
| **Mudstone**, blocky, mottled reddish and olive, with root impressions, scattered calcareous nodules, and thin sandy to shaly zone at top (strat. sec. 9, units 10–12) | 11 | 3.4 |
| **Mudstone**, olive, with conchoidal fracture, large impure calcareous concretions, and siltstone-filled channellike feature (strat. sec. 9, unit 9) | 6 | 1.8 |
| **Shale**, gray to greenish, with thin, impure, flaggy calcareous layers (strat. sec. 9, units 7 and 8) | 6 | 1.8 |
| LENAPAH LIMESTONE, Norfleet Limestone Member | | |
| **Calcarenite**, skeletal, with glauconite and crinoid debris (strat. sec. 9, unit 6) | 0.5 | 0.2 |
| NOWATA SHALE | | |
| **Mudstone**, gray, chippy to blocky, weathered in the main part to reddish (strat. sec. 9, units 2–5) | 15 | 4.6 |
| ALTAMONT LIMESTONE, top of Worland Limestone Member (strat. sec. 9, unit 1) | | |

**OUTCROP 7**—In stream east of Sni Mills, Jackson County, Missouri (near west line of SW-NW sec. 28, T. 48 N., R. 29 W.; Tarsney Lakes Quadrangle). This is Stratigraphic Section 5 of Howe (1953), the type section of the Sni Mills Limestone Member, condensed and reclassified for the present purposes. This outcrop was not visited because Howe indicated that it was poorly exposed. Therefore the principal reference section of the Sni Mills is designated at a good creek bank exposure 2 mi (3 km) to the south (outcrop 8).

| | | |
|---|---|---|
| LOWER PLEASANTON UNIT | | |
| **Sandstone** (Hepler), even-bedded (unit 13) | 8 | 2.4 |
| LOST BRANCH FORMATION | 11 | 3.4 |
| **Shale**, gray (unit 12, not sampled) | 10 | 3.0 |
| Sni Mills Limestone Member (type section) | | |
| **Calcilutite**, skeletal, dense, with shale parting in lower third (units 8–11) | 1 | 0.3 |
| MEMORIAL SHALE | 24.5+ | 7.5+ |
| **Sandstone**, calcareous, with pelecypods and root markings (unit 7) | 0.5 | 0.2 |
| **Clay**, red and green (unit 6) | 4.5 | 1.4 |
| **Shale**, sandy, with limestone nodules (unit 5) | 2 | 0.6 |
| **Sandstone**, friable, massive (unit 4) | 1.5 | 0.5 |
| **Shale**, gray, with calcareous sandy zones and limestone nodules in upper part (units 1–3) | 16 | 4.9 |

**OUTCROP 8**—In stream bank south of Sni Mills, Jackson County, Missouri (cutbank in west side of south bend in Sni-A-Bar Creek just west of County Road F, in east half of NE-SE sec. 5, T. 47 N., R. 29 W.; Tarsney Lakes Quadrangle). This is Stratigraphic Section 1 of Kinerney (1961), slightly modified and reclassified for the present purposes. All units were well exposed on several visits in the 1980s, but the dark shale usually needs to be dug out. This exposure serves as the principal reference section for the Sni Mills Limestone Member.

| | | |
|---|---|---|
| LOWER PLEASANTON UNIT | | |
| **Sandstone** (Hepler), micaceous, with thin laminae (unit 5) | 11 | 3.4 |
| LOST BRANCH FORMATION | 10.5 | 3.2 |
| **Shale**, gray, micaceous, sandy toward top, with foraminifers near base (unit 4, upper part) | 9.8 | 3.0 |
| **Shale**, dark-gray, mottled green, with phosphate nodules and abundant conodonts characteristic of the Nuyaka Creek black shale bed (unit 4, base) | 0.2 | 0.06 |

| Outcrop 8 (continued) | Thickness ft | Thickness m |
|---|---|---|
| Sni Mills Limestone Member | | |
| **Calcilutite**, skeletal, dense, with brachiopods, snails, foraminifers, crinoids, and bryozoans; forms resistant ledge (unit 3) | 0.5 | 0.15 |
| MEMORIAL SHALE | | |
| **Mudstone**, blocky, mottled reddish toward top, with sandy zones and irregular calcareous nodules (units 1 and 2) | 5 | 1.5 |

**OUTCROP 9**—In Grand River cut north of Archie, Cass County, Missouri (cuts on both sides of dredged channel of South Grand River in west half of NW-SW sec. 21, T. 43 N., R. 31 W.; Austin Quadrangle). This is Stratigraphic Section 3 of Howe (1953), condensed, reclassified, and partly remeasured on the south side for the present purposes. The lower beds are on the south side, and the higher beds are on the north side; all were well exposed in the autumn of 1981.

| | ft | m |
|---|---|---|
| LOWER PLEASANTON UNIT | | |
| **Sandstone** (Hepler), massive, in channel fill (unit 9) | 6 | 1.8 |
| LOST BRANCH FORMATION | 9 | 2.8 |
| **Shale**, gray, with lenses of cone-in-cone structures (unit 8) | 6 | 1.8 |
| **Shale**, black, fissile (Nuyaka Creek black shale bed); contains abundant characteristic conodonts, with phosphate nodules, cone-in-cone structures, and black limestone concretions containing ammonoids (units 6 and 7) | 2.5 | 0.8 |
| Sni Mills Limestone Member | | |
| **Calcilutite**, skeletal, lenticular, with brachiopods; grades laterally into dark-gray fossiliferous **shale** (unit 5, laterally) | 0.5 | 0.2 |
| MEMORIAL SHALE | 10+ | 3.0+ |
| **Mudstone**, sandy, with thin-bedded lenticular **sandstones**; coal horizon with large log impressions at top (units 3 and 4) | 2 | 0.6 |
| **Sandstone** ledges, hard, calcareous, rippled, interbedded with sandy **shale** (units 1 and 2) | 8 | 2.4 |

Howe (1953, p. 20) thought that his unit 5, a thin fossiliferous dark shale, represented the Sni Mills Limestone Member; this has been confirmed by the discovery of a lenticular brachiopod-bearing calcilutite laterally eastward at this horizon.

**OUTCROP 10**—At Walley Mound, northeast of Amsterdam, Bates County, Missouri (in creek bed south of bridge and up road to west, near center of north line of NW sec. 15, T. 41 N., R. 33 W.; Amoret Quadrangle). This is Stratigraphic Section 37 of Gentile (1976), condensed and modified for the present purposes. The black shale of the Lost Branch Formation was well exposed in the west bank of the creek in 1981, but the Exline fossils were not apparent.

| | ft | m |
|---|---|---|
| PLEASANTON GROUP | 31+ | 9.4+ |
| **Shale**, mostly covered (unit 14) | 20 | 6.1 |
| **Shale**, gray, with ironstone concretions containing mollusks characteristic of the Exline limestone in top (units 10–13) | 7 | 2.1 |
| **Sandstone** (Hepler), thin-bedded, micaceous (unit 9) | 4 | 1.2 |
| LOST BRANCH FORMATION | 16 | 4.9 |
| **Shale**, gray, sandy toward top (unit 8,upper part) | 14 | 4.3 |
| **Shale**, dark-gray, with brachiopods and ostracodes (unit 8, base) | 1 | 0.3 |
| **Shale**, black, platy (Nuyaka Creek black shale bed), with abundant characteristic conodonts (unit 7) | 1 | 0.3 |
| MEMORIAL SHALE | 11.5+ | 3.5+ |
| **Shale**, dark-gray, with coaly debris in lower part (units 5 and 6) | 4.5 | 1.4 |

| | Thickness ft | m |
|---|---|---|
| **Shale**, gray; grades upward to **underclay** with root impressions and thin coal horizon at top (units 2–4) | 5 | 1.5 |
| **Sandstone**, gray (unit 1) | 2 | 0.6 |

**OUTCROP 11**—In Marais des Cygnes River at Trading Post, Linn County, Kansas (starting in northeast bank of river, just northwest of US–69 bridge, extending southeastward to rapids, all near center of sec. 5, T. 21 S., R. 25 E.; Pleasanton Quadrangle). Measured by P. H. Heckel in 1981. The Lost Branch Formation is well exposed at normal water level. This is the same as Stratigraphic Section 6 of Jewett (1945), who regarded the lower part of the Lost Branch Formation as the Lenapah Limestone and the Lenapah Limestone as upper Altamont Limestone.

| | ft | m |
|---|---|---|
| LOWER PLEASANTON UNIT | | |
| **Sandstone** (Hepler), gray, thin-bedded, shaly | 10 | 3.0 |
| LOST BRANCH FORMATION | 16 | 4.9 |
| **Shale**, gray; becomes sandy upward | 11 | 3.4 |
| **Ironstone**, reddish, concretionary, in gray **shale** | 1 | 0.3 |
| **Shale**, dark-gray; grades upward to gray | 2 | 0.6 |
| **Shale**, black, fissile (Nuyaka Creek black shale bed), with phosphate nodules and laminae and abundant characteristic conodont fauna | 1 | 0.3 |
| Sni Mills Limestone Member | | |
| **Calcilutite**, skeletal, dark, dense, lenticular, with brachiopods and snails; grades laterally into 0.1 ft (0.03 m) of dark-gray fossiliferous **shale** with brachiopods, crinoids, and bryozoans | 1 | 0.3 |
| MEMORIAL SHALE | 23 | 7.0 |
| **Shale** to **mudstone**, gray, with scattered invertebrates at top and plant fossils downward (seen in dry river bed northwest of bridge in October 1983) | 5 | 1.5 |
| **Shale**, gray, with horizons of ironstone concretions, extending southeast of bridge; contains dark-gray shale zone 2 ft (0.6 m) above base that lacks conodonts | 15 | 4.6 |
| **Coal** [may be landward equivalent of Idenbro Limestone Member; see Greenberg (1986)] | 0.3 | 0.09 |
| **Mudstone**, gray, blocky (underclay) | 3.0 | 0.9 |
| LENAPAH LIMESTONE, Norfleet Limestone Member [see Greenberg (1986)] | | |
| **Calcarenite**, skeletal, sandy, medium-bedded, with brachiopods; forms rapids in river bed; exposed and collected in October 1983 | 5.5 | 1.7 |

**OUTCROP 12**—On Elk Creek north of Mantey, Linn County, Kansas (in gully entering west side of creek near center of west half of SE-SE sec. 6, T. 23 S., R. 24 E.; Mantey Quadrangle). Measured by P. H. Heckel in 1984. This is the same as the Elk Creek Section of Greenberg (1986, p. 185), which was measured at the same place, not in NE sec. 7.

| | ft | m |
|---|---|---|
| LENAPAH LIMESTONE | 6.5 | 2.0 |
| Idenbro Limestone Member | | |
| **Calcilutite**, skeletal, light-gray | 1 | 0.3 |
| Perry Farm Shale Member | | |
| Covered, probably shale | 5 | 1.5 |
| Norfleet Limestone Member | | |
| **Calcarenite**, skeletal, sandy, with conspicuous crinoid debris | 0.5 | 0.2 |
| NOWATA SHALE | | |
| **Shale**, gray, silty, down to creek bed | 15+ | 4.6+ |

**OUTCROP 13**—On Opossum Creek, west of Mapleton, Bourbon County, Kansas (in east cutbank of creek near center east line of west half of NE-SE sec. 29, T. 23 S., R. 23 E.; Mapleton Quadrangle). Measured by P. H. Heckel in 1984.

| | Thickness ft | m |
|---|---|---|
| LOST BRANCH FORMATION | 5.5+ | 1.7+ |
| **Shale**, gray, sparsely fossiliferous; top eroded | 4.0 | 1.2 |
| **Shale**, black, fissile (Nuyaka Creek black shale bed), with phosphate lenses and rare nodules and abundant characteristic conodont fauna | 1 | 0.3 |
| **Shale**, gray, with brachiopods (chonetids, *Crurithyris*, productids) and ostracodes | 0.5 | 0.2 |
| MEMORIAL SHALE, upper member | 2+ | 0.6+ |
| **Shale**, gray, with plant impressions | 1 | 0.3 |
| **Mudstone**, blocky, with coal smut on top (Dawson coal) | 1+ | 0.3+ |

Downstream 0.25 mi (0.4 km) [in NE-SE-SE sec. 29, probably Stratigraphic Section 32 of Jewett (1945)], badly weathered Lenapah Limestone, probably the Idenbro Limestone Member, crops out above silty shale, probably the Perry Farm Shale Member, but no intervening interval was estimated.

**OUTCROP 14**—East of Uniontown, Bourbon County, Kansas (along north side of paved road on south line of SE-SE-SW sec. 23, T. 25 S., R. 22 E., then north at small lane along new fence line; Uniontown Quadrangle). Measured by P. H. Heckel in 1984. This is probably the same as Stratigraphic Section 51 of Jewett (1945), which was mislocated "near cen. N line sec. 23, T. 25 S., R. 22 E." Also the same as Sutton (1985), section H–7, and Greenberg (1986), east of Uniontown (UTE) section.

| | ft | m |
|---|---|---|
| MEMORIAL SHALE, upper member (top not exposed) | 9+ | 2.7+ |
| **Sandstone**, argillaceous, with **shale** | 3 | 0.9 |
| **Shale**, gray, sandy | 5 | 1.5 |
| **Shale**, gray, clayey | 1 | 0.3 |
| LENAPAH LIMESTONE | 18 | 5.5 |
| Idenbro Limestone Member | | |
| **Calcilutite**, skeletal, rubbly, argillaceous, with **shale** in lower part | 2 | 0.6 |
| Perry Farm Shale Member | 14 | 4.2 |
| **Shale**, gray | 2 | 0.6 |
| **Sandstone**, brown-weathering, crossbedded [called Hepler sandstone by Jewett (1945)] | 6 | 1.8 |
| **Shale**, mostly covered | 6 | 1.8 |
| Norfleet Limestone Member (slumped blocks) | | |
| **Calcarenite**, skeletal, with crinoid debris | 2 | 0.6 |

Less than 1 mi (1.6 km) to the northwest, in a creek bed in SE-SE-NE sec. 22, T. 25 S., R. 22 E., A. P. Bennison found a black, fissile shale that yielded abundant conodonts characteristic of the Nuyaka Creek black shale bed of the Lost Branch Formation. Although apparently stratigraphically higher than the top of the above section, no intervening thickness is estimated.

**OUTCROP 15**—Along K–3 and in ravine west of K–3 road cut, south of Uniontown, Bourbon County, Kansas (steep ravine ~400 ft west of K–3 road cut, SW-NE-NW sec. 34, T. 25 S., R. 22 E.; Uniontown Quadrangle). Ravine discovered by A. P. Bennison; measured and sampled by P. H. Heckel in 1988 (UT3N–W).

| | ft | m |
|---|---|---|
| CRITZER LIMESTONE (exposed below culvert on east side of K–3) | | |
| **Calcilutite**, skeletal, argillaceous, in two layers | 1 | 0.3 |
| MIDDLE PLEASANTON SHALE UNIT | | |
| **Shale**, gray, partly exposed | 15 | 4.5 |

| | Thickness ft | m |
|---|---|---|
| EXLINE LIMESTONE | | |
| **Shale**, fossiliferous, with beds of argillaceous skeletal **calcilutite**; contains snails, crinoid debris, clams, brachiopods, ostracodes, and abundant conodonts | 1 | 0.3 |
| HEPLER UNIT (upper part is partly exposed on east side of K–3) | 21.5 (est.) | 6.5 (est.) |
| **Shale**, gray | 15 (est.) | 4.5 (est.) |
| [Lower 6.5 ft (2.0 m) is exposed in ravine] | | |
| **Sandstone**, carbonaceous (forms top of waterfall) | 0.7 | 0.2 |
| **Coal** ("Hepler") | 0.3 | 0.09 |
| **Mudstone** to **shale**, gray, blocky, with fine coaly plant debris | 5.5 | 1.7 |
| LOST BRANCH FORMATION | 11 (est.) | 3.4 (est.) |
| **Shale**, hard, silty, calcareous, with brachiopods, ostracodes, lingulids, and coaly fragments in top and crinoids and bryozoans as well below | 2 | 0.6 |
| **Limestone**, argillaceous, shelly, with ostracodes, brachiopods, bryozoans, snails, and coaly fragments | 0.5 | 0.2 |
| **Shale**, gray, with brachiopods, bryozoans, snails, ostracodes, foraminifers, holothurian plates, and coaly fragments; also contains conodonts, including highest occurrence of *Neognathodus* | 1.2 | 0.3 |
| **Limestone**, gray-brown, conglomeratic; consists of rounded calcilutite pebbles in calcilutite to calcarenite matrix, with carbonaceous fragments, brachiopods, bryozoans, clams, and crinoid debris | 0.3 | 0.09 |
| [The above 4 ft (1.2 m) of strata is regarded as the Glenpool limestone bed] | | |
| **Shale**, gray, silty, with abundant coaly plant debris and scattered ostracodes, brachiopods, foraminifers, snails, clams, and crinoid fragments | 5.5 | 1.7 |
| Top of black fissile **shale** (Nuyaka Creek black shale bed), reported by A. P. Bennison. | | |

Section continues in cutbank near confluence of small ravine and Marmaton River, just to the west (near center of south line of north half of NW sec. 34, T. 25 S., R. 22 E.). Measured by A. P. Bennison, with samples sent to P. H. Heckel (UT3N–W2).

| | ft | m |
|---|---|---|
| **Shale**, black, hard, phosphatic (Nuyaka Creek black shale bed), with abundant characteristic conodonts | 1.5 | 0.5 |
| MEMORIAL SHALE, upper member | | |
| **Mudstone**, yellow-gray, blocky; grades downward to **shale** and very fine grained **sandstone** | 4 | 1.2 |

**PRONG CREEK CORE (KPC)** (Kansas Geological Survey, Troike 1)—0.25 mi (0.40 km) north of K–39, 1.6 mi (2.6 km) west of K–39 bridge over Prong Creek (outcrop 16), Bourbon County, Kansas (SE-SE-NE-SE sec. 5, T. 27 S., R. 22 E.; Porterville Quadrangle). Described by J. A. French; summarized and classified by P. H. Heckel.

| | ft | m |
|---|---|---|
| HERTHA LIMESTONE (21.1–86.6 ft) | 65.5 | 19.7 |
| Sniabar Limestone Member (21.1–41.4 ft) | | |
| **Limestone**, undifferentiated | 20.3 | 6.1 |
| Mound City Shale Member (41.4–86.6 ft) | 45.2 | 13.6 |
| **Shale**, gray, undifferentiated, with calcareous beds | 44.6 | 13.4 |
| **Shale**, black, phosphatic | 0.6 | 0.2 |
| UPPER PLEASANTON SHALE UNIT (86.6–101.0 ft) | | |
| **Shale**, gray, undifferentiated | 14.4 | 4.3 |
| CRITZER LIMESTONE (101.0–103.4 ft) | | |
| **Calcarenite** to **calcilutite**, skeletal, argillaceous, with two **shale** beds | 2.4 | 0.7 |
| MIDDLE PLEASANTON SHALE UNIT (103.4–105.4 ft) | | |
| **Shale**, dark-gray, silty | 2.0 | 0.6 |
| EXLINE LIMESTONE (105.4–106.1 ft) | | |
| **Calcarenite** to **calcilutite**, skeletal, argillaceous, in two thin beds separated by dark-gray **shale** | 0.7 | 0.2 |

| Prong Creek core (continued) | Thickness ft | m |
|---|---|---|
| HEPLER UNIT (106.1–165.0 ft) | 58.9 | 17.7 |
| **Shale**, gray, silty, with large plant fragments | 0.7 | 0.2 |
| **Mudstone**, light-gray, blocky | 2.5 | 0.8 |
| **Siltstone**, gray, argillaceous, with carbonate nodules | 2.7 | 0.8 |
| **Sandstone**, gray, micaceous, locally rippled, with thin, silty, shaly interbeds and scattered plant fragments | 16.0 | 4.8 |
| **Siltstone**, argillaceous, with thin beds of micaceous **sandstone**, especially just above base | 37.0 | 11.1 |
| LOST BRANCH FORMATION (165.0–173.2 ft) | 8.2 | 2.5 |
| **Shale**, gray, silty | 6.9 | 2.1 |
| **Shale**, black, phosphatic (Nuyaka Creek black shale bed), with zone of fossils, including brachiopods, toward base and thin layer of cone-in-cone limestone at base | 1.3 | 0.4 |
| MEMORIAL SHALE, upper member (173.2–181.8 ft) | 8.6 | 2.6 |
| **Shale**, gray, with scattered silty laminae and plant fragments and zone of fossil fragments at base | 7.4 | 2.2 |
| **Siltstone**, argillaceous, with slickensides | 1.2 | 0.4 |
| LENAPAH LIMESTONE (181.8–211.2 ft) | 29.4 | 8.8 |
| Idenbro Limestone Member (181.8–189.2 ft) | | |
| **Limestone**, peloidal; occurs as irregular, corroded, fractured, and bored nodules in micaceous, silty **mudstone** matrix; scattered encrusting foraminifers and crinoids | 7.4 | 2.2 |
| Perry Farm Shale Member (189.2–210.7 ft) | 21.5 | 6.5 |
| **Siltstone**, gray, argillaceous, with very fine **sandstone** laminae and lenses and tan nodules | 16.7 | 5.0 |
| **Shale**, gray | 4.8 | 1.4 |
| Norfleet Limestone Member (210.7–211.2 ft) | | |
| **Calcarenite**, skeletal, argillaceous, with crinoids, brachiopods, and corals | 0.5 | 0.15 |
| NOWATA SHALE (211.2–214.0 ft) | | |
| **Shale**, gray, silty, with irregular nodules and fissure (?) fillings | 2.8 | 0.8 |
| ALTAMONT LIMESTONE (214.0–230+ ft) | 16.0+ | 4.8+ |
| Worland Limestone Member (214.0–227.7 ft) | | |
| **Calcilutite**, skeletal, with **calcarenite** bed at top | 13.7 | 4.1 |
| Lake Neosho Shale Member (227.7–229.6 ft) | | |
| **Shale**, black, phosphatic; grades upward into gray | 1.9 | 0.6 |
| Amoret Limestone Member (229.6+ ft) | 0.4+ | 0.1+ |

This core was taken as a stratigraphic test from a surface elevation of 1,105 ft, under the supervision of J. A. French of the Kansas Geological Survey. It confirms that the sandstone cropping out 1 mi (1.6 km) to the east at the southeast corner of sec. 4, T. 27 S., R. 22 E., at an elevation of 995 ft is underlain by the Lost Branch Formation (identified by the Nuyaka Creek black shale bed from depths of 171.9 to 173.2 ft in the core, which is 1,105 – 172 = 933 ft elevation in the core; adding 20 ft estimated for regional westward dip yields 953 ft projected elevation, a covered interval in the vicinity of the sandstone outcrop). This sandstone is overlain in the core by the Exline limestone (identified at 106 ft depth, which is 1,105 – 106 = 999 ft in elevation in the core; adding 20 ft for regional dip yields 1,019 ft projected elevation, an interval eroded at and covered west of the sandstone outcrop). Therefore this sandstone is in the position traditionally regarded as the Hepler sandstone by the Kansas and Missouri geological surveys. This core also confirms that the sandstone cropping out 1.6 mi (2.6 km) to the east along Prong Creek at the K–39 bridge (outcrop 16, described next) at 935 ft in elevation is overlain by the Idenbro Limestone Member (which consists of limestone nodules in a mudstone matrix from depths of 181.8 ft to 189.2 ft in the core, or 1,105 – 185 = 920 ft in elevation; adding 30 ft estimated for regional westward dip yields 950 ft projected elevation, an eroded or covered interval at and west of the Prong Creek K–39 bridge). This confirms that the sandstone at the bridge is in the Perry Farm Shale

Member of the Lenapah Limestone, as apparently is also the originally designated type section of the Hepler sandstone nearly 2 mi (3 km) to the southeast, as explained in the description of outcrop 16. This core also shows that the sandstone in the Perry Farm Member at the K–39 bridge grades westward into siltstone, which confirms the findings of Sutton (1985) that only the sandstone above the Lost Branch Formation (traditional Hepler) is widespread in the subsurface.

**OUTCROP 16**—On Prong Creek at K–39 bridge, Bourbon County, Kansas (in creek bed and bank just south of bridge at center of north line of NW-NW-NE sec. 10, T. 27 N., R. 22 E.; Hepler Quadrangle). Measured by P. H. Heckel in 1985. This is the same section as Sutton's (1985) section H–8 and Greenberg's (1986) section PRC.

| | Thickness ft | m |
|---|---|---|
| LENAPAH LIMESTONE | 18+ | 5.5+ |
| Idenbro Limestone Member | | |
| **Limestone**, argillaceous, in small cobbles; similar to Idenbro strata east of Uniontown (outcrop 14); occurs as float above sandstone just southeast of bluff south of K–39 | | |
| Perry Farm Shale Member | 17 | 5.2 |
| **Sandstone**, thin-bedded, fine-grained (probably the same unit as the original type Hepler sandstone; see discussion below) | 6 | 1.8 |
| **Shale**, gray; becomes increasingly sandy upward | 8 | 2.4 |
| Two layers of lenticular, skeletal **calcarenite** separated by gray **shale**; contain bryozoans, brachiopods, crinoid debris, and ostracodes | 0.5 | 0.2 |
| **Shale**, gray, micaceous, sandy | 2.5 | 0.8 |
| Norfleet Limestone Member | | |
| **Calcarenite**, skeletal, with crinoids; forms bed of creek; at least 3 ft (0.9 m) thick in a ditch just north of K–39, 3.3 mi (5.3 km) east of this outcrop (Greenberg, 1986, p. 179) | 1+ | 0.3+ |

About 3 mi (4.8 km) northward in a creek bed near the east line of SE-NE sec. 28, T. 26 S., R. 22 E., A. P. Bennison found a black fissile shale that yielded abundant conodonts characteristic of the Nuyaka Creek black shale bed of the Lost Branch Formation. Although stratigraphically higher than the top of the Prong Creek section, no intervening thickness is estimated.

Less than 2 mi (3.2 km) to the southeast, Jewett (1940, p. 9) designated the type exposure of the Hepler sandstone in the center of sec. 14, T. 27 S., R. 22 E., about 16 ft (4.9 m) above the Lenapah Limestone. The sandstone at Prong Creek appears to be statally continuous with the originally designated Hepler type section [see also Bennison (1985) fig. 7], requiring a westerly dip of 15 ft/mi (2.8 m/km), which is reasonable in this area considering that regional dip in southeastern Kansas is about 30 ft/mi (5.7 m/km) and that the main ledge of the Lenapah Limestone displays an average westward dip of only 5 ft/mi (0.9 m/km) between Prong Creek and the exposure 3.3 mi (5.3 km) to the east along K–39. The Hepler type section is now poorly exposed in the road ditches along K–3, but the discovery of Idenbro float above the same sandstone horizon at Prong Creek (outcrop 16) 2 mi (3.2 km) away and the occurrence of the Idenbro Limestone Member in place above a similar sequence of sandstone [called Hepler by Jewett (1945)] above the main ledge of the Lenapah Limestone east of Uniontown (outcrop 14), 10 mi (16 km) to the north, indicate that the type Hepler sandstone is really a sandstone facies of the Perry Farm Shale Member of the Lenapah Limestone. The main ledge of the Lenapah Limestone in this area is now determined to be the Norfleet Limestone Member (Greenberg, 1986) rather than the Idenbro Limestone Member, as believed by Jewett (1945, Strat. Secs. 51 and 92).

Sandstone that occurs in the probable stratigraphic position of what has traditionally been considered Hepler sandstone in Linn County, Kansas (e.g., at Trading Post, outcrop 11), and in western and north-central Missouri (Howe, 1982) and in the subsurface [Hepler-C of Sutton (1985)] is found along K–39, 0.6 mi (1 km) west of the Prong Creek exposure (outcrop 16), and roughly 50 ft (15 m) higher in elevation, at the southeast corner of sec. 4, T. 27 S., Outcrop 16 (continued)

R. 22 E. This sandstone is stratigraphically higher also than the Lost Branch black shale locality in sec. 28, T. 26 S., R. 22 E., mentioned earlier, which means that the interval of the Lost Branch Formation is covered by colluvium along K–39 between the two prominent sandstone outcrops at Prong Creek and 0.6 mi (1 km) westward. These conclusions have been confirmed by the Prong Creek core (KPC) described previously.

Sutton (1985) referred to the sandstone in the Perry Farm Shale Member at Uniontown (outcrop 14) as Hepler–A and the sandstone at Prong Creek (outcrop 16) as Hepler–B, because at that time I thought that the thin limestones 2.5–3 ft (0.8–0.9 m) above the Norfleet Member might be the Idenbro Limestone Member. But with the more recent discovery of typical Idenbro float above the sandstone at Prong Creek, Sutton's (1985) Hepler–A at Uniontown and Hepler–B at Prong Creek appear to represent the same sandstone unit, the one that is in the Perry Farm Shale Member.

**OUTCROP 17**—On western tributary to Bachelor Creek, 3.5 mi (5.6 km) north of South Mound, Neosho County, Kansas (along creek eastward from NE-SW-SE-SW sec. 28, T. 29 S., R. 20 E.; South Mound Quadrangle). This is Stratigraphic Section 126 of Jewett (1945), in which A. P. Bennison discovered exposures of black shale of the Lost Branch Formation in 1982. Measured by P. H. Heckel in 1984.

| | Thickness ft | m |
|---|---|---|
| LOST BRANCH FORMATION | 1.3+ | 0.4+ |
| **Shale**, black, fissile (Nuyaka Creek black shale bed), with phosphate nodules and abundant characteristic conodonts | 1 | 0.3 |
| **Shale**, black, massive, with sparse small brachiopods (part of Nuyaka Creek black shale bed) | 0.1 | 0.03 |
| **Shale**, gray, massive, with irregular limestone nodules, coaly fragments, and scattered shells | 0.2 | 0.06 |
| MEMORIAL SHALE, upper member | | |
| **Mudstone**, gray, blocky | 2.5 | 0.8 |
| LENAPAH LIMESTONE | 13+ | 4+ |
| Idenbro Limestone Member | | |
| **Calcarenite**, skeletal, light-gray; grades downward to **calcilutite** | 3 | 0.9 |
| Perry Farm Shale Member | | |
| **Shale**, gray, with limestone nodules in upper part and limestone flags in lower part | 10+ | 3.0+ |

Nearly 0.4 mi (0.6 km) to the southwest, along the south bank of the same tributary, in the center of the west half of NW-NW sec. 33, T. 29 S., R. 20 E., A. P. Bennison found a black shale that yielded coaly fragments but no conodonts; this shale is probably at the horizon of the "Hepler" coal, as it lies approximately 3 ft (0.9 m) below sandstone to the west that probably is traditional Hepler sandstone. This partial sequence is similar to that seen in the Hepler unit at the Lost Branch stratotype (outcrop 19) and is arbitrarily estimated to start 16 ft (4.9 m) above the exposed Lost Branch black shale [cf. Jewett (1945), interval of 18 ft (5.5 m) from poorly exposed Hepler sandstone to top of Idenbro Limestone Member].

**OUTCROP 18**—In road cut 1 mi (1.6 km) east of South Mound, Neosho County, Kansas (along south side of road on north line of NE-NE-NE-NW sec. 15, T. 30 S., R. 20 E.; South Mound Quadrangle). Measured by P. H. Heckel in 1983 and proposed as the principal reference section for the South Mound shale near the village of South Mound.

| | ft | m |
|---|---|---|
| SOUTH MOUND SHALE | 13.5 | 4.1 |
| **Sandstone**, gray-brown; forms resistant ledge | 1 | 0.3 |
| **Shale**, gray-brown, with sandstone lenses at top; becomes sparsely fossiliferous downward (brachiopods, crinoid debris, foraminifers) | 12 | 3.7 |

| | Thickness | |
|---|---|---|
| | ft | m |
| Lenses of **skeletal calcilutite**, argillaceous, sandy, with brachiopods and crinoid debris | 0.2 | 0.06 |
| **Shale**, fossiliferous, with abundant crinoid debris and bryozoans, brachiopods, and snails | 0.3 | 0.09 |
| HEPLER UNIT | | |
| Top of **sandstone** in road ditch (Hepler) | | |

This outcrop section is essentially the same as the lower part of locality 9 of Emery (1962) measured just north of the road in section 10. Emery apparently misidentified the 0.2-ft (0.06-m) zone of limestone lenses as Checkerboard Limestone and included the overlying shale and sandstone in the Tacket Formation, even though the type Tacket Formation 20 mi (32 km) to the southwest is mainly black and gray shale with thin nodular limestone but no sandstone reported. Therefore Emery identified as South Mound shale only the 0.3 ft (0.09 m) of shale below the sandy limestone and above the Hepler sandstone. Current work suggests that the horizon identified as Checkerboard Limestone at Mound Valley (outcrop 19) lies above the ledge-forming sandstone at South Mound (outcrop 18) in the base of the gray and black shale sequence reasonably correlated with the type Tacket Formation and exposed in the ditch less than 1 mi (1.6 km) to the northwest along center of west line of sec. 10, T. 30 S., R. 20 E. (the upper part of Emery's locality 9) but not developed as limestone at that place. Dense, skeletal, oolitic limestone does occur at this horizon below Tacket dark shale and above the sandstone ledge less than 1 mi (1.6 km) to the southwest in the spillway to the large pond just east of South Mound in center of west half of SE-NE sec. 16, T. 30 S., R. 20 E. Because this limestone appears to be the same horizon as that identified as Checkerboard Limestone at and near the original South Mound stratotype near Mound Valley (outcrop 19), the entire sequence from the top of the ledge-forming sandstone down to the top of the Hepler sandstone east of South Mound (outcrop 18) belongs to the South Mound shale and is an excellent and more accessible reference section than is the original stratotype.

**OUTCROP 19**—On Lost Branch and nearby, 1 mi (1.6 km) southwest of Mound Valley, Labette County, Kansas (stratotype of Lost Branch Formation) [composite from west highbank of Pumpkin Creek along the east line of SW-SW-NE sec. 10, T. 33 S., R. 18 E. (Checkerboard Limestone, South Mound shale) through gully in NW-SW-NE-NE sec. 10 (lower South Mound shale, Hepler unit, top of Lost Branch Formation) to northwest cutbank of Lost Branch just east of gully near the center of NE-NE-NE sec. 10 (Lost Branch stratotype and upper Memorial Shale); Mound Valley Quadrangle]. This is the section illustrated by Moore (1937, p. 34) but mislocated in NE-NW sec. 10 and lost to the geologic literature until rediscovered by A. P. Bennison in 1981. Measured by P. H. Heckel in 1983 and illustrated in fig. 6.

| | ft | m |
|---|---|---|
| TACKET FORMATION | | |
| Several feet of black **shale** in pit northwest of highbank | | |
| CHECKERBOARD LIMESTONE | | |
| **Calcarenite**, skeletal, dense; thickens to 1.3 ft (0.4 m) in ravine to southwest | 1 | 0.3 |
| SOUTH MOUND SHALE (in highbank). This exposure is 1 mi (1.6 km) west-southwest of the South Mound type section designated by Jewett et al. (1965) in sec. 2, T. 33 S., R. 18 E. (see fig. 5a) | 28.2 | 8.6 |
| **Shale**, gray, with scattered crinoid debris, brachiopods, bryozoans, snails, and clams in lower part | 28 | 8.5 |
| **Calcilutite**, skeletal, argillaceous (at foot of highbank); this bed occurs as shell-rich lenses in fossiliferous shale in gully to northeast with fauna similar to that above | 0.2 | 0.06 |
| HEPLER UNIT (in gully) | 4 | 1.2 |
| **Sandstone** (traditional Hepler sandstone), gray, argillaceous | 0.6 | 0.2 |
| **Shale**, dark-gray to black, carbonaceous, with megaspores but no conodonts | 1.0 | 0.3 |

| Outcrop 19 (continued) | Thickness ft | Thickness m |
|---|---|---|
| **Coal** ("Hepler"), with zone of silicified log casts at top | 0.4 | 0.1 |
| **Shale** to **mudstone**, blocky, gray (underclay) | 2.0 | 0.6 |
| LOST BRANCH FORMATION (in cutbank; stratotype) | 14.6 | 4.5 |
| **Sandstone**, fossiliferous, calcareous, to sandy skeletal **calcarenite** (Glenpool limestone bed) with brachiopods, crinoid debris, and foraminifers | 1.0 | 0.3 |
| **Shale**, gray, with sandy zones in upper part and abundant diverse invertebrate fauna throughout [crinoid debris, brachiopods (including *Mesolobus*), bryozoans, snails, clams, ostracodes, foraminifers] | 12 | 3.7 |
| **Shale**, black, fissile (Nuyaka Creek black shale bed), with phosphate laminae and abundant characteristic conodont fauna | 1.3 | 0.4 |
| **Shale**, soft, dark-gray, with scattered invertebrates (snails), mica, coaly fragments, and megaspores | 0.3 | 0.09 |
| MEMORIAL SHALE, upper member (at base of cutbank) | 2.0 | 0.6 |
| **Coal** (Dawson) | 0.3 | 0.09 |
| **Mudstone**, gray, blocky (underclay) | 1.7 | 0.5 |
| LENAPAH LIMESTONE, Idenbro Limestone Member | | |
| Irregular top of sandy skeletal **calcarenite**; forms bed of Lost Branch | | |

**OUTCROP 20**—Near KGGF radio towers, 3 mi (4.8 km) north-northwest of Angola, Labette County, Kansas (along small drainage from center of west half of SE-SE sec. 19, T. 33 S., R. 18 E., eastward to west cutbank of Pumpkin Creek and southward toward southwest corner of sec. 20; Mound Valley Quadrangle). Discovered by A. P. Bennison; measured by P. H. Heckel in 1984.

| | ft | m |
|---|---|---|
| SOUTH MOUND SHALE (lower part) | | |
| **Calcarenite**, skeletal, argillaceous | 0.1 | 0.03 |
| **Shale**, gray, mostly covered | 0.5 (est.) | 0.2 (est.) |
| HEPLER UNIT | 7.0 | 2.0 |
| **Sandstone** ("Hepler"), gray, shaly, carbonaceous, micaceous, with mollusk shells in top, upstream | 1 | 0.3 |
| **Shale**, gray | 1 | 0.3 |
| **Shale**, dark-gray, with coalified plant fragments and megaspores but no conodonts | 1 | 0.3 |
| **Coal** ("Hepler"), locally up to 1 ft (0.3 m) thick | 0.5 | 0.2 |
| **Mudstone**, gray, blocky (underclay), to **shale** | 3.5 | 1.1 |
| LOST BRANCH FORMATION | 9.5+ | 2.9+ |
| **Calcarenite**, skeletal, sandy (Glenpool limestone bed), with crinoid debris, brachiopods, bryozoans, and snails | 0.5 | 0.2 |
| **Shale**, gray, with scattered crinoid debris, snails, bryozoans, and limestone nodules containing brachiopods; exposed eastward down drainage toward Pumpkin Creek | 9 | 2.7 |

A. P. Bennison reported black shale (Nuyaka Creek black shale bed) overlying Dawson coal and its underclay above the Idenbro Limestone Member exposed at low water in Pumpkin Creek. Also, the Hepler sandstone thickens 0.2 mi (0.3 km) southeastward to 10 ft (3 m) in a pit at the southeast corner of sec. 19, where it overlies the dark, coaly shale and "Hepler" coal just as it does in the measured section along the drainage.

**OUTCROP 21**—At Perry Farm Shale Member type section, 1.5 mi (2.4 km) west of Angola, Labette County, Kansas (in bank south of road at driveway east of bridge over Pumpkin Creek, center north line of NW-NE sec. 7, T. 34 S., R. 18 E.; Valeda Quadrangle). This is Greenberg's (1986) section TPR with intervals remeasured by P. H. Heckel.

| | ft | m |
|---|---|---|
| LENAPAH LIMESTONE | 20.5+ | 6.2+ |

| | Thickness ft | m |
|---|---|---|
| Idenbro Limestone Member | | |
| **Calcilutite**, skeletal, gray, somewhat slumped | 3 | 0.9 |
| Perry Farm Shale Member [type section, as designated by Jewett (1941, p. 339)] | | |
| **Shale**, gray, with limestone nodules, brachiopods, crinoid debris, snails, and clams | 12 | 3.7 |
| Norfleet Limestone Member | 2.5+ | 0.8+ |
| **Calcarenite**, skeletal, dark-gray, dense, with crinoid debris, brachiopods, snails, clams, ammonoids, and abundant conodonts | 0.5 | 0.2 |
| **Shale**, dark-gray, with clams, snails, and small ammonoids | 2.5 | 0.8 |

Jewett (1941, p. 340) indicated that another 2 ft (0.6 m) of shale underlain by another thin [0.5 ft (0.2 m)], dark, dense limestone forms the lower half of the Norfleet Member here. At its type section near center of east half of SW-SE sec. 35, T. 32 S., R. 18 E., just east of Mound Valley, 8 mi (13 km) northeast of here (see fig. 5a), the Norfleet Limestone Member consists of 3 ft (0.9 m) of skeletal calcilutite above 0.5 ft (0.2 m) of gray shale overlying a 0.5-ft (0.2-m) ledge of skeletal calcarenite that carries the conodont fauna characteristic of the base of the Norfleet Member elsewhere and of the upper thin limestone of the Norfleet Member exposed here at the Perry Farm type section; therefore the upper part of the Norfleet type section appears equivalent to the lower part of the Perry Farm type section (Greenberg, 1986), as shown in figs. 4 and 8.

**SOUTH COFFEYVILLE CORE (OSC)** (Oklahoma Geological Survey C–CN–3)—4 mi (6.4 km) west-southwest of South Coffeyville, Nowata County, Oklahoma (SW-SW-SW-NW-SW sec. 28, T. 29 N., R. 15 E.; Elliott Quadrangle). Described by L. A. Hemish, summarized and classified by P. H. Heckel.

| | ft | m |
|---|---|---|
| CHECKERBOARD LIMESTONE (230.1–234.0 ft) | | |
| **Calcilutite**, skeletal, shaly | 3.9 | 1.2 |
| SOUTH MOUND SHALE (234.0–253.1 ft) | 19.1 | 5.8 |
| **Shale**, gray, with scattered fossils, especially brachiopods | 17.4 | 5.3 |
| **Calcilutite**, skeletal, shaly, with conodont fauna similar to that found in base of South Mound shale in Kansas | 1.7 | 0.5 |
| HEPLER UNIT (253.1–253.3 ft) | | |
| **Siltstone**, gray, calcareous, with clasts of underlying unit above sharp irregular contact | 0.2 | 0.06 |
| LOST BRANCH FORMATION (253.3–255.9 ft) | 2.6 | 0.8 |
| **Mudstone**, gray, blocky, with conodonts as below | 1.5 | 0.5 |
| **Shale**, dark green-gray, phosphatic, with black streaks and abundant conodont fauna characteristic of Nuyaka Creek black shale bed | 1.1 | 0.3 |
| MEMORIAL SHALE, upper member (255.9–258.0 ft) | | |
| **Mudstone**, gray, blocky (underclay of Dawson coal) | 2.1 | 0.6 |
| LENAPAH LIMESTONE (258.0–267.4 ft) | 9.4+ | 2.9+ |
| Idenbro Limestone Member (258.0–263.0 ft) | | |
| **Calcarenite**, skeletal, to **calcilutite** | 5.0 | 1.5 |
| Perry Farm Shale Member (263.0–264.3 ft) | | |
| **Shale**, greenish, fossiliferous | 1.3 | 0.4 |
| Norfleet Limestone Member (264.3–267.4 ft) | | |
| **Calcilutite**, skeletal (to base of core) | 3.1+ | 0.9+ |

**LENAPAH CORE (OLC)** (Oklahoma Geological Survey C–CN–2)—4 mi (6.4 km) west-southwest of Lenapah, Nowata County, Oklahoma (SW-NE-NW-SE-SE sec. 9, T. 27 N., R. 15 E.; Delaware Quadrangle). Described by L. A. Hemish; summarized and classified by P. H. Heckel.

Lenapah core (continued)

| | Thickness ft | m |
|---|---|---|
| CHECKERBOARD LIMESTONE (77.9–85.0 ft) | | |
| **Calcilutite**, skeletal, shaly, interbedded with fossiliferous **shale** | 7.1 | 2.2 |
| SEMINOLE FORMATION (85.0–121.0 ft) | 36.0 | 11.0 |
| **Sandstone**, gray; grades downward to sandy **shale** | 29.8 | 9.1 |
| **Coal** ("Tulsa" = "Hepler") | 0.1 | 0.03 |
| **Underclay** | 1.0 | 0.3 |
| **Sandstone**, gray, shaly, with some fossils | 5.1 | 1.6 |
| LOST BRANCH FORMATION (121.0–123.5 ft) | 2.5 | 0.8 |
| **Calcilutite**, skeletal, shaly (Glenpool limestone bed), with phosphate nodules in base and conodont fauna that includes highest *Neognathodus* in this core | 0.8 | 0.2 |
| **Shale**, black, fissile, phosphatic (Nuyaka Creek black shale bed) | 1.2 | 0.4 |
| **Shale**, gray, fossiliferous | 0.5 | 0.2 |
| MEMORIAL SHALE, upper member (123.5–124.5 ft) | 1.0 | 0.3 |
| **Mudstone**, gray, blocky (underclay of Dawson coal) | 1.0 | 0.3 |
| LENAPAH LIMESTONE (124.5–137.0 ft) | 12.5+ | 3.8+ |
| Idenbro Limestone Member (124.5–131.4 ft) | | |
| **Calcarenite**, skeletal, to **calcilutite** | 6.9 | 2.1 |
| Perry Farm Shale Member (131.4–132.3 ft) | | |
| **Shale**, greenish, fossiliferous | 0.9 | 0.3 |
| Norfleet Limestone Member (132.3–137.0 ft) | | |
| **Calcilutite**, skeletal (to base of core); Parkinson (1982, p. 82) measured at least 12 ft (3.7 m) of this unit (then regarded as a carbonate facies of the Perry Farm Shale Member) in the type area of the Lenapah Limestone 5 mi (8 km) northeast of this core (see fig. 8) | 4.7+ | 1.4+ |

Oakes (1940, p. 204, section 115) erroneously regarded the Glenpool limestone bed as the top of the Lenapah Limestone in a section near old US–169 north of Lenapah and 6 mi (9.7 km) northeast of this core and thereby included the phosphatic shale of the Lost Branch Formation and the entire thin upper Memorial Shale in the upper Lenapah Limestone. Later, Oakes and Jewett (1943) used the absence of these beds elsewhere (where the Memorial Shale and the Lost Branch Formation are thicker and/or the Glenpool limestone bed is not observed) to support their contention that the Desmoinesian–Missourian unconformity cuts into the top of the Lenapah Limestone in this part of Oklahoma.

**OUTCROP 22**—In Wolf Creek, 3 mi (4.8 km) west of Delaware, Nowata County, Oklahoma (along southwest bank of creek in NE-NE-SE-NW sec. 34, T. 27 N., R. 15 E.; Delaware Quadrangle). Section discovered by A. P. Bennison; measured by P. H. Heckel in 1984.

| | ft | m |
|---|---|---|
| SEMINOLE FORMATION | 16+ | 4.9+ |
| **Shale**, gray, interbedded with thin-bedded, fine-grained **sandstone** | 5.0+ | 1.5+ |
| **Shale**, dark-gray to black, fissile, with coaly fragments, but no conodonts | 4 | 1.2 |
| **Coal** ("Tulsa" = "Hepler") | 2 | 0.6 |
| **Underclay** | 2 | 0.6 |
| Covered, probably mudstone | 3 | 0.9 |
| LOST BRANCH FORMATION | 3.7 | 1.1 |
| **Calcilutite**, skeletal, argillaceous (Glenpool limestone bed), with brachiopods, crinoids, and bryozoans | 0.2 | 0.06 |
| **Shale**, gray, with abundant crinoid debris, brachiopods, bryozoans, clams, and snails | 1.0 | 0.3 |
| **Phosphorite** nodule bed | 0.2 | 0.06 |
| **Shale**, black, fissile (Nuyaka Creek black shale bed) | 1.8 | 0.5 |
| **Shale**, gray | 0.5 | 0.2 |

| | Thickness ft | m |
|---|---|---|
| MEMORIAL SHALE, upper member | 2.2 | 0.7 |
| **Coal** (Dawson) | 0.2 | 0.06 |
| **Mudstone**, gray, blocky (underclay) | 2.0 | 0.6 |
| LENAPAH LIMESTONE, Idenbro Limestone Member | | |
| **Limestone**, gray, fossiliferous, with hummocky surface | 2+ | 0.6+ |

Four-tenths of a mile (0.7 km) upstream (northwestward) in SW-SW-SE-SW sec. 27 and above an undetermined thickness of scattered exposures of northward-dipping gray shale with thin sandstone beds (upper part of Seminole Formation) are two beds of dense, skeletal calcilutite [0.5–1.0 ft (0.2–0.3 m) thick] separated by 5 ft (1.5 m) of gray shale. The possibility that both limestones correlate southward with the type Checkerboard Limestone and that the lower limestone correlates northward with the limestone in the base of the South Mound shale whereas the upper limestone correlates northward with what has been called Checkerboard Limestone at Mound Valley, Kansas, is the basis for the questioned correlations between the Checkerboard Limestone and the South Mound shale in figs. 4 and 8.

**OUTCROP 23**—In Mormon Creek, northwest of Nowata, Nowata County, Oklahoma (in northwest bluff of creek in NW-NW-NW-NE sec. 15, T. 26 N., R. 15 E.; Nowata West Quadrangle). Discovered by A. P. Bennison, this outcrop is the Mormon Creek Section of Parkinson (1982, p. 74).

| | ft | m |
|---|---|---|
| SEMINOLE FORMATION | 15+ | 4.6+ |
| **Sandstone**, tan | 3+ | 0.9+ |
| **Shale**, gray | 6 | 1.8 |
| Covered | 6 | 1.8 |
| LOST BRANCH FORMATION | 7 | 2.1 |
| **Calcilutite**, skeletal (Glenpool limestone bed), with phylloid algae | 1.5 | 0.5 |
| **Shale**, gray | 1.5 | 0.5 |
| **Shale**, black, fissile (Nuyaka Creek black shale bed) | 1.0 | 0.3 |
| **Shale**, gray | 3.0 | 0.9 |
| MEMORIAL SHALE, upper member | 3.5 | 1.1 |
| **Coal** (Dawson) | 1.0 | 0.3 |
| **Mudstone**, gray, blocky (underclay) | 1.5 | 0.5 |
| Covered | 1.0 | 0.3 |
| LENAPAH LIMESTONE, Idenbro Limestone Member | | |
| **Calcarenite**, skeletal, in creek bed | 2.0 | 0.6 |

**NOWATA CORE (ONC)** (Oklahoma Geological Survey C–CN–1)—4 mi (6.4 km) west of Nowata, Nowata County, Oklahoma (NE-SE-SE-NE-NE sec. 32, T. 26 N., R. 15 E.; Nowata West Quadrangle). Described by L. A. Hemish; summarized and classified by P. H. Heckel.

| | ft | m |
|---|---|---|
| CHECKERBOARD LIMESTONE (base at 100.7 ft) | | |
| SEMINOLE FORMATION (100.7–159.4 ft) | 58.7 | 17.9 |
| **Sandstone**, gray; grades downward to dark **shale** | 30.8 | 9.4 |
| **Mudstone**, gray, blocky, sandy; possibly a paleosol at "Tulsa" coal horizon (top at 131.5 ft) | 4.5 | 1.4 |
| **Sandstone**, gray, with shale near middle and top | 23.4 | 7.1 |
| LOST BRANCH FORMATION (159.4–165.8 ft) | 6.4 | 2.0 |
| **Calcilutite**, skeletal, shaly (Glenpool limestone bed) | 0.9 | 0.3 |
| **Shale**, gray, fossiliferous, with thin sandy layer near base | 3.6 | 1.1 |
| **Shale**, black, fissile, phosphatic (Nuyaka Creek black shale bed) | 1.1 | 0.3 |
| **Shale**, dark-gray, with pyritized shell zone in base | 0.8 | 0.2 |

Nowata core (continued)

| | Thickness ft | m |
|---|---|---|
| MEMORIAL SHALE (165.8–230.0 ft) | 64.2+ | 19.6+ |
| **Coal** (Dawson) | 0.3 | 0.09 |
| **Mudstone**, gray, blocky (underclay) | 3.4 | 1.0 |
| **Sandstone**, gray, with marine fossils; probably equivalent to the Idenbro Limestone Member, which is purer limestone in the creek bed north of Talala (outcrop 24), 8 mi (12.9 km) to the south | 8.3 | 2.5 |
| **Sandstone**, gray (to base of core); possibly channel fill | 52.2+ | 15.9+ |

**OUTCROP 24**—In creek 3.5 mi (5.6 km) north of Talala, Rogers County, Oklahoma (starts in east side of creek with the Lost Branch Formation and Dawson coal just north of bridge, at south line of SE-SW-SE-SE sec. 4, T. 24 N., R. 15 E.; extends downstream, southward, to the Idenbro Limestone Member in northeast bend of creek, SW-NE-NE-NE sec. 9, and to the Eleventh Street limestone in southeast cutbank of creek, near the center of NE-SE-NE sec. 9, T. 24 N., R. 15 E.; Talala Quadrangle). This is the Talala North Section of Parkinson (1982, p. 71); discovered by A. P. Bennison, with intervals estimated by P. H. Heckel.

| | ft | m |
|---|---|---|
| LOST BRANCH FORMATION (exposed part) | 1+ | 0.3+ |
| **Shale**, black, fissile, with phosphate nodules (Nuyaka Creek black shale bed) | 1 | 0.3 |
| MEMORIAL SHALE, upper member | 8 | 2.4 |
| **Coal** (Dawson) | 0.5 | 0.2 |
| **Mudstone**, gray, rooted at top (underclay) | 1.5 | 0.5 |
| Covered | 6 (est.) | 1.8 (est.) |
| LENAPAH LIMESTONE | 10 (est.) | 3.0 (est.) |
| Idenbro Limestone Member | | |
| **Calcilutite**, skeletal, with myalinids | 1 | 0.3 |
| Perry Farm Shale Member | | |
| **Shale**, gray-tan, with limestone nodules | 6 (est.) | 1.8 (est.) |
| Eleventh Street limestone (=Norfleet Limestone Member) | | |
| **Calcarenite**, skeletal, with conspicuous crinoids | 3 | 0.9 |
| NOWATA SHALE | | |
| **Shale**, gray | 2+ | 0.6+ |

Just 4 mi (6.4 km) southward, strip mines have been worked in the Dawson coal.

**RAMONA CORE (ORC)** (Oklahoma Geological Survey C–TW–2)—5 mi (8 km) east-southeast of Ramona, Washington County, Oklahoma (SE-SE-SE-SW-SE sec. 32, T. 24 N., R. 14 E.; Bartlesville Southeast Quadrangle). Described by L. A. Hemish; summarized and classified by P. H. Heckel.

| | ft | m |
|---|---|---|
| CHECKERBOARD LIMESTONE (base at 76.0 ft) | | |
| SEMINOLE FORMATION (76.0–220.0 ft) | 144.0 | 43.9 |
| **Sandstone,** gray | 6.0 | 1.8 |
| **Shale**, gray, interbedded with thin-bedded **sandstone** | 42.6 | 13.0 |
| **Coal** ("Tulsa") (124.6–124.7 ft) | 0.1 | 0.03 |
| **Siltstone**, dark, massive | 1.0 | 0.3 |
| **Sandstone**, gray; grades downward to sandy **shale** | 94.3 | 28.7 |
| LOST BRANCH FORMATION (220.0–228.0 ft) | 8.0 | 2.4 |
| **Shale**, gray, fossiliferous, with highest occurrence of *Neognathodus* in this core in basal 0.6 ft (0.2 m) | 5.3 | 1.6 |
| **Shale**, black, fissile (Nuyaka Creek black shale bed) | 2.2 | 0.7 |
| **Limestone** nodules | 0.2 | 0.06 |
| **Shale**, dark-gray, with brachiopods in top | 0.3 | 0.09 |

| | Thickness ft | m |
|---|---|---|
| MEMORIAL SHALE (228.0–260.0 ft) | 32.0+ | 9.8+ |
| Upper member | 25.8 | 7.9 |
| **Coal** (Dawson) | 0.9 | 0.3 |
| **Sandstone** (Jenks), gray, clayey at top | 22.2 | 6.8 |
| **Limestone**, conglomeratic | 0.8 | 0.2 |
| **Shale**, gray, calcareous | 1.9 | 0.6 |
| Idenbro Limestone Member (253.8–257.3 ft) | 3.5 | 1.1 |
| **Limestone**, skeletal, shaly, with conspicuous bivalves | 3.5 | 1.1 |
| Lower member (257.3–260.0 ft) | | |
| **Shale**, gray, fossiliferous (to base of core) | 2.7+ | 0.8+ |

**VERA CORE (OVC)** (Oklahoma Geological Survey C–TW–1)—4.5 mi (7.2 km) west-southwest of Vera, Tulsa County, Oklahoma (SE-SW-NE-NE-SE sec. 6, T. 22 N., R. 13 E.; Vera Quadrangle). Described by L. A. Hemish; summarized and classified by P. H. Heckel.

| | | |
|---|---|---|
| CHECKERBOARD LIMESTONE (base at 300.3 ft) | | |
| SEMINOLE FORMATION (300.3–450.0 ft) | 149.7 | 45.6 |
| **Sandstone**, gray, and **shale**, sandy, with coal stringers at 314.5–314.9 ft | 31.4 | 9.6 |
| **Coal** ("Tulsa") (331.7–331.9 ft) | 0.2 | 0.06 |
| **Sandstone**, gray, with zones of sandy **shale** near top and at base | 118.1 | 36.0 |
| LOST BRANCH FORMATION (450.0–465.2 ft) | 15.2 | 4.6 |
| **Shale**, gray, fossiliferous | 5.8 | 1.8 |
| **Limestone**, with cone-in-cone structure | 0.3 | 0.09 |
| **Shale**, dark-gray, with fossils in base | 7.2 | 2.2 |
| **Shale**, black, fissile, phosphatic (Nuyaka Creek black shale bed), with pyritized fossils in base | 1.9 | 0.6 |
| MEMORIAL SHALE (465.2–470.0 ft) | 4.8+ | 1.5+ |
| **Coal** (Dawson) | 1.8 | 0.5 |
| **Mudstone**, gray, blocky (underclay) | 2.0 | 0.6 |
| **Sandstone** (Jenks), gray (to base of core) | 1.0+ | 0.3+ |

**OUTCROP 25**—In strip mine south of Collinsville, Tulsa County, Oklahoma (NE-SW sec. 31, T. 22 N., R. 14 E.; Collinsville Quadrangle). Estimated by P. H. Heckel in a pit active in October 1980.

| | | |
|---|---|---|
| LOST BRANCH FORMATION | 4.5+ | 1.4+ |
| **Shale**, black, fissile (Nuyaka Creek black shale bed), with pyritiferous limestone nodules and characteristic conodont fauna | 4 | 1.2 |
| **Shale**, dark-gray, with limonitized clams, snails, and brachiopods | 0.5 | 0.2 |
| MEMORIAL SHALE | | |
| **Coal** (Dawson) | 3 | 0.9 |

The conodont fauna in the black shale is essentially the same as that reported by Jones (1935, 1941) from at least three other localities in the same township (sec. 32; NW sec. 20; SE sec. 20). Some of the limestone nodules, particularly in the south half of sec. 32, carry ammonoids (Miller and Owen, 1937). None of the older localities are known to be exposed today. All previous authors reported a sequence above the black shale consisting of 1 ft (0.3 m) of fossiliferous, calcareous sandstone to impure limestone overlain by perhaps 20 ft (6.1 m) of gray shale that is fossiliferous in the middle and becomes sandier upward. It is not determined how much of this sequence belongs to the Lost Branch Formation or to overlying units.

**OUTCROP 26**—Along Eleventh Street east of Sheridan Road and in adjacent gullies; on east side of Tulsa and nearby localities, Tulsa County, Oklahoma (south line of SW sec. 2 and gullies to north in sec. 2, T. 19 N., R. 13 E.; Tulsa Quadrangle). Most of this section is the original type section of the Memorial Shale designated by Dott (1941), which is measured section 71 of Oakes (1952), summarized and reclassified by P. H. Heckel; sections of higher beds now included in the upper Memorial Shale have been added from nearby areas [from Oakes (1952)] in view of the apparent lack of a complete exposed section of the revised Memorial Shale in the Tulsa region.

| | Thickness ft | m |
|---|---|---|
| MEMORIAL SHALE | 82.7–101.7 | 25.2–31.0 |
| Upper member | 22.5–41.5 | 6.9–12.6 |
| Dawson **coal** [strip-mined in sec. 22, T. 20 N., R. 13 E. (Oakes, 1952, meas. sec. 110), 4 mi (6.4 km) north of the type Memorial Shale, near Dawson, Oklahoma, which is the type area of the Dawson coal] | 1.5 | 0.5 |
| **Underclay** and **shale** (Oakes, 1952, meas. secs. 110, 111, and 72) | 5 | 1.5 |
| **Sandstone** (Jenks); reported by Oakes (1952, meas. secs. 111 and 112) within 1 mi (1.6 km) of the strip pit; this sandstone is 25 ft (7.6 m) thick, 5 mi (8 km) south of the strip pit at Oakes's measured section 72, along the west line of sec. 11, within 1 mi (1.6 km) of the type Memorial Shale; the base of this sandstone forms the top of the original type Memorial Shale of Dott (1941, pp. 1,595–1,596, unit 12) | 6–10 | 1.8–3.0 |
| **Shale**, silty, with limonite (Dott's unit 11) | 10.0 | 3.0 |
| Middle member | | |
| **Limestone**, brown, crinoidal (unit 10), probably equivalent to the Idenbro Limestone Member | 0.2 | 0.06 |
| Lower member | 60 | 18.3 |
| **Shale**, silty (unit 9) | 18.0 | 5.5 |
| **Sandstone**, thin-bedded, and **shale** (unit 8) | 10.0 | 3.0 |
| **Shale**, silty, with a few sandy streaks (unit 7) | 32.0 | 9.8 |
| LENAPAH LIMESTONE, Eleventh Street limestone [essentially the type section of the Eleventh Street limestone, proposed by F. C. Greene (reported by Dott, 1941, p. 1,593), which was in NE sec. 11, T. 19 N., R. 13 E., along the south side of Eleventh Street at this place] | 8.2 | 2.5 |
| **Limestone**, brown, fossiliferous (unit 6) | 1.5 | 0.5 |
| **Shale**, gray, calcareous (unit 5) | 2.5 | 0.8 |
| **Limestone**, nodular, fossiliferous (unit 4) | 0.2 | 0.06 |
| **Shale**, gray (unit 3) | 3.0 | 0.9 |
| **Limestone**, brown, earthy (unit 2) | 1.0 | 0.3 |
| NOWATA SHALE | | |
| **Shale**, gray | 5+ | 1.5+ |

**OUTCROP 27**—At tank farm on Coal Creek, 2 mi (3.2 km) north of Glenpool, Tulsa County, Oklahoma (from west bank of Coal Creek near the center of NW-SW sec. 2, westward to road cut on US–75, along the west line of NW-NW-SW sec. 2, T. 17 N., R. 12 E.; Sapulpa South Quadrangle). Measured by A. P. Bennison [see Bennison et al. (1979, p. 9) for top and Bennison (1984, p. 45) for main part]. This section was indicated as the type section of the "Watkins shale member" by Bennison et al. (1984), a preoccupied name (see text). It now serves as the principal reference section for the Glenpool limestone bed.

| | ft | m |
|---|---|---|
| SEMINOLE FORMATION | 11+ | 3.4+ |
| **Sandstone** ("Tulsa"), thin-bedded, shaly | 5 | 1.5 |
| **Shale**, gray, silty | 6 | 1.8 |
| LOST BRANCH FORMATION | 34.0 | 10.4 |
| **Calcilutite**, skeletal (packstone), pale-orange, lenticular, dolomitized (Glenpool limestone bed), with crinoids, brachiopods, bryozoans, snails, and clams | 0.5 | 0.2 |
| **Shale**, gray, with crinoid debris, brachiopods, bryozoans, and snails, especially at top | 26 | 7.9 |

| | Thickness ft | m |
|---|---|---|
| **Shale**, black, fissile (Nuyaka Creek black shale bed), with phosphate nodules and abundant characteristic conodont fauna | 2.5 | 0.8 |
| **Shale**, gray, with septarian nodules and sparse foraminifers and snails, megaspores, and coaly fragments; varies from 2 ft to 7 ft (0.6–2.1 m) along this exposure | 5 | 1.5 |
| MEMORIAL SHALE, upper member | 5.5+ | 1.7+ |
| **Coal** (Dawson) | 2 | 0.6 |
| **Mudstone**, gray (underclay) | 1.5 | 0.5 |
| **Sandstone** (Jenks), gray, calcareous, with mollusks | 2+ | 0.6+ |

Nearly 3 mi (4.8 km) southward along US–75, on the center of west line of SW-NW-NW sec. 23, T. 17 N., R. 12 E., 1 ft (0.3 m) of orange-weathering, partly dolomitized, skeletal calcarenite was designated the type section of the Glenpool limestone bed by Bennison (1984, p. 118). It overlies several feet of fossiliferous shale that contains well-preserved brachiopods (including *Mesolobus*), bryozoans, crinoid debris, echinoid debris, snails, and small corals.

Three miles (4.8 km) to the east, along the north line of NE-NW sec. 5, T. 17 N., R. 13 E., below the Jenks sandstone, A. P. Bennison recently discovered a sandy, fossiliferous limestone (middle member of the Memorial Shale) that may be the southern equivalent of the Idenbro Limestone Member. No thickness is estimated for the upper Memorial interval.

**OUTCROP 28**—West of Alt. US–75 bridge over South Duck Creek, 2.5 mi (4.0 km) south of Mounds, Okmulgee County, Oklahoma (in gully in south bank of creek near center of east line of SE-NE sec. 30, T. 16 N., R. 12 E.; Lake Boren Quadrangle). Measured by A. P. Bennison in 1982. From this outcrop southward, the formational classification of east-central Oklahoma, in which formational units of Kansas and northeastern Oklahoma introduced or revised in this report are recognized as members of the Holdenville Shale, is used. This change in rank of the Lost Branch Formation and Memorial Shale coincides with the southward loss of definite recognition of the middle limestone member of the Memorial Shale (which is probably equivalent to the Idenbro Limestone Member).

| | | |
|---|---|---|
| SEMINOLE FORMATION | 10.2+ | 3.1+ |
| **Sandstone**, gray, thin- to medium-bedded | 6+ | 1.8+ |
| **Shale**, brownish-gray | 1 | 0.3 |
| **Shale**, dark-gray, coaly | 0.4 | 0.1 |
| **Coal** ("Tulsa") | 0.2 | 0.06 |
| **Mudstone**, gray (underclay), with silicified wood | 1.8 | 0.5 |
| **Sandstone** ("Tulsa"), gray, calcareous | 0.8 | 0.2 |
| HOLDENVILLE SHALE | | |
| Lost Branch Member | 12+ | 3.7+ |
| **Calcilutite**, skeletal, yellowish (Glenpool limestone bed), with brachiopods, crinoid pieces, and bryozoans | 0.6 | 0.2 |
| **Shale**, gray, with sparse brachiopods and foraminifers | 11+ | 3.4+ |

**BEGGS CORE (OBC)** (Oklahoma Geological Survey C–OO–11)—4 mi (6.4 km) north-northwest of Beggs, Okmulgee County, Oklahoma (SW-NE-NE-NE-SE sec. 1, T. 15 N., R. 11 E.; Lake Boren Quadrangle). Described by L. A. Hemish; summarized by P. H. Heckel.

| | | |
|---|---|---|
| CHECKERBOARD LIMESTONE (53.0–56.5 ft) | 3.5 | 1.1 |
| **Calcilutite**, skeletal, gray, shaly toward top | 3.5 | 1.1 |
| SEMINOLE FORMATION (56.5–83.8 ft) | 27.3 | 8.3 |
| **Siltstone**, gray, interbedded with cross-laminated **sandstone** and **shale** with macerated plant debris | 25.3 | 7.7 |
| **Shale**, dark, with coal stringers toward base | 1.1 | 0.3 |

| Beggs core (continued) | Thickness ft | m |
|---|---|---|
| **Coal** ("Tulsa") | 0.2 | 0.06 |
| **Mudstone**, gray (underclay) | 0.7 | 0.2 |
| HOLDENVILLE SHALE | 73.2+ | 22.3+ |
| Lost Branch Member (83.8–149.5 ft) | 65.7 | 20.0 |
| **Limestone**, gray, sandy, fossiliferous (Glenpool limestone bed) | 0.5 | 0.2 |
| **Shale**, gray to dark-gray, calcareous | 16.7 | 5.1 |
| **Shale**, dark-gray, with thin light sandstone lenses and burrows | 11.0 | 3.4 |
| **Shale**, dark-gray, with thin light sandstone layers, decreasing in lower 4 ft (1.2 m) | 25.0 | 7.6 |
| **Shale**, dark-gray | 3.0 | 0.9 |
| **Shale**, black, hard (Nuyaka Creek black shale bed), with sparse fossils in basal foot | 5.8 | 1.8 |
| **Shale**, dark-gray, carbonaceous at base | 3.7 | 1.1 |
| Memorial Shale Member (149.5–157.0 ft) | 7.5+ | 2.3+ |
| **Coal** (Dawson) | 0.7 | 0.2 |
| **Shale**, gray to light-gray, with plant fragments | 4.6 | 1.4 |
| **Sandstone** (Jenks), gray (to base of core) | 2.2+ | 0.7+ |

**OUTCROP 29**—On tributary to Salt Creek, 2 mi (3.2 km) northwest of Beggs, Okmulgee County, Oklahoma (along north and west banks of creek from center of north line of the north half to the center of the north half of SE-NE sec. 23, T. 15 N., R. 11 E.; Lake Boren Quadrangle). Discovered by A. P. Bennison; estimated by P. H. Heckel.

| | | |
|---|---|---|
| HOLDENVILLE SHALE | 20.5+ | 6.3+ |
| Lost Branch Member | 20+ | 6.1+ |
| **Shale**, dark-gray, with limestone nodules | 12 | 3.7 |
| **Shale**, black (Nuyaka Creek black shale bed), with sparse conodonts, including one characteristic species | 5 | 1.5 |
| Covered | 3 | 0.9 |
| Memorial Shale Member | 0.5+ | 0.2+ |
| **Coal** (Dawson) | 0.5 | 0.2 |

The type area of the Checkerboard Limestone is along Checkerboard Creek, 1 mi (1.6 km) to the west and up-section. The orange limestone exposed 1.2 mi (1.9 km) to the east, near the center west line of NW sec. 19, T. 15 N., R. 12 E., would appear from consideration of topography and regional dip to be below the Dawson coal and thus not Glenpool limestone as once thought.

**OUTCROP 30**—In creek bed southwest of Dentonville, Okmulgee County, Oklahoma (NW-NE-NW-NW sec. 4, T. 14 N., R. 11 E.; Nuyaka Quadrangle). This is stop 22 of Bennison et al. (1984); measured by P. H. Heckel in 1983.

| | | |
|---|---|---|
| CHECKERBOARD LIMESTONE | 2.0 | 0.6 |
| **Calcilutite**, skeletal (exposed upstream) | 2.0 | 0.6 |
| SEMINOLE FORMATION | 7.1 | 2.2 |
| **Shale**, gray, darker toward base, with megaspores | 5.0 | 1.5 |
| **Coal** ("Tulsa") | 0.1 | 0.03 |
| **Mudstone**, gray (underclay) | 2.0 | 0.6 |
| HOLDENVILLE SHALE | 3.0+ | 0.9+ |
| Lost Branch Member | 1.5+ | 0.5+ |
| **Calcarenite**, skeletal, sandy, yellowish-weathering (Glenpool limestone bed), with brachiopods, crinoid debris, bryozoans, foraminifers, and sparse conodonts, including the highest occurrence of *Neognathodus* in this section | 0.5 | 0.2 |
| **Shale**, gray | 1.0+ | 0.3+ |

**EDNA CORE (OEC)** (Oklahoma Geological Survey C–OO–17)—2.5 mi (4 km) north-northeast of Edna, Okmulgee County, Oklahoma (NW-NW-NE-SW-NW sec. 31, T. 15 N., R. 11 E.; Nuyaka Quadrangle). Described by L. A. Hemish; summarized and classified by P. H. Heckel.

| | Thickness ft | m |
|---|---|---|
| CHECKERBOARD LIMESTONE (252.8–256.4 ft) | 3.6 | 1.1 |
| **Calcilutite**, skeletal, gray, shaly at base | 3.6 | 1.1 |
| SEMINOLE FORMATION (256.4–262.6 ft) | 6.2 | 1.9 |
| **Shale**, dark, with light silty **sandstone** laminae | 3.9 | 1.2 |
| **Shale**, dark-gray, with plant fragments | 0.6 | 0.2 |
| **Coal** ("Tulsa") | 0.4 | 0.1 |
| **Mudstone**, greenish-gray (underclay) | 1.3 | 0.4 |
| HOLDENVILLE SHALE | 62.4+ | 19.0+ |
| Lost Branch Member (262.6–321.4 ft) | 58.8 | 17.9 |
| **Limestone**, sandy, fossiliferous (Glenpool limestone bed); grades upward to fossiliferous **sandstone** | 0.8 | 0.2 |
| **Sandstone**, gray, shaly, calcareous | 1.7 | 0.5 |
| **Shale**, gray, calcareous, with sparse fossils and small carbonate nodules | 10.4 | 3.2 |
| **Shale**, dark, with light **sandstone** lenses and laminae | 32.5 | 9.9 |
| **Shale**, dark-gray, with sparse fossils, including ammonoids | 9.0 | 2.7 |
| **Shale**, black (Nuyaka Creek black shale bed), with sparse pyritized fossils, including cephalopods and brachiopods | 3.9 | 1.2 |
| **Shale**, dark-gray, calcareous, with pyrite and carbonaceous debris in base | 0.5 | 0.2 |
| Memorial Shale Member (321.4–325 ft) | 3.6+ | 1.1+ |
| **Coal** (Dawson) | 0.5 | 0.2 |
| **Shale**, dark-gray, with coal stringers | 0.2 | 0.06 |
| **Mudstone**, gray (underclay) | 0.9 | 0.3 |
| **Sandstone** (Jenks), gray (to base of core) | 2.0 | 0.6 |

**MORSE CORE (OMC)** (Oklahoma Geological Survey C–OO–18)—1.2 mi (1.9 km) north-northwest of Morse, Okfuskee County, Oklahoma (SE-SW-NW-SW-SE sec. 31, T. 13 N., R. 10 E., Mason Quadrangle). Described by L. A. Hemish; summarized and classified by P. H. Heckel.

| | ft | m |
|---|---|---|
| CHECKERBOARD LIMESTONE (322.0–324.3 ft) | 2.3 | 0.7 |
| **Calcilutite**, skeletal, gray, impure, with conspicuous brachiopods and crinoids | 2.3 | 0.7 |
| SEMINOLE FORMATION (324.3–330.4 ft) | 6.1 | 1.9 |
| **Shale**, dark-gray, calcareous, with sparse fossils | 0.5 | 0.2 |
| **Shale**, dark-gray, with coal stringers in upper third | 1.2 | 0.4 |
| **Coal** ("Tulsa") | 0.1 | 0.03 |
| **Mudstone**, dark (underclay) | 0.4 | 0.1 |
| **Mudstone**, gray, crumbly (underclay) | 3.9 | 1.2 |
| HOLDENVILLE SHALE | 59.6+ | 18.2+ |
| Lost Branch Member (330.4–378.3 ft) | 47.9 | 14.6 |
| **Shale**, dark, silty, interbedded with **sandstone**, gray, bioturbated, calcareous in upper two thirds; top is position of Glenpool limestone bed in Edna core (OEC) | 29.6 | 9.0 |
| **Shale**, dark-gray, silty, with thin **sandstone** stringers | 6.0 | 1.8 |
| **Shale**, dark-gray, with scattered shells | 4.2 | 1.3 |
| **Shale**, black (Nuyaka Creek black shale bed), with phosphate nodules and scattered fossils | 6.1 | 1.9 |
| **Shale**, dark, with pyrite and brachiopods | 2.0 | 0.6 |
| Memorial Shale Member (378.3–390.0 ft) | 11.7+ | 3.6+ |
| **Coal** (Dawson) interbedded with **mudstone**, gray | 0.7 | 0.2 |
| **Mudstone**, gray, blocky (underclay) | 1.0 | 0.3 |

| Morse core (continued) | Thickness ft | m |
| --- | --- | --- |
| **Mudstone**, gray, interbedded with **sandstone**, dark and light | 8.5 | 2.6 |
| **Sandstone** (Jenks), gray, crossbedded (to base of core) | 1.5+ | 0.5+ |

**OUTCROP 31**—On Nuyaka Creek at O–56, 3 mi (4.8 km) northeast of Okemah, Okfuskee County, Oklahoma (in cutbank of creek just west of O–56 bridge in NE-SE-NE sec. 32, T. 12 N., R. 10 E.; Okemah Quadrangle). This is stop 7 of Dott and Bennison (1981, p. 27), designated the type locality of the Nuyaka Creek black shale bed [Bennison (1981, p. 5), as emended from the west line to the east line of NE sec. 32]. Because J. E. Barrick and D. R. Boardman reported that only the lower 2 ft (0.6 m) of the Nuyaka Creek black shale bed and the upper 4 ft (1.2 m) of the underlying gray shale bed were well exposed when they collected the conodonts and ammonoids in May 1990, the principal reference section for the Nuyaka Creek black shale bed is chosen 12 mi (19 km) to the southwest at outcrop 32, where a complete vertical sequence is exposed.

| | ft | m |
| --- | --- | --- |
| HOLDENVILLE SHALE | 23.5+ | 7.2+ |
| Lost Branch Member | 15.5+ | 4.7+ |
| **Shale**, gray, with limestone nodules | 5 | 1.5 |
| **Shale**, black, with phosphate nodules (Nuyaka Creek black shale bed, type section); contains abundant conodont fauna characteristic of this bed elsewhere, 1–2 ft (0.3–0.6 m) above base | 5.5 | 1.7 |
| **Shale**, gray, with zone of limestone nodules 1 ft (0.3 m) below top; contains ammonoids and other mollusks | 5 | 1.5 |
| Covered | 2 | 0.6 |
| Memorial Shale Member | 6.0+ | 1.8+ |
| **Sandstone** (Jenks), gray, calcareous, interbedded with **shale**, gray, silty, reported at bridge footing | 6.0+ | 1.8+ |

Bennison (1981, p. 5) reported 10–40 ft (3–12 m) of fossiliferous gray shale overlying the black shale in this area, which in turn is overlain and channeled by massive sandstones of the Seminole Formation.

**OUTCROP 32**—In ravine into North Canadian River, 2 mi (3.2 km) east-southeast of Bearden, Okfuskee County, Oklahoma (south bank of ravine near center of SW-SW sec. 15, T. 10 N., R. 9 E.; Okemah Southeast Quadrangle). Discovered and measured by A. P. Bennison; partly sampled by P. H. Heckel in 1983. This section is chosen as the principal reference section of the Nuyaka Creek black shale bed because it is the best exposure of the vertical sequence of this unit known in this region.

| | ft | m |
| --- | --- | --- |
| SEMINOLE FORMATION | 5.0+ | 1.5+ |
| **Sandstone**, brown-gray, thin-bedded | 5.0+ | 1.5+ |
| HOLDENVILLE SHALE | 55.0+ | 16.8+ |
| Lost Branch Member | 34 | 10.4 |
| **Shale**, gray, with ironstone nodules, siltier toward top (poorly exposed) | 25 | 7.6 |
| **Shale**, black, fissile (Nuyaka Creek black shale bed), with phosphate nodules and characteristic conodont fauna | 7 | 2.1 |
| **Shale**, dark-gray, with limestone nodules and brachiopods, snails, clams, ammonoids, and crinoid debris | 2 | 0.6 |
| Memorial Shale Member | 21+ | 6.4+ |
| **Shale**, dark-gray, with coaly fragments (Dawson equivalent) | 0.1 | 0.03 |
| **Mudstone**, gray | 1.3 | 0.4 |
| **Sandstone**, calcareous, with crinoidal zone in middle (Jenks?) | 5.5 | 1.7 |
| **Shale**, gray to reddish | 10 | 3.0 |
| **Sandstone**, brownish, with mollusks (equivalent to Idenbro limestone?) | 4.0+ | 1.2+ |

It is not known whether the lower fossiliferous sandstone is also a marine facies of the Jenks sandstone of the upper unit of the Memorial Shale or a southern equivalent of the middle unit (=Idenbro limestone, the upper member of the Lenapah Limestone).

The High Spring shale type section of Bennison (1984, pp. 115–116) was designated 3 mi (4.8 km) to the northeast in SE sec. 1, T. 10 N., R. 9 E. Samples from an exposure just to the south, near center of north line of NE-NE sec. 12, T. 10 N., R. 9 E., contain a sparse conodont fauna that suggests possible correlation with the Eleventh Street limestone, the lower member of the Lenapah Limestone; a red-weathering, skeletal limestone exposed in the field a little farther southward may be a southern extension of the Eleventh Street limestone. A shale sample sent to me by A. P. Bennison from a locality in NE-NE-SE sec. 22, T. 10 N., R. 9 E., nearly on strike 3 mi (4.8 km) southwestward from the High Spring shale type area and 1 mi (1.6 km) southeast of the Lost Branch locality (outcrop 32), and estimated to be at least 70 ft (21 m) below the Nuyaka Creek black shale, contains a more abundant *Neognathodus*-dominated conodont fauna similar to that found in the Eleventh Street limestone in northeastern Oklahoma.

**OUTCROP 33**—On road 2.5 mi (4 km) west of Spaulding, Hughes County, Oklahoma (along south line of SW-SE sec. 5, T. 6 N., R. 8 E.; Holdenville Quadrangle). This is stop 5 of Dott and Bennison (1981, p. 20).

| | Thickness ft | m |
|---|---|---|
| SEMINOLE FORMATION | 70.0+ | 21.3+ |
| **Sandstone**, massive, with lenses of chert conglomerate in lower part | 70.0 | 21.3 |
| HOLDENVILLE SHALE | 22.5+ | 6.8+ |
| Lost Branch Member | 17.5 | 5.3 |
| **Shale**, gray | 15 | 4.6 |
| **Shale**, black (Nuyaka Creek black shale bed) | 2.0 | 0.6 |
| **Limestone** (Homer School limestone bed), weathered; A. P. Bennison reported a better exposure less than 1 mi (1.6 km) to the southwest (center west line of SW-SW-NW sec. 8) where it contains conspicuous phylloid algae | 0.5 | 0.2 |
| Memorial Shale Member | 5.0+ | 1.5+ |
| **Shale**, green over red | 5.0+ | 1.5+ |

This is essentially the type area of the Seminole Formation, which was named by Taff (1901) in a Geologic Folio that covers the region extending southward from 1 mi (1.6 km) south of this outcrop. It is also the type area of the Holdenville Shale. Although the Nuyaka Creek black shale bed is not well exposed at outcrop 33, it is well exposed in a gully near the center of sec. 35, T. 8 N., R. 8 E., approximately 8 mi (13 km) north-northeast of here [and 2.5 mi (4.0 km) northwest of Holdenville] in the upper part of the Holdenville Shale, where it contains an abundant fauna that includes ammonoids, fusulinids, and the characteristic conodonts (D. R. Boardman, personal communications, 1984–1990).

**OUTCROP 34**—In riverbank 1 mi (1.6 km) north of Sasakwa, Seminole County, Oklahoma (south cutbank of Little River in SW-NE-SE-NW sec. 25, T. 6 N., R. 7 E.; Sasakwa Quadrangle). This is the lower part of the section illustrated as stop 4 of Dott and Bennison (1981, p. 18).

| | ft | m |
|---|---|---|
| SEMINOLE FORMATION | 16 | 4.9 |
| **Sandstone**, brown | 9 | 2.7 |
| **Shale**, red to green, with siltstone lenses | 7 | 2.1 |
| HOLDENVILLE SHALE | 28+ | 8.5+ |
| Lost Branch Member | 23 | 7.0 |
| **Shale**, gray | 17 | 5.2 |
| **Shale**, black (Nuyaka Creek black shale bed), with phosphate nodules and characteristic conodont fauna according to D. R. Boardman and J. E. Barrick | 5 | 1.5 |
| **Calcilutite**, skeletal, gray, dense, with chaetetids (Homer School limestone bed) | 1 | 0.3 |

Outcrop 34 (continued)

| | Thickness ft | m |
|---|---|---|
| Memorial Shale Member | 5.0+ | 1.5+ |
| **Shale**, gray, and **sandstone**, shaly | 5.0+ | 1.5+ |

Twenty feet (6 m) of gray shale in gullies above the brown Seminole sandstone contains a conodont fauna (Pavlicek, 1986) and an ammonoid fauna (Boardman et al., in press) that indicate correlation with the Exline limestone of Kansas and Missouri. Less than 1 mi (1.6 km) south of here, the top of the Homer School limestone bed is well exposed for some distance in the creek bed just south of the bridge on the east-west road, just east of the northwest corner of sec. 36, T. 6 N., R. 7 E. There the Homer School bed contains chaetetids, small corals, brachiopods, crinoid pieces, and bryozoans.

**OUTCROP 35**—On hillside 2 mi (3.2 km) south of Sasakwa, Seminole County, Oklahoma (in clearing around oil well and eastward down the road ditch along the south line of SE-SW-SE sec. 12, T. 5 N., R. 7 E.; Sasakwa Quadrangle). This is stop 2 of Dott and Bennison (1981, pp. 14–16), partly remeasured by J. E. Barrick and D. R. Boardman; summarized and classified by P. H. Heckel. The exposure in the road ditch is regarded as the principal reference section of the Homer School limestone bed.

| | ft | m |
|---|---|---|
| SASAKWA LIMESTONE | 5.0+ (?) | 1.5+ (?) |
| **Calcilutite**, skeletal-algal, somewhat slumped | 5 | 1.5 |
| SEMINOLE FORMATION | 14 | 4.3 |
| **Mudstone**, gray-brown, mottled | 3 | 0.9 |
| **Sandstone**, yellowish | 0.5 | 0.2 |
| **Shale**, reddish to green-gray, with caliche nodules in lower part | 6 | 1.8 |
| **Sandstone** and **shale** with chert pebbles | 2 | 0.6 |
| **Sandstone**, gray | 2.5 | 0.8 |
| HOLDENVILLE SHALE | 55.0+ | 16.6+ |
| Lost Branch Member | 38.0 | 11.4 |
| **Shale**, gray, with lenses of brachiopods and bryozoans; contains crinoid pieces, fish debris, ostracodes, and sparse conodonts, including highest occurrence of *Neognathodus* 5 ft (1.5 m) below top | 5 | 1.5 |
| **Shale**, gray, with scattered fossils (not sampled) | 28.0 | 8.4 |
| **Shale**, dark-gray, phosphatic (Nuyaka Creek black shale bed); contains characteristic conodont fauna according to J. E. Barrick and D. R. Boardman | 4.0 | 1.2 |
| **Limestone**, skeletal, with chaetetids (Homer School limestone bed) | 1.0 | 0.3 |
| Memorial Shale Member | 17.0+ | 5.2+ |
| **Shale**, gray, sandy | 3 | 0.9 |
| **Sandstone**, gray, crossbedded, with chert pebbles | 14 | 4.3 |

Only the Seminole and the upper half and the base of the Lost Branch Formations are well exposed. The Sasakwa limestone type section is in an old quarry, 2 mi (3.2 km) to the north, on the south edge of Sasakwa in NE-NW-NW sec. 1, T. 5 N., R. 7 E., where there is at least 20 ft (6 m) of skeletal-algal calcilutite (Dott and Bennison, 1981, p. 14). This limestone is probably equivalent to the Checkerboard Limestone.

**OUTCROP 36**—West of Homer School, east of Ada, Pontotoc County, Oklahoma [bluff in south-central sec. 25, T. 4 N., R. 6 E., 0.5 mi (0.8 km) west of Homer School; Ada and Francis quadrangles]. This information has been modified from Morgan (1924, p. 104), who implicitly designated this the type section of the Homer limestone (now Homer School limestone bed). Because Morgan's (1924) exposure has not been rediscovered, the principal reference section of the Homer School limestone bed is chosen in the road ditch 2 mi (3 km) south of Sasakwa (outcrop 35), approximately 12 mi (19 km) northeast of here.

| | Thickness ft | m |
|---|---|---|
| SASAKWA LIMESTONE (no thickness given) | | |
| [Interval of 40 ft (12 m), presumably shale and sandstone; would include Seminole Formation and upper part of Lost Branch Member of Holdenville Shale] | | |
| HOMER SCHOOL LIMESTONE BED | | |
| **Limestone**, dark-gray, with scattered chaetetids and fusulinids; although no thickness was given for this locality, Morgan (1924) reported this limestone to be 3 ft (0.9 m) thick to the northeast | | |

# Sections for figure 9

**AMERADA CORE (NAC)** (Schroeder no. 1)—4.4 mi ( 7.1 km) north-northwest of Nehawka, Cass County, Nebraska (NE-SE sec. 26, T. 11 N., R. 12 E.; reposited at Nebraska Geological Survey, Lincoln). Description by Condra (1939); classification modified by P. H. Heckel based on biostratigraphy of samples taken from core.

| | ft | m |
|---|---|---|
| HERTHA LIMESTONE [considered most of Swope Limestone by Condra (1939)] (322.0–338.2 ft) | 16.2 | 4.9 |
| Sniabar Limestone Member [considered Bethany Falls Limestone Member by Condra (1939)] (322.0–336.8 ft) | | |
| **Calcilutite**, skeletal, with shale near middle | 14.8 | 4.5 |
| Mound City Shale Member [considered upper part of Hushpuckney Shale Member by Condra (1939)] (336.8–338.2 ft) | | |
| **Shale**, dark-gray, with thin dense limestone at base and abundant conodont fauna like that found in Mound City Shale Member in Kansas City area | 1.4 | 0.4 |
| UPPER PLEASANTON UNIT [considered lower part of Hushpuckney Shale Member by Condra (1939)] (338.2–341.4 ft) | | |
| **Mudstone**, gray, blocky | 3.2 | 1.0 |
| EXLINE LIMESTONE [considered Middle Creek Limestone Member by Condra (1939)] (341.4–343.0 ft) | | |
| **Calcarenite**, osagia-grain; overlies skeletal **calcilutite** with large oncolites | 1.6 | 0.5 |
| LOWER PLEASANTON UNIT [considered Ladore Shale by Condra (1939)] (343.0–348.0 ft) | | |
| **Shale**, gray, micaceous, with small limy concretions | 5.0 | 1.5 |
| LOST BRANCH FORMATION [considered Hertha Limestone by Condra (1939)] (348.0–353.0 ft) | 5.0 | 1.5 |
| Cooper Creek Limestone Member (348.0–351.0 ft) | | |
| **Calcilutite**, skeletal, gray, with "cavernous reticulate" fabric | 3.0 | 0.9 |
| Shale unit (351.0–351.7 ft) | | |
| **Shale**, gray, fossiliferous, with abundant conodont fauna like that described by Swade (1985) from thin shale below Cooper Creek Limestone Member in Iowa core CP–37 | 0.7 | 0.2 |
| Sni Mills Limestone Member (351.7–353.0 ft) | | |
| **Calcilutite**, skeletal, dark-gray, with brachiopods, crinoids, and fusulinids | 1.3 | 0.4 |
| NOWATA–MEMORIAL SHALE [considered Bourbon (=Pleasanton) group by Condra (1939)] (353.0–370.7 ft) | 17.7 | 5.4 |
| **Mudstone**, bluish, with small limy concretions | 3.5 | 1.1 |
| **Mudstone**, bluish to reddish, sandy | 9.5 | 2.9 |
| **Shale**, dark-gray, sandy | 1.0 | 0.3 |
| **Shale**, reddish, micaceous, sandy | 3.7 | 1.1 |
| ALTAMONT LIMESTONE [considered probably Pawnee Limestone by Condra (1939)] (370.7–374.5 ft) | 3.8 | 1.2 |
| Worland Limestone Member (370.7–373.2 ft) | | |
| **Calcilutite**, skeletal, gray, shaly | 2.5 | 0.8 |
| Lake Neosho Shale Member (373.2–373.8 ft) | | |
| **Shale**, gray, fossiliferous (noted as borrowed for class purposes by M. K. Elias) | 0.6 | 0.2 |

| Amerada core (continued) | Thickness ft | m |
|---|---|---|
| Amoret Limestone Member (373.8–374.5 ft) | | |
| **Calcilutite**, skeletal, gray, with shaly zones that yield conodonts characteristic of Lake Neosho Shale and Amoret Limestone Members in Iowa cores CP–37 and CP–22 studied by Swade (1985) | 0.7 | 0.2 |

**OFFUTT CORE (NOC)**—Offutt Air Force Base (DH no. 247), Sarpy County, Nebraska (center of south half of SE-SE-NW sec. 11, T. 13 N., R. 13 E.; reposited at the Nebraska Geological Survey, Lincoln). Described and classified by P. H. Heckel.

| | ft | m |
|---|---|---|
| HERTHA LIMESTONE (192.7–214.3 ft) | 21.6 | 6.6 |
| Sniabar Limestone Member (192.7–211.7 ft) | | |
| **Calcilutite**, skeletal, with osagia-grain **calcarenite** toward top and interbedded with fossiliferous shale throughout | 19.0 | 5.8 |
| Mound City Shale Member (211.7–214.3 ft) | 2.6 | 0.8 |
| **Shale**, gray, fossiliferous, with dark-gray zone at base; contains abundant conodont fauna like that found in Mound City Shale Member in Kansas City area | 2.3 | 0.7 |
| **Shell bed** | 0.3 | 0.09 |
| UPPER PLEASANTON UNIT (214.3–217.4 ft) | 3.1 | 0.9 |
| **Coal** (Ovid) | <0.1 | <0.03 |
| Missing interval | 1.2+ | 0.4+ |
| **Mudstone**, gray, blocky | 1.8 | 0.5 |
| EXLINE LIMESTONE (217.4–224.0 ft) | 6.6 | 2.0 |
| **Calcilutite**, barren, brecciated in yellow **shale** at top | 2.3 | 0.7 |
| **Calcarenite**, skeletal, massive | 3.5 | 1.1 |
| **Calcilutite**, skeletal, with coated grains | 0.8 | 0.2 |
| LOWER PLEASANTON UNIT (224.0–229.4 ft) | 5.4 | 1.6 |
| **Mudstone**, blocky, gray with red mottling | 2.1 | 0.6 |
| Missing interval | 2.0 | 0.6 |
| **Shale**, gray, mottled reddish, calcareous | 1.3 | 0.4 |
| LOST BRANCH FORMATION (229.4–232.9 ft) | 3.5 | 1.1 |
| Cooper Creek Limestone Member (229.4–232.0 ft) | | |
| **Calcilutite**, skeletal, with shale-filled fractures in top and shale partings in base | 2.6 | 0.8 |
| Shale unit (232.0–232.9 ft) | | |
| **Shale**, dark-gray, with shell concentration at base and fish teeth and abundant conodont fauna like that described by Swade (1985) from thin shale below Cooper Creek Limestone Member in Iowa core CP–37 | 0.9 | 0.3 |
| NOWATA–MEMORIAL SHALE (232.9–258.1 ft) | 25.2 | 7.7 |
| **Mudstone**, blocky, green, to crumbly **shale** | 9.0 | 2.7 |
| **Mudstone**, red, sandy, with limy nodules at top | 16.2 | 4.9 |
| ALTAMONT LIMESTONE (258.1–262.1 ft) | | |
| **Calcilutite**, skeletal, and fossiliferous **shale** (undifferentiated) with conodont fauna in lower foot similar to that of lower part of Altamont Limestone in Iowa cores CP–37 and CP–22 studied by Swade (1985) | 4.0 | 1.2 |

**LOGAN CORE (ILC)** (Iowa Geological Survey WC–22)—East side of Logan, Harrison County, Iowa (NW-SE-NE-NE sec. 19, T. 79 N., R. 42 W.; reposited at Iowa Geological Survey, Iowa City). Described by P. H. Heckel.

| | ft | m |
|---|---|---|
| HERTHA LIMESTONE (48.6–62.8 ft) | 14.2 | 4.3 |
| Sniabar Limestone Member (48.6–60.8 ft) | 12.2 | 3.7 |
| **Calcarenite**, skeletal, abraded, coated-grain, with shale bed | 3.4 | 1.0 |
| **Calcilutite**, skeletal, argillaceous toward base | 8.8 | 2.7 |

| | Thickness ft | m |
|---|---|---|
| Mound City Shale Member (60.8–62.8 ft) | | |
| **Shale**, gray, fossiliferous, with thin, argillaceous **limestone** at base and thin, dark **shale** below middle containing abundant conodont fauna like that found in Mound City Shale Member in Kansas City area | 2.0 | 0.6 |
| UPPER PLEASANTON UNIT (62.8–68.2 ft) | | |
| **Shale**, gray, with fossils at top and irregular limestone nodules in middle; becomes **mudstone** at base | 5.4 | 1.6 |
| EXLINE LIMESTONE (68.2–71.7 ft) | | |
| **Calcilutite**, skeletal, shaly, with zones of fine-grained **calcarenite** and shale-filled fractures toward top | 3.5 | 1.1 |
| LOWER PLEASANTON UNIT (71.7–84.3 ft) | 12.6 | 3.8 |
| **Mudstone**, red, with limy nodules near base | 3.0 | 0.9 |
| **Sandstone**, gray, argillaceous; grades downward to **shale** with scattered red mottling and fracture filling | 9.6 | 2.9 |
| LOST BRANCH FORMATION (84.3–90.7 ft) | 6.4 | 2.0 |
| Cooper Creek Limestone Member (84.3–89.4 ft) | | |
| **Calcilutite**, skeletal, with spar-filled fractures and shale partings; argillaceous at top | 5.1 | 1.6 |
| Shale unit (89.4–90.7 ft) | | |
| **Shale**, dark-gray, fossiliferous, with darker layers and abundant conodont fauna like that described by Swade (1985) from shale below Cooper Creek Limestone Member in Iowa core CP–37 | 1.3 | 0.4 |
| NOWATA–MEMORIAL SHALE (90.7–117.6 ft) | 26.9 | 8.2 |
| **Mudstone**, gray, blocky, with small limy nodules | 6.7 | 2.0 |
| **Mudstone**, red, blocky, to **shale** with limy nodules | 16.0 | 4.9 |
| **Calcilutite**, barren, dolomitized, with vertical fractures | 0.3 | 0.09 |
| **Mudstone**, green to red-mottled, with limy nodules | 3.9 | 1.2 |
| ALTAMONT LIMESTONE (117.6–121.3 ft) | 3.7 | 1.1 |
| Worland Limestone Member (117.6–120.4 ft) | 2.8 | 0.9 |
| **Calcilutite**, skeletal, with birdseye and red-shale-filled fractures | 1.0 | 0.3 |
| **Shale**, gray-green, fossiliferous, interbedded with skeletal **calcilutite** | 1.8 | 0.5 |
| Lake Neosho Shale Member (120.4–121.1 ft) | | |
| **Shale**, gray, fossiliferous, with abundant conodont fauna like that described by Swade (1985) from Lake Neosho Shale Member in Iowa cores CP–37 and CP–22 | 0.7 | 0.2 |
| Amoret Limestone Member (121.1–121.3 ft) | | |
| **Calcilutite**, skeletal | 0.2 | 0.06 |

**JEFFERSON QUARRY CORE (IJC)** (lower) (Iowa Geological Survey 41–74)—East of IA–25, 11 mi (18 km) north of Greenfield, Adair County, Iowa (NW-SE-NE-SW-NW sec. 17, T. 77 N., R. 31 W.; reposited at Iowa Geological Survey, Iowa City). Described by J. Newbury of Schildberg Construction Company; summarized and classified by P. H. Heckel.

| | ft | m |
|---|---|---|
| HERTHA LIMESTONE (99.1–107.4 ft) | 8.3 | 2.5 |
| Sniabar Limestone Member (99.1–106.3 ft) | | |
| **Calcilutite**, skeletal, interbedded with fossiliferous **shale** | 7.2 | 2.2 |
| Mound City Shale Member (106.3–107.4 ft) | | |
| **Shale**, greenish, fossiliferous, with black phosphatic zone in middle | 1.1 | 0.3 |
| UPPER PLEASANTON UNIT (107.4–114.6 ft) | | |
| **Mudstone**, gray with purple mottling, red zone in lower part | 7.5 | 2.3 |
| EXLINE LIMESTONE? (see comment on core ISC) (114.6–114.9 ft) | | |
| **Calcilutite**, skeletal, nodular, in green shale with conodont *Idiognathodus* | 0.3 | 0.09 |
| LOWER PLEASANTON UNIT (apparently missing at disconformity) | | |
| LOST BRANCH FORMATION (114.9–119.9 ft) | 5.0 | 1.5 |

| Jefferson Quarry core (continued) | Thickness ft | m |
|---|---|---|
| Cooper Creek Limestone Member (114.9–118.2 ft) | | |
| **Calcilutite**, skeletal, with abundant spar-filled voids; shale-parted, brecciated calcilutite in top 0.5 ft (0.2 m) yielded no conodonts | 3.3 | 1.0 |
| Shale unit (118.2–119.3 ft) | | |
| **Shale**, green, fossiliferous, with abundant conodont fauna like that described by Swade (1985) from shale below Cooper Creek Limestone Member in Iowa core CP–37 | 1.1 | 0.3 |
| Sni Mills Limestone Member (119.3–119.9 ft) | | |
| **Calcilutite**, skeletal, with shale bed near base | 0.6 | 0.2 |
| NOWATA–MEMORIAL SHALE (to base of core; 119.9–124.9 ft) | | |
| **Mudstone**, red, blocky, with limy pebbles and gray zone at top | 5+ | 1.5+ |

**STANZEL QUARRY CORE (ISC)** (Iowa Geological Survey 12–68)—North of IA–92, 10 mi (16 km) west of Winterset, Madison County, Iowa (NE-NW-SE-SW-NE, sec. 5, T. 75 N., R. 29 W.; reposited at Iowa Geological Survey, Iowa City). Described by J. Newbury of Schildberg Construction Company; summarized and classified by P. H. Heckel.

| | ft | m |
|---|---|---|
| HERTHA LIMESTONE (154.0–164.3 ft) | 10.3 | 3.1 |
| Sniabar Limestone Member (154.0–162.7 ft) | | |
| **Calcilutite**, skeletal, interbedded with fossiliferous **shale** | 8.7 | 2.7 |
| Mound City Shale Member (162.7–164.3 ft) | | |
| **Shale**, black, with gray zone at top | 1.6 | 0.5 |
| UPPER PLEASANTON UNIT (164.3–172.1 ft) | | |
| **Mudstone**, gray, blocky, with limy nodules | 7.8 | 2.4 |
| EXLINE LIMESTONE? (172.1–173.4 ft) | | |
| **Calcilutite**, skeletal, nodular, brecciated, with shale-filled fractures and voids; occurrence of conodonts *Idiognathodus* and *Idioprioniodus*, reported by Nielsen (1987, p. 75), suggests that this bed may represent the Exline limestone by comparison with conodont faunas described by Swade (1985) from Iowa core CP–37 where the Exline limestone rests on a very thin [(0.3 ft (0.09 m)] lower Pleasanton shale unit above the Cooper Creek Limestone Member; core IJC is tentatively interpreted in a similar fashion, although the conodont evidence is less definite | 1.3 | 0.4 |
| LOWER PLEASANTON UNIT (apparently missing at disconformity) | | |
| LOST BRANCH FORMATION (173.4–178.2 ft) | 4.8 | 1.5 |
| Cooper Creek Limestone Member (173.4–177.0 ft) | | |
| **Calcilutite**, skeletal, nodular, brecciated, with shale partings and shale-filled voids; conodont fauna, reported by Nielson (1987, p. 75), has common *Diplognathodus*, as reported also by Swade (1985) from Cooper Creek Limestone Member in core CP–37 | 3.6 | 1.1 |
| Shale unit (177.0–177.8 ft) | | |
| **Shale**, gray, with dark-gray zones and abundant conodont fauna like that reported by Swade (1985) from shale below Cooper Creek Limestone Member in core CP–37 | 0.8 | 0.2 |
| Sni Mills Limestone Member (177.8–178.2 ft) | | |
| **Calcilutite**, skeletal | 0.4 | 0.1 |
| NOWATA–MEMORIAL SHALE (to base of core; 178.2–183.7 ft) | | |
| **Mudstone**, red, blocky, with gray zone at top | 5.5+ | 1.7+ |

**OSCEOLA CORE (CP–37)**—Described at beginning of appendix.

**MYSTIC CORE (CP–22)**—3 mi (4.8 km) northwest of Mystic, Appanoose County, Iowa (SE-SW-SE sec. 36, T. 70 N., R. 19 W.). This core did not cut the Lost Branch Formation but is included in fig. 9 because it and CP–37 form the basis for the conodont zonation of the upper Desmoinesian Marmaton Group of Swade (1985), which is used to confirm correlation of the formations in this group among the cores and outcrops from Iowa to Oklahoma.

| **NODAWAY COUNTY CORE (MNC)** (Missouri Geological Survey WM–5)—8 mi (13 km) north-northwest of Maryville, Nodaway County, Missouri (SE-NW sec. 10, T. 65 N., R. 36 W.; reposited at Missouri Geological Survey, Rolla). Described by K. Deason; summarized and classified by P. H. Heckel. | **Thickness** ft | m |
|---|---|---|
| HERTHA LIMESTONE (851.5–874.0 ft) | 22.5 | 6.9 |
| Sniabar Limestone Member (851.5–870.9 ft) | | |
| **Calcilutite**, skeletal, with shale in top, near middle, and at base | 19.4 | 5.9 |
| Mound City Shale Member (870.9–874.0 ft) | | |
| **Shale**, black, phosphatic, with gray zones at top and base and limy horizon at base | 3.1 | 0.9 |
| UPPER PLEASANTON UNIT (874.0–892.6 ft) | 18.6 | 5.7 |
| **Mudstone**, gray, blocky, with coal smut at top (Ovid coal) and limy nodules in base | 6.0 | 1.8 |
| **Sandstone**, gray, argillaceous; coarsens upward | 12.6 | 3.8 |
| EXLINE LIMESTONE (892.6–900.8 ft) | | |
| **Calcilutite**, skeletal, dense, brownish, with thin dark shale partings | 8.2 | 2.5 |
| LOWER PLEASANTON UNIT (900.8–903.6 ft) | | |
| **Mudstone**, gray, blocky | 2.8 | 0.9 |
| LOST BRANCH FORMATION (903.6–911.9 ft) | 8.3 | 2.5 |
| Cooper Creek Limestone Member (903.6–911.0 ft) | | |
| **Calcilutite**, skeletal, gray | 7.4 | 2.3 |
| Shale unit (911.0–911.9 ft) | | |
| **Shale**, black, phosphatic (Nuyaka Creek black shale bed), with abundant conodont fauna like that described by Swade (1985) from shale below Cooper Creek Limestone Member in Iowa core CP–37 | 0.9 | 0.3 |
| MEMORIAL SHALE (911.9–920.0 ft) | | |
| **Mudstone**, blocky, gray, with coal smut at top and limy nodules below | 8.1 | 2.5 |
| LENAPAH LIMESTONE, Norfleet Limestone Member (920.0–921.7 ft) | | |
| **Calcilutite**, skeletal, nodular, in green mudstone matrix | 1.7 | 0.5 |
| NOWATA SHALE (921.7–927.2 ft) | | |
| **Mudstone**, blocky, gray, with reddish mottling and limy nodules | 5.5 | 1.7 |
| ALTAMONT LIMESTONE (927.2–936.7 ft) | 9.5 | 2.9 |
| Worland Limestone Member (927.2–934.6 ft) | | |
| **Calcilutite**, skeletal; grades upward to **calcarenite** | 7.4 | 2.3 |
| Lake Neosho Shale Member (934.6–935.5 ft) | | |
| **Shale**, green-gray, laminated, with abundant conodont fauna like that described by Swade (1985) from Lake Neosho Shale Member in Iowa cores CP–37 and CP–22 | 0.9 | 0.3 |
| Amoret Limestone Member (935.5–936.7 ft) | | |
| **Calcilutite**, skeletal, shaly in base | 1.2 | 0.4 |

**ROCHESTER CORE (MRC)** (Missouri Geological Survey WM–10)—3.5 mi (5.6 km) north-northwest of Rochester, Andrew County, Missouri (SE-SE sec. 4, T. 59 N., R. 34 W.; reposited at Missouri Geological Survey, Rolla). Described by B. Netzler and K. Deason; summarized and modified by P. H. Heckel.

| | ft | m |
|---|---|---|
| HERTHA LIMESTONE (506.8–517.0 ft) | 10.2 | 3.1 |
| Sniabar Limestone Member (506.8–515.9 ft) | | |
| **Calcilutite**, skeletal, with shale beds near middle and base | 9.1 | 2.8 |
| Mound City Shale Member (515.9–517.0 ft) | | |
| **Shale**, black | 1.1 | 0.3 |
| UPPER PLEASANTON UNIT (517.0–585.6 ft) | 68.6 | 20.9 |
| **Mudstone**, blocky, gray, with limy nodules | 2.3 | 0.7 |
| **Sandstone**, gray, with shale toward base and top | 14.7 | 4.5 |
| **Shale**, gray, interbedded with **sandstone** and two coaly horizons (Locust Creek) in upper part (at 535 ft and 540 ft) | 15.2 | 4.6 |
| **Sandstone**, gray, micaceous | 36.4 | 11.1 |

| Rochester core (continued) | Thickness ft | Thickness m |
|---|---|---|
| Exline limestone (585.6–586.6 ft) | | |
| **Calcilutite**, skeletal, dense, brownish | 1.0 | 0.3 |
| Lower Pleasanton unit (586.6–593.1 ft) | 6.5 | 2.0 |
| **Shale**, gray, fossiliferous | 2.5 | 0.8 |
| **Coal** (Grain Valley) | 0.2 | 0.06 |
| **Mudstone**, blocky, gray, with plant remains in top and limy nodules in base | 3.8 | 1.2 |
| Lost Branch Formation (593.1–597.4 ft) | 4.3 | 1.3 |
| Cooper Creek Limestone Member (593.1–595.2 ft) | | |
| **Calcilutite**, skeletal, with shale partings and fracture fillings at top | 2.1 | 0.6 |
| Shale unit (595.2–597.4 ft) | | |
| **Shale**, gray, with shell hash in lower part and dark phosphatic zone above middle carrying abundant conodont fauna like that described by Swade (1985) from shale below Cooper Creek Limestone Member in Iowa core CP–37 | 2.2 | 0.7 |
| Memorial Shale (597.4–624.4 ft) | 27.0 | 8.2 |
| **Coal** (Dawson) | 0.1 | 0.03 |
| **Mudstone**, blocky, gray, reddish in lower part, with limestone nodules | 12.5 | 3.8 |
| **Sandstone**, gray | 10.0 | 3.0 |
| **Shale**, gray with reddish spots | 4.4 | 1.3 |
| Lenapah Limestone, Norfleet Limestone Member (624.4–625.5 ft) | | |
| **Calcarenite**, skeletal, with conodont fauna [reported by Greenberg (1986, p. 199)] similar to that of basal Lenapah Limestone southward in outcrop | 1.1 | 0.3 |
| Nowata Shale (625.5–634.0 ft) | | |
| **Shale**, gray, with reddish zone near middle; grades downward into blocky **mudstone** | 8.5 | 2.6 |
| Altamont Limestone (634.0–640.3 ft) | 6.3 | 1.9 |
| Worland Limestone Member (634.0–637.0 ft) | | |
| **Calcarenite**, abraded-skeletal; overlies skeletal, shaly **calcilutite** | 3.0 | 0.9 |
| Lake Neosho Shale Member (637.0–640.3 ft) | | |
| **Shale**, gray, fossiliferous, with dark phosphatic zone in lower part carrying abundant conodont fauna like that described by Swade (1985) from Lake Neosho Shale Member in Iowa cores CP–37 and CP–22 | 3.3 | 1.0 |

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