KANSAS GEOLOGICAL SURVEY
OPEN-FILE REPORT 92-60

Revision of Missourian (Lower Upper Pennsylvanian)
Stratigraphy in Kansas and Adjacent States

by

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REVISION OF MISSOURIAN (LOWER UPPER PENNSYLVANIAN) STRATIGRAPHY IN KANSAS AND ADJACENT STATES

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AUTHOR S NOTE: This lengthy detailed manuscript was submitted to the Kansas Geological Survey in 1992 for review by stratigraphers in Kansas and adjacent states, following the discovery in the late 1980s of significant miscorrelations within Kansas of several named Missourian rock units whose names had been used across the several states along the midcontinent Pennsylvanian outcrop belt. It was intended as the first step toward gaining consensus as to what modifications of nomenclature and classification were now required in the then-current stratigraphic nomenclature that was relatively consistent across the several states. Therefore, it contains much more detail concerning history of nomenclature of many of the units, many more localities where the rock units are exposed, and much more information on the nature of the rock units and their correlatives in the adjacent states than were necessary for the required redefinition and reclassification of many old named rock units and for the introduction of new units in the formal publication that ultimately ensued as Kansas Geological Survey Bulletin 246 in 2002. Because it is considered desirable to make all this additional unpublished data available to interested stratigraphers, the original manuscript is provided in this Open-file Report of the Kansas Geological Survey, with only a small amount of updating of references that were then in press. Therefore, it must be noted that one of the new names used in this manuscript was changed for the Bulletin (Unity Farm to Mantey Shale Member), and several suggestions for reclassification (e. g., establishment of Supergroups, inclusion of the Checkerboard Limestone Member in the Tacket Formation, and reinstatement of the Pedee Group of MIssouri in Kansas) were dropped before publication of Bulletin 246. Because of time constraints, these changes were not made retroactively in this Open-file Report. Thus readers must keep in mind for example, that the strata classified in the Pedee Group in this report are now split again between the Lansing Group (Rock Lake Shale and South Bend Limestone) and the Douglas Group (Stranger Formation and its Weston Shale and Iatan Limestone members), where they originally had been classified in Kansas. Also, because this manuscript was only a working draft, most of the figures are only photocopies of pencil-drafted diagrams, only certain of which were updated and drafted on computer for incusion in Bulletin 246.

INTRODUCTION

Missourian strata in Kansas since 1963 have comprised the succession from the base of the Pleasanton Group to the top of the Stanton Limestone (South Bend Limestone Member) at the top of the Lansing Group (Fig. 1). As a result of ongoing lithostratigraphic and biostratigraphic work along outcrop in Kansas and adjacent states since the mid 1960s by myself, students and other geologists (currently largely under the auspices of the Midcontinent Pennsylvanian Stratigraphic Working Group of the Midcontinent Section of the Society of Economic Paleontologists and Mineralogists), enough miscorrelations have been discovered both within Kansas and between Kansas and adjacent states to necessitate a revision of the correlation of certain formations within the Missourian. This recorrelation in turn requires a certain amount of revision of nomenclature and classification of the Missourian succession (Fig. 2). The philosophy of this revision follows two basic guidelines.

The first guideline is to change the nomenclature currently in use in Kansas and the other states along the Midcontinent outcrop belt (Missouri, Nebraska, Iowa, and Oklahoma) as little as possible beyond that which is mandated by the corrections of the miscorrelations. In some cases, this requires setting up new reference sections, including neostratotypes in place of the original type sections of two well-known units (Hepler, Hertha), for which the name has become familiarly attached, through miscorrelation, to strata across the entire rest of the Midcontinent that do not correlate with the original type sections. This procedure tempers Article 8c of the North American Stratigraphic Code (1983) on the immutability of stratotypes with Article 7c regarding the preferability of preserving well established names. Precedence for this procedure in the Midcontinent Missourian lies in the discovery by Newell (1935, p. 74) that the original type section of the Stanton Limestone in Kansas is equivalent to the contemporaneously named Plattsburg Limestone in Missouri, with common usage of the name Stanton shifted to a higher limestone because of miscorrelation between the type sections, and in his pragmatic resolution of the problem by recognizing the higher limestone in the Stanton type area as type Stanton, rather than replacing the name Plattsburg with Stanton, or Stanton with a little-used name from southern Kansas. In other cases, slight to moderate redefinitions of formations, boundaries, and component members are required to adequately characterize the stratigraphic relations of the units as now understood.

The second guideline is to keep the marine transgressive-regressive units separate from the terrestrial-nearshore detrital units at the formal formation/member rank as much as it is lithically possible, considering that the North American Stratigraphic Code requires lithic definitions for formations and members. This will allow distinct unambiguous names to be applied to individual marine units and thereby to provide an appropriate format for correlation at all scales, because it is the lateral continuity of the marine units (regardless of lithic change within them) that underpins correlation within the Midcontinent basin and provides the framework for detailed correlation with the coeval succession in other basins. The principles behind this guideline were discussed and utilized by Moore (1936, p. 20ff.), and the guideline is readily applied in cases where the marine units (e.g., Swope Limestone) consist of a widespread transgressive limestone, offshore shale, and regressive limestone (see Heckel, 1977), which are lithically distinct from the underlying and overlying terrestrial-nearshore shales (e.g., Elm Branch Shale, Galesburg Shale). It is relatively straightforward even in cases where the transgressive limestone is missing along much of the outcrop (e.g., Dennis Limestone, Dewey Limestone) because the definitely marine offshore shale members (Stark Shale, Quivira Shale) provide good lithic markers distinct from the underlying terrestrial shale/paleosol (Galesburg Shale, Nellie Bly Formation). Furthermore, this type of boundary between formations is essentially the marine flooding surface, an important genetic boundary in the more recently developed conceptual framework of sequence stratigraphy.

Application of this guideline is not as straightforward, however, when the regressive limestone is missing along most of the outcrop, and the offshore marine shale grades upward less perceptibly into nearshore marine detrital deposits, which commonly are overlain by terrestrial detrital deposits that typically are difficult to distinguish from the marine regressive sequence. In these cases it is just as important to separate the marine transgressive to highstand units, which contain most of the fossils useful for distant correlation (conodonts, ammonoids), from the terrestrial units that represent marine lowstand and may contain palynomorphs or other terrestrial fossils of distinctly later age. The most pragmatic procedure is to choose the most conspicuous lithic change upward from obviously marine strata (typically fossiliferous shale) to possibly terrestrial strata (typically unfossiliferous sandstone or unfossiliferous blocky mudstone) as Heckel (1991) did in drawing the Lost Branch-Hepler formational boundary, recognizing that the boundary so chosen is very probably of slightly different age in different places. This procedure is a pragmatic compromise between 1) a more rigidly sequence-stratigraphic (but difficult) alternative of trying to distinguish unfossiliferous regressive marine sandstones from lowstand fluvial or other terrestrial sandstones in order to draw a boundary between them, and 2) the strictly lithic alternative of terminating the marine limestone-dominated formation vertically and laterally where the limestone disappears and thus placing a biostratigraphically important marine shale interval into more than one formational name in the same part of the same basin, leading to nomenclatural awkwardness and potential confusion when attempting distant correlation by means of its fossil content.

Using these guidelines (initially developed by Newell, 1935, and Moore, 1936), formations are either 1) the generally limestone-dominated (but occasionally shale-dominated) deposits of a marine transgressive-regressive stratigraphic sequence resulting from a glacial-eustatic inundation and withdrawal of the sea (see Heckel, 1986, 1990; in press), or 2) the generally sandy shale or mudstone to locally sandstone-dominated deposits of late regression, sea-level lowstand (and locally early transgression) between the marine formations.

Named members generally represent the distinctive lithic unit (shale or limestone) deposited during a particular phase of deposition. In the marine limestone formations (1), they correspond to a position of high sea-level stand (shale member), or a trend of sea-level change (deepening for the transgressive limestone member, or shallowing for the regressive limestone member). In the shale-dominated formations (2), they represent a minor marine incursion that formed a less widespread limestone member during an interval of generally lower sea-level stand.

Both named and unnamed beds representing distinctive locally mapped rock units are recognized within certain members and formations. All previously named sandstone members are now recognized only as beds in their type regions because of their notorious lenticularity and generally only local development, which has led to misleading and sometimes seriously incorrect correlations (e.g., Hepler) when they were ranked as named members and treated with presumed lateral extent on the same scale as the named limestone and shale members.

MISSOURIAN STRATA

The history of the name Missourian and the extent of strata to which it has been applied were outlined by Moore (1936, 1949). In those works, and in Moore et al. (1951), the Missourian was ranked as a series, one of the ascending sequence of Midcontinent provincial series recognized within the Pennsylvanian System: Morrowan, Atokan, Desmoinesian, Missourian, Virgilian (Bradley, 1956). In some recent works (O'Connor, 1963; Zeller, 1968), the Missourian has been ranked as the lower stage of the Upper Pennsylvanian Series.

Because both the terms "stage" and "series" apply formally only to chronostratigraphic units based on ranges of fossil organisms (North American Commission on Stratigraphic Nomenclature, 1983, Articles 73,74,29a), it is appropriate to follow the rationale of the Iowa Geological Survey (Ravn et al., 1984) and recognize the lithostratigraphic entities upon which these series are based in their type regions along the Midcontinent outcrop belt as supergroups. Hence the basic subdivisions of outcropping Pennsylvanian rocks in Kansas comprise in ascending order: Des Moines Supergroup, Missouri Supergroup, and Virgil Supergroup. Because these are lithostratigraphic units, they have lithostratigraphic boundaries. The derived chronostratigraphic units Desmoinesian, Missourian, Virgilian, have boundaries based on first appearances of biostratigraphically significant taxa, and therefore may not exactly coincide with the supergroup boundaries.

Missouri Supergroup

The Missouri Supergroup as defined herein extends from the base of the Hepler Formation (as redefined) at the base of the Pleasanton Group, to the top of the Pedee Group, as reinstated and redefined to include the formation (Stranger) formerly included in the base of the overlying Douglas Group. The lower boundary is close to the traditional lower Missourian Stage boundary traditionally at the base of the Hepler Sandstone Member (of the Seminole Formation; see later section) but with corrections of certain miscorrelations explained by Heckel (1991). This lower boundary, with the underlying Lost Branch Formation at the top of the Marmaton Group and Desmoines Supergroup, is a lithic contact of unfossiliferous mudstone above limestone (where present) or of mudstone or unfossiliferous sandstone above at least sparsely fossiliferous shale as outlined previously, and is of slightly different age in different places (Heckel, 1991). It is not coincident with, but rather slightly older than the base of the Missourian Stage, which is designated at the first appearance of a particular conodont taxon in the base of the marine South Mound Shale Member in the upper part of the Hepler Formation, as explained in the following section. The upper boundary of the Missouri Supergroup, with the overlying Haskell Limestone Member of the Cass Limestone at the base of the redefined Douglas Group and Virgil Supergroup, is a lithic contact of limestone above mudstone, shale, or locally sandstone throughout Kansas, which is also a marine flooding surface. This boundary is considered essentially the same as the Missourian-Virgilian Stage boundary, which is redefined herein at the first appearance of a particular conodont taxon in the top of the Haskell Limestone Member, and particularly in the overlying Little Pawnee Shale Member of the Cass Limestone in the more offshore part of that widespread marine interval (see later section).

The subdivision of the Missouri Supergroup in Kansas (Fig. 1) is now into four groups in ascending order: Pleasanton Group (2 dominantly shale formations with thin limestone members), Kansas City Group (15 limestone and shale formations in cyclic sequence), Lansing Group (3 limestone and shale formations in cyclic sequence), and Pedee Group (2 dominantly shale formations separated by a thin limestone formation). Because the Kansas City Group is much thicker than the other three groups and contains many more component formations (15) than the other three (2 to 3 each), it has been divided into 3 subgroups, in ascending order: Bronson (3 prominent limestone formations separated by 2 thin shale formations with 2 additional formations, a limestone and a shale, southward), Linn (2 locally thicker shale formations, 1 thick shale-limestone formation and 1 thin limestone formation), and Zarah (2 limestone and 2 shale formations each with substantially different thicknesses dominant in different areas). Because of recorrelation that involves the boundaries of the Pleasanton Group and Bronson Subgroup, and of the Linn and Zarah Subgroups, and also because of reinstatement and redefinition of the Pedee Group as a result of upward extension of strata

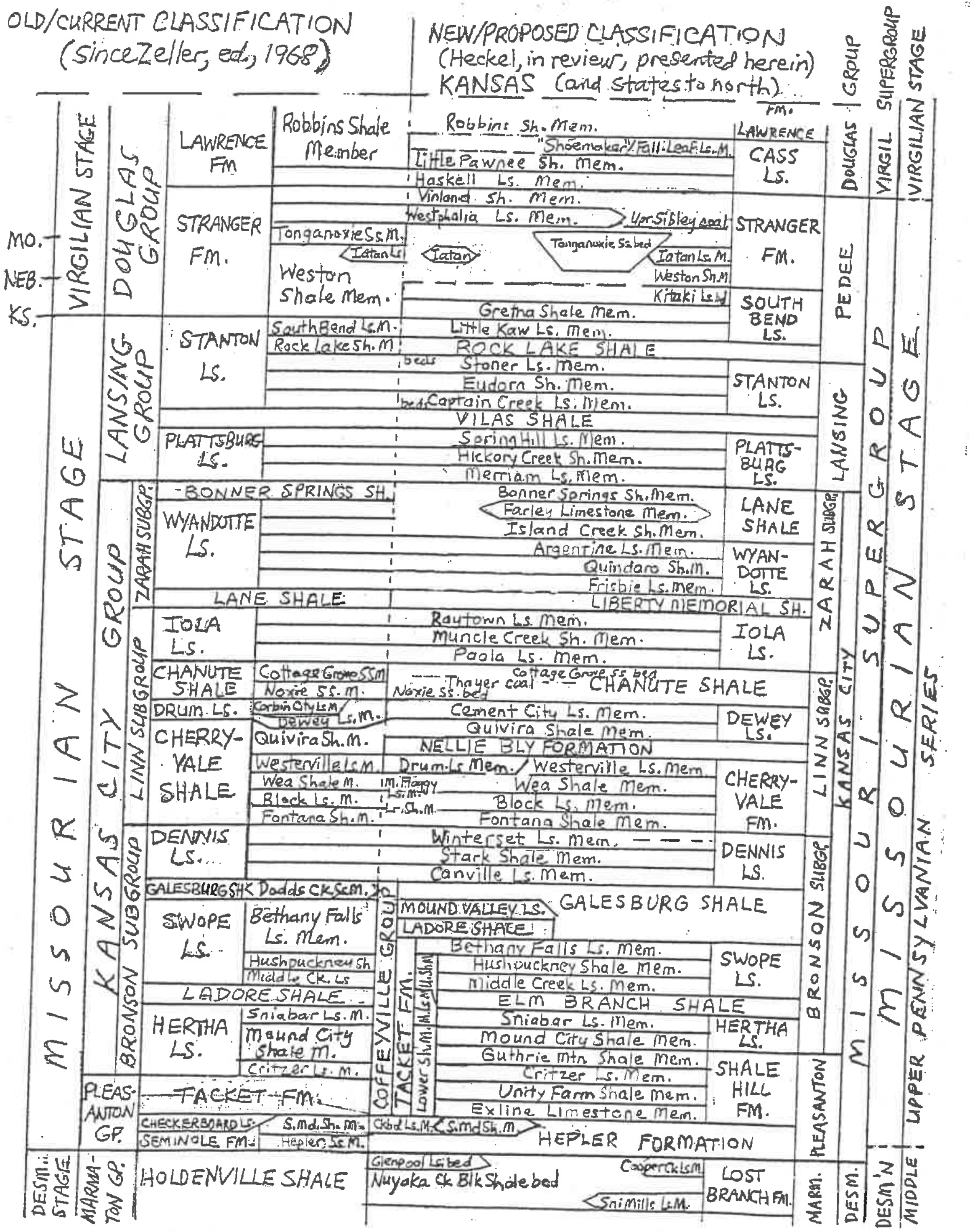


Figure 1.--Comparison of previous stratigraphic classification of Missourian succession in Kansas (Zeller, ed., 1968), with that revised herein, based on corrections of miscorrelations, and on more precise definitions of stage boundaries, following guidelines in North American Stratigraphic Code (1983). Short lines with state abbreviations in upper left show different positions of Missourian-Virgilian Stage boundary previously recognized in those 3 states. [This figure was modified to become Figure 1 in KGS Bulletin 246]

considered Missourian to a position where faunal change is sufficient to properly define the base of the Virgilian Stage (see later section), a certain amount of revision of groups is involved.

Nevertheless, the formation is the basic lithostratigraphic unit of the geologic record, and the groups are mainly convenient groupings of formations for various geologic and historical purposes. This is particularly true in the Midcontinent Pennsylvanian where the formations reflect closely the widespread advances and retreats of the sea that gave rise to the genetic units long termed cyclothems and now recognized as distinctive types of stratigraphic sequences that are very useful for interpreting geologic history. In order to facilitate depositional understanding of each of the named formational and member units, a sea-level curve is presented as Figure 3. This is the most recently updated version of the Missourian portion of the curve illustrated by Heckel (1986), and related to the stratigraphic units in the Midcontinent succession by Heckel (1989). Heckel (1986, 1990; in press) presented the rationale as to why this curve appears to reflect glacial eustatic fluctuations in sea-level as the main controlling factor in Midcontinent Pennylvanian stratigraphy.

A major purpose of this revision, in addition to correcting the miscorrelations alluded to previously, is to clarify the formal stratigraphic nomenclature of the Midcontinent Pennsylvanian succession as much as possible, in order to facilitate continental and eventually worldwide correlation of coeval Pennsylvanian successions elsewhere with that in the Midcontinent. Because of its easy accessibility, tectonically undisturbed nature, and high degree of completeness of section, in conjunction with its interlayering of fossiliferous marine and terrestrial rocks, the Midcontinent succession may be the most useful de facto stratotype for late Middle and Upper Pennsylvanian strata in the world. Therefore, its stratigraphic nomenclature and classification in Kansas and adjacent states (where it is best exposed) should be straightforward, pragmatic, and reflective of the glacial-eustatic fluctuations in sea level that are responsible for its alternation of marine and terrestrial rocks and for the resulting potentiality of worldwide correlation of these relatively short-term events at a refined scale.

Missourian Stage

The Missourian Stage is now recognized as the lower of two constituent stages of the Upper Pennsylvanian Series in the Midcontinent basin. Its defining lower boundary is now considered coincident with the base of the Upper Pennsylvanian Series (Boardman et al., 1990), and its upper boundary is the redefined base of the Virgilian Stage.

Recently, the Lower, Middle, and Upper Pennsylvanian Series have been defined in the Appalachian basin, the type region of the Pennsylvanian System (Englund, 1979; Arndt, 1979; Henry et al., 1979). The Middle-Upper Pennsylvanian Series boundary was placed at the contact between the gray Charleston Sandstone below and the reddish mudstone-dominated

Conemaugh Formation above (Henry et al., 1979, p. 83) at a locality in West Virginia. This lithic boundary is allowable according to the North American Commission on Stratigraphic Nomenclature (1983, Art. 67), but only provided that it has properties allowing chronocorrelation with rock sequences elsewhere (Art. 66c, 68). However, the correlation problems involving the "Mahoning" sandstone at the boundary level within the Appalachian basin (discussed in the next section), and the paucity of marine fossiliferous intervals (see also Henry and Gordon, 1979), particularly of those carrying the groups commonly used for distant correlation (ammonoids, fusulinids and conodonts), and the paucity of palynomorph-bearing coals in this interval in West Virginia where the Pennsylvanian stratotype is proposed (Kosanke, 1988), would appear to render the Appalachian basin inadequate for useful stratotypes for at least the younger of these subdivisions.

Based on current knowledge, the Midcontinent is probably the most appropriate area to define the stratotypes of the later part of the Middle (Desmoinesian) and the entire Upper Pennsylvanian Series (Missourian and Virgilian) as ongoing intensive work progresses on the conodonts, ammonoids, fusulinids, and palynomorphs. Not only is the marine portion of this part of the succession on the lower shelf margin of the foreland basin of Oklahoma far more complete than in the Appalachian basin, particularly near the traditional stage and series boundaries (Heckel, in press), but also the widespread interlayering of many intervals of marine and terrestrial biotas across the northern Midcontinent shelf will more readily allow both entirely marine and entirely terrestrial successions to be correlated with it.

In the Midcontinent, previous work had grouped the provincial series as stages of Lower (Springeran plus Morrowan), Middle (Atokan plus Desmoinesian), and Upper (Missourian plus Virgilian) Series of the Pennsylvanian System (Cheney et al. 1945; Moore and Thompson, 1949; see Boardman et al., 1990 for more detail). Therefore, with this precedent, it is proposed to establish preliminary pragmatic ("working") boundaries between the Desmoinesian and Missourian Stages (equivalent to that between the Middle and Upper Pennsylvanian Series) and between the Missourian and Virgilian Stages in the Midcontinent, pending international agreement on actual boundary stratotypes in areas of more continuous marine successions. (Considering the cyclic glacial-eustatic nature of Pennsylvanian stratigraphy, with many substantially low sea-level stands, such continuous marine successions may be difficult to find in presently exposed basins). This strongly glacial-eustatic cyclic nature of Pennsylvanian stratigraphy so well expressed in the Midcontinent through the alternation of thin widespread marine and terrestrial units, however, provides an opportunity for distant biostratigraphic correlation of cyclic stratigraphic-sequence events at a scale of refinement that may be unparalleled in most of the geologic record (Boardman et al., 1990; see Boardman and Heckel, 1989; Heckel and Weibel, 1991).

Desmoinesian-Missourian Stage boundary.--This boundary defines the base of the Missourian Stage and automatically fixes the top of the Desmoinesian Stage (North American Commission on Stratigraphic Nomenclature, 1983, Article 67a). Because of important changeovers in marine faunas long recognized in the Midcontinent at this position (Moore, 1949), which happen to essentially coincide with an important changeover in terrestrial plant and palynomorph floras (Peppers, 1984), this boundary is also regarded pragmatically as the base of the Upper Pennsylvanian Series (Boardman et al., 1990). The most conspicuous characteristic of the changeover in marine faunas at this position is the highest occurrences of several abundant genera in several different phyla in the Lost Branch Formation at the top of the Desmoinesian (see Boardman et al., 1990, for details). These extinctions at the boundary include the brachiopod *Mesolobus*, the fusulinid *Beedeina*, the ammonoid *Gonioglyphioceras*, and the conodont *Neognathodus*. The highest occurrences of the palynomorph *Granasporites* (=*Cappasporites*) and of abundant Lycospora and Thymospora are in the Dawson coal and its correlatives at the top of the Memorial Shale just below the Lost Branch Formation. First appearances of new taxa in the basal marine beds of the Missouri Supergroup above the Lost Branch Formation appear limited to the ammonoid genus *Pennoceras* in Oklahoma and species-level morphotypes of the conodont *Idiognathodus* in Oklahoma and Kansas (Boardman et al., 1990, p. 331-3).

The Subcommission on Devonian Stratigraphy (Ziegler, 1975) adopted several guidelines for selecting a chronostratigraphic boundary, which are sensible and appropriate to the current issue, and are summarized as follows: 1) It should be selected at a consistently recognizable point in a phyletic lineage of a fossil group that underwent rapid evolution, and achieved widespread geographic distribution. 2) It should have as many other fossil groups represented as possible in order to ensure effective worldwide correlation. 3) It should be selected at a point in the phylogeny of the definitive group that the greatest agreement can be attained with marker levels for other fossil groups. 4) Historic usage should be disturbed as little as possible.

Because it also is common practice to define the base of a chronostratigraphic unit on the first appearance of a taxon, and strongly advisable to utilize a taxon of sufficient abundance to allow a better likelihood of recovery from the rocks available in most exposures, it is recommended that the first appearance of the conodont *Idiognathodus sulciferus* Gunnell 1933 (=*I. sagittalis* Kosenko 1975 of Boardman et al., 1990: see Barrick et al., 1990) define the base of the Missourian Stage and Upper Pennsylvanian Series. In Kansas, this taxon first appears in the base of the South Mound Shale Member of the Hepler Formation in exposures at the stratotype of the Lost Branch Formation (Heckel, 1991) near Mound Valley in Labette County. Because the South Mound Shale appears to be the lateral equivalent of the type Checkerboard Limestone of Oklahoma (see later sections on those units), this first appearance is consistent with those in the Checkerboard Limestone and southward-equivalent shale in Oklahoma, where the ammonoid *Pennoceras* first appears in the Little River section near Sasakwa in Seminole County (Boardman et al., 1989b; 1990). In both the Kansas and Oklahoma sections mentioned (outcrops 19 and 34 in Heckel, 1991) the marine Lost Branch Formation is exposed below the first appearance of I. sulciferus and contains all the characteristic Desmoinesian fossils mentioned previously. The type Glenpool Limestone bed at the top of the Lost Branch Formation in the Tulsa area contains an undescribed morphotype of *Idiognathodus*, which is the probable ancestor of *I. sulciferus* (D.R. Boardman pers. commun. 1992).

Because the South Mound-Checkerboard marine unit represents a minor cycle of inundation confined to the basin-margin area of southern Kansas and Oklahoma (Fig. 3), the first appearance of *I. sulciferus* will be in younger marine units elsewhere (Exline Limestone Member of northern Midcontinent and equivalent Bath Bend unit in north-central Texas: Boardman and Heckel, 1989). Even younger units lie at the base of the Missourian Stage in the Illinois and Appalachian basins, based on first appearances of descendent taxa from younger Midcontinent marine units (Hertha, Swope) in the lowest widespread marine units (Cramer, Brush Creek, respectively) above the correlated boundary in those places studied (P.H. Heckel and J.E. Barrick in preparation; see Heckel and Weibel, 1991; Heckel, in press). Therefore, the hiatus above the top of the Desmoinesian Stage increases away from the southern Midcontinent, and the South Mound-Checkerboard unit provides the oldest first appearances of new taxa so far known above the extinctions of the distinctive Desmoinesian taxa mentioned above.

The presence of terrestrial beds (lower Hepler Formation) in Kansas and of possible terrestrial deposits or a possible minor erosional gap between the highest Desmoinesian and lowest Missourian marine strata in Oklahoma (Heckel, 1991, outcrop 34) attests to a larger than usual sea-level drop terminating the latest Desmoinesian Lost Branch marine incursion. This may explain the post-Desmoinesian extinctions in both the marine and terrestrial realms by crowding of the marine organisms into a smaller basinal area, and by reducing the area of lycopod-inhabited fresh-water swamps as a result of lowering the shoreline to steeper slopes along the lower part of the basin (Schutter and Heckel, 1985; Heckel, 1991). The probable presence of even a slight break in marine sedimentation at this horizon in Oklahoma, the most basinal area along outcrop, requires further search of this stratigraphic interval in exposed deeper basins before designating a final boundary stratotype.

An unavoidable artifact of designating the base of the Missourian Stage at the first appearance of the appropriate marine fossil in the base of the South Mound Shale, somewhere near the middle of the Hepler Formation, is the automatic inclusion of that part of the Hepler Formation below this position in the top of the Desmoinesian Stage, even though it contains the basal strata of the Missouri Supergroup (Fig. 1,2). This procedure is consistent with the North American Stratigraphic Code (1983, Art. 48b), which emphasizes the independence of biostratigraphic units (and by extension chronostratigraphic units that are based on biostratigraphic concepts) from lithostratigraphic units (implicitly even those from which the name was derived). The only bed in the generally unfossiliferous Hepler Formation that is immediately affected by this definition is the "Hepler" (=Tulsa) coal (and two slightly younger sub-Checkerboard coals in Oklahoma), which contain palynomorph floras of low diversity and general composition similar to those of Missourian coals above the base of the South Mound Shale Member (R.A. Peppers, pers. communs., 1983-4). However, no new taxa are so far known to appear in these lower Hepler coals (which by definition are now latest Desmoinesian) that would allow a palynological definition of the base of the Missourian. Therefore the current conodont-based definition does have the effect of imposing a little less certainty on the base of the Missourian Stage and the Upper Pennsylvanian Series in successions that are terrestrial throughout this part of the interval.

The proposed conodont-based definition of the base of the Upper Pennsylvanian Series in the Midcontinent may require a slight shift of strata from the previously proposed Middle-Upper Pennsylvanian boundary in the Appalachian basin at the Charleston Sandstone-Conemaugh Formation contact in West Virginia (Henry et al., 1979). This is because the Mahoning coal, which lies between the "lower" and "upper" Mahoning sandstones in the base of the Conemaugh Group in Ohio (Sturgeon and Hoare, 1968) contains a lycospore-dominated palynoflora correlated with the Dawson coal (Peppers, 1988) below the Lost Branch Formation in the Midcontinent. This means that the Mahoning coal in Ohio and Pennsylvania is late Desmoinesian in age and therefore would be shifted to the top of the Middle Pennsylvanian Series. However, if the Mahoning coal interval lies within the "Mahoning" sandstone, which Henry et al. (1979) considered to be the top member of the Charleston Sandstone in West Virginia, then no shift would be necessary. Nevertheless, their uncertain lithic correlation (ibid., Fig. 72) of the designated boundary in West Virginia with the Allegheny-Conemaugh contact in Ohio and Pennsylvania, which lies below the Mahoning coal in its type region, casts doubt both on their correlation of the Mahoning sandstone between Pennsylvania and West Virginia and on the advisability of designating a series boundary solely on a lithic change, particularly one involving sandstones, so notorious for their lenticularity.

An additional point to consider is that the lowest widespread marine horizon above the Mahoning coal, the lower Brush Creek Limestone of Ohio, is fairly well correlated with the Swope Limestone of the Midcontinent (Boardman et al., 1990; Heckel, in press), which is younger than both the lower Missourian Exline and Hertha marine cycles in the Midcontinent. This point draws important attention to the lack of correlatives of the lowest Missourian (along with many other) Midcontinent marine intervals in the Appalachian basin, which must have resulted from nondeposition or possibly erosion. This further emphasizes both the incompleteness of the Appalachian succession and the appropriateness of establishing both a working Middle-Upper Pennsylvanian series boundary and the late Middle and Upper

Pennsylvanian Series stratotypes in the Midcontinent. It also mitigates the slight uncertainty of this boundary in solely terrestrial palynomorph successions, because drawing this boundary at the top of the next exposure surface above the Mahoning coal would place it within the large stratigraphic gap that apparently encompasses this boundary in the Appalachian basin.

Missourian-Virgilian Stage boundary.--This boundary defines the base of the Virgilian Stage and automatically fixes the top of the Missourian Stage. The base of the Virgilian was originally placed at the base of the channel-filling Tonganoxie Sandstone in northeastern Kansas because it was believed to represent a widespread disconformity across the entire Midcontinent (Moore, 1936), separating the overlying Douglas Group from the partially eroded underlying Pedee Group (as originally defined). Moore (1949, p. 66) noted that a pronounced evolutionary break in the succession of species of the fusulinid Triticites occurs across this disconformity and marks this boundary elsewhere, which by this time had been agreed upon by the state geological surveys of the other Midcontinent states (Moore, 1948).

Later detailed stratigraphic work on the Douglas and Pedee Groups by Ball (1964) showed that the disconformity at the base of the Tonganoxie Sandstone in northeastern Kansas could not be traced laterally. As a result, O'Connor (1963) dropped the name Pedee Group in Kansas, included its component units in an expanded Douglas Group, and lowered the base of the Virgilian to the top of the South Bend Limestone Member of the Stanton Limestone at the top of the Lansing Group, without providing any new biostratigraphic information. Since then, the Nebraska Geological Survey lowered the base of the Virgilian to the top of the South Bend Limestone in that state (Burchett and Reed, 1967), and the Iowa Geological Survey eventually followed suit. However, the Missouri Geological Survey maintained the original Missourian-Virgilian boundary at the base of the Tonganoxie Sandstone just above the Iatan Limestone, which was now regarded as Virgilian in Kansas. The Oklahoma Geological Survey also maintained the original boundary of Moore (1948), which was indicated to be somewhere above the Birch Creek Limestone (then correlated with the South Bend Limestone), and below the Labadie Limestone (correlated with the Haskell and Cass limestones of Kansas and Nebraska, respectively) at a position indicated later to be the base of the Cheshewalla Sandstone at the base of the Vamoosa Formation (Fay et al., 1979) in a very sparsely fossiliferous succession. More recent work (explained later in the discussion of the South Bend Limestone) shows that the top of the South Bend Limestone in Kansas is the top of its transgressive limestone member (Little Kaw) whereas the top of the South Bend Limestone in Nebraska is the top of its younger regressive limestone (Kitaki), which is absent in Kansas. This means that the base of the Virgilian Stage is placed at three definitely different positions in three different states (Kansas, Nebraska, and Missouri), none of them biostratigraphically defined, and at an uncorrelatable position in Oklahoma, all in its type region of the Midcontinent. This is an untenable situation for the base of a chronostratigraphic unit of wide usage in North America.

Therefore, it is most appropriate to select a properly defined biostratigraphic Missourian-Virgilian boundary at a position where significant faunal change occurs in close proximity to a laterally traceable lithic contact that can serve as a boundary between the Missouri and Virgil Supergroups. The Iatan Limestone, the closest fossiliferous unit to the original 1948 boundary is missing across nearly all of Kansas, and therefore is not sufficiently laterally traceable. Either the base of the South Bend Limestone or the top of its transgressive Little Kaw Limestone Member (which can be distinquished in Nebraska and adjacent states) is laterally traceable along the Midcontinent outcrop, but there are as yet no detectable first appearances of species among conodonts or ammonoids in the South Bend Limestone, and fusulinids (which classically have been used in Pennsylvanian biostratigraphy) are being increasingly questioned for distant correlation because of problems with endemism of both species and genera. Important first appearances among both conodonts and ammonoids occur in both the major cyclothems below (Stanton) and above (Cass/Haskell) the South Bend Limestone. Because lowering the boundary to include the Stanton Limestone in the Virgilian would essentially decapitate the Missourian as traditionally recognized and not find favor among Midcontinent geologists, Boardman et al. (1989a) proposed that the boundary be placed at the base of the Haskell Limestone Member (now included as the base of the Cass Limestone as explained in a later section). This position is closer to the originally defined Missourian-Virgilian boundary, as the Haskell Limestone is the next major marine unit above the Iatan Limestone in northern Kansas, Missouri and northward.

The base of the Virgilian Stage, therefore, is defined by the first appearance of a distinct lobed morphotype of the conodont genus *Streptognathodus* cf. *S. xethus* Chernikh and Reshetkova 1987 (pending final taxonomic determination by J. E. Barrick). This species first appears in the top of the thin (2-3 foot) Haskell Limestone in Kansas and is particularly abundant in the overlying Little Pawnee Shale Member of the Cass Limestone along the entire Midcontinent outcrop. Important first appearances of ammonoids (e.g., *Pseudoaktubites stainbrooki* and *Vidrioceras conlini*) also occur in the Little Pawnee Shale, and more are known from the correlative lower Colony Creek Shale in Texas (Boardman et al., 1989a, 1989b; in press). Collections from the older Iatan Limestone near Dearborn, Missouri, and the Iatan equivalent unit west of Niotaze, Kansas, and at Hulah Dam in Oklahoma, contain an unnamed morphotype of *Streptognathodus* with incipient lobes, which is the likely ancestor of *S.* cf. *S. xethus*. The first appearance of *S.* cf. *S. xethus* places the base of the Virgilian just below the base of the Omega Limestone in Illinois (Heckel and Weibel 1991), and first appearances of other conodont species in Conemaugh marine units places its position between the Noble and Ames limestones in the Appalachian basin. Because of the particular nature of Pennsylvanian cyclothemic deposition discussed by Boardman et al. (1990), the stage boundary is placed at the base of the Haskell Limestone, which is transgressive over largely terrestrial deposits, particularly northward. However, because the underlying Vinland Shale Member of the Stranger Formation is marine in parts of Kansas, and apparently entirely marine at the Woodson County State Lake spillway 8 miles southwest of Yates Center, this locality is under strong consideration for a boundary stratotype.

In order to align the lithostratigraphic nomenclature appropriately with the chronostratigraphic nomenclature that uses names derived from it, the boundary between the Missouri and Virgil Supergroups is also placed at the base of the Haskell Limestone Member of the Cass Limestone. The main change in age and classification at the formation level that is required by this new Missourian-Virgilian Stage boundary is the transferral of the Stranger Formation from the base of the Virgilian Stage to the top of the Missourian Stage to form the top of the Missouri Supergroup. Because this splits the Douglas Group at the base of the Virgilian between two supergroups, the Pedee Group is reinstated in Kansas and expanded to include the Stranger Formation (which is transferred from the Douglas Group) and the South Bend Limestone and Rock Lake Shale as well (see later sections). The original constituent formations of the Pedee Group, the Iatan Limestone and Weston Shale, have been considered members of the Stranger Formation in Kansas since the report by O'Connor (1963).

PLEASANTON GROUP

The Pleasanton Group constitutes the lowest major lithic subdivision of the Missouri Supergroup (and Missourian Stage) in Kansas. It encompasses all the strata from the top of the Marmaton Group (top of the Des Moines Supergroup), marked by the Lost Branch Formation recently defined by Heckel (1991), to the base of the Hertha Limestone as redefined herein. The Pleasanton Group is subdivided into two formations, the redefined Hepler Formation overlain by the new Shale Hill Formation (Fig. 2). The Shale Hill Formation includes at the top strata formerly contained within the overlying Hertha Limestone, specifically the Critzer Limestone Member and the newly named Guthrie Mountain Shale Member, formerly the lower part of the Mound City Shale Member.

The Pleasanton Group as stabilized by Moore (1949) was not subdivided into formations in Kansas until Jewett et al. (1965) named an ascending sequence: Seminole Formation (with two members: Hepler Sandstone, overlain by South Mound Shale), Checkerboard Limestone, and Tacket Formation. Seminole and Checkerboard were older names extended into Kansas from central Oklahoma. Hepler was an older name from eastern Kansas, and Tacket and South Mound were new names introduced from southern Kansas. Recent findings show that the Tacket Formation is equivalent to several overlying formations (including the Hertha and Swope Limestones) as well as to the upper part (Shale Hill Formation) of the Pleasanton Group (Fig. 2).

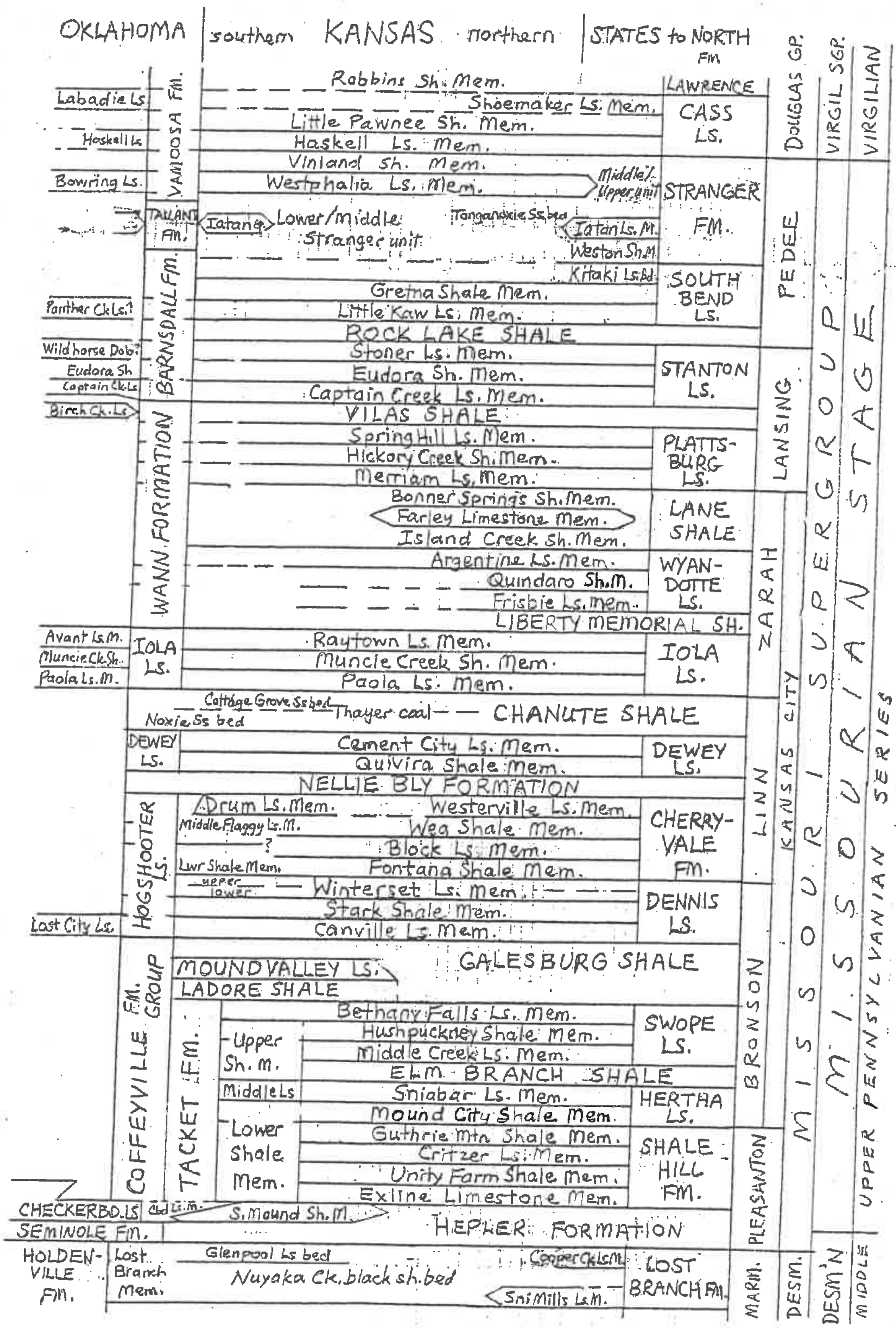


Figure 2.--Revised stratigraphic classification and nomenclature of Missourian succession in Kansas and adjacent states showing changes in nomenclature between northern and southern Kansas and probable equivalence with stratigraphic units recognized in Oklahoma. [This figure was not used in KGS Bulletin 246]

This precludes its use for a formal subdivision of the Pleasanton, and it is now regarded as a separate formation confined to southern Kansas. The Checkerboard Limestone is now recognized as the basal member of the Tacket Formation in southern Kansas. The South Mound Shale is recognized as a local member of the Hepler Formation in southern Kansas.

The term Seminole Formation is used in northeastern Oklahoma for the thick, dominantly sandstone succession between the Lost Branch Formation and the Checkerboard Limestone in that region, an interval that is partly equivalent to the Hepler Formation as redefined herein. However, because the South Mound Shale Member of the Hepler Formation appears to be largely equivalent to the Checkerboard Limestone above the Seminole, the Seminole Formation as used in northern Oklahoma appears to be equivalent to only the pre-South Mound portion of the Hepler (Fig. 2). Because the top of the Seminole Formation (named by Taff, 1901) as has been used in its type area of east-central Oklahoma (DeNay Limestone) appears to be much higher than the type Checkerboard Limestone (Krumme, 1981, p. 26), indicating unresolved problems with usage of the name in Oklahoma, the name Seminole is, for now, dropped from use in Kansas. If the name Seminole is confined to its usage in northeastern Oklahoma (interval from top of Lost Branch to base of Checkerboard), then it can be reinstated in Kansas for the lower member of the Hepler Formation where the overlying South Mound Shale Member is present.

The Pleasanton was named as a shale by Haworth (1895, p. 274) for exposures at Pleasanton in Linn County, Kansas. The history of its usage is given in Moore (1936, p. 63) and Moore (1949, p. 69-70). As far as can be ascertained, no type section was ever designated. Jewett et al. (1965) mentioned a fairly complete exposure along a county road west of Pleasanton (SW sec 27, T21S, R24E), which can be regarded as the type section, but the roadcut in this area (actually in NW sec 34) exposes only the upper part of the Shale Hill Formation, and the upper boundary (as redefined) is now covered. The best exposed part of the other more complete exposure of "Pleasanton" mentioned by Jewett et al. (1965), along Ks Rte 3 south of Uniontown in Bourbon County, is now known to be a thickened sequence of the Mound City Shale Member of the Hertha Limestone, and the Pleasanton part of the roadcut is mostly covered. Probably the most complete exposure of most of the Pleasanton Group in one place near Pleasanton is the northern US 69 roadcut 4 miles south of Pleasanton (W line NW-NW-SW sec 19, T22S, R25E), which can be regarded as the principal reference section.

Most of the lower Pleasanton Group in Kansas consists of unfossiliferous shale and sandstone of probable fluvial to locally deltaic origin, whereas the upper part comprises mainly thick masses of gray, probably prodeltaic shale (with local sandstone toward the north) separated by intervals of limestone to fossiliferous calcareous shale. This upward change from largely terrestrial deposits at the base to largely marine deposits toward the top forms the basis for subdivision of the Pleasanton Group into two formations (Hepler below and Shale Hill above), with significantly different internal stratigraphic trends in addition to the differences in depositional environment. Their boundary is the widespread marine flooding surface represented by the base of the Exline Limestone Member of the Shale Hill Formation.

The Pleasanton Group attains nearly 100 feet in thickness near the Missouri border, then thins southwestward through about 70 feet in Bourbon County to about 30 feet in Neosho and Labette counties. Most of the thinning results from abrupt thinning and southward disappearance of the shale members of the Shale Hill Formation as they pinch out into the base of the Tacket Formation in southern Kansas.

Northward the Pleasanton Group reaches its greatest thickness (120 feet) and lithic differentiation with prominent sandstone bodies in Missouri (Fig. 4), where it is subdivided into as yet formally unnamed formations, members, and possibly subgroups by the Missouri Geological Survey. In Iowa and Nebraska, the Pleasanton is a thin (10- to 20-foot) shale/mudstone unit with a medial limestone (Exline); the entire unit is recognized in Iowa as a formation of the overlying group.

Hepler Formation

The name Hepler is redefined to apply to a formation that comprises all the strata in the lower part of the Pleasanton Group from the top of the marine Lost Branch Formation to the base of the marine Exline Limestone Member of the Shale Hill Formation. It includes at its top the marine South Mound Shale Member, which is confined to southern Kansas (Fig. 4). The name Hepler was originally applied to a sandstone by Jewett (1940) based on a type section in southern Bourbon County a short distance north of the town of Hepler, and it was regarded as a persistent 3 to 4-foot marker bed to be used as a key horizon for surface mapping. Recent work elaborated by Heckel (1991; see also Sutton, 1985; Bennison, 1985) has shown that sandstones occurring in three different stratigraphic intervals in Bourbon County have been identified as Hepler: 1) within the Lenapah Limestone; 2) above the Lenapah and below the Lost Branch Formation (both positions 1 and 2 are Desmoinesian and below the Pleasanton); and 3) above the Lost Branch and at the base of the Pleasanton, which is the position generally accorded the Hepler by the Kansas and Missouri Geological Surveys.

The Hepler type section (ctr sec 14, T27S, R22E) designated by Jewett (1940) fairly certainly lies within the Lenapah Limestone (Heckel, 1991, p. 42-44), and thus it represents a sandstone facies of the Perry Farm Shale Member of that formation (Fig. 4). Because only the highest interval that has been called Hepler appears to be well developed as sandstone on outcrop or in the subsurface outside this area, and because this is the position traditionally regarded as Hepler by the Kansas Survey (and the only position identified as Hepler by the Missouri Survey), it is deemed preferable to establish a new principal reference section for the Hepler nearby, rather than to attach the name Hepler to an interval that has never been regarded by that name anywhere else. Also, because this stratigraphic problem arose partly through the dubious practice of formally naming lenticular sandstones with the implicit assumption that they are laterally continuous, the name Hepler is expanded herein to include all strata associated with the sandstones. Accordingly, exposures of sandstone and shale along Ks Rte 39 at SE cor sec 4 and NW cor sec 10, T27S, R22E (and supplemented in nearby ravines to the north and west, 2 miles northwest of the original type Hepler), are designated as the principal reference section or neostratotype of the Hepler Formation. However, because of incomplete exposure of the entire unit here, the Prong Creek core taken 1 mile farther west (SE-SE-NE-SE sec 5) and other reference sections are necessary to adequately characterize the boundaries of the formation and the other included lithotypes.

The Hepler Formation in the Prong Creek core consists of 55.7 feet of sandstone and shaly siltstone overlain by 3.2 feet of mudstone and shale (Heckel, 1991, p. 42). The lower contact of the Hepler Formation is the top of the capping limestone of the Lost Branch Formation, where present, or the base of the lowest persistent sandstone bed where the upper Lost Branch is shale, as in the Prong Creek core. The latter type of contact may mark either a point in an upward transition from a marine to a shoreline or terrestrial deposit or a minor erosional disconformity below an alluvial or deltaic channel. The upper contact of the Hepler Formation is the base of the marine limestone or calcareous shale at the base of the Exline Limestone Member of the Shale Hill Formation. This is commonly at the top of a blocky mudstone that marks subaerial exposure at the top of the Hepler Formation, as in the Prong Creek core.

Overall in Kansas, the Hepler Formation consists of roughly subequal amounts of shale and sandstone, but one or the other may dominate almost exclusively at any one exposure. Thus rather than being a single persistent marker horizon, the sandstones appear to be quite lenticular, which is consistent with their probable origin in a variety of deltaic and fluvial environments that became established during and following the regression that terminated Lost Branch deposition and prior to the transgressions that initiated South Mound Shale and then Exline Limestone deposition (Fig. 3).

Toward the north in Linn County, the Hepler Formation is largely sandstone, which is micaceous, thin to medium bedded, and ranges from ferruginous and somewhat friable to calcareous and very hard in places. Partial exposures of particularly the hard layers are plentiful in the vicinity of Pleasanton (e.g., road corner in NW cor NE-NE sec 3, T22S, R25E; along US 69, E line SE-SE sec 13, T22S, R24E; creekbed at ctr S line SW-NE sec 14). One remarkable old quarry exposure just north of Pleasanton (SW-NE-NE sec 25, T21S, R24E) shows about 16 feet of cross-bedded, oil-saturated sandstone. The most complete reference exposure of the lower part of the Hepler Formation is in the northeast bank of the Marais des Cygnes River just north of the U.S. 69 bridge (near ctr sec 5, T21S, R25E) at Trading Post, where about 10 feet of thin-bedded shaly sandstone of the Hepler overlies a complete sequence of Lost Branch Formation, mostly shale. The lower boundary of the Hepler is placed at the base of the lowest conspicuous laterally persistent sandstone bed in this gradational sequence. The top of the Hepler is rarely exposed in this area, but in the northern U.S. 69 roadcut south of Pleasanton (a good reference section for several higher Shale Hill

Fig.3

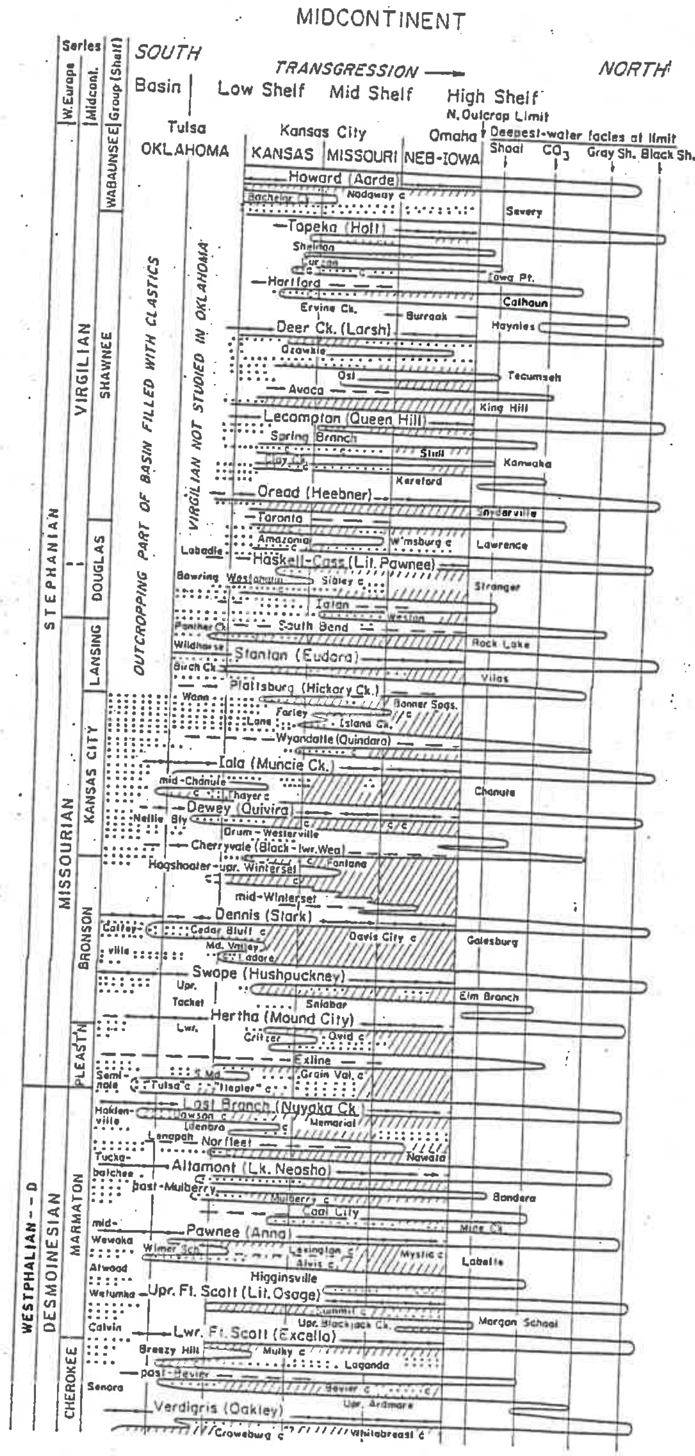


Figure 3.--Sea-level curve for Missourian (and adjacent) strata on northern Midcontinent shelf (recently revised from Heckel, 1986, 1989; Boardman and Heckel, 1989), showing sea-level changes that account for much of the lithostratigraphic variation in the succession exposed in Kansas and adjacent states. [This figure was not used in KGS Bulletin 246]

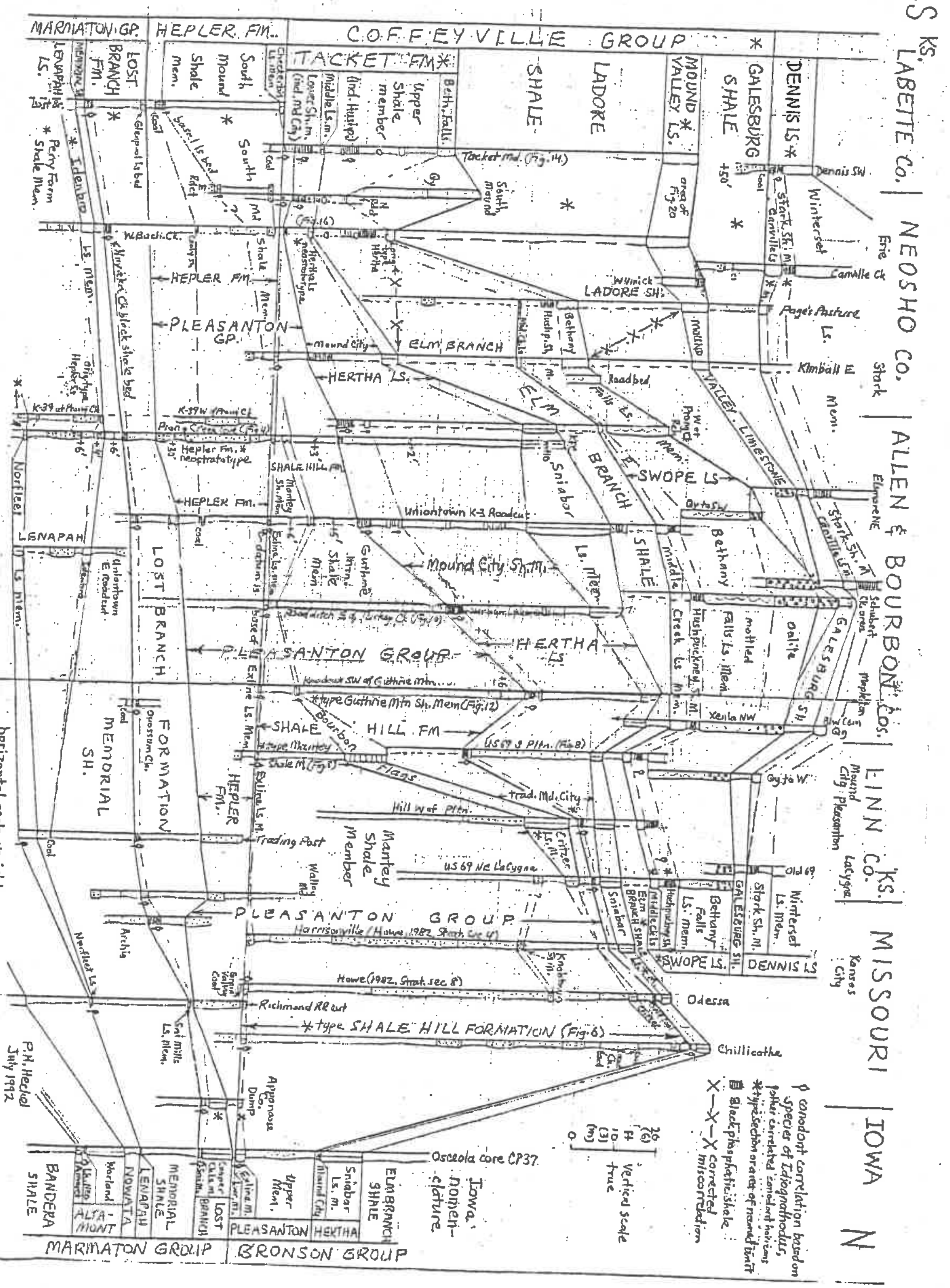


Figure 4.--Stratigraphic cross-section of lower Missourian (South Mound through Dennis) and uppermost Desmoinesian (Lenapah through Lost Branch) strata from Iowa and Missouri southward to southern Kansas, showing stratigraphic control in measured sections and cores, upon which corrections of two major miscorrelations (marked by X-covered lines) are based. Corrections of these miscorrelations has mandated large-scale revision of nomenclature and classification of lower Missourian strata (see also Figure 1). [This figure was modified to become Figure 2 in KGS Bulletin 246]

units), the top of the sandstone facies is exposed in the roadditch on the east side at the north end (ctr W line sec 19, T22S, R25E), and is overlain by about 4 feet of largely slumped shale including about 1 foot of gray blocky mudstone at the top, dug out below the overlying Exline Limestone Member of the Shale Hill Formation in the bank just to the south.

Southward into Bourbon County, the Hepler Formation is poorly exposed, as sandstone becomes rare in the increasingly shaly sequence. It is about 21.5 feet thick at the Ks Rte 3 roadcut south of Uniontown, where the upper 15 feet is poorly exposed gray shale, but the lower 6.5 feet is well exposed in a ravine west of the highway (SW-NE-NW sec 34, T25S, R22E) and serves as an important reference section for the base of the formation in this area. Here 5.5 feet of gray blocky shale, resting on hard calcareous fossiliferous shale at the top of the Lost Branch Formation, is overlain by 0.3 foot of coal and capped by 0.7 foot of carbonaceous sandstone (Heckel, 1991, p. 41). The coal is informally called "Hepler", and this lithic sequence appears again southward, dominating the lower part of the Hepler Formation in Labette County.

In southern Bourbon and Neosho County, the Hepler Formation is only spottily exposed, but sandstone increases in abundance and locally in thickness. At the neostratotype on Ks Rte 39, the sandstone bed is 8 feet thick, and in the nearby Prong Creek core the sandstone is 16 feet thick in a total formational thickness of 58.9 feet (Heckel 1991, p. 42). Thin sandstone beds appear in the upper part below the Exline Limestone and the featheredge of the South Mound Shale Member in the ravine 3.3 miles east of Kimball (SW-SE-SW sec 27, T27S, R21E). A 2-foot sandstone bed forms the top of the Hepler in the west tributary to Bachelor Creek 7 miles south of Erie (near ctr W line NE-NE sec 32, T29S, R20E), where the upper part of the formation is grading further into the South Mound Shale. In the lower part of the same sequence (streambank at bridge W line NW-NW sec 33), a 1-foot coaly black shale containing only megaspores, but no conodonts, is thought to be at the position of the "Hepler" coal.

Southward in Labette County, the Hepler Formation is dominated by the South Mound Shale Member, and that part of the formation below the South Mound Shale has thinned to 4 feet thick at a good reference section above the stratotype of the Lost Branch Formation southwest of Mound Valley (NW-SW-NE-NE sec 10, T33S, R18E). Here it consists of an ascending succession of: 1) 2 feet of gray blocky mudstone; 2) 0.3 feet of "Hepler" coal capped by a distinctive bed of silicified logcasts; 3) 1 foot of dark coaly shale containing megaspores but no conodonts; 4) 0.7 foot of shaly sandstone (Heckel, 1991, p. 45-46). This is overlain by the thin argillaceous fossiliferous limestone marking the base of the South Mound Shale Member. This underclay-coal-coaly shale succession is found at several localities from just southwest of Parsons (W line NW-SW-NW sec 26, T31S, R19E) to the KGGF Tower section north of Angola (ctr W line SE- SE sec 19, T33S, R18E), where the sandstone at the top thickens locally from 1 foot to about 15 feet only 0.2 mile away (SE cor sec 19). This succession rests upon the Lost Branch Formation and is also found at Wolf Creek (NE-SE-NW sec 34, T27N, R15E), 3 miles west of Delaware in Nowata County, Oklahoma, 25 miles to the south, where the coal is termed "Tulsa". Here, however, the succession (Heckel, 1991, p. 48) forms the basal part of the

Seminole Formation, which lacks the South Mound Shale and is dominated by sandstone throughout northern Oklahoma.

Northward from Kansas, the Hepler interval as defined herein comprises all strata in the Pleasanton Group below the Exline Limestone and above the Lost Branch Formation at the top of the Marmaton Group. In Missouri, the Hepler interval is mostly sandstone overlain by various amounts of nonmarine shale, and includes a blocky mudstone (underclay) near or at the top, overlain locally by a thin coal termed Grain Valley by Howe (1982) from a locality east of Kansas City. The entire Hepler interval in Missouri ranges from 10 to 20 feet thick. The blocky mudstone extends into Kansas at the top of the Hepler Formation just below the Exline Limestone (as seen in the northern US 69 cut south of Pleasanton), thus showing that the Grain Valley coal is stratigraphically higher than the "Hepler" coal, which lies some distance below the Exline and below the underlying South Mound Shale Member as well.

In Iowa and Nebraska, the Hepler interval is mostly blocky mudstone lying above the Cooper Creek Limestone Member of the Lost Branch Formation and below the Exline Limestone. It averages between 2 and 6 feet thick, but ranges up to 12.6 feet thick in a core (ILC) near Logan in western Iowa, where it contains about 6 feet of sandstone in the middle. The Hepler ranges down to no more than a disconformable surface between the Exline and Cooper Creek limestones in two cores in west-central Iowa (Heckel, 1991, p. 61-62). The Hepler blocky mudstone is mottled red to the west and north, and it represents a widespread horizon of subaerial exposure and soil formation that occurred throughout the northern Midcontinent during the sea level lowstand separating the Lost Branch and Exline marine inundations (Fig. 3), while terrestrial and possibly deltaic deposition was producing the thicker sandier Hepler strata in Kansas and Missouri.

<u>South Mound Shale Member</u>.--The South Mound Shale Member forms the top of the Hepler Formation in southern Kansas (Fig. 4). It underlies the Checkerboard Limestone Member (as recognized in Kansas; see later section) of the Tacket Formation or the Exline Limestone Member of the Shale Hill Formation or its equivalent in the Tacket where the Checkerboard is absent. The South Mound Shale was named by Jewett et al. (1965), who designated a type section just south of Mound Valley (ctr SE-SW sec 2, T33S, R18E) in western Labette County, Kansas (near the stratotype of the Lost Branch Formation designated by Heckel, 1991), even though the name was taken from the village of South Mound in southeastern Neosho County, 20 miles to the northeast. A complete exposure of South Mound Shale along a road one mile east of South Mound (just W of ctr N line sec 15, T30S, R20E), which apparently was misidentified as part of the Tacket Formation by Jewett et al. (1965), has been designated as the principal reference section by Heckel (1991, p. 44-45). Because the original type section near Mound Valley is now poorly exposed, the South Mound exposures above the Lost Branch stratotype (see Heckel, 1991, p. 14) about 1 mile to the west (SW-NE sec 10, T33S, R18E) are designated as a reference section for that area. The underclay and coal now recognized as

"Hepler" were originally included in the base of the type South Mound Shale by Jewett et al. (1965) because they had misidentified as Hepler sandstone the underlying sandy fossiliferous limestone (Glenpool) that is now defined as the top of the Lost Branch Formation. This apparently happened because the friable sandstone above the coal, which is more readily recognizable as Hepler, is absent at the original type section. The underclay and coal have been removed by Heckel (1991) from the South Mound Shale, and, along with the overlying dark shale and sandstone, are recognized as constituting all that part of the Hepler Formation below the South Mound Shale Member in the Mound Valley area (Fig. 4).

In the two best reference sections, the South Mound Shale Member consists of a basal unit of fossiliferous argillaceous limestone to calcareous shale usually less than 1 foot thick, overlain by a thicker 12-foot (at South Mound) to 28-foot (at Mound Valley) sequence of sparsely fossiliferous shale. Between the two reference sections, this shale contains a coal near the top in creek beds around Tacket Mound (SW-SW-NE sec 7, T32S, R19E; and S line SE-SW-SE-SE sec 12, T32S, R18E). The shale is overlain in the reference section near South Mound by 1 foot of sandstone. This sandstone is overlain in the spillway to a large pond less than 1 mile to the southwest (in ctr W line SE-NE sec 16, T30S, R20E) by about 1 foot of dense skeletal-oolitic calcilutitic limestone that appears to be the northern end of the Checkerboard Limestone (as recognized in Kansas), which overlies the upper shale facies of the South Mound Shale at Mound Valley. The South Mound Shale is recognizable as far north as are the overlying and underlying marker beds, which currently is in the stream bank 3.3 miles east of Kimball (SW-SE-SW sec 27, T27S, R21E) in northeastern Neosho County, where the South Mound is 3 feet thick below the Exline Limestone (Fig. 4). The entire South Mound Shale Member becomes sandier northward as it passes laterally into the top of the undivided Hepler Formation, with the loss of the basal fossiliferous limy bed.

The South Mound Shale Member represents a minor transgression (Fig. 3) into southern Kansas marked by the basal limestone, followed by a minor regression that formed a deltaic-prodeltaic sequence that constitutes the main body of South Mound Shale from South Mound across Labette County into northernmost Oklahoma. The delta probably originated from one of the fluvial channels that occur in the upper part of the Hepler Formation to the north. The South Mound delta thickens from 13 feet at South Mound to 28 feet at Mound Valley, then thins across an area of poor exposure around Coffeyville to 17.4 feet in the South Coffeyville core (OSC) taken 3 miles south of the Kansas-Oklahoma border (Fig. 5). In this core, the 17.4 feet of fossiliferous marine shale overlie 1.7 feet of basal South Mound fossiliferous limestone, which rests on a truncated Lost Branch succession, and is separated from it by 0.2 ft of sandstone assigned to the Hepler Formation. In all exposures and cores south of here, the entire succession between the Lost Branch Formation below and the Checkerboard Limestone above is occupied by 36 to 150 feet of terrestrial sandstone and subordinate shale containing the "Hepler"/Tulsa coal horizon, and assigned to the Seminole Formation. Thus, the marine South

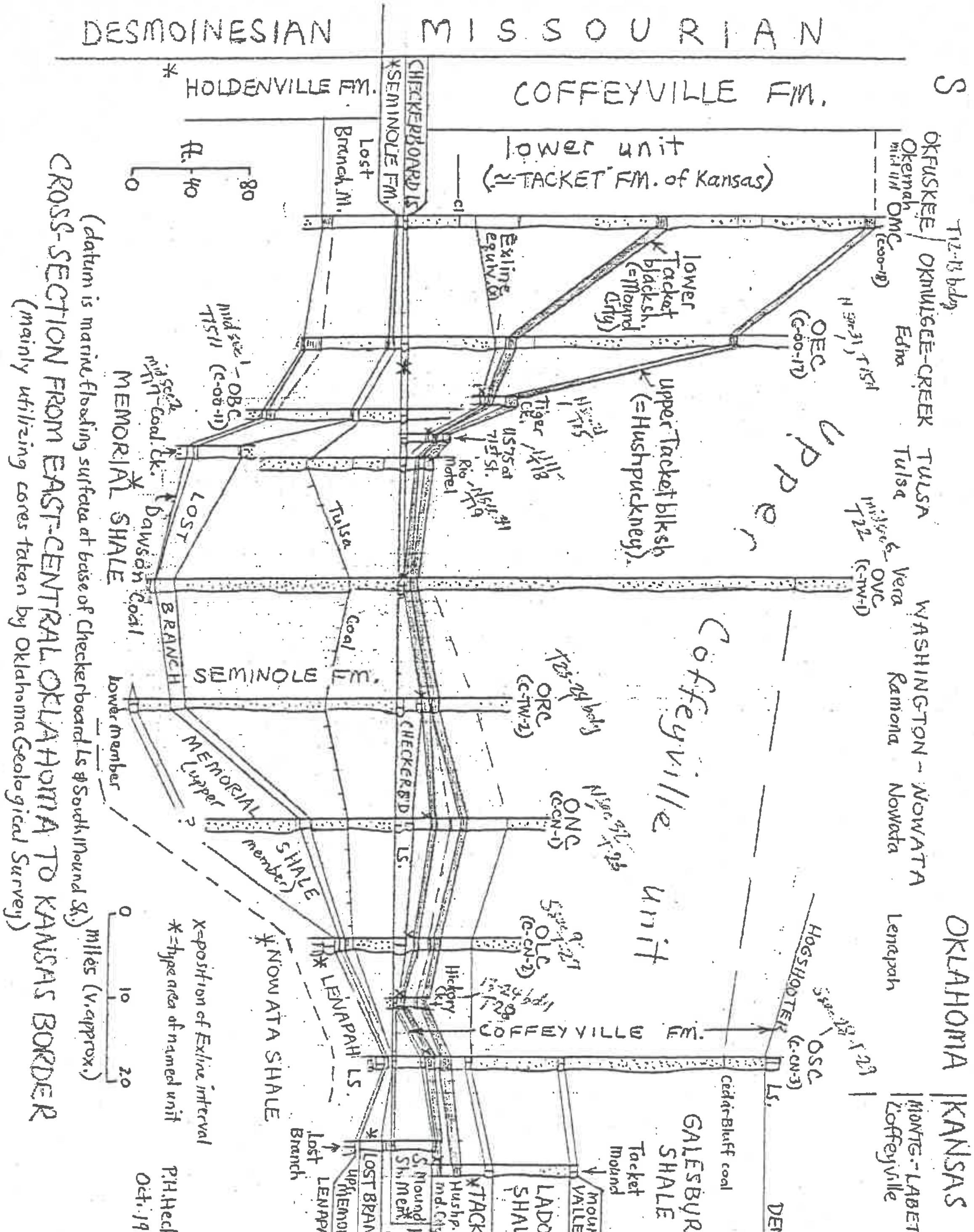


Figure 5.--Stratigraphic cross-section of lower Missourian (and uppermost Desmoinesian) strata from southern Kansas to east-central Oklahoma showing stratigraphic control in cores (held by Oklahoma Geological Survey) and measured sections. [This figure was not used in KGS Bulletin 246, but was modified to become part of Figure 3 in Heckel et al., 2002, cited in KGS Bulletin 246]

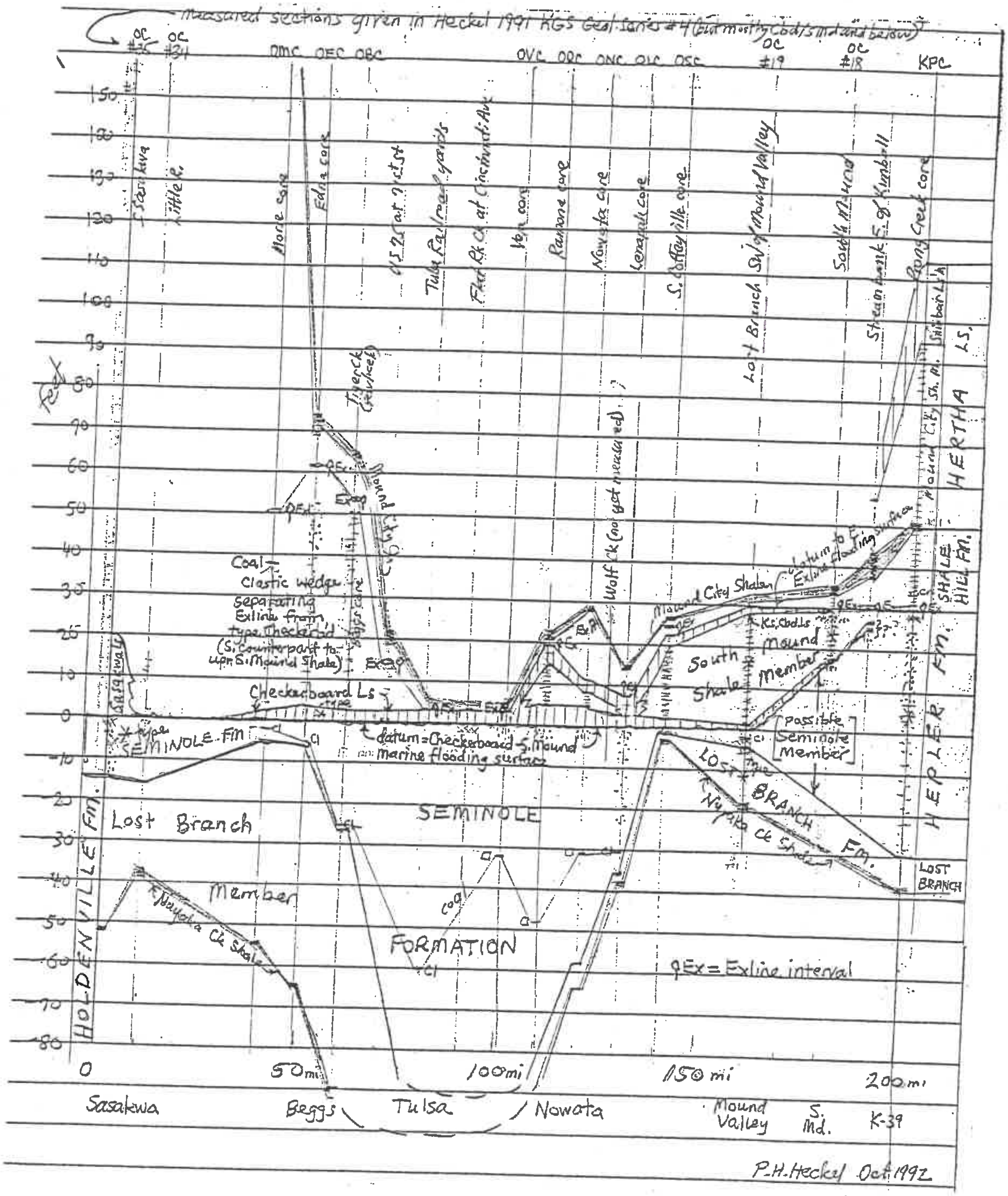


Figure 5A.--Expanded vertical exaggeration of interval in Figure 5 that includes Seminole Formation, Checkerboard Limestone, and lower part of Tacket Formation, showing relations with Hepler Formation, South Mound Shale Member, and Exline interval. [This figure was not used in KGS Bulletin 246]

Mound Shale in the South Coffeyville core appears to fill a channel cut during the Hepler regression or lowstand, but not filled with sediment until the South Mound transgression.

Of further significance in the South Coffeyville core is the transitional contact of the South Mound Shale with the overlying Checkerboard Limestone, suggesting facies relations. Also, the Checkerboard Limestone is more argillaceous and locally thicker with a shale split in two of the next three cores southward from South Coffeyville (Fig. 5) and in the Wolf Creek section west of Delaware (Heckel, 1991, p. 48), than in southern Kansas above the South Mound delta. Therefore, the southward-thinning distal prodeltaic shale of the South Mound appears to grade basinward (southward) into the marine Checkerboard Limestone, a situation considered more likely than gradation into the terrestrial Seminole clastics. In further support, the Checkerboard Limestone thins and and becomes purer farther southward in the Tulsa region beyond the reach of South Mound prodeltaic influx.

Shale Hill Formation

The Shale Hill Formation overlies the Hepler Formation, underlies the Hertha Limestone (Mound City Shale Member as redefined herein), and forms the top of the Pleasanton Group in Kansas (Fig. 2). The name is derived from Shale Hill north of Utica near Chillicothe, Livingston County, Missouri, where a complete exposure of the entire formation is available in the shale pit of the Midland Brick and Tile Company (Fig. 4). The name Shale Hill was applied by Howe (1982) from this exposure to the upper part of this succession, and he has tentatively accepted (letter of August 26, 1992), for the Missouri Geological Survey the downward expansion of the interval included, in view of the large vertical extent of stratal coverage provided by this unique exposure of such a great thickness of normally poorly exposed rocks. The principal reference section in Kansas is the set of US 69 roadcuts 4 to 5 miles south of Pleasanton in Linn County where most of the lower three members are fairly well exposed in the northern roadcut (W line NW-NW-SW sec 19, T22S, R25E) and the interval of the upper member is measurable in the southern roadcut (E line NE-SE-NE sec 25, T22S, R24E).

The Shale Hill Formation in Kansas consists mainly of two regionally thick gray shales of probable prodeltaic origin, each underlain by generally thinner limestone to calcareous shale intervals, which are traced throughout most of the outcrop belt in Kansas (Fig. 4). The carbonate units represent marine inundations (Fig. 3) that interrupted deltaic progradation for a while, but were neither deep nor long-term enough to produce classic "Kansas" cyclothems described by Heckel (1977, 1980, 1984, 1986). The traceability of these carbonate intervals allow subdivision of the Shale Hill Formation into a succession of four members in Kansas, in ascending order: 1) Exline Limestone Member, 2) Unity Farm Shale Member, 3) Critzer Limestone Member, including the informal Bourbon flags as a southern facies, and 4) Guthrie Mountain Shale Member (Fig. 2). The Exline Limestone and Unity Farm Shale are extended into Kansas from Iowa and Missouri, respectively. The Critzer Limestone Member is removed herein from the Hertha Limestone, and the Guthrie Mountain Shale Member is established as a separate unit herein and removed from the lower part of the Mound City Shale Member of the Hertha Limestone. The lower boundary of the Shale Hill Formation is the base of the Exline Limestone, which represents a widespread marine transgression above the largely terrestrial deposits of the Hepler Formation, commonly including a paleosol and locally a thin coal (Grain Valley) at the top. The upper boundary of the Shale Hill Formation is the base of the widespread phosphatic black shale bed (or its thin underlying limestone bed or local green-gray shale equivalent), which marks the base of the redefined Mound City Shale Member of the Hertha Limestone over the entire outcrop belt (Fig. 4) and throughout cores in the Forest City basin (Fig. 6).

The Shale Hill Formation is about 80 feet thick in northern Linn and north-central Bourbon counties, thinning southeastward to about 50 feet thick in the US 69 roadcuts south of Pleasanton in southeastern Linn County and southward to 35 feet south of Uniontown in southwestern Bourbon County. It thins to about 20 feet in the Prong Creek core and to 8 feet east of Kimball in northeastern Neosho County as it pinches out into the base of the Tacket Formation in southern Neosho and Labette counties (Fig. 4).

Northward the Shale Hill Formation thickens to 110 feet at its stratotype in north-central Missouri, where it encompasses a well-developed deltaic complex recognized by Howe (1982). Farther northward it thins to a range of 5 to 20 feet in Iowa and Nebraska, where the part above the Exline Limestone contains blocky mudstone representing paleosol development in this region.

Exline Limestone Member.--The Exline Limestone Member at the base of the Shale Hill Formation overlies the Hepler Formation and southward its South Mound Shale Member (or the Checkerboard Limestone Member of the Tacket Formation where present). The Exline underlies the Unity Farm Shale Member, possibly combined with the higher Guthrie Mountain Shale Member in the greatly thinned Shale Hill interval southward (Fig. 4). Named by Cline (1941) from a streambed exposure south of Exline, Iowa, about 2.5 miles north of the Missouri border, the Exline Limestone has long been known from northern to western Missouri. Recent field work has shown that the Exline extends throughout eastern Kansas as an argillaceous limestone to fossiliferous calcareous shale interval averaging about 1 foot in thickness. It rests upon unfossiliferous to sparsely fossiliferous sandy gray shale to blocky mudstone of the Hepler Formation with a sharp to somewhat diffuse contact. It is overlain by sparsely fossiliferous gray shale of the Unity Farm Shale Member with a sharp to transitional contact.

The principal reference section of the Exline Limestone Member in Kansas is the roadcut east of Turkey Creek (north side, in ctr NW-NW-NW sec 12, T25S, R22E) 3 miles northeast of Uniontown in Bourbon County, where it is about 1 foot thick. Other good reference sections are in the spillway of Bourbon County State Lake (NW-NE-SW sec 12, T26S, R21E), where it is the lowest limestone ledge in the succession; in the northern U.S. 69 roadcut south of Pleasanton (north end, east side, W line NW-NW-SW sec 19, T22S, R25E) in Linn County,

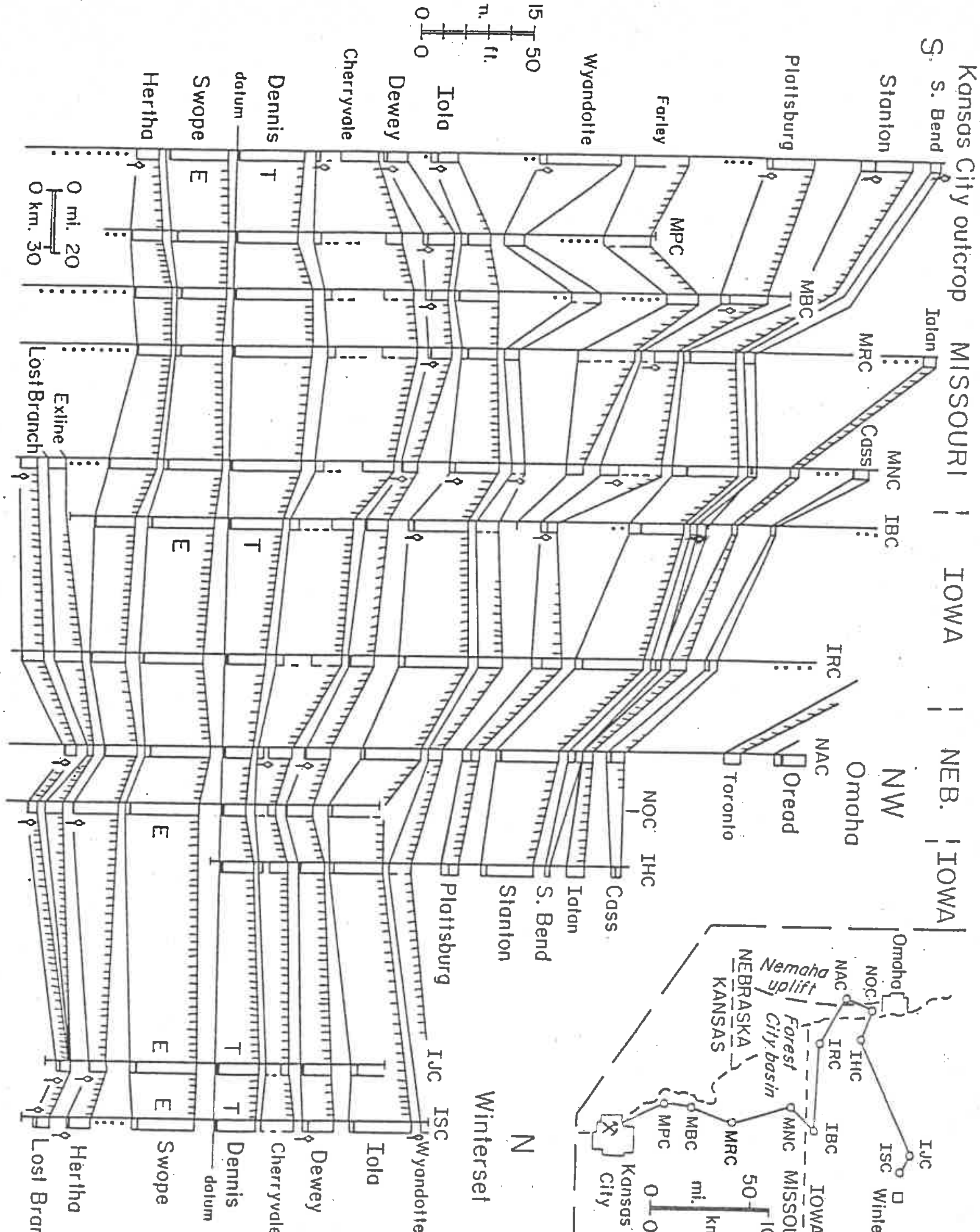


Figure 6.--Stratigraphic cross-section of Missourian strata (from top of Lost Branch to base of Cass) from Kansas city northward through Missouri to Nebraska and Iowa, via long cores held by respective state geological surveys. Biostratigraphic control is shown by letters for fusulinids (E = sole occurrence of Eowaeringella ultimata; T = first appearance of triticitids) and by tailed diamond symbols for conodonts in dark phosphatic shales. Vertical hachures represent exposure surfaces and overlying paleosols. [This figure was not used in KGS Bulletin 246]

where it is a thin crinoidal shale that must be dug out; the Ks Rte 3 roadcut south of Uniontown (SE-NE-NW sec 34, T25S, R22E) where it is crinoidal shale 15 feet below the limestone below the culvert; and in the stream bank east of Kimball (SW-SE-SW sec 27, T27S, R21E) in Neosho County, where it is 0.4 ft of shaly limestone that is well exposed, but not easily accessible from the road.

The Exline Limestone Member carries a relatively diverse marine fauna in Kansas, which is conspicuously dominated by small crinoid debris, but contains small brachiopods, bryozoans, forams, snails, clams, and rare corals as well. The mollusks commonly are limonitized, pyritized, or phosphatized. The Exline also carries an extremely abundant conodont fauna, which is strongly dominated by smooth-ridged species of *Idiognathodus*, many of them juveniles, and includes *I. sulciferus*; it also contains a fair number of *Idioprioniodus*, and in some samples, a scattering of other genera. This fauna is distinct from those of the black shales in the Lost Branch Formation (Nuyaka Creek shale bed) below (Heckel, 1991, p. 22) and the Hertha Limestone (Mound City Shale Member) above, and allows identification of the Exline interval in areas of different facies development. The diverse open marine fauna in conjunction with the lateral continuity of the horizon above the mainly terrestrial deposits of the Hepler Formation marks the Exline as a widespread horizon of marine transgression over the entire Midcontinent (Fig. 3). It is regarded as a marine cycle of intermediate scale because it is conodont-rich but lacks the black fissile shale facies that characterizes the major cyclothems.

Northward in most of Missouri, the Exline Limestone is 1 to 2 feet of more conspicuous argillaceous crinoidal limestone with interbedded fossiliferous calcareous shale. It carries a diverse fauna similar to that in Kansas, including abundant conodonts but with more abundant phosphatized clams and snails, which allowed earlier workers to trace the Exline across this area as the "*Trepospira* zone". In both cores and on outcrop across northernmost Missouri and in southern Iowa, including the type section, a harder and purer skeletal calcilutite facies, ranging from 1 to 8 feet thick, appears beneath the argillaceous crinoidal facies. Its biota is dominated by the phylloid red alga *Archaeolithophyllum*, and it contains a much sparser conodont fauna that lacks *Idioprioniodus*. It is considered a transgressive limestone facies deposited in shallower water than the more offshore crinoidal facies (Heckel, 1984; Nielsen, 1987).

Northward in central to western Iowa and Nebraska, the Exline Limestone ranges up to 7 feet thick and consists of an ascending sequence of relatively conodont-rich skeletal calcilutite overlain by abraded skeletal calcarenite and capped locally (core NOC) by barren calcilutite facies with shale-filled fractures and pockets, which appear also in the calcarenite at the top in core ILC (Heckel, 1991, p. 60-61). This is a regressive sequence that shallows upward to a surface of subaerial exposure (Fig. 6), and it is present in the Exline Limestone only in the north. Southward in Missouri and Kansas, large amounts of Unity Farm detrital influx terminated Exline deposition at an earlier phase of regression. In core NAC in Nebraska, the Exline Limestone was misidentified as the Middle Creek Limestone Member of the higher Swope Limestone by Condra (1939).

Southward, in southern Neosho and Labette counties in Kansas and across northern Oklahoma to the Ramona core (ORC on Fig. 5), the Exline interval is represented by a thin (1 foot or less) layer of dark fossiliferous, calcareous, conodont-rich shale in the base of the Tacket Formation (described later), resting with abrupt, probably diastemic contact upon the Checkerboard Limestone Member. Where the Checkerboard is absent as just north of South Mound, Kansas (W line SW cor NW sec 10, T30S, R20E), the Exline interval rests upon mudstone just above the upper sandstone bed of the South Mound Shale. The Exline is overlain in this region by a few feet of dark gray, poorly fossiliferous, noncalcareous shales equivalent to the greatly thinned distal ends of higher Pleasanton shales (Fig. 4) and in places by the black phosphatic basal Mound City Shale Member of the Hertha Limestone, all included within the Tacket Formation in this region. In the Vera core (OVC on Fig. 5) and at the railroad yards on the west side of Tulsa (D.R. Boardman, pers. commun., 1991) the Exline interval lies in the top of the Checkerboard Limestone lithosome as indicated by the abundant Exline conodont fauna recovered from the top of the Checkerboard in those places.

South of Tulsa, the Exline Limestone Member is redeveloped as a separate thin limestone bed exposed recently east of the northbound offramp of US 75 to 71st Street (NW-NE-NW sec 11, T18N, R12E) about 13 feet above the Checkerboard Limestone. It is traced farther southward in cores (Fig. 5) as limestone beds in thicker gray fossiliferous shale in the southward-thickening detrital succession above the Checkerboard Limestone and its equivalents. Throughout this region, the Exline Limestone is identified by its calcareous marine lithologies and its abundant conodont fauna that is distinct from the faunas in the widespread conodont-rich units both above and below.

Unity Farm Shale Member.--Lying above the Exline Limestone Member, the Unity Farm Shale Member is overlain by the Critzer Limestone Member and its southern facies, the Bourbon flags, in Kansas (Fig. 2,4). The Unity Farm Shale was named by Howe (1982) from a locality in Jackson County, Missouri, where its upper boundary was drawn at the base of the sandy fossiliferous Knobtown Limestone Member, which lies about 30 feet below the Critzer Limestone Member. Because few exposures of possible Knobtown are known in Kansas, the upperboundary of the Unity Farm Shale Member is extended upward to the CritzerLimestone in Kansas, recognizing that the top of the Unity Farm Shale in Kansas contains strata equivalent to higher named units in Missouri (Fig. 4).

In western and northern Linn County, Kansas, where the Unity Farm Shale constitutes essentially all of the original type Pleasanton, it attains a thickness of at least 100 feet and consists largely of gray, very sparsely fossiliferous shale with various thicknesses of sandstone locally in the upper part. Some of this sandstone is locally fossiliferous (e.g., road west of Mound City along N line NE-SE sec 8, T22S, R23E) and may represent a southwestern facies of the Knobtown Limestone of west-central Missouri. The roadcut down the hill west of the north end of Pleasanton (near N line NW-NW sec 34, T21S, R24E) exposes about the upper one half of the Unity Farm Shale Member, comprising 14 feet of lenticular noncalcareous sandstone overlying 36 feet of sandy shale, but the lower part of the member is generally obscured by colluvium at the foot of the prominent Bronson escarpment throughout this region. The Unity Farm Shale thins southeastward, along the northeast-southwest line of outcrop of the overlying Bourbon flags facies of the Critzer Limestone, into southeastern Linn County and north-central Bourbon County.

The principal reference section of the Unity Farm Shale Member in Kansas, a nearly complete exposure showing relations to both higher and lower units, is in this region at the northern U.S. 69 roadcut south of Pleasanton (W line NW-NW-SW sec 19, T22S, R25E), where it is about 20 feet of extremely sparsely fossiliferous gray shale. A thin zone at the top of the Unity Farm, in darker clay shale here and in gray clay shale above sandstone toward the north, carries a relatively abundant conodont fauna, which is related to the transgression responsible for the overlying Critzer Limestone Member. The Unity Farm Shale is about 15 feet thick at the Ks Rte 3 roadcut south of Uniontown, and it thins southward to 2 feet in the Prong Creek core (Heckel, 1991, p. 41) and southwestward to 1 foot at the spillway to Bourbon County State Lake. South of the pinchout of the Critzer/Bourbon flags unit in northern Neosho County, the Unity Farm is undifferentiated from the overlying Guthrie Mountain Shale Member.

Northward in Missouri, the interval encompassed by the Unity Farm Shale Member in Kansas attains well over 100 feet in thickness (Fig. 4). It contains a variety of thick sandstone facies, which are recognized as separate members in Missouri (including the sandy Knobtown Limestone), and at least two horizons of coal in the upper part, the Locust Creek coals of Howe (1982). This interval is good example of a deltaic complex, as recognized by Howe (1982), with prodeltaic gray uniform shale at the base (type Unity Farm), various deltaic to fluvial sandstones in the middle to upper part, and alluvial deposits that contain the coals in the upper part toward the north. The Kansas development of this interval consists mainly of gray prodeltaic shales, mostly undifferentiable from type Unity Farm but locally containing distal delta-front sands that disappear abruptly into the prodeltaic shales, which in turn thin southward toward the basin. In Iowa and Nebraska, this interval (including also the thin north end of the uppermost Pleasanton Guthrie Mountain Shale Member north of the pinchout of the Critzer Limestone) is 3 to 8 feet of gray blocky mudstone with local red mottling, which represents long-term subaerial exposure north of the Missouri deltaic complex.

<u>Critzer Limestone Member</u>.--The Critzer Limestone Member overlies the Unity Farm Shale Member and underlies the Guthrie Mountain Shale Member in the Shale Hill Formation (Fig. 2,4). It was named by Jewett (1932) from a type locality in NW sec 17, T22S, R23E, just south of the former town of Critzer, 5 miles west of Mound City in Linn County. It had been included as the lower member of the Hertha Limestone (e.g., Moore, 1949), presumably because of the

relative thinness (0 to 8 feet) of the overlying original Mound City Shale, which intervenes between it and the upper (and main) limestone member (Sniabar) of the Hertha in central Linn County, where all three members were first differentiated, and the lower two named. Recent work by myself and Underwood (1984) shows that in southeastern Linn and north-central Bourbon counties, the original Mound City Shale thickens dramatically southward, and the Critzer Limestone changes facies into the argillaceous flaggy limestone sequence known informally as the Bourbon flags (Jewett et al., 1965, p. 8) and long considered part of the Pleasanton Group. This relationship was overlooked by earlier workers, probably in part because the Sniabar Limestone southward contains shale beds up to 2 feet thick that were apparently misidentified as the Mound City Shale (e.g., Jewett et al., 1965, p. 7), causing the lower limestone bed of the Sniabar to be misidentified as Critzer. As now understood, the Critzer Limestone diverges southward up to 100 feet below the Sniabar Limestone (Fig. 4), which alone formed the main part of the classic Hertha Limestone from Bourbon County southward and from northeastern Linn County northward. Therefore the Critzer is now removed from the Hertha Limestone and recognized as a member of the Shale Hill Formation in the Pleasanton Group, with which it is much more closely associated (Fig. 4).

The Critzer Limestone in its type area of central Linn County and extending from northwesternmost Bourbon County to northeastern Linn County, is a massive, brown-weathering, fine-grained skeletal calcarenite from 5 to 11 feet thick and containing conspicuous macrofossils, particularly large bellerophontid snails. Contacts are sharp with shales both above and below. The type locality is now slumped, but excellent reference sections include the hill west of the north end of Pleasanton (southwest of ctr N line NW sec 34, T21S, R24E), the Kansas Rte 52 roadcut 2.5 miles southwest of Mound City (near ctr SW sec 23, T22S, R23E), and the Xenia northwest roadcut (S line SW-SE SE sec 20, T23S, R22E) in northwesternmost Bourbon County. This lithotype is a shelf facies developed on top of the thick, often sandy, delta-front facies of the Unity Farm Shale Member. Northeastward in Linn County, the Critzer thins to 2 feet of shaly nodular algal calcarenite, which is well exposed in the second U.S. 69 roadcut north of LaCygne Junction (NW-NW-SE sec 31, T19S, R25E). Farther northeastward, the Critzer Limestone is traced into north-central Missouri as less than 1 foot of sparsely fossiliferous earthy limestone with diffuse contacts, which appears to have undergone alteration from subaerial exposure shortly after deposition. This is a higher shelf facies above the thickest part of the Unity Farm deltaic complex.

Bourbon flags facies. Southeastward from an east-northeast--west-southwest line extending from about Pleasanton and passing south of Mound City to northwest of Xenia, the shelf facies of the Critzer Limestone passes laterally into a thick- to medium-bedded dense calcilutite facies up to 12 feet thick. This facies contains zones of abundant brachiopods toward the northeast and locally abundant phylloid algae toward the top, particularly toward the southwest. Corals and snails are conspicuous locally. Farther southeastward, fossils become sparse, and in south-central Linn and northwestern Bourbon Counties, from north of Mapleton to south of Xenia, the lower part becomes a much thicker (35 feet) and shalier succession of alternating 0.3 to 1-ft beds of flaggy calcilutites and silty shales, which are the classic Bourbon flags. The upper contact is sharp with the overlying Guthrie Mountain Shale Member (formerly the lower part of the Mound City Shale). The lower contact ranges from sharp in the northeast where thick flaggy limestone overlies the dark shale at the top of the Unity Farm Shale Member, to more gradational southward where it is placed at the base of the lowest limestone bed in the shalier sequence.

The two best reference sections for the Bourbon flags are the northern U.S. 69 roadcut south of Pleasanton (W line NW-NW-SW sec 19, T22S, R25E), where they are less shaly and hold up the bluff, and the spillway to Hidden Valley Lake 2 miles northeast of Xenia (in SE-SW-SE sec 23, T23S, R22E) where they have been completely exposed. Here, about 6 feet of algal-skeletal calcilutite at the top, more recognizable as a facies of the Critzer Limestone overlies about 35 feet of interbedded flags and shale, which are accessible in nearby roadcuts (S line sec 23), where their eastward depositional dip was shown by Underwood (1984). To the northeast, the Bourbon flags hold up the range of hills 4 miles southeast of Pleasanton, with several partial exposures along roads separating sections 10, 15, 14 and 11, T22S, R25E. Other accessible exposures that show variations in this facies include a roadcut 3 miles south of Mound City along Kansas Rte 7 (ctr E line SE-SE sec 30, T22S, R24E), where 5 feet of algal skeletal calcilutite overlie 2 feet of brachiopod-rich calcilutite; a roadcut 1 mile to the east (W line SW-SW NW sec 28, T22S, R24E) where the member is 12 feet of bedded phylloid algal-dominated calcilutite; a roadcut 2 miles north of Mapleton (W line SW NW NW sec 15, T23S, R23E) where algal-skeletal calcilutite with brachiopods and snails overlies a shalier flag sequence; and the quarry just north of Ks Rte 65, 2 miles east of Xenia (SW-SE-SW sec 36, T23S, R22E) where about 12 feet of thick-bedded phylloid algal moundrock is exposed above shalier flags nearby.

Southward the flags thin to about 2 feet in the roadditch at the abandoned house below the type Guthrie Mountain Shale (Fig. 4) in the roadcut southeast of the Little Osage River bridge 2.5 miles southwest of Mapleton (near ctr N line SW-NW sec 8, T24S, R23E). They nearly pinch out into shale southward as they appear to be represented by only 0.1 foot of argillaceous limestone 2 feet above the Exline Limestone in the Shale Hill succession exposed east of Turkey Creek 3 miles northeast of Uniontown (ctr NW-NW-NW sec 12, T25S, R22E). Farther southwestward at the spillway to Bourbon County State Lake, 6 miles southwest of Uniontown, and more on strike with the main belt of flags facies, 9 feet of medium- to thick-bedded phylloid-algae-dominated calcilutite not far above the Exline Limestone Member represents the bedded algal facies of this member. This unit thins eastward along the south bluff of the Marmaton River valley to about 1 foot of shaly skeletal calcilutite at the Ks Rte 3 roadcut south of Uniontown (just below the culvert and 15 feet above the Exline horizon), and it thins southward to 2.4 feet of argillaceous limestone and shale 2 feet above the Exline in the Prong Creek core (Heckel, 1991, p. 41).

The algal and brachiopod calcilutite facies of the Critzer/Bourbon flags represent a carbonate slope facies developed on the southeastward-thinning distal prodeltaic facies of the Unity Farm Shale Member (Fig. 4). The classic shaly Bourbon flags developed closest to the last active delta lobe in northwestern Bourbon County when the minor transgression responsible for the Critzer Limestone stymied delta-lobe outbuilding but did not overwhelm the last pulses of detrital influx for some time. The less shaly, algal- and brachiopod-dominated calcilutites developed farther away from the source of detrital influx during the time of the Critzer inundation, and developed later during the inundation over the shaly flags near the last detrital source. The transgression is marked away from the detrital source by the dark, relatively conodont-rich shale bed at the top of the Unity Farm Shale and base of the flags south and east of Pleasanton, by the thin conodont-rich distal end of the Unity Farm Shale at Bourbon County State Lake, and by a slightly conodont-rich shale carrying shallow-water conodonts below the regressive Critzer shelf facies in hills west and north of Pleasanton. This transgression took marine deposits only to north-central Missouri, and therefore it is considered a minor inundation (Fig. 3).

Guthrie Mountain Shale Member.--Lying above the Critzer Limestone Member and below the redefined base of the Mound City Shale Member of the Hertha Limestone, the newly defined Guthrie Mountain Shale Member forms the top of the Shale Hill Formation and Pleasanton Group in Kansas (Fig. 2). The Guthrie Mountain Shale formed about the lower half of the Mound City Shale as it was originally defined between the Critzer and Sniabar Limestones. However, much of the immense southward thickening of the original Mound City Shale above the Bourbon flags slope facies of the Critzer takes place in this newly defined member, (Fig. 4), such that all thick exposures of it known to earlier workers were considered to be Pleasanton without question. Therefore, including it in the Pleasanton Group poses no problems as to prior usage. Furthermore, it is lithologically indistinguishable from the dominant shale facies of the Unity Farm Shale Member, which forms most of the original type Pleasanton.

The Guthrie Mountain Shale Member is named herein from Guthrie Mountain, a prominant knob south of Mapleton capped by Swope Limestone. The top of the Guthrie Mountain Shale crops out along the lane up the southeast side, but the stratotype is designated 1.5 miles to the southwest along the roadcut east of the Little Osage River bridge (along N line S« NW sec 8, T24S, R23E), where the entire unit (Fig. 4) along with both lower and upper contacts are well exposed. The base of the Guthrie Mountain Shale is an abrupt contact of shale over limestone where the Critzer Limestone Member is present. Both north of the disappearance of the Critzer Limestone in north-central Missouri, and south of the disappearance of its Bourbon flags facies in southern Bourbon County, Kansas, the Guthrie Mountain Shale Member is indistinguishable from the underlying Unity Farm Shale Member (Fig. 4). The upper contact of the Guthrie Mountain Shale is the base of the Mound City Shale as redefined herein. At nearly all localities, this is a relatively sharp contact at the base of a black to dark gray shale bed that is essentially continuous from Iowa to Oklahoma, though locally with thin basal limestone lenses, as at the type section.

The Guthrie Mountain Shale Member is almost entirely a monotonous sequence of nearly unfossiliferous gray shale in Kansas. It is 70 feet thick above the thinned Bourbon flags at its type section south of Mapleton, and it thins gradually southward through 44 feet at the roadcut east of Turkey Creek to 15 feet at the Ks Rte 3 roadcut, north and south of Uniontown respectively. It is 8 feet thick in the creekbank 3.3 miles east of Kimball in northeastern Neosho County, where it has merged with the Unity Farm Shale Member, and the combined unit thins to 1 to 2 feet of dark gray shale southward above the Exline interval just above the base of the Tacket Formation. The main mass of the Guthrie Mountain Shale Member is a prodeltaic shale lobe that is thickest above the Bourbon flags lower slope facies just south of the main mass of the Unity Farm prodeltaic shale (Fig. 4), and it thins distally basinward from a northeastern source. No sandstone is known yet on exposure in this member, but the Emerson core taken in an eastward prong of outcrop (near ctr NE NE sec 14, T24S, R23E) 4 miles southeast of Mapleton shows sandy zones in this direction (J.A. French, pers. commun., 1991). The Guthrie Mountain Shale Member thins more abruptly northward through about 20 feet above the purer flags facies south of Pleasanton to about 2 to 4 feet of prodeltaic gray shale above the shelf facies of the classic Critzer Limestone from northwestern Bourbon County (Xenia northwest roadcut) across central Linn County to the second US 69 roadcut north of LaCygne Junction (Fig. 4).

Northeastward throughout Missouri, the Guthrie Mountain Shale Member ranges from 2 to 4 feet mainly of gray blocky mudstone, which is an underclay capped locally by the Ovid coal, named from Ray County, Missouri (see Howe, 1982). In Iowa and Nebraska north of the Critzer Limestone pinchout, the Guthrie Mountain is inseparable from the Unity Farm Shale Member, and the combined unit ranges from 3 to 8 feet of gray blocky mudstone with reddish mottling northward and local coaly zones southward, both attesting to terrestrial environments with paleosol formation north of the prodeltaic facies.

COFFEYVILLE GROUP

The Coffeyville Group is now recognized as a useful subdivision of the shale-dominated lower Missourian succession in southern Kansas. It overlies the Hepler Formation (specifically the South Mound Shale Member) of the Pleasanton Group, and underlies the Dennis Limestone of the Bronson Subgroup of the Kansas City Group (Fig. 2,4). It therefore includes strata equivalent to the Shale Hill Formation of the upper Pleasanton Group and to the succession from the Hertha Limestone through the Galesburg Shale of the lower and middle Bronson Subgroup of the Kansas City Group. The Coffeyville Group comprises 4 formations in ascending order: Tacket Formation, Ladore Shale, Mound Valley Limestone, and Galesburg Shale. The Tacket Formation is transferred from the Pleasanton Group and redefined herein because of corrections of longstanding miscorrelations of lower Bronson units (treated under discussion of the Bronson Subgroup). The Mound Valley Limestone is a reinstated name for a unit also involved in the miscorrelations. The Ladore, Mound Valley and Galesburg formations are also part of the Bronson Subgroup to the north and are treated under that heading.

The name Coffeyville Formation was applied by Schrader and Haworth (1905) to strata exposed at Coffeyville, Kansas, but the name has been used mainly in Oklahoma, where its use was stabilized by Moore et al. (1937) and Oakes (1940a) for the strata from the top of the Checkerboard Limestone to the base of the Hogshooter (Dennis) Limestone. The best exposures of this unit in the Coffeyville area are to the north, in the bluffs along the Verdigris River, which expose mainly the upper, dominantly sandstone and sandy shale succession equivalent to the Galesburg Shale. The currently most accessible of these exposures is in the shale pit at the south end of the bluffs in SW-NW sec 26, T34S, R16E, with a thin limestone in the bank of the Verdigris River 11 feet below road level just south of the pumping station probably representing the Mound Valley Limestone. This exposure can be regarded as the type section of the Coffeyville Group. The lower part of the group, however, must be pieced together from the type sections of its component units elsewhere on outcrop.

A complete section of the Coffeyville Group/Formation is available in the South Coffeyville core (OSC on Fig. 5) taken 3 miles south of the Kansas-Oklahoma border. Here it totals 223 feet in thickness, with about 26 feet of dark shaly Tacket Formation at the base followed upward by 60 feet of Ladore Shale, which is mainly sandstone, 3 feet of shaly Mound Valley Limestone, and capped by 134 feet of Galesburg Shale, also mainly sandstone, with the Cedar Bluff coal bed 28 feet below the top. In this core, the Coffeyville Formation rests upon 4 feet of Checkerboard Limestone, which in Kansas is included in the base of the Tacket Formation (and therefore is part of the Coffeyville Subgroup). Southward, the Tacket equivalent can be traced at least to Seminole County, Oklahoma, just north of the Canadian River, based on the distinctive conodont fauna and lateral continuity of the upper Tacket (Hushpuckney) black shale bed. The Mound Valley Limestone appears to be lenticular south of the South Coffeyville core, but where it is identified, as at the Sapula shale pit in Creek County, the Ladore and Galesburg units can be recognized as well. Otherwise the post-Tacket beds can be termed Ladore-Galesburg or upper Coffeyville.

Tacket Formation

The Tacket Formation overlies the South Mound Shale Member of the Hepler Formation of the Pleasanton Group and underlies the Ladore Shale in southern Kansas (Fig. 2). The Tacket was formally named by Jewett et al. (1965) from a type exposure near Tacket Mound between Parsons and Mound Valley in Labette County, to comprise the strata, mainly dark shale, between the Checkerboard Limestone below and the Hertha Limestone (as it was then understood) above, and it was regarded as the upper formation in the Pleasanton Group. Analysis of the conodont faunas of the Tacket Formation by Pavlicek (1986), supplemented by more recent field work that was motivated by his findings, has shown that the Tacket in its type area encompasses strata equivalent not only to the Shale Hill Formation of the Pleasanton Group but also to the overlying Hertha, Elm Branch and Swope formations in the lower Bronson Subgroup as well (Fig. 4).

The type exposure of the Tacket Formation designated by Jewett et al. (1965, p. 7-8) along the west side of sec 17, T32S, R19E, is now so poorly exposed that a new reference section is required. It apparently was not very well exposed at the time that it was measured by Jewett and his co-workers, as indicated by covered intervals in their description of their "lower shale unit" of the Tacket and middle "shale unit" of the Checkerboard Limestone. In fact, the strata originally designated as Tacket Formation by Jewett et al. (1965) may be equivalent to only the Elm Branch Shale and the Middle Creek Limestone and Hushpuckney Shale members of the Swope Limestone. As explained by Pavlicek (1986, p. 7-11), Ravn (1981) and Bennison (1984) discovered new and better exposures of Tacket strata around Tacket Mound in section 7 nearby, which clarify the stratigraphy of the interval to which the name Tacket Formation had been attached. Particularly significant was the discovery of a lower phosphatic black shale apparently in the mostly covered interval that had been considered the middle "shale unit" of the Checkerboard Limestone by Jewett et al. (1965), as explained later under the Middle Limestone and Upper Tacket Shale members. Therefore, the stratal content of the Tacket Formation is herein redefined at a much better exposed neostratotype, and follows fairly much the usage of Bennison (1984) and Pavlicek (1986), as modified by the more recent discovery that what they and earlier workers had called Sniabar (upper Hertha) Limestone at the top is really the younger Bethany Falls Limestone.

As herein redefined, the Tacket Formation is a succession of dark gray to black shales with thin limestone beds and nodule horizons (including the featheredge of part of the Checkerboard Limestone as a member at the base) lying above the South Mound Shale Member of the Hepler Formation, and below the Ladore Shale in Kansas (or the equivalent sandy beds in the lower Coffeyville Formation in northern Oklahoma). From about 40 feet in its type region in Labette County, the Tacket Formation thins to perhaps 30 feet in the type Hertha region of central Neosho County, north of which it thickens into its northern equivalent formations as their various members become recognizable (Fig. 4). Southward the Tacket shale interval reaches about 65 feet near Nowata, Oklahoma (core ONC), then thins to 10 to 20 feet through the Vera-Tulsa region, thickening southward again to over 300 feet in Okfuskee County where the interval is penetrated by southerly-derived sandstones (Fig. 5).

The neostratotype (and principal reference section) for the Tacket Formation is in a well exposed drainage down the northeast shoulder of Tacket Mound near the NE cor SW sec 7, and along the south bank of the creek into which it empties in SW-SW-NE sec 7, T32S, R19E, Labette County, Kansas. Here the Tacket is about 40 feet thick and consists of the upper 4 of the 5 recognized members, of which the middle 3 are informal but with known named northern equivalents. The members are listed in ascending order: 1) Checkerboard Limestone, 2) Lower Tacket Shale, 3) Middle Tacket Limestone, 4) Upper Tacket Shale, 5) Bethany Falls Limestone.

The Checkerboard Limestone Member is a lenticular limestone in Kansas, classified at the base of the Tacket Formation. It overlies the South Mound Shale Member of the Hepler Formation and underlies the Lower Tacket Shale Member in Kansas. The Checkerboard Limestone was named from Checkerboard Creek west of Beggs in Okmulgee County, Oklahoma, south of Tulsa (see Oakes, 1940a), where it overlies the Seminole Formation and underlies the Coffeyville Formation (which includes the Tacket interval at its base). Throughout its type region the Checkerboard is a distinctive dense skeletal calcilutite 2 to 4 feet thick, which is readily recognized on outcrop and in cores from Okfuskee County northward to the Kansas-Oklahoma border. It generally has sharp contacts with marine shale above and with terrestrial shale or sandstone below. North of Tulsa County, it becomes more argillaceous but maintains its sharp lower contact above coarse Seminole clastics to the Lenapah core (OLC on Fig. 5). In the Nowata and Ramona cores (ONC,ORC) just to the south, it forms a thicker succession (up to 11 to 19 feet) that appears to split into two limestone beds separated by fossiliferous shale (Fig. 5). A similar succession is seen also in the bed of Wolf Creek (SW-SE-SW sec 27, T27N, R15E) 3 miles west of Delaware in Nowata County.

The sudden northward appearance below the Checkerboard Limestone, in the northernmost Oklahoma core (OSC), of the marine South Mound Shale in gradational contact with it (in contrast to its sharp lower contact with the sandy Seminole Formation) suggests that both the South Mound Shale and the Checkerboard above it here are part of the same marine interval and are equivalent to the entire Checkerboard southward in Oklahoma. This is supported by the shale split in the Checkerboard Limetone in cores ONC and ORC, which appears to be the South Mound Shale. Thus, the South Mound Shale is apparently a northern detrital facies of the type Checkerboard Limestone (see discussion under South Mound Shale) and both units together represent the same minor transgression delineated on Figure 3 as the South Mound cycle of marine deposition. In further support of this correlation, the terrestrial deposits that intervene between the type Checkerboard Limestone and the Exline Limestone south of Tulsa (mentioned with the lower gray shale unit of the Lower Tacket Shale Member) separate the type Checkerboard depositionally from the Exline above, such that the Checkerboard Limestone and overlying deltaic shale south of Tulsa constitute a minor transgressive-regressive unit by themselves, as does the South Mound Shale in the north, prior to the more widespread Exline transgression (Fig. 3).

Although the Checkerboard Limestone as recognized above the South Mound Shale in Kansas is probably stratally continuous with at least the upper part of the Checkerboard of northern Oklahoma, it also appears to be a younger horizon than the type Checkerboard of central Oklahoma, which lies below the detrital wedge that separates type Checkerboard from the Exline horizon south of Tulsa. This is because in Kansas the limestone termed Checkerboard lies above the regressive South Mound deltaic complex in the position of a transgressive limestone to the overlying Exline interval. Thus the Checkerboard Limestone in its entirety is a basinal carbonate lithotope centered in the Tulsa-Vera region, with the Exline horizon at its top (see section on Exline Limestone), and is split both northward and southward by detrital wedges representing the regressive phase of the South Mound cycle (Fig. 3).

With this relationship in mind, the Checkerboard Limestone is recognized in a few exposures in Kansas, classified in the base of the overlying marine unit (Tacket Formation) rather than in the top of the underlying regressive unit (upper South Mound Shale). The best exposure is above the thick prodeltaic South Mound Shale just southwest of Mound Valley along the top of the high bank of Pumpkin Creek and in adjacent ravines (in SW-NE sec 10, T33S, R18E) in Labette County, where it is 1 to 1.3 feet of dense skeletal calcarenite. The most informative Checkerboard exposure is in the spillway of the pond east of South Mound (NE-SW-SE-NE sec 16, T30S, R20E) in Neosho County, where it overlies (with a 1-foot covered interval) the sandstone at the top of the South Mound Shale, and underlies slumped black shale of the Tacket Formation. The most accessible exposure is along the paved road about 3.5 miles to the north (in SW-SW-NW-SW sec 28, T29S, R20E) near the old Hertha townsite. In both latter exposures the Checkerboard is 1 to perhaps 2 feet of dense skeletal oolitic calcarenite to calcilutite, which is lenticular in view of its absence less than one mile from each locality (in the west tributary to Bachelor Creek near ctr W line NE-NE sec 32, T29S, R20E; and at the roadcut just north of South Mound along W line SW-SW-NW sec 10, T30S, R20E). The Checkerboard Limestone is also absent in the exposures around Tacket Mound between Parsons and Mound Valley in Labette County. Although the basal shaly limestone bed of the South Mound Shale is probably time equivalent to the base of the type Checkerboard Limestone, the two beds may not be stratally continuous, nor do they closely resemble one another. Thus the entire South Mound Shale is classified in the upper part of the Hepler Formation as a separate unit from the Checkerboard Limestone Member included at the base of the Tacket Formation in Kansas.

The Lower Tacket Shale Member is about 8.5 feet thick at the Tacket type section, where it consists of roughly equal thirds of dark gray shale at the base, black fissile shale in the middle, and dark gray shale at the top. The basal contact is abrupt, with dark gray Tacket shale overlying an apparently oxidized surface upon 3 to 4 feet of gray shale that overlies a coal and underclay above more gray shale with limy nodules, all of which belong to the South Mound Shale Member of the Hepler Formation. The lower 0.5 foot of the Lower Tacket here is fossiliferous calcareous shale with argillaceous skeletal calcilutite nodules, which represent the Exline Limestone because they carry the abundant conodont fauna characteristic of that unit. The middle fissile black shale unit carries small phosphorite nodules and a zone of large limestone concretions that contain well preserved small ammonoids and tiny spheroidal fossils that may be altered radiolarians (Pavlicek, 1986). It also carries the abundant conodont fauna that is characteristic of the black shale bed in the Mound City Shale Member of the Hertha Limestone, with which it is correlated on that basis. The 2 to 3 feet of lower gray shale between the black shale and the nodular Exline unit thus are the distal featheredge of over 100 feet of

Shale Hill (upper Pleasanton) deltaic to prodeltaic shale and sandstone in east-central Kansas and Missouri.

Northward, the Lower Tacket Shale is fairly well exposed in the road ditch north of South Mound (just N of ctr W line sec 10, T30S, R20E) in southern Neosho County, where about 5 feet of fissile black shale overlie perhaps 3 feet of poorly exposed dark gray shale with small crinoids and an abundant conodont fauna characteristic of the Exline Limestone at the base. This lies upon a foot or two of gray mudstone above a 1.5-foot sandstone ledge, which together form the top of the South Mound Shale in this area. Just 2.5 miles to the northwest (ctr N« NE sec 32, T29S, R20E), the Lower Tacket merges with the lower part of the neostratotype of the Hertha Limestone near the old Hertha townsite.

Southward, the Lower Tacket Shale Member is well exposed in the banks and bed of Hickory Creek (just S of ctr N line NE sec 24, and just N of ctr S line SE sec 13, T28N, R15E) in northern Nowata County, Oklahoma, where it overlies definite Checkerboard Limestone above sandstone of the Seminole Formation. Here it consists of the same 3 units as at Tacket Mound: 2 feet of fossiliferous dark gray shale with abundant conodonts characteristic of the Exline Limestone in the base, overlain by 3 feet of black platy shale with phosphate nodules and the abundant conodont fauna characteristic of the Mound City Shale (Pavlicek, 1986), overlain by about 9 feet of dark gray sparsely fossiliferous shale. This sequence, with 2 to 3 feet of black phosphatic shale in the middle, is detected in the northern Oklahoma cores, ranging in thickness from over 30 feet near Nowata (ONC) to about 3 feet near Vera (OVC) and slightly more in exposures in the Tulsa region (Fig. 5). On the south side of Tulsa (U.S. 75 northbound offramp to 71st St. in NW-NE-NW sec 11, T18N, R12E) and southward, a 13-foot wedge of lighter-colored sparsely fossiliferous shale intervenes between the Checkerboard Limestone and the Exline Limestone in the Lower Tacket interval. This thickens southward to over 50 feet in Okfuskee County, where it contains sandstone and a coal horizon, and separates the Exline marine unit from the Checkerboard marine unit.

The <u>Middle Tacket Limestone Member</u> is about 1 foot of hard, dense, dark fossiliferous calcilutite at the Tacket Mound neostratotype. It is exposed at several other places in the vicinity (the streambed in the roadditch east of Tacket Mound, along S line SW-SE-SW sec 8, T32S, R19E; in the road south of Wilsonton Cemetery, about ctr E line SE-SE sec 17, same township), where it has been misidentified easily as the Checkerboard Limestone. Based on their published description, Jewett et al. (1965, p.8) apparently called it "Upper limestone unit" of the Checkerboard along W line NW sec 17, same township, thereby relegating the poorly exposed Lower Tacket black shale below it there to a classification as the middle "shale unit" of the Checkerboard. In reality, the Middle Tacket Limestone in this area may be equivalent to the early regressive carbonate and shale units in the upper Mound City Shale (above the black shale bed) and/or perhaps to the Sniabar Limestone Member at the top of the Hertha, which it somewhat resembles northward at the Hertha neostratotype near the Hertha townsite.

Southward, the Middle Tacket Limestone Member at Hickory Creek in northern Oklahoma is about 1 foot of skeletal calcilutite overlain by about 0.5 foot of argillaceous crinoid-rich calcarenite, a sequence seen also in nearby cores (OSC, OLC, ONC). This earthy crinoidal calcarenite has been referred to as the "marl zone" by A.P. Bennison, who has traced it throughout the Tulsa region to exposures west of Beggs, where it still separates the Lower and Upper Tacket dark shales. Its abundant conodont fauna resembles that of the underlying black Mound City shale more than that of the overlying Upper Tacket Shale, but it contains in places a few forms anticipatory of a distinctive Hushpuckney form, thus it probably represents diastemic deposition during the lesser sea level fluctuations represented by the upper Hertha Sniabar Limestone or perhaps the overlying Elm Branch Shale to the north.

The Upper Tacket Shale Member is about 28 feet thick at Tacket Mound where it, like the Lower Tacket Shale, consists of three units in ascending order: 1) lower dark gray fossiliferous shale about 6 feet thick, partly covered, with a dense sparsely fossiliferous calcilutite bed at the top; 2) middle black fissile shale with phosphate nodules, about 5 feet thick, 3) upper dark gray shale about 17 feet thick, with fossils toward the top, a darker zone in the middle and 3 zones of large dark calcilutite nodules in the lower half, the highest one essentially fused into a laterally continuous bed of dark barren calcilutite (Pavlicek, 1986). The Tacket Formation as originally delineated by Jewett et al. (1965) apparently included only the Upper Tacket Shale Member as now defined, because their description of their middle "Limestone unit" (p.8) as light gray weathering and conchoidal in fracture better characterizes these large nodule beds than the fossiliferous browner colored Middle Tacket Limestone, which fits better their description of the "Upper limestone unit" of the "Checkerboard".

The black and darker gray shale zones in the Upper Tacket Shale carry an abundant conodont fauna that contains three species that are not found anywhere in the Mound City Shale or lower beds, but were reported by Ellison (1941) from the Hushpuckney Shale in the Kansas City area. This was the information that led to restudy of field relations in northeastern Neosho County, which uncovered the long-standing miscorrelation of beds there, and established lithostratigraphically as well as biostratigraphically, that the Upper Tacket Shale Member is correlative with the Hushpuckney Shale Member of the Swope Formation, instead of with the Mound City Shale or upper Pleasanton units as previously believed.

The Upper Tacket Shale Member is more accessibly exposed nearby, south of the Wilsonton Cemetery (along E line SE sec 17 T32S, R19E). The upper 2 units of this member are the best exposed part of the entire Tacket Formation in Labette and Neosho counties (e.g., hill southwest of Parsons, N line NE-NE NW sec 27, T31S, R19E; U.S. 160 at Parsons Country Club entrance, N line NW NE NE sec 21, same township; Kansas Rte 57 roadcut 3 miles west of St. Paul, S line SE-SE-SE sec 17, T29S, R20, and NE cor sec 20 just to the south). The Upper Tacket Shale thins somewhat northward to about 18 feet in the west tributary to Bachelor Creek near the Hertha townsite where the lower two units are exposed, and it apparently thins to about 8 feet southward just 2.5 miles in the South Mound north roadcut, where it is mostly covered.

Southward into Oklahoma, the Upper Tacket Shale Member retains its 3-part subdivision with 2 to 5 feet of black phosphatic shale in the middle. It ranges from 16 to 32 feet in thickness (the majority of it in the upper gray shale unit) in the 3 northernmost Oklahoma cores, (OSC, OLC, ONC, on Fig. 5), and it is especially well exposed in a high bank along California Creek (NE SE-NW sec 10, T27N, R15E) 3 miles west of Lenapah in Nowata County. Southward the phosphatic black shale bed, ranging from 4 to 10 feet thick, is traced easily through the Tulsa area above the "marl zone" of A. P. Bennison, to Beggs and through scattered exposures to the Canadian River around Sasakwa in Seminole County. Both the lower gray shale and upper gray shale units are penetrated by thick sandstones from just south of Beggs in Okmulgee County, southward (Fig. 5).

The Bethany Falls Limestone Member, described thoroughly under the Swope Limetone, is herein classified as the top member of the Tacket Formation south of the disappearance of the Middle Creek Limestone Member where the Swope Limestone thus becomes undefined at the base. This allows the Tacket Formation to be considered the exact southern equivalent of the Exline through Swope limestones, and avoids having the Bethany Falls Limestone stand alone as a separate formation or be attached to the next higher formation (Ladore Shale, which contains no other limestone units) in the area where the Tacket Formation rather than the Swope Limestone is recognized. The upper boundary of the Tacket Formation is the sharp limestone to shale contact at the top of the Bethany Falls Limestone, where it is present, to the area just southwest of Nowata, Oklahoma. Southward, the upper contact of the Tacket Formation is gradational from fossiliferous shale upward into increasingly sandy, less fossiliferous shale in the prodeltaic upper Coffeyville succession.

The entire Tacket Formation is the thin marine dysoxic to anoxic basinal dark shale and limestone facies of several lower Missourian formations through two major, one intermediate, and two minor cycles of sea level rise and fall (Exline to Swope on Fig. 3). It is situated across a 130-mile-long extent of outcrop, between thick prodeltaic shales and shelf limestones on the north in east-central Kansas, and thick deltaic sandstones and shales on the south in central Oklahoma (Fig. 4,5).

KANSAS CITY GROUP

The Kansas City Group encompasses the majority of Missourian strata in Kansas above the Pleasanton Group and below the Lansing Group. It comprises 15 formations, generally alternating between limestones and shales, from the Hertha Limestone through the Lane Shale as redefined herein to extend upward to the base of the Lansing Group. The Kansas City Group is divided into three subgroups in ascending order: Bronson, Linn, and Zarah, each with somewhat different lithic characters, as it has been since 1947, but with the Iola Limestone now transferred from the Linn to the Zarah Subgroup.

The name Kansas City was applied by Hinds (1912) and Hinds and Greene (1915) to the succession of strata from the base of the Hertha Limestone through what is now recognized as the Wyandotte Limestone, and the top was extended upward to its present position by Moore (1936). Moore (1932) excluded from the Kansas City Group the lower part (Hertha through Dennis Limestone) as the lithologically distinct Bronson Group with thicker limestones and thinner shales than the remainder, but later accepted a 1947 agreement among the several state geological surveys returning Bronson strata to the base of the Kansas City Group as more in accordance with long-standing usage in the subsurface (Moore, 1948, 1949).

The Kansas City Group was named from the excellent exposures in the river bluffs in the Kansas City area. There is no single type section, but all component units are exposed more accessibly today mainly in newer roadcuts into the bluffs throughout the area, as indicated under the individual units. The entire group averages about 300 feet in thickness in the Kansas City area, thickening southward through 350 feet around Iola in Allen County to perhaps 500 feet along the Kansas-Oklahoma border. Profound facies changes in the lower part of the Bronson Subgroup in southern Kansas render recognition of the Coffeyville Group (described previously) as a more reasonable classification for the top of the Pleasanton and base of the Kansas City Groups in the Kansas-Oklahoma border region. Northward, strata encompassed by the Kansas City Group in Kansas and Missouri thin to about 200 feet in Iowa (where the Bronson Group is recognized as a separate unit) and to about 160 feet in the Platte River valley of Nebraska (Burchett and Reed, 1967).

BRONSON SUBGROUP

The Bronson Subgroup comprises 7 formations at the base of the Kansas City Group, in ascending order, Hertha Limestone, Elm Branch Shale, Swope Limestone, Ladore Shale, Mound Valley Limestone, Galesburg Shale, and Dennis Limestone. The Ladore Shale and Mound Valley Limestone, formerly miscorrelated northward with the Elm Branch shale and Swope Limestone, respectively, are present only from southern Bourbon County southward. South of central Neosho County, the Hertha Limestone, Elm Branch Shale, and Swope Limestone become difficult to distinguish as they grade, along with the underlying Shale Hill Formation at the top of the Pleasanton Group, into the succession of dark shale with thin limestones in the Tacket Formation. In this area the Tacket along with the overlying Ladore Shale, Mound Valley Limestone, and Galesburg Shale are combined into the Coffeyville Group, which encompasses a succession that has long been recognized as the Coffeyville Formation in northeastern Oklahoma.

The name Bronson was applied by Adams (1904) to the "triple limestone" (Hertha, Mound Valley and Dennis) recognized by earlier stratigraphers in the more northern part of southeastern Kansas. Moore (1932) classified these limestones (substituting Swope for Mound

Valley) and intervening shales as the Bronson Group, for which the chief distinguishing feature is the prominence of limestone (Moore, 1936). The prominence of limestone is conspicuous in the well defined Bronson escarpment, which can be traced from northeastern Neosho County northeastward through Bourbon, Linn and southern Miami counties in Kansas, through Cass and eastern Jackson counties into Ray and Carroll counties in Missouri, where it becomes obscured by Pleistocene deposits. The Bronson is distinguished similarly throughout the subsurface of the Forest City basin to the northern outcrop limit in Iowa and Nebraska by the prominence of the three thick limestones separated by two thin shales. Nevertheless, Moore (1949) accepted the reduction in rank of the Bronson to subgroup and its inclusion as the lower part of the Kansas City Group in order to accommodate the original definition and usage of that group in Missouri and in the subsurface of Kansas. Iowa, however, recognizes the Bronson as a group and includes the underlying thin Pleasanton as a formation at its base (Ravn et al., 1984).

The type locality of the Bronson Subgroup was given as the vicinity of Bronson in Bourbon County, Kansas, but no type section was designated. Parts of the major component units are exposed along US 54 from 1 to 5 miles east of Bronson where it descends the Bronson escarpment, but the boundaries are not exposed and the entire constituency of the subgroup must be pieced together from many better exposed reference sections throughout Bourbon and adjacent counties. The Bronson Subgroup averages about 80 feet in thickness from Kansas City northward to the Iowa-Nebraska outcrop belt, thinning to 65 feet on the Nemaha uplift (core NAC on Fig. 6). Southward it thickens to perhaps 160 feet in its type region in Bourbon County where the major limestone units thicken commonly into algal mound complexes (Heckel and Cocke, 1969). The Bourbon Subgroup thickens further to perhaps 200 feet southward in places where the intervening shale formations, particularly the Ladore and Galesburg, thicken significantly between the thinning limestone units in the basinward direction.

Hertha Limestone

The Hertha Limestone overlies the Shale Hill Formation of the Pleasanton Group and underlies the Elm Branch Shale (Fig. 2). It was named by Adams (1903) from exposures around the former town of Hertha situated at ctr S line sec 29, T29S, R20E, between Erie and South Mound in southern Neosho County, Kansas. After a certain amount of confusion as to which limestone was originally designated (explained by Moore, 1936, p. 77-81), the name Hertha was attached to the lowest bed of the "triple limestone" around Erie, to the lowest of the three limestones in the Bronson escarpment northward in Bourbon and Linn counties, and to the lowest of the several limestones in the Kansas City succession in Missouri. In both latter cases, this unit is what is known as the Sniabar Limestone Member, but the Hertha also included the shelf facies of the older Critzer Limestone in central Linn County.

Recent field work in northeastern Neosho County, carried out as a result of conodont information presented by Pavlicek (1986) for the Tacket Formation to the south, has shown that the lowest bed of the "triple limestone" around Erie is, in fact, stratally continuous northward with the Bethany Falls Limestone (Fig. 4), the thickest limestone member in the Swope Limestone above what has been considered Hertha Limestone northward. Thus, the type Hertha stabilized by Moore (1936) as the limestone exposed just east of the town of Hertha, is actually Bethany Falls, which, as it was named in 1865, would have priority. Rather than dropping the name Hertha, which has been in common use for a long time consistently for the same limestone unit from northeastern Neosho County northward to Iowa, it is preferable to denote a new principle reference section (neostratotype) near Hertha. Accordingly, 0.5 foot of fossiliferous limestone and about 6 feet of underlying gray to black shale, discovered by A. P. Bennison near ctr N« NE sec 32, T29S, R20E along a western tributary to Bachelor Creek just southeast of the old Hertha townsite (and below the limestone originally called Hertha and its underlying black shale, now known to be the Bethany Falls Limestone and Hushpuckney Shale members of the Swope Limestone, respectively), are designated as the neostratotype of the Hertha Limestone.

Because the Critzer Limestone Member has been transferred from the Hertha Limestone to the Pleasanton Group for reasons explained in the previous section, the Hertha Limestone now consists of only two members, in ascending order, Mound City Shale and Sniabar Limestone. These constitute a major Kansas cyclothem that differs in certain minor respects (see member descriptions) from the classic Kansas cyclothems represented in many higher Missourian limestone formations. Good reference sections of the entire Hertha Limestone in Kansas include the Ks Rte 3 roadcut 1 mile south of Uniontown (NE-SE-NW sec 34, T25S, R22E) in Bourbon County, where both members are thick (totaling about 60 feet), and the second US 69 roadcut north of LaCygne junction (NW-NW-SE sec 31, T19S, R25E) in Linn County where both members are thin (totaling about 7 feet). The base of the Hertha Limestone, as redefined, is the base of the Mound City Shale Member as it is redefined (see next section) at the top of the underlying redefined Pleasanton Group. The top of the Hertha is the top of the Sniabar Limestone Member beneath the Elm Branch Shale, an old name revived for the overlying formation as a consequence of the recorrelation of the Hertha and younger strata in Neosho County.

Southward from the neostratotype, the Sniabar Limestone Member at the top of the Hertha Limestone becomes lenticular as the Hertha merges with the lower part of the Tacket Formation in southernmost Kansas and northern Oklahoma. Northward from LaCygne, both members of the Hertha are readily traced with minimal change along the outcrop belt and throughout the Forest City basin in Missouri, Iowa and Nebraska. In Nebraska, the Hertha has been misidentified as the higher Swope Limestone, both in the Amerada core (NAC) by Condra (1939) and on outcrop by numerous workers (e.g., Burchett and Reed, 1967). Conodont faunas in several of the Missourian black shales and fusulinid faunas in the higher Bethany Falls Limestone form the basis for the recorrelation of these strata in Nebraska.

Mound City Shale Member.--The Mound City Shale as redefined herein overlies the Guthrie Mountain Shale Member of the Shale Hill Formation at the top of the Pleasanton Group, underlies the Sniabar Limestone Member, and forms the base of the Hertha Limestone (Fig. 2). The name Mound City Shale was originally applied by Jewett (1932) to the strata above the Critzer Limestone Member and below the Sniabar Limestone, from a type locality "near Mound City in Linn County" (Jewett 1933, p. 136). Because of the immense southward thickening into Pleasanton-like shale of the lower part of these strata above the Bourbon flags facies of the Critzer Limestone, about the lower one half of the original type Mound City Shale has been transferred to the Pleasanton Group as the Guthrie Mountain Shale Member of the Shale Hill Formation (see previous section). Therefore, the Mound City Shale Member is herein redefined with a new lower boundary that is far more widely traceable (Fig. 4) than the northern or southern extremities of the Critzer Limestone, the old lower boundary. The lower contact of the Mound City Shale is defined now as the base of the black conodont-rich shale bed or of its equivalent macrofossiliferous (as well as conodont-rich) green-gray shale facies (where the black facies locally is absent), or of the immediately underlying thin fossiliferous limestone where it is present, all lying above the gray, silty, poorly fossiliferous Guthrie Mountain Shale at the top of the Pleasanton. This contact is sharp in most places but is diffuse below the green-gray shale facies of the basal bed.

The Mound City Shale Member as redefined comprises three subdivisions, in ascending order: 1) thin basal black (to gray) conodont-rich shale bed, 2) thin crinoidal limestone bed, and 3) thin to thick gray shale unit with local flaggy limestone and local thin sandstone beds. The exposures around Mound City are currently fairly badly slumped, thus obscuring the internal subdivision and precluding current designation of the stratotype. Good reference sections of the Mound City Shale that show the constituent units and member contacts where it is thin (about 3 feet, above thin Guthrie Mountain Shale and the shelf facies of the Critzer Limestone) are the second US 69 roadcut north of LaCygne Junction in Linn County, and also the Xenia northwest roadcut in northwesternmost Bourbon County (S line SW-SE-SE sec 20, T23S, R22E), where the basal black shale bed is represented by its green-gray facies. Good exposures of all three subdivisions and contacts of the Mound City Shale where it is thicker (above the thicker Guthrie Mountain Shale above the Bourbon flags facies of the Critzer Limestone) include the Mapleton northwest roadcut (NW cor sec 29, T23S, R23E), which shows well the correlation with the shelf facies at Xenia northwest, 5 miles westward; the southern US 69 roadcut south of Pleasanton (E line NE sec 25, T22S, R24E), which shows the sandy facies of the upper shale unit; and the Kansas Rte 3 Uniontown roadcut, where the entire Mound City Shale Member is 40 feet thick and shows well the flaggy limestone facies of the upper shale unit.

The basal black shale bed ranges from 0.3 foot of soft dark clayey shale in northeastern Linn County to 1 to 4 feet of harder black fissile shale with small phosphate nodules southward in southeastern Linn and Bourbon Counties, where the entire Mound City Shale thickens above the Bourbon flags and the thickening Guthrie Mountain Shale Member. In some of these thicker sections, large dark limestone nodules occur locally in the black shale, some of which contain ammonoids and are known as "bullion". Southward from southern Neosho County across northern Oklahoma, the basal phosphatic shale bed of the Mound City becomes the lower black shale bed of the Tacket Formation (Fig. 4), which can be traced in cores to central Okfuskee County above southwest-thickening sandstones south of Beggs in Okmulgee County (Fig. 5). Northward, the black shale facies is persistent as a 0.3- to 1.0-foot-thick clayey to locally fissile bed throughout Missouri, Iowa, and Nebraska (although in Nebraska it has been misidentified as the higher Hushpuckney Shale).

Locally in Bourbon County (e.g., east of Turkey Creek in NE-NW-NW sec 12, T25S, R22E), and in places in the northern outcrop belt, a thin limestone bed usually less than 0.2 foot thick appears at the base of the black shale. From central Linn County to northwesternmost Bourbon County, above one of the thicker parts of the middle Pleasanton (Unity Farm) delta, the black shale facies is replaced by a phosphatic green-gray shale facies carrying small calcareous macrofossils, mainly crinoids and brachiopods, in addition to the same abundant and distinctive conodont microfauna that is characteristic of the entire black shale facies from Iowa to Oklahoma. The conodont fauna contains the lowest occurrence of distinctive nodose species of Idiognathodus, and their lowest appearance in both Nebraska cores (NOC,NAC) at this horizon forms one of the bases for recorrelation of the Nebraska sequence. The black shale bed is the core shale of the Hertha cyclothem, marking maximum marine inundation of the shelf at this time (Fig. 3). The local thin limestone at the base represents a transgressive limestone that is too lenticular and thin to be named as a separate unit. It may be equivalent, however, to the thin DeNay Limestone named by Morgan (1923, 1924) from east-central Oklahoma, which in Seminole County (S line SW-SW-SW sec 6, T6N, R8E) underlies shale containing a conodont fauna similar to that of the lower bed of the Mound City Shale Member.

The thin crinoidal limestone bed overlies the basal black and gray conodont-rich shale bed in Linn County and northern Bourbon County. In the shelf area across most of Linn County, it is about 0.2 foot of distinctive hard limestone consisting mainly of crinoids and containing asphalt in intergranular pores, and it has been used as a marker bed for identifying the Mound City Shale Member. It also contains an abundant conodont fauna similar to that in the underlying black or gray shale. Brachiopods become more conspicuous than crinoids in this bed to the northeast near LaCygne, and it is not reported as a distinct bed in adjacent Missouri, where it may merge with the base of the overlying Sniabar Limestone Member. Southward, the crinoidal limestone bed thickens to 1 to 2 feet of very earthy crinoid-rich limestone in north-central Bourbon County where locally it weathers to a vuggy mass, the "boxwork" bed of J. M. Jewett's notes in the KGS stratigraphic file books. This bed is an incipient regressive limestone of the Hertha (Mound City) transgression (Fig. 3), which was smothered by prodeltaic detrital influx of the upper Mound City gray shale unit.

The upper gray shale unit of the Mound City Shale Member is only one to 3 feet thick above the thin northward extension of the Guthrie Mountain Shale Member and the shelf facies of the

Critzer Limestone Member across central Linn to northwesternmost Bourbon County, but like the Guthrie Mountain Shale below, it thickens southeastward above the Bourbon flags facies of the Critzer Limestone (Fig. 4). Eastward, it attains 28 feet and contains thin beds of platy sandstone in the southern US 69 roadcut south of Pleasanton. Southwestward, it reaches 30 feet in the Kansas Rte 3 roadcut south of Uniontown, where it contains unfossiliferous flaggy calcilutitic limestones in the upper part that are easily mistaken for the Bourbon flags, which disappeared southward 10 miles north of here at a lower stratigraphic horizon. A more persistent one-foot-thick, light-weathering barren calcilutite bed near the middle here (18 feet below the top) apparently was referred to as the "Uniontown limestone" by Jewett (1932, p. 103), but apparently also was miscorrelated with the earthy fossiliferous (crinoidal) limestone above the (basal) black shale below this unit northward, as indicated by his description of it (ibid., p. 99). The name has not been used since, and had been preempted by a Pennsylvanian unit in the Appalachian basin named in 1877. No formal name is deemed necessary at this time for any of these subdivisions of the Mound City Shale Member.

The southward equivalent of the earthy crinoidal limestone bed above the basal black shale bed of northern Bourbon County is probably the 4 feet of thin dark argillaceous limestones and intervening dark calcareous shale lying several feet above the basal Mound City black shale bed at the Uniontown roadcut, as they contain fossils including relatively abundant conodonts in the upper bed. The upper gray shale unit of the Mound City maintains its general thickness and character (including the dense light limestone near the middle and the darker limestones near the base) southward 8 miles to the less complete Prong Creek exposures near Kansas Rte. 39. This unit thins to about 20 feet westward with a few flags at Bourbon County State Lake, and it thins southward through poor exposure in Neosho County to a few feet of dark gray shale above the Mound City black shale bed in the lower part of the Tacket Formation. The upper Mound City gray shale unit is a minor regressive prodeltaic complex with a source east of the sandy facies exposed south of Pleasanton. It developed a limestone flag facies in its thickest area just basinward of the thickest area of the underlying upper Pleasanton (Guthrie Mountain) prodeltaic lobe, and it thinned distally both northward over the shelf and southward toward the basin (Fig. 4). The upper contact of the Mound City Shale Member is probably gradational, and is placed at the base of the lowest limestone bed of the overlying Sniabar Limestone Member.

<u>Sniabar Limestone Member</u>.--The Sniabar Limestone overlies the Mound City Shale Member, underlies the Elm Branch Shale, and forms the top of the Hertha Limestone (Fig. 2). It was first named by Jewett (1932) based on a term to be proposed by N.D. Newell, who in 1935 (p. 25) denoted the characteristic exposure along the highway one half mile north of Knobtown, Jackson County, Missouri (which is in the valley of the Little Blue River several miles southwest of Sni-A-Bar Creek, from which the name is derived). The Sniabar Limestone Member is 4 to 6 feet thick in northern Linn and adjacent Miami County, Kansas, where it consists mainly of a massive ledge of skeletal calcilutite with oolite and osagia-grain calcarenite locally at the top.

Both boundaries are abrupt contacts with underlying and overlying shale. The principal reference section for the Sniabar Limestone Member in Kansas is the second US 69 roadcut north of LaCygne Junction, where the thin oolite is overlain by a thin laminated ostracode-bearing calcilutite. Northward in Missouri, Iowa and Nebraska, the Sniabar averages about 15 feet thick, ranging from 7 feet in central Iowa to 21 feet in core NOC in southeastern Nebraska (Fig. 6), a region where it has been misidentified as the higher Bethany Falls Limestone. In this northern area, the Sniabar Limestone contains shaly beds at several horizons, and it may contain strata in the base that are the thin northern equivalent of the upper gray shale unit of the Mound City Shale Member. The Sniabar Limestone in the north is usually capped by abraded-grain calcarenites and/or laminated calcilutites that locally contain birdseye structures and/or paleocaliche; thus it represents the classic shallowing-upward sequence of a typical regressive limestone throughout this area.

In southern Linn and northwestern Bourbon County, above both the thicker part of the middle Pleasanton (Unity Farm) delta and the adjacent slightly more southward thicker trend in the upper Pleasanton (Guthrie Mountain) delta, the Sniabar Limestone Member thins down to about 2 feet thick and is marked by both a rubbly weathered appearance and an exposure surface at the top. Reference sections in this area include the southern US 69 roadcut south of Pleasanton (especially at SW cor sec 19, T22S, R25E), where the Sniabar is rich in fossils, and the Kansas Rte 52 roadcut southwest of Mound City (SW NE SW sec 23, T22S, R23E) and the Xenia northwest roadcut in northwesternmost Bourbon County, where it is poor in macrofossils. Southward above the southward-thinning middle Pleasanton (Unity Farm) prodeltaic slope and Bourbon flags across north central Bourbon County, the Sniabar Limestone thickens to a fine calcarenite facies that weathers characteristically pale rusty brown, carries scattered macrofossils and attains 12 feet in thickness at a reference section in a roadcut 3 miles south of Mapleton (ctr E line NE SE sec 9, T24S, R23E) where the middle part is shaly. The resemblance of this fine calcarenite facies of the Sniabar Limestone to the shelf facies of the Critzer Limestone farther north apparently led to miscorrelation of these units in this area by Jewett (1932; see also Moore, 1936, p. 79-80).

Farther southward across central western Bourbon County, the Sniabar Limestone Member grades into a phylloid-algal-rich facies, which attains about 20 feet of spar-rich algal moundrock (in the sense of Heckel and Cocke, 1969) in the well exposed reference section in the Kansas Rte 3 roadcut south of Uniontown (Fig. 4). This facies was named Schubert Creek limestone from a locality 4 miles west of Uniontown by Jewett (1932), who thought that it lay beneath the horizon of the more northern facies of the Sniabar, which he apparently had misidentified as Critzer (see Jewett, 1932, p. 103). The base of the Sniabar Limestone around Uniontown (and at places northeastward toward the Mapleton northwest roadcut) consists of 1 to 2 feet of skeletal to oolitic calcarenite that locally is cross-bedded and represents a shoal-water facies developed early during the deposition of the Sniabar. Taken in conjunction with the underlying regressive prodeltaic gray shale wedge of the upper unit of the Mound City, this basal Sniabar calcarenite suggests that the beginning of Sniabar deposition in this region resulted from a minor transgression that stymied the local upper Mound City delta and interrupted the general regression represented by the Sniabar in the north. It is not yet known if this minor sea-level rise (Fig. 3) is detectable in lower Sniabar strata higher on the shelf toward the north.

West of Uniontown, the Sniabar Limestone Member maintains its thickness to a reference section in an old quarry above the Marmaton River bridge (SE-NE NE sec 12, T26S, R21E) northeast of Bourbon County Lake, but the phylloid algal facies disappears into sparsely skeletal calcilutite to fine calcarenite, which appears also in a thick exposure not far above the basal black Mound City shale bed in a creek bank (along N line NE-NW sec 30, T24S, R22E) 7 miles northwest of Uniontown and 3 miles northeast of Bronson. This latter thick Sniabar exposure, in conjunction with the westward-thickening Critzer Limestone at Bourbon County State Lake 10 miles to the south, provide small outcrop views of part of the thick lower Missourian limestone sequence that characterizes the subsurface west of Bourbon County (J.A. French, in prep.).

Southwest of Uniontown, the Sniabar Limestone Member grades into a brachiopod-rich skeletal calcilutite with distinctive large tan chert nodules. This facies appears in a reference section above Prong Creek (NE cor sec 17, T27S, R22E) and marks the slumped Sniabar escarpment into northeastern Neosho County, where 10 feet are exposed in a quarry (in NE-SE-SE sec 10, T27S, R21E) 1 mile southwest of Porterville. Southwest of a roadbed exposure of very fossiliferous Sniabar two miles due east of Kimball (south of NW cor sec 33, T27S, R21E), definite exposures are unknown in the area of low relief across the Neosho River valley to the new Hertha type section 6 miles south of Erie, where the Sniabar is only 0.5 foot thick. This is the area where the next higher limestone, now known to be the Bethany Falls, had been misidentified as the Sniabar when traced by earlier workers from the north (Fig. 4). South of the new Hertha type section, the Sniabar Limestone seems lenticular, but may be the thin bed of dense skeletal calcilutite that appears near the middle of the Tacket dark shale succession (Middle Tacket Limestone Member), and which has been readily misidentified as the Checkerboard Limestone around Tacket Mound in northwest-central Labette County.

Elm Branch Shale

The Elm Branch Shale overlies the Hertha Limestone (Sniabar Limestone Member) and underlies the Swope Limestone (Middle Creek Limestone Member) in Kansas (Fig. 2). The name Elm Branch was first mentioned by Jewett (1932) as a term to be proposed by N.D. Newell to include strata between the Sniabar Limestone below and the Middle Creek Limestone above. The publication of Newell's work in 1935, however, shows the unit between the Sniabar and Middle Creek limestones as Ladore Shale, a name applied by Adams (1904) to the shale between the Hertha Limestone below and Mound Valley Limestone above, in southern Neosho County. The discarding of the name Elm Branch occurred apparently as a result of the correlation of the Mound Valley Limestone with the Bethany Falls Limestone (the top member of the Swope Limestone), and in spite of the recognition that type Ladore Shale then would include, at its top, shale equivalent to the two lower members (Hushpuckney Shale and Middle Creek Limestone) of the overlying Swope Limestone to north (Moore, 1936, p. 82-83). However, the recent discovery that the Bethany Falls Limestone was miscorrelated with the Mound Valley Limestone in northeastern Neosho County (Fig. 4) and that it actually correlates with the original type Hertha Limestone as explained in a previous section, places the type Ladore Shale above the Bethany Falls (and thus above the Swope). Therefore the strata below the Swope Limestone between the Sniabar and Middle Creek Limestones do not correlate with any part of the type Ladore Shale. Because the Ladore Shale is a well delineated unit in its type region throughout Neosho and Labette counties, Newell's original term Elm Branch Shale is still valid for the strata known incorrectly as Ladore from northeastern Neosho County, Kansas, to Iowa and Nebraska.

The name Elm Branch Shale was derived by Newell (personal communication via telephone, 1987) from a small stream that flows through the hamlet of Block, about 7 miles east of Osawatomie in Miami County. The closest section of this unit to Elm Branch that Newell (1935, p. 26) mentioned (ctr S line sec 18, T18S, R24E) was indicated in his measured section (1935, p. 144-145, #152) to be 12 feet thick but poorly exposed, and it is now entirely covered. A steep roadcut just to the south (along E side of road, ctr E line NE sec 19, T18S, R24E) exposes well only 5 feet, about the top one half of the Elm Branch Shale below the Middle Creek Limestone. Newell (1935, p. 26) mentioned a "typical section" of "Ladore" at the west edge of NE sec 10, T19S, R23E, 1 mile southwest of Fontana and 5 miles southwest of Elm Branch. In 1990, J.A. French and I readily exposed a complete section of Elm Branch Shale across the road along center E line W« sec 10, T19S, R23E, which is herein designated as its principal reference section.

The Elm Branch Shale at its principal reference section southwest of Fontana is 9 feet of gray shale, with rusty nodules in the lower part and a 0.5-foot bed of barren argillaceous limestone nearly 3 feet below the top. Both lower and upper boundaries of the Elm Branch are abrupt contacts of shalewith underlying and overlying limestone. The unit ranges from 1 to 12 feet thick in Miami County, and is locally sandy with plant impressions (Miller, 1966). Southward in Linn and the adjacent part of Bourbon County, the Elm Branch Shale ranges from 5 to 13 feet thick (Seevers, 1969) and carries several thin beds of argillaceous limestone and locally abundant marine fossils. Well exposed reference sections in this region include a roadcut just north of Rte K-135, 5 miles west of LaCygne (near ctr E line SW sec 34, T19S, R23E); the southern US 69 roadcut south of Pleasanton (SE cor sec 24, T22S, R24E), where it contains abundant derbyiid and chonetid brachiopods; the Rte K-52 roadcut southwest of Mound City (near ctr SW sec 23, T22S, R23E), where one of the argillaceous limestone beds above the derbyiid-chonetid-bearing shale yielded a clump of linoproductid brachiopods with a remarkable small crinoid fauna described by Strimple and Heckel (1978); and the Xenia northwest roadcut (near ctr S line SE sec 20, T23S, R22E) in northwesternmost Bourbon County. The fossiliferous shales and thin limestones are largely shallow marine facies probably associated with the early stages of the Swope transgression in view of the exposure surface on top of the underlying Sniabar Limestone. Southward across western Bourbon and into Neosho County, the Elm Branch Shale is poorly exposed, and its interval between the top of the Sniabar and base of the Middle Creek is very thin in places, as exemplified by the Rte K-3 roadcut south of Uniontown where the Elm Branch is 1 foot of gray blocky mudstone above the massive Sniabar phylloid algal mound (E side of road near ctr E line SE-NW sec 34, T25S, R22E). Above the mudstone at this roadcut are several 1- to 2-foot beds of algal calcilutite, which lithologically could be included in the overlying Middle Creek Limestone, but probably represent a southward facies transition of the marine shale and thin limestone beds in the Elm Branch farther north.

South of the thinning of both the Sniabar Limestone Member and the underlying upper gray shale unit of the Mound City Shale Member of the Hertha Limestone, the Elm Branch Shale thickens to at least 40 feet of partly exposed gray shale, with 3 feet of gray brachiopod-bearing sandstone in the middle (Fig. 4) at the Page's pasture locality (NW SE-NW sec 6, T28S, R21E), a little over 1 mile south of Kimball in northeastern Neosho County. A more accessible reference section of this sandstone is exposed along the road running south from Kimball about 0.5 mile to the southwest (along ctr W line SW sec 6, T28S, R21E). Farther southward, the Elm Branch merges with several feet of dark gray shale containing limestone nodules in the middle of the Tacket Formation in southern Neosho and Labette Counties. The thickened sequence of Elm Branch Shale near Kimball is probably a prodeltaic lobe of easterly source, filling in around the south ends of the upper Mound City prodeltaic gray shale unit and of the overlying Sniabar algal mound; it was probably deposited during the sea-level lowstand at the end of the Sniabar regression.

Northward from Kansas, throughout most of Missouri, Iowa and Nebraska, the Elm Branch Shale generally ranges from 0.5 to 6 feet of gray shale, often with blocky mudstone in the base and marine fossils in the top. The mudstone probably represents a paleosol developed on top of the Sniabar Limestone during withdrawal of the sea to southeastern Kansas, and the overlying marine shale, as in Kansas, probably is an early shallow-water facies of the Swope transgression. Two thicker successions of Elm Branch Shale that contain sandstone, one up to 30 feet thick in west-central Missouri, and the other up to 20 feet thick with impure limestone as well in south-central Iowa (Fig. 6), probably represent local deltas with easterly sources that were formed either during the Sniabar regression or during a pause in the Swope (Middle Creek) transgression. It is noteworthy that in their description of the Middle River traverse at Winterset, Iowa, Condra and Upp (1933) correctly identified the 14 feet of prodeltaic deposits between the Sniabar and Middle Creek limestones as Elm Branch Shale at a time just after Newell had suggested the name verbally, but before the name Ladore was incorrectly extended north of Neosho County, Kansas, in 1935. In Nebraska, the Elm Branch Shale for some time has been misidentified as the higher Galesburg Shale.

Swope Limestone

The Swope Limestone overlies the Elm Branch Shale, and it underlies the Galesburg Shale in east-central Kansas and the Ladore Shale in southeastern Kansas (Fig. 2). The term Swope Limestone was first used by Moore (1932), and it was stabilized by Newell (1935) to comprise 3 members in ascending order: Middle Creek Limestone, Hushpuckney Shale, and Bethany Falls Limestone. Moore (1936) noted that these members constitute an excellent example of the typical cyclothem of the Missouri Series, now regarded as the marine part of the basic Kansas or northern Midcontinent cyclothem, a stratigraphic sequence that consists of a thin "middle" (transgressive) limestone, a thin "core" (offshore) shale, and a thick "upper" (regressive) limestone (Heckel, 1977, 1986), and which represents a major eustatic transgression and regression of the sea across the Midcontinent shelf. The type section of the Swope Limestone is near Swope Park in Kansas City, Missouri, and the formation has long been recognized as currently constituted from Bourbon County, Kansas, northward through Missouri to the northern limit of outcrop in Iowa and Nebraska (Fig. 6). In Nebraska, however, the Swope has been misidentified as the higher Dennis Limestone, as will be explained under discussion of the individual members. South of Bourbon County, Kansas, all three members of the Swope can be traced to the region of Kimball in northeastern Neosho County. Southward, the Swope merges with the top of the Tacket Formation as the Middle Creek Limestone disappears, the Hushpuckney becomes the black shale in the Upper Tacket Shale Member (Fig. 4), and the Bethany Falls becomes the bed regarded by Moore (1936) as type Hertha (see previous section), which herein is redefined as the top of the revised Tacket Formation (see previous section).

Complete sections of the Swope Limestone exposing all three members in eastern Kansas include the third US 69 roadcut north of LaCygne Junction (ctr E line NW sec 31, T19S, R25E) in northern Linn County, the Ks Rte 52 roadcut 3 miles southwest of Mound City (near ctr SW sec 23, T22S, R23E) in southern Linn County, and the Xenia northwest roadcut (ctr S line SE sec 20, T23S, R22E), 2 miles northwest of Xenia in northwestern Bourbon County, which is regarded as the principal reference section for the entire formation in Kansas.

<u>Middle Creek Limestone Member</u>.--Forming the base of the Swope Limestone, the Middle Creek Limestone Member overlies the Elm Branch Shale and underlies the Hushpuckney Shale Member (Fig. 2). First introduced by Jewett (1932) as a term to be proposed by N.D. Newell, the Middle Creek Limestone was named for exposures east of Middle Creek, with a type section on the highway 3 miles east of LaCygne (W of SE cor sec 36, T19S, R24E) in Linn County, Kansas (Newell, 1935, p. 26, 148). This is well enough exposed today that Moore's (1936) designation of a type locality 8 miles northward on Middle Creek (SW sec 22, T18S, R24E) is considered superfluous. Throughout its type region in Linn and Miami counties, the Middle Creek is about 2 feet of dense bluish limestone, a typical transgressive limestone with sharp

contacts with both underlying and overlying shales. Reference sections include the principal reference section of the Elm Branch Shale southwest of Fontana (ctr E line W« sec 10, T19S, R23E), the third US 69 roadcut north of LaCygne Junction, and the southern U.S. 69 roadcut south of Pleasanton (SE cor sec 24, T22S, R24E). The Middle Creek is a skeletal calcilutite with a diverse and abundant fauna of marine invertebrates, which are difficult to collect because of the hardness of the rock.

Northward, the Middle Creek Limestone is a remarkably persistent unit throughout Missouri to Iowa and Nebraska, where it gradually thins to 1 foot or less of similar-appearing limestone. In Nebraska it has been misidentified as the Canville Limestone Member of the higher Dennis Limestone, even though the Canville pinches out northward south of Kansas City and rarely appears as more than a thin layer of shells or lenses of limestone at the base of the Dennis north of Kansas City.

Southward, the Middle Creek Limestone thickens to 4 to 5 feet in western Bourbon County, where it contains more conspicuous phylloid algae in the skeletal calcilutite. This is seen in reference sections at the Xenia northwest roadcut and along Kansas Hwy 3 just south of the main Uniontown roadcut (E line NE SW sec 34, T25S, R22E), where it may reach 14 feet in thickness if it were to include the 1- to 2-foot ledges of conspicuously algal calcilutite that appear to be a facies of the marine shale northward in the underlying Elm Branch Shale. South of Uniontown, the Middle Creek Limestone apparently thins to 1 foot or less, as it is not well exposed; but it can be seen below the Hushpuckney Shale in the floor of the east end of the quarry north of Hinton Creek (SE SW SW sec 19, T26S, R22E); and also in the roadditch just south of ctr E line sec 8, T27S, R22E, west of Prong Creek; along the road along S line SE-SE sec 11, T27S, R21E; piled as slabs around a pond in NW-NW-SW-of the same section southwest of Porterville; and in the field just north of the road west of ctr S line sec 29, T27S, R21E, 1.5 miles east of Kimball. In these latter four localities the overlying Hushpuckney Shale is not exposed, but the Middle Creek is recognized by its denser darker appearance than either the lower Sniabar or higher Bethany Falls limestones, which are exposed at places nearby in this area of low relief. The southernmost exposure of Middle Creek Limestone known is a thin lens of dark limestone collected about 20 feet above the sandstone in the Elm Branch Shale and below phosphatic Hushpuckney Shale at the Page's pasture locality (NW-SE NW sec 6, T28S, R21E) 1.3 miles south of Kimball. Southward it disappears into dark shale in the upper middle of the Tacket Formation (Fig. 4).

The Middle Creek Limestone represents quiet water deposition below effective wave base during a major transgression of the sea over the deltaic, other shallow-marine, and terrestrial deposits of the Elm Branch Shale from southern Kansas to beyond the Iowa-Nebraska outcrop belt.

<u>Hushpuckney Shale Member</u>.--The Hushpuckney Shale is the middle member of the Swope Limestone, overlying the Middle Creek and underlying the Bethany Falls Limestone Members

(Fig. 2). First introduced by Jewett (1932) as a term to be proposed by N.D. Newell, the Hushpuckney Shale was named for Hushpuckney Creek in south-central Miami County and was noted as "typically shown" in a railroad cut near ctr N line sec 13, T19S, R23E, 2 miles southeast of Fontana (Newell, 1935, p. 27). It is more recently better exposed about 1 mile southwest of Fontana and 1 mile east of Hushpuckney Creek in the roadcut along ctr E line W« sec 10, T19S, R23E, the site of the principal reference section of the Elm Branch Shale, and this roadcut is now designated as the principal reference section of the Hushpuckney Shale as well. Throughout Miami and Linn Counties, the Hushpuckney Shale is 4 to 5 feet thick with sharp contacts with the underlying and overlying limestones. The lower one-half to two thirds of the Hushpuckney is the distinctive fissile black shale facies with lighter-colored phosphorite nodules and laminae, and the upper part is gray shale with sparse macrofossils. A thin layer of gray shale is present locally at the base. Well exposed reference sections include the third US 69 roadcut north of LaCygne Junction, and the southern US 69 roadcut south of Pleasanton, where it occurs with the Middle Creek Limestone in NE cor sec 25, T22S, R24E.

Northward, the Hushpuckney Shale Member is traced through Missouri, Iowa and Nebraska, averaging about 3 feet thick and consisting largely of the black facies in the lower part. In Nebraska it has been misidentified as the higher Stark Shale Member of the Dennis Limestone, which it closely resembles in field appearance.

Southward in Bourbon County, Kansas, the Hushpuckney Shale Member is not as well exposed, but it thins to 2 feet at the Swope reference section in the Xenia northwest roadcut and to 1.5 feet in the exposure at the east end of the Hinton Creek quarry (SE SW SW sec 19, T26S, R22E). Farther southward, it is not often exposed in the thin interval between the Middle Creek and Bethany Falls Limestone Members (apparently on the southward slope of thinning underlying units), until it thickens again to about 4 feet at the Page's pasture locality 1.3 miles south of Kimball. South of there it merges with the upper Shale Member of the Tacket Formation (Fig. 4), which contains 3 to 5 feet of black fissile phosphatic shale that is apparently continuous with the same facies of the Hushpuckney Shale.

The black facies of the Hushpuckney Shale Member carries an abundant conodont fauna that contains the first appearance of several distinctive species, including *Idiognathodus cancellosus*, *Gondolella denuda*, and *G. sublanceolata*. This fauna was described by Pavlicek (1986) from the Upper Tacket black shale and is the same as both that reported by Ellison (1941) from the Hushpuckney in the Kansas City area, and that collected by J.W. Swade from the Hushpuckney near Pammel Park in Madison County, Iowa. This distinctive fauna caused me to reinvestigate the Kimball-Stark region in northeastern Neosho County, where it turned out that a long-standing miscorrelation of two overlying limestones had been made in the 1930s. Correction of this miscorrelation now allows the Hushpuckney Shale to be traced southward in the top of the Tacket Formation past Tulsa, Oklahoma, and, ascending above southward-thickening sandstones (Fig. 5), through east-central Oklahoma to the vicinity of Sasakwa in southeastern Seminole County just north of the Canadian River (e.g., creek bank, W« NW-NW-NW sec 9, T5N, R7E).

Throughout its entire extent from Iowa to Oklahoma, the Hushpuckney Shale represents deep-water deposition during maximum marine inundation (Fig. 3) when both shelf and basin lay beneath a thermocline that allowed deposition of the black phosphatic facies over an immense area.

Bethany Falls Limestone Member.--The Bethany Falls Limestone overlies the Hushpuckney Shale Member, and underlies the Galesburg Shale in east-central Kansas, the Ladore Shale in southeastern Kansas (Fig. 2) and locally the Mound Valley Limestone in Bourbon County. This venerable unit was named by Broadhead (1865) from exposures at the falls in Big Creek near Bethany in Harrison County, Missouri (Newell, 1935) and was classified as the upper member of the Swope Limestone when that formation was erected. The Bethany Falls Limestone Member in eastern Kansas from Bourbon County northward generally ranges from about 15 to 35 feet thick and consists of two major lithofacies.

The lower Bethany Falls lithofacies is 10 to 25 feet of relatively massive skeletal calcilutite that becomes medium-bedded with gray shale layers toward the base. The lower contact is the base of the lowest limestone bed above the underlying Hushpuckney Shale. In the upper part of this lower unit (near the middle of the entire member), a distinctive diagenetic color mottling (Mossler, 1973) of darker patches of microspar within a lighter micritic background locally weathers to dark nodules in a crumbly light matrix. This mottled calcilutite becomes particularly conspicuous southward in Linn and Bourbon counties and renders the Bethany Falls the most readily identified unit in the Bronson escarpment, where it is often exposed in both roadcuts and quarries.

The upper Bethany Falls lithofacies is oolitic (typically oomoldic) and ranges from a few feet of oolitic calcilutite in the northern counties to up to 16 feet of cross-bedded oolitic calcarenite in western Bourbon County. The contact with the underlying calcilutite is sharp beneath the calcarenite but diffuse beneath the oolitic calcilutite. Laminar and nodular caliche illustrated by Heckel (1983) appears at the top in the fourth US 69 roadcut north of LaCygne junction (W line NW-NW-NE sec 31, T19S, R25E), and similar laminar caliche occurs at the top 11 miles to the southwest in a quarry north of Farlinville (NE-SE-SE sec 34, T20S, R23E) where vertical shale-filled pipes penetrate the underlying oolite (French et al., 1989). This general shallowing-upward vertical sequence shows that the Bethany Falls Limestone is a typical regressive limestone that attained subaerial exposure accompanied by meteoric leaching from Bourbon County northward.

The most accessible complete exposure of the Bethany Falls Limestone Member in Kansas is the Xenia northwest roadcut in northwestern Bourbon County, which is considered the principal reference section for this unit as well as for the entire Swope Limestone in the state. Other complete or otherwise distinctive reference sections of the Bethany Falls include the third

US 69 roadcut north of LaCygne Junction, the Kansas Rte 52 roadcut southwest of Mound City, the Schubert Creek quarry and adjacent roadcut (NW NE sec 24, T25S, R21E) showing the leached oolite facies 4 miles west of Uniontown, and the quarry west of Berlin (SE-SW-SW sec 30, T24S, R23E) and the Hinton Creek quarry (SW-SW sec 19, T26S, R22E) showing the weathered mottled calcilutite facies 5 miles northeast and 7 miles southwest of Uniontown, respectively.

From Kansas City northward, the Bethany Falls Limestone Member ranges from 15 to 25 feet thick in Missouri and from 23 to 30 feet thick in Iowa and Nebraska. The lower to middle part is skeletal calcilutite that locally displays similar color mottling, which is particularly conspicuous in the Kansas City region. The middle to upper part is oolite to skeletal calcarenite up to several feet thick in Missouri. About the upper one third in Missouri and Iowa is a distinctive, essentially barren, locally laminated calcilutite that is typically heavily penetrated by shale-filled fractures and pockets, which are considered to be "cryptokarst" formed by fresh-water dissolution along rooted and cracked zones during subaerial exposure. The upper contact of the Bethany Falls Limestone with the overlying Galesburg Shale is relatively sharp over the oolitic facies in eastern Kansas, but is diffuse above the cryptokarsted calcilutite around Kansas City and northward, where the fractured limestone becomes nodular upward into the overlying shale.

In Nebraska, the Bethany Falls Limestone Member has been misidentified as the Winterset Limestone, the upper member of the higher Dennis Limestone, perhaps because the Bethany Falls is the thickest limestone in the lower Missourian there, whereas the Winterset is the thickest limestone in this part of the sequence from Kansas City southward. However, lithic tracing of both Winterset and Bethany Falls limestones through cores in northwestern Missouri and southwestern Iowa shows that the Bethany Falls thickens and the Winterset thins from Kansas City northward to the Platte River valley of Nebraska. This recorrelation is strongly confirmed by the unique Midcontinent occurrence of the fusulinid *Eowaeringella* (formerly *Wedekindellina*) *ultimata* only in the Bethany Falls Limestone, based on collections from the Kansas City area of Kansas and Missouri, and the Winterset area of Iowa reported by Thompson (1957), and on collections from the thickest limestone in western Iowa and Nebraska cores (IBC, ISC, IJC, NOC on Fig. 6) and Platte River valley outcrops (Richfield PWA Quarry) reported by Heckel and Meacham (1981). Stewart (1968) noted that *Eowaeringella ultimata* forms a nearly continent-wide marker biozone in the lower Missourian below the biozone of Triticites, which first appears in the Midcontinent in the higher Winterset Limestone.

Southwestward from Bourbon County, Kansas, the Bethany Falls Limestone Member thins but retains its characteristic mottling at several exposures in northeastern Neosho County to an exposure at least 8 feet thick in a roadbed (along S line at SE cor sec 20, T27S, R21E) about 1 mile southeast of Stark. About 1 mile southwestward, the Bethany Falls appears along N line NW NE NW sec 32 as several slumped feet of flaggy, sparsely fossiliferous (brachiopods) calcilutite with some vague mottling, several feet above the level of the Middle Creek Limestone Member just a short distance to the east. This flaggy bed, which may be a slope facies of the

Bethany Falls above southward-thinning lower units, is traceable southwestward through the abandoned farm in E« SW NW sec 32 to the roadditch along ctr E line SE sec 31, T27S, R21E, and into the Page's pasture section (Fig. 4) in ctr N« NW sec 6, T28S, R21E, where it lies 25 ft below the Mound Valley Limestone (a reinstated name--see later section). The Mound Valley Limestone had been mapped from here southward as Bethany Falls (Swope) Limestone by earlier workers, as illustrated in Jungmann (1966) who drew the Swope outcrop trace from the farmyard in E SW NW sec 32, T27S, R21E, some 20 or 30 feet upslope to the escarpment at ctr E line sec 31, which is held up by the Mound Valley and overlying Dennis Limestones.

Southwestward from the Page's pasture locality (where it overlies phosphatic Hushpuckney Shale and lenticular Middle Creek Limestone in the hill in NW SE NW sec 6), the Bethany Falls Limestone Member is readily traced as the brachiopod-bearing skeletal calcilutite that had been mapped by previous workers as Hertha Limestone through its type area in southern Neosho County, and throughout Labette County, where it forms the top member of the Tacket Formation as redefined at Tacket Mound. The Bethany Falls Limestone throughout this area is probably a more basinal facies, and it averages about 5 feet in thickness in Neosho County thinning to 4 feet and less in Labette County, where it contains thin skeletal calcarenite at the top at Tacket Mound. Phylloid algae become abundant locally in the Bethany Falls in southern Neosho County, as seen in the Kansas Rte 57 roadcut (along S line SE SE SE sec 17, T29S, R20) 3 miles west of St. Paul and in the quarry at South Mound (NW-NE sec 16, T30S, R20E) where it forms algal moundrock about 30 feet thick; this may be another outcrop hint of the thick mass of lower Missourian limestone in the subsurface to the northwest. The Bethany Falls Limestone thins further, southward into Oklahoma, where it is detected in the three northernmost cores as an argillaceous skeletal calcilutite 1 foot thick and less. In the area west of Nowata, outcrops in SE SW SW sec 28, T26N, R15E, and near ctr W line NW sec 8, T25N, R15E may represent the southernmost exposures of this unit.

Ladore Shale

The Ladore Shale overlies the Bethany Falls Limestone Member of the Swope and Tacket formations and underlies the Mound Valley Limestone in southern Kansas (Fig. 2). It was named by Adams (1904), and the unit to which the name applies was stabilized by Moore (1936), who indicated a type locality at the former town of Ladore in sec 27, T30S, R19E, in southern Neosho County. Moore (1936) noted that the town is built on Hertha Limestone, that the Swope Limestone scarp crosses the northwest corner of sec. 27, and that the type Ladore is the thick shale between the two limestones. Because what Moore then regarded as Hertha there is now known to be Bethany Falls (upper Swope Limestone) and what he regarded as Swope there is now known to be validly called Mound Valley Limestone as it was originally named (see next section), and because the type Ladore Shale is a well delineated unit that has been mapped correctly throughout its type region from central Neosho to western Labette Counties, the name Ladore is retained for the strata to which it was applied in the type region, but with recorrelated bounding units. Thus the strata to which the name Ladore had been erroneously applied north of Neosho County, between the top of the Hertha Limestone and the base of the Swope Limestone, are herein termed Elm Branch Shale, a reinstated name, as explained in a previous section.

Nowhere in its type area is the Ladore Shale completely exposed, but a partial exposure of about the upper two thirds in the spillway of Parsons Lake (NW NW NE sec 33, T30S, R19E), about 1 mile southwest of the originally designated type section, is considered the principal reference section. Here the well exposed 20-foot sequence in the middle of the formation consists largely of gray shale with thin sandstone beds, zones of fossils (mainly clams and plant debris), and a coal bed. The entire Ladore averages perhaps 60 feet in thickness in its type area of southern Neosho County. Where seen, its boundaries are sharp with overlying and underlying limestone units. The Ladore Shale is partly exposed northward along US 59 north of Erie (W line SW–SW–NW sec 20, T28S, R20E), as it thins northward (Fig. 4) to about 25 feet of more uniform gray shale above the flaggy facies of the Bethany Falls at the Page's pasture locality (NE-NW-NW sec 6, T28S, R21E) south of Kimball (confirmed in the core taken just north of Kimball near ctr E line SE sec 25, T27S R20E). Farther northward the Ladore thins further above the familiar mottled shelf facies of the Bethany Falls Limestone, where it is traceable only as a covered interval, perhaps 10 to 15 feet thick, from east of Kimball and Stark northeastward to the Bourbon County line. The Ladore Shale appears to pinch out in western to central Bourbon County where the overlying Mound Valley Limestone rests directly on the Bethany Falls, but it would also merge with the base of the higher Galesburg Shale any place where the Mound Valley Limestone pinches out into shale.

Southward, the Ladore Shale is about 60 feet thick in west-central Labette County, where a fair exposure on the western slope of Tacket Mound (S« NW-SW sec 7, T32S, R19E) and a good exposure of the top 22 feet in the east slope of Dixon Mound just northwest of Mound Valley (ctr S line SE sec 27, T32S, R18E) provide reference sections. In this area, the Ladore contains marine fossiliferous zones, thin coaly deposits near the top and in the lower middle, and local sandstone near the top. The Ladore Shale is poorly exposed southwest of Mound Valley, and is mostly covered by alluvium in the Verdigris River valley at Coffeyville. Southward it is 60 feet of mostly sandstone overlying about 10 feet of fossiliferous shale in the South Coffeyville core (OSC) in northern Oklahoma (Fig. 5). South of there, it merges with the lower middle of the thick sequence of Coffeyville Formation deltaic clastics in places where the overlying Mound Valley Limestone is not found.

The Ladore Shale is a good example of a deltaic unit, with a probable southern source (Nimmer, 1992), which prograded rapidly near the end of the Bethany Falls regression (Fig. 3). It grades northward in Neosho County into prodeltaic shale, which filled in the basinal area south of the Bethany Falls slope facies then lapped out northward over the higher shelf area.

Mound Valley Limestone

The Mound Valley Limestone overlies the Ladore Shale and underlies the Galesburg Shale in southern Kansas (Fig. 2). The name Mound Valley was applied by Adams (1896) to the limestone capping the row of hills northwest of Mound Valley in Labette County, but it was later discarded because that limestone was thought to correlate with the Bethany Falls Limestone, which was named in 1865 and therefore had priority (Moore, 1936, p. 86). However, recent field work around Kimball and Stark in northeastern Neosho County shows that the Mound Valley Limestone extends northward some distance above the typical Bethany Falls, which now is traced southward into the limestone that had been regarded as type Hertha since the work of Moore (1936). Therefore the name Mound Valley is still valid and is herein reinstated for the unit to which it was originally applied, the limestone above the Ladore Shale and below the Galesburg Shale, also known as the middle limestone of the "triple system" of Erie among older workers. It is ironic that Haworth and Bennett (1908) had regarded the name Mound Valley as valid, stating that their field study showed that the lower limestone of the "triple system" is the same as the Bethany Falls at Kansas City, because this correlation, which was discounted by later workers, is now shown to be correct.

Although no specific type section was indicated for the Mound Valley Limestone, there is no doubt as to which unit the name was applied, and an exposure of the lower 5 feet at the top of Dixon Mound along the road near ctr S line SE sec 27, T32S, R18E, about 1 mile northwest of Mound Valley, is herein designated as the stratotype. In its type area of northwestern Labette County, the Mound Valley is easily traceable as 6 to 8 feet of medium-bedded to nearly massive skeletal calcilutite, locally dolomitic, locally cherty, and locally with phylloid algae, especially toward the north. Other reference sections include an exposure southwest of the bend in the Mound Valley-Dennis road (SW cor sec 11, T32S, R18E), the roadcut east of Big Hill Dam (S line SE SW SE sec 8, T32S, R18E), and formerly the now water-filled quarry just south of the dam (N« SE-NE sec 18), where good fresh exposures of both overlying and underlying shales, in abrupt contact with the limestone, in 1982 yielded conodont faunas inconsistent with that of the Hushpuckney Shale, which was puzzling until the work of Pavlicek (1986) led to discovery of the miscorrelation.

Northward, the Mound Valley Limestone thickens substantially to 30 feet as a phylloid-algal mound complex, consisting largely of sparry algal calcilutite where it is well exposed in a roadcut (SW, NW, NE sec 33, T30S, R19E) south of the Parsons Lake outlet in southern Neosho County. Farther northward, it thins to about 10 feet largely of algal calcilutite along US 59 (W line NW cor sec 30, T29S, R20) and in a roadcut just west of U.S. 59 (NW cor sec 7) where there is a 1-foot shale in the middle, both south of Erie. It is 8 feet thick in a well exposed cut on both sides of US 59 (W line NW NW sec 20, T28S, R20E) north of Erie, where it consists of 2 feet of brachiopod-bearing calcilutite overlain by 4 feet of algal calcilutite and capped by 2 feet of somewhat mottled calcilutite (which undoubtedly lent credence to its former correlation with the Bethany Falls Limestone), and where it displays both contacts with underlying and overlying sandy shale and sandstone.

North of here, the mottled zone disappears, but 1 to 2 feet of oolite appears at the top of the Mound Valley Limestone above 7 feet of skeletal to algal calcilutite with 1 foot of dolomitized brachiopod-bearing calcilutite at the base, exposed in a waterline excavation (October, 1986) at the crest of the hill (along S line SW-SE-SE sec 9, T28S, R20E) west of Fourmile Creek. This capping oolite appears lenticular, but is observed in several places from southwest of Kimball to west of Stark, including ledges in the field in ctr S« NW sec 1, T28S, R20E; and in the bed of Canville Creek at the U.S. 59 bridge (NE cor sec 22, T27S, R20E) where it has long been misidentified as Bethany Falls Limestone. The algal calcilutite facies also may be lenticular because it is present below the oolite in the ledges in the field mentioned above, but apparently is absent just to the northeast along the road south of Kimball (ctr E line NE-NE sec 1, T28S, R20E) where only the basal rusty-weathering dolomitic brachiopod calcilutite is exposed. It reappears 5 feet thick, lying upon the brachiopod calcilutite just to the east at Page's pasture (along ctr N line NW sec 6, T28S, R21E) about 25 feet above the flaggy facies of the Bethany Falls Limestone (Fig. 4).

From here, the Mound Valley Limestone along with the higher Dennis Limestone, visible in places as two separate (although slumped) ledges, form the escarpment extending northeastward toward ctr E line sec 31, T27S, R21E, where the escarpment curves to the north-northwest and the two ledges separate. Northward, the Mound Valley is exposed as algal calcilutite overlying rusty-weathering brachiopod calcilutite in the ditch along N line NE NW NE NE sec 31, and the Dennis is exposed 0.2 mile westward and about 18 feet higher along N line NW-NE-NW-NE sec 31. This confirms the long-standing miscorrelation of Mound Valley Limestone in the nose of the escarpment at ctr E line sec 31 with the Bethany Falls Limestone exposed at least 20 feet lower about 0.2 mile to the northeast in the old farmyard in ctr E« SW-NW sec 32, T27S, R21E. The Mound Valley can be traced northeastward through exposures of rusty brachiopod calcilutite at the gate near ctr E line SE sec 30 and in the lane in NW-SW-NW sec 29, to algal and skeletal calcilutite and calcarenite in the field near ctr E line NE-NE sec 20 and peloidal calcarenite along the road near ctr S line SW-SW sec 16, to oolitic skeletal calcarenite along the road at ctr W line SW sec 10, to limestone in the ditch at ctr E line SE sec 3 on the Bourbon County line, all in T27S, R21E. All these exposures are sufficiently higher than nearby exposures of mottled Bethany Falls as well as below nearby exposures of both Galesburg sandstone and Dennis Limestone to show definitely the outcrop traces of 3 separate limestone beds above the Hertha Limestone in northeasternmost Neosho County.

Northeast of here, the oolitic Mound Valley Limestone is difficult to separate from the oolite at the top of the Bethany Falls Limestone in the rangeland of western Bourbon County where there are fewer roads to provide critical exposures. An exposure northeast of Elsmore in eastern Allen County (roadditch along ctr N line NE sec 4, T26S, R21E) shows 5 feet of well preserved oolite (unlike the typical oomoldic oolite that caps the Bethany Falls) above a 6-foot covered interval above mottled Bethany Falls calcilutite. Four miles to the northeast, a similar 5-foot unit of well-preserved oolite overlies 16 feet of oomoldic/sparry oolite at the top of the Bethany Falls in the Schubert Creek quarry (NE NW-NE sec 24, T25S, R21E) in western Bourbon County. Seven miles farther northeastward 0.2 foot of well-preserved oolite overlies typical Bethany Falls oolite just south of the south wall of the quarry 2 miles west of Berlin (SE-SW-SW sec 30, T24S, R23E), which apparently represents the featheredge of the Mound Valley Limestone in central Bourbon County. The Mound Valley Limestone is definitely absent at the Boulware Cemetery quarry in northwesternmost Bourbon County (SW NW sec 20, T23S, R22E), where Bethany Falls mottled calcilutite and oomoldic oolite is overlain by a completely exposed sequence of Galesburg Shale in which no marine horizon has been detected.

Southwestward from its type area, the Mound Valley Limestone thins through a good exposure along the road (S line SE-SW-SE sec 34, T32S, R17E) east of Big Hill Creek to about 3 feet of skeletal algal calcilutite exposed along the west side of US 169 just north of the railroad crossing northeast of Liberty (N« NE-SE sec 7, T33S, R17E) in Montgomery County. It is probably present low in the escarpment along the Verdigris River north of Coffeyville (e.g., just south of the Pumping Station in NE-SW-NW sec 26, T34S, R16E), and A. P. Bennison reports it in the creek in NE-NE sec 15, T35S, R16E, south of Coffeyville, as rusty argillaceous skeletal calcilutite.

In Oklahoma, the Mound Valley Limestone is detected as 3 feet of argillaceous limestone and shale in the South Coffeyville core (osc on Fig. 5) nearly 3 miles south of the Kansas border. Southward, A.P. Bennison believes that the exposures of "Layton stray limestone" in the thick Coffeyville sequence around Tulsa may be the Mound Valley. At Sapulpa in Creek County southwest of Tulsa, the conodont fauna associated with the thin limestone exposed at the middle level of the shale pit (N« SE sec 34 T18N, R11E) in the Coffeyville Formation strongly suggests that this horizon is the Mound Valley Limestone.

The Mound Valley Limestone represents a minor transgressive-regressive cycle of marine inundation that punctuated the general sea-level lowstand following the Bethany Falls-Ladore regression (Fig. 3). It was nearly confined to the basinal area of southeastern Kansas, and did not extend very far onto the northern shelf.

Galesburg Shale

The Galesburg Shale overlies the Swope Limestone in northern Kansas and the Mound Valley Limestone in southern Kansas. It underlies the Dennis Limestone throughout Kansas (Fig. 2) specifically the Canville Limestone Member from southeastern to east-central Kansas and the Stark Shale Member in the Kansas City region. The Galesburg Shale was named by Adams (1903) from Galesburg in southern Neosho County, where the unit makes the slope south of town in sec 5, T30S, R19E (Moore, 1936). In its type area, the name applies to the strata below the Dennis and above the limestone originally termed Mound Valley, which Moore

(1936) and succeeding authors believed to correlate with the Swope Limestone. Even though the Mound Valley Limestone is now known to be a valid unit above the Swope, the stratal content of what has been considered Galesburg Shale has not changed. Although some strata at the base of the Galesburg Shale north of the disappearance of the Mound Valley may be age-equivalent to the underlying Ladore Shale, these are most reasonably retained in the Galesburg (Fig. 2) because they cannot be separated from the main body of the thin Galesburg to the north.

In its type area, the Galesburg Shale is about 70 feet of gray sandy shale with scattered horizons of plant fossils, at least 1 coal, and beds of sandstone, particularly toward the top. Nowhere in its type area is the entire Galesburg well exposed, but the upper 10 to 20 feet of sandy shale and sandstone is locally partially exposed at the base of escarpments held up by the overlying Dennis Limestone. Where visible, the upper and lower contacts are sharp with the overlying and underlying limestones. The Galesburg thins northward through 40 feet of reported sandy shale with plant fossils along the road 2.5 miles east of Shaw (S line SW- SW sec 18, T28S, R20E) in central Neosho County (K.G.S. stratigraphy files), to 16 feet in a good reference exposure in a gully leading into Canville Creek on the south side of the U.S. 59 bridge (NE cor sec 22, T27S, R20E), where it consists largely of sandy shale to shaly sandstone with two sandstone beds up to 1 foot thick, above and below 2 thin coal beds in the middle. The Galesburg is 12 feet of partly exposed shaly sandstone in the pond spillway at Page's pasture (SW SE SW SW sec 31, T27S, R21E) about 4 miles to the southeast. A measure of the significant lateral variation and lenticularity of units within the Galesburg in this area is provided by the core taken just north of Kimball (near ctr E line SE sec 25, T27S, R20E), about halfway between these two localities, where the Galesburg is 50 feet thick, with 31 feet of sandstone but no coals in the middle.

Northward in Allen and Bourbon counties, the Galesburg Shale ranges from 2.5 feet of gray blocky mudstone in the road ditch northeast of Elsmore (N line NE-NW-NE sec 4, T26S, R21E) to over 20 feet of shale and sandstone in other localities reported in the K.G.S. stratigraphy files. A good reference section in the Boulware Cemetery Quarry (SW-SW-NW sec 20, T23S, R22E) in northwesternmost Bourbon county displays about 8 feet of Galesburg consisting of 6.5 feet of blocky mudstone with small carbonate nodules near the top, overlain by about 1 foot of sandy shale with plant fossils and coaly streaks, and capped by a thin layer of clayey shale.

Northward in Linn and Miami counties, the Galesburg Shale ranges from 2 to 12 feet mainly of gray blocky mudstone, with sandy zones in some of the thicker sections. Good reference sections include a quarry 1 mile west of the US 69 roadcuts south of Pleasanton (NW-NW sec 25, T22S, R24E) and a quarry off Ks Rte 7 north of Farlinville (NE-SE-SE sec 34, T20S, R23E) in Linn County and the US 69 roadcut by Jingo (S line SW corner SE sec 31, T18S, R25E) in Miami County. In the Kansas City area, a reference section at the north end of the cold storage plant quarries on Inland Drive along the Kansas River (about ctr N line NW-NE sec 27, T11S, R24E) in Wyandotte county shows about 1 to 2 feet of Galesburg overlain with sharp contact by black shale of the Stark Shale Member of the Dennis Limestone and underlain with a diffuse contact by shaly nodular limestone of the highly weathered top of the Bethany Falls Limestone.

Northward in Missouri, Iowa and Nebraska, the Galesburg Shale ranges from 1 to 9 feet of gray blocky mudstone. This is overlain by a coal, named Davis City coal bed by Schutter and Heckel (1985), in northern Missouri and southern Iowa, and is locally capped by fossiliferous shale. In Nebraska, the Galesburg has been misidentified as the higher Fontana Shale. A detailed study of the Galesburg by Schutter (1983) shows the blocky mudstone to be a well developed paleosol from east-central Kansas to the northern limit of outcrop. The capping fossiliferous shale in a few sections is the nearshore facies of the overlying Dennis transgression.

Southward from its type area, the Galesburg Shale in Labette County exceeds 70 feet in thickness reported in the KGS stratigraphy files from the valley of Big Hill Creek (S« SE« sec 5, T32S, R18E) now partly inundated below Big Hill Lake. A good reference exposure along the spillway west of the dam (about ctr S« sec 7, same township) shows a vertical succession of about 10 feet of sandy shale overlain by underclay and coal, followed by about 15 feet of sandstone and sandy shale, all in the middle of the Galesburg. Fair exposures of the top of the Galesburg occur along Big Hill Creek in NW cor sec 16, T31S, R18E, and in the roadcut and stream southwest of Dennis (along E line SE-NE-NE sec 21, T31S, R18E) now better exposed 1 mile westward (ctr E line NE-NE sec 20) where a coal nearly at the top of the Galesburg overlies sandy shale and thin bedded sandstone. The base of the Galesburg Shale, which is otherwise rarely exposed, displays 10 feet of sparsely fossiliferous prodeltaic shale becoming sandy upward above the Mound Valley Limestone in the water-filled quarry just south of Big Hill dam (NE-SE-NE sec 18, T32S, R18E).

Southwestward in Montgomery county, the Galesburg Shale ranges from about a 20-foot largely covered interval between the Mound Valley and Dennis Limestones along US 169 northeast of Liberty (in SE-NE sec 7, T33S, R17E) to a 35-foot well exposed sequence within the Galesburg, of sandy shale with thin bedded sandstones and a 0.3 foot coal near the top overlain by massive sandstone along the road just 2 miles to the southeast (ctr E line NE-SE sec 16, T33S, R17E). Southwestward 7 to 9 miles, it attains perhaps 130 feet in thickness in the claypit (SW-NW sec 26, T34S, R16E) and bluff (NW sec 14, same township) along the Verdigris River north of Coffeyville. Both pit and bluffs provide good, although not easily accessible, reference exposures of thick sandy shale overlain by thick beds of sandstone.

A coal bed reported from about the middle of The Galesburg succession in a hill west of the Verdigris River a few miles north of Coffeyville was named Cedar Bluff coal by Jewett (1932) without an exact location. Coal with an underclay is known near the middle of the Galesburg in many exposures along the course of Big Hill Creek from the area around Big Hill Lake (e.g., spillway section mentioned previously) southwestward to the hills east of Liberty (e.g., roadcut exposure mentioned previously), and west of the Verdigris River from north of the bluffs (roadcut at ctr NE sec 3, T34S, R16E) to southwest of Coffeyville (e.g., near ctr E line NE- SE sec 6, T35S, R16E, and roadcut north of ctr W line SW-NW sec 10, same township). The informal name Cedar Bluff thus appears useful for coal near the middle of the Galesburg in this area, recognizing that the coal at the top of the Galesburg southwest of Dennis is probably not the same bed because it has no underclay.

The sandstone in the upper Galesburg Shale above the Cedar Bluff coal was named Dodds Creek by Jewett (1932,1933) from Dodds Creek in western Labette County (which he did not locate exactly and which is not found on the recent 7«-minute topographic maps of the region), and this unit was recognized by Moore et al. (1951) as a formal member of the Galesburg. The notorious lenticularity of sandstones in general and the confusion arising from original application of the name Dodds Creek to sandstone in the upper Galesburg above the Cedar Bluff coal, but denotation by Moore et al. (1951, p. 83) and Zeller (1968) of sandstone in the base of the Galesburg as Dodds Creek, raise serious question as to the utility of the name. The informal terms "upper" or "lower Galesburg sandstone" of a particular region are more informative and less confounding in terms of multiple names for the same unit, and I suggest that the name Dodds Creek be abandoned.

Southward in Oklahoma, the Galesburg Shale is recognizable in the South Coffeyville core (OSC) as 134 feet of sandstone with subordinate shale and two coal beds (each with an underclay) one 28 feet below the top (Cedar Bluff) and one 1.4 feet below the top (unnamed). South of the disappearance of the underlying Mound Valley Limestone, the Galesburg merges with the top (and the thickest part) of the Coffeyville succession, which is dominantly sandstone and shale throughout the Tulsa region and southward (Fig. 5). The Cedar Bluff coal bed is traced into Tulsa County.

The thicker sandy Galesburg Shale from Bourbon County southward in Kansas is mostly a fluvial to deltaic complex (Stermer, 1992) with alluvial coals, and with deltas encroaching Mound Valley limestone deposition locally. In northern Oklahoma, the equivalent upper Coffeyville Formation has long been recognized as a large deltaic complex. All of the southern Galesburg represents coarse clastic basin filling attending a major drop in sea level after the Swope and Mound Valley marine inundations (Fig. 3). This deltaic to alluvial basin filling occurred late during the time while continuing long-term subaerial exposure after the Bethany Falls regression, and even during the limited Mound Valley inundation in the south, was forming a well developed paleosol over the entire shelf north of the pinchout of the Mound Valley Limestone.

Dennis Limestone

The Dennis Limestone overlies the Galesburg Shale and underlies the Cherryvale Formation (Fig. 2). It was named by Adams (1903) from conspicuous exposures near Dennis in northwestern Labette County, Kansas. Stratal content of the Dennis was stabilized by Jewett (1932), Newell (1935), and Moore (1936) to include 3 members in ascending order: thin Canville Limestone Member, black Stark Shale Member, and thick Winterset Limestone Member. These constitute the marine part of a typical Kansas cyclothem, which represents a major eustatic transgression and regression of the sea across the northern Midcontinent shelf (Heckel 1977, 1986) above the Galesburg terrestrial deposits and paleosol. The typical outcrops listed by Moore (1936) near northwest corner sec 14, T31S, R18E, are now incomplete exposures. Therefore the roadcut 1 mile southwest of Dennis (ctr E line NE sec 21, T31S, R18E), which exposes all 3 members (Fig. 4), is designated the principal reference section. Complete sections of the entire Dennis Limestone are rare to the north because of the great thickness of the Winterset Limestone Member, but the complete exposure in the US 69 rodcut by Jingo (S & W lines SW cor SE sec 31, T18S, R25E) in Miami County is an excellent reference section for eastern Kansas.

In Nebraska, the Dennis has been misidentified as the 3 middle members (Block Limestone, Wea Shale, Westerville Limestone) of the overlying Cherryvale Formation, and was named Sarpy Formation by Condra (1949). Sarpy, however, is a junior synonym of Dennis (see Heckel and Meacham, 1981) and should be abandoned, or reassigned to those three members of the Cherryvale higher in the Nebraska succession. Southward in Oklahoma, the Hogshooter Limestone, named by Ohern in 1910, has been considered the essential equivalent of the Dennis (Fig. 7A). Although the name Dennis has priority, the Oklahoma Geological Survey has retained the name Hogshooter for reasons largely of usage given by Oakes (1940a, p. 41). Recent findings suggest that the Hogshooter Limestone as used in its type area in northern Oklahoma is a more complex basinal equivalent of both the Dennis Limestone and the higher Cherryvale Formation (Fig. 7B), as is explained in later sections. Therefore the name Hogshooter should be retained in Oklahoma, but perhaps with some modification for more stratigraphically refined use in Kansas as well.

<u>Canville Limestone Member</u>.--The Canville Limestone overlies the Galesburg Shale and underlies the Stark Shale Member of the Dennis Limestone (Fig. 2), both with sharp contacts in most places. It was named from Canville Creek in northern Neosho County by Jewett (1932) as the basal member of the Dennis Limestone. Typical exposures were listed by Moore (1936) in roadcuts at NE cor sec 26, T27S, R20E, about 2 miles southwest of Stark, and in SE sec 20, T27S, R19E, about 11 miles west of Stark, of which only the latter is even poorly exposed today. Therefore a new principal reference section for the Canville Limestone Member is chosen in the excellent exposure along US Rte 59 1.4 miles east of Canville Creek and 1.7 miles west of Stark (S line SW SE SW sec 13, T27S, R20E). The Canville is the transgressive limestone of the Dennis cyclothem, but is less laterally extensive northward (Fig. 4) than most other transgressive limestones in the Missourian succession.

In its type region, the Canville Limestone is generally 2 to 3 feet of dense dark skeletal calcilutite like other transgressive limestones. Locally at the principal reference section along U.S. 59 west of Stark, it thickens to about 6 feet by addition at the top of a lens of phylloid algal calcilutite up to 2.5 feet thick above the more typical brachiopod-rich skeletal calcilutite. This local bed may represent an incipient algal mound in this region of variable depositional topography on the underlying units. Northward the Canville ranges from 1 to 3 feet of typical skeletal calcilutite in Allen, Bourbon and southern Linn counties (Fig. 4), where it is exposed in the roadcut northeast of Elsmore (ctr N line NE sec 4, T26S, R21E), the Boulware Cemetery quarry (SW-SW-NW sec 20, T23S, 22E), and the quarry west of the southern U.S. 69 roadcut south of Pleasanton (NW-NW sec. 25, T22S, R24E). Farther northward in Linn and Miami counties, it thins to 0.1 to 0.2 foot of somewhat lenticular, more argillaceous and calcarenitic limestone, which can be observed in the quarry off Ks Rte 7 north of Farlinville (NE-SE-SE sec 34, T20S, R23E), in the roadcut on Ks Rte 135, 3 miles east of LaCygne (ctr E line SE-SE sec 36, T19S, R24E), and in the US 69 roadcut by Jingo.

Farther northward, the Canville Limestone Member is mostly absent in the Kansas City area and throughout Missouri, Iowa, and Nebraska, but occurs locally as scattered lenses of shells or skeletal calcilutite generally less than 0.5 foot thick. In Nebraska, a thin but more continuous bed of Canville has been misidentified as the higher Block Limestone and included in the Sarpy Formation. Where the Canville Limestone Member is absent, the Stark Shale Member forms the base of the Dennis Limestone, and overlies the Galesburg Shale with a rather sharp contact of black fissile shale over lighter shale or mudstone.

Southward from its type area, the Canville Limestone Member is traced into northern Labette County to the Dennis Limestone reference section (ctr E Line NE sec 21, T31S, R18E) where it has thinned to a zone of 0.5-foot-thick lenses of dense skeletal calcilutite in a bed of shell-rich fossiliferous shale, which lies with more diffuse contact between the Galesburg Shale below and the Stark Shale Member above. Westward in the quarry east of Drum Creek 3.5 miles north of Cherryvale (S of ctr N line NE sec 29, T31S, R17E) the Canville thickens to at least 18 feet of largely phylloid algal facies, another local algal mound up to 26 feet thick in the Gaddy core taken 2 miles to the west by J.A. French. From here southward in Kansas, the Canville Limestone is absent in known exposures except for one locality above the Verdigris River 2.5 miles north of Coffeyville (nose of bluff at road level SE-SW-SW sec 14, T34S, R16E), where it is about 5 feet of skeletal calcarenite with coaly fragments below a thick sequence of Stark Shale in a probable channel filling. Elsewhere in Labette and Montgomery Counties, exposures of the lower Dennis show limestone of the higher Winterset Limestone Member with a distinctive basal bed containing phosphate nodules resting directly on the Galesburg. This situation obtains throughout most of northern Oklahoma, where the Canville Limestone is known

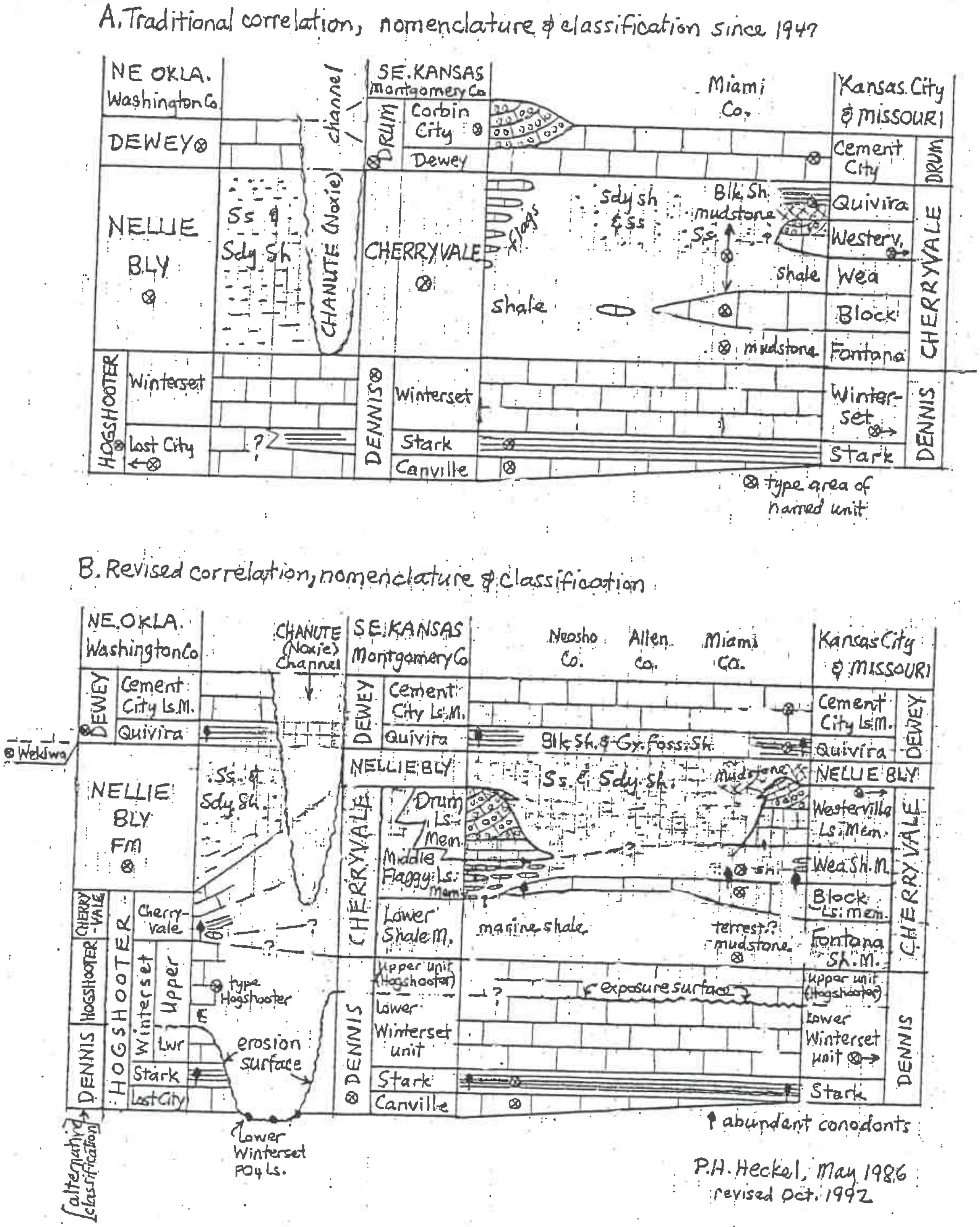


Figure 7.--Comparison of previous correlation, nomenclature and classification (A) of middle Missourian strata (Dennis, Cherryvale, Dewey) with revised nomenclature and classification (B) mandated by correction of miscorrelation of Dewey Limestone of Oklahoma and Cement City Limestone of Missouri with Drum Limestone of southern Kansas. See Figure 8A, B for stratigraphic documentation of revised correlation. Figure 7B also shows alternative possibility for slightly amended definition of Hogshooter Limestone in Oklahoma so that it could be used also for upper Winterset unit in Kansas. [This figure was modified to become Figure 21 in KGS Bulletin 246]

along with the overlying Stark Shale in only a few clustered localities (e.g., T27N around Ruthdale in central western Nowata County, across the boundary of T25N and T26N around Hogshooter in east-central Washington County, and at the railroad bridge over South Fork of Double Creek just northwest of Ramona in T24N in southern Washington County).

Southward in western Tulsa County and adjacent parts of Osage and Creek Counties (T18N to T20N), the Lost City Limestone Member of the Hogshooter Limestone underlies a thin gray facies of the Stark Shale Member (Niemann, 1986), and therefore is the stratigraphic equivalent of the Canville. The Lost City Limestone attains at least 30 and possibly 70 feet in thickness as a phylloid algal mound complex, south of Sand Springs in Tulsa County. The Lost City Limestone was named from an abandoned settlement west of Tulsa by Gould (1911), and therefore has priority over the name Canville. However, the large gap separating continuous outcrops of type Lost City Limestone from type Canville Limestone, in conjunction with consistent uniform usage of each name for the continuous outcrops in each state, argue for maintaining each as a valid name in its type region, while recognizing that they are stratigraphic equivalents. In view of their position beneath the Stark Shale, the scattered outcrops designated Canville Limestone by Oakes (1940a) and by Cronoble and Mankin (1965) in northern Oklahoma might reasonably be designated Lost City Limestone because the former stratigraphic distinction between Canville and Lost City (=Canville plus Stark) made by Oakes (1940a) is no longer valid (see later discussion of Hogshooter Limestone).

<u>Stark Shale Member</u>.--The Stark Shale overlies the Canville Limestone Member and northward the Galesburg Shale (where the Canville is absent), and it underlies the Winterset Limestone Member (Fig. 2). It was named from the town of Stark in northeastern Neosho County by Jewett (1932) as the middle member of the Dennis Limestone. The type locality was given as "near Stark" by Jewett (1933). Moore (1936) listed typical exposures in SE sec 18, T27S, R21E, and NW sec 28, T27S, R20E, neither of which are well exposed today. Therefore a new principal reference section is designated (along with that of the Canville Limestone) in the roadcut along US 59, 1.7 miles west of Stark (along S line SW-SE-SW sec 13, T27S, R20E). Other reference sections along US 59 nearby include a roadcut to the northeast along W line NW SW NW sec 18, T27S, R21E), where the Stark Shale lies in sharp contact with both overlying and underlying limestones extending horizontally for a distance then dipping northward into a synclinal feature in the Dennis Limestone (mentioned by Heckel and Cocke, 1969, p. 1060, 1069, as along their alignment 1), and the road ditch and stream west of the road intersection a half mile westward (near ctr S line SE-SE sec 14, T27S, R20E), where a good horizontal surface of most of the Stark Shale and its upper contact can be observed.

The Stark Shale Member in its type region and northward throughout Kansas (Fig. 4,7,8) generally is 1 to 4 feet of mostly black fissile phosphatic shale overlain by gray fossiliferous shale, a typical core shale for the Dennis cyclothem. The lower black facies is nearly uniformly 1 to 2 feet thick, whereas the upper gray shale varies from nearly absent in the thinner exposures to thicker than the black facies in the thicker sections. The Stark Shale contains an abundant conodont fauna characterized by the first appearance of new species of idiognathodids, especially the distinctive form Streptognathodus confragus. Good reference sections of the Stark are exposed in the road ditch northeast of Elsmore (ctr N line NE sec 4, T26S, R21E) in Allen County, the quarry off Ks Rte 7 north of Farlinville (NE-SE-SE sec 34, T20S, R23E) and the roadcut on Ks Rte 135 east of LaCygne (near ctr E line SE-SE sec 36, T19S, R24E) in Linn County, and the roadcut by Jingo (S line near SW core SE sec 31, T18S, R25E) in Miami County, where the entire Stark Shale is 6 feet thick and the upper gray facies constitutes the upper three quarters of the unit. In the Kansas City region, the Stark Shale is well exposed along Inland Drive at the north end of the cold storage quarries (near ctr N line NW-NE sec 27, T11S, R24E) in Wyandotte County, where the Stark is nearly 4 feet thick and the upper gray facies forms less than half of the unit. Northward along outcrop and throughout the subsurface in Missouri, Iowa, and Nebraska, the Stark Shale Member varies little from its nature in Kansas, consisting of 2 to 5 feet of black fissile shale grading upward to gray shale. In Nebraska, the Stark Shale has been misidentified as the higher Wea Shale Member and included in the Sarpy Foundation.

South of its type area, the Stark Shale Member is traceable southward to the principal reference section of the Dennis Limestone along ctr E line NE sec 21, T31S, R18E, in northern Labette County. Westward it thins to less than 1 foot of gray shale, with phosphate nodules and the characteristic conodont fauna, above the thick Canville algal mound in the Drum Creek quarry north of Cherryvale. South of here it is known in Kansas only from the nose of the Verdigris River bluff at road level 2.5 miles north of Coffeyville (in SE-SW-SW sec 14, T34S, R16E) where it is about 10 feet of black shale with limestone concretions lying abruptly above the Canville Limestone and below the Winterset Limestone with a gradational contact of alternating thin shale and limestone beds. This locality may represent a channel filling because the Winterset here is about 50 feet lower along strike than it is either to the north at Cedar Bluff camp (near ctr W« NW sec 14) or to the south along the old road down Big Hill (NW-SW-SW sec 23, T34S, R16E). Elsewhere in this region, the Stark Shale, like the Canville Limestone, is absent, and limestone from higher in the Winterset, with a thin phosphatic bed at the base, directly overlies the sandy Galesburg Shale. Similarly in northern Oklahoma, the Stark Shale is found only in the same clusters of exposures where the Lost City (=Canville) Limestone is found, and in most of these, the Stark is overlain by the basal phosphatic limestone bed of the Winterset Limestone, which elsewhere overlies sandy beds of the upper Coffeyville Formation (=Galesburg Shale).

The Stark Shale reappears southward above the Lost City Limestone in Tulsa County, where it is black and fissile only where the Lost City is thin (e.g., at Turley Mountain). It is gray (and possibly lenticular) above the thick Lost City phylloid algal mound complex west of Tulsa (Niemann, 1986) where it is identified as Stark at the quarry west of Prattville (SW-NW sec 21, T19N, R11E) by an abundant conodont fauna typical of the black facies of the Stark Shale elsewhere. Southward the Stark appears again as a black shale on Frank Henry Creek (SW-NW-SW sec 4, T14N R10E) in southeastern Creek County, and it has been traced from here intermittently southward by A.P. Bennison through Okfuskee to southern Seminole County.

The Stark Shale, like the similar Hushpuckney Shale below, represents the maximum transgressive phase of a major cyclothem, deposited below a thermocline in a widespread relatively deep sea. Its absence in parts of southern Kansas and northern Oklahoma above probably paleotopographically high parts of the Galesburg delta complex is a unique departure from the lateral continuity of other core shales, which may lose their black facies as they thin over paleotopographic highs, but are nevertheless laterally continuous across the entire region from the northern limit of outcrop well into Oklahoma. The presence of the thick Stark Shale remnant beneath shaly Winterset Limestone in the probable channel north of Coffeyville, along with the presence of an abundant conodont fauna like that of the Stark in the phosphatic bed at the base of the Winterset above coarse Galesburg/Coffeyville detrital rocks, suggest that the Stark (and probably also the Canville/Lost City) were deposited over this entire area, but soon were winnowed of their finer sediment fraction, perhaps largely by marine currents, during the lowest of the several lower stands of sea level involved in forming the overlying thick, generally regressive but stratigraphically complex Winterset Limestone Member (Fig. 3).

Winterset Limestone Member.--The Winterset Limestone overlies the Stark Shale Member and underlies the Cherryvale Formation, specifically the basal Fontana Shale Member, throughout most of Kansas (Fig. 2). It was classified as the upper member of the Dennis Limestone by Jewett (1932). The Winterset Limestone was named by Tilton and Bain (1897) from a locality near Winterset, Iowa, where they specifically referred to the upper of the two thick limestones that overlie black shales in that region. The lower of the two black shales (Hushpuckney) has an immediately underlying thin limestone (Middle Creek), whereas the upper one (Stark) does not. Furthermore, the occurrence of the fusulinid Eowaeringella ultimata only in the lower (Bethany Falls) of these two thick limestones both at Winterset and at Kansas City, combined with the first appearance of triticitids in the upper limestone (Winterset) in both places (Thompson, 1957), provides biostratigraphic confirmation for the lithic tracing of the Winterset Limestone across western Iowa as it thins into southeastern Nebraska (Fig. 6), where it has been misidentified as the higher Westerville Limestone and classified as the upper member of the Sarpy Formation (Condra, 1949).

The Winterset Limestone in its type area in Iowa averages about 22 feet thick, of which the lower two thirds in an accessible section along US 169 southwest of Winterest (Heckel, 1987) is a distinct shallowing-upward sequence of skeletal calcilutite overlain by osagia-grain calcarenite and capped by laminated calcilutite; the upper one third is shale overlain by weathered laminated calcilutite, perhaps the nearshore facies of higher Winterset beds to the south (but included in the overlying Cherryvale Formation by Heckel, 1987). Westward in Nebraska, the Winterset Limestone thins to an average of 11 feet, probably by loss of the upper shaly beds, as it consists of a single shoaling-upward sequence capped with calcarenite. Southward in Missouri, the Winterset Limestone thickens to 30 feet or more, probably by addition of beds at the top, judging from the apparent northward shaling out of the upper beds as a unit that is distinct from the main shoaling-upward sequence near Winterset, Iowa. Gray conodont-rich shales known in the lower part of the Winterset in the greater Kansas City region appear to descend southward and join the top of the Stark Shale where its upper gray facies is thickest in east-central Kansas (Felton and Heckel, 1992). They indicate that the lower Winterset of the north is probably equivalent to the top of the Stark Shale southward and that minor cycles of transgression and regression are superimposed on the generally regressive Winterset sequence (Fig. 3), rendering it a more complex regressive limestone (to the Dennis cyclothem) than others in the Missourian succession.

The best and most complete exposure of the Winterset Limestone Member in Kansas is the US 69 roadcut by Jingo (along W line SW-SW-SE sec 31, T18S, R25E) in Miami County, where the Winterset is 34 feet thick, and which serves as principal reference section for the state. Here the lower two-thirds, informally termed lower Winterset, comprises 3 shallowing-upward sequences, the lower capped with thin oolite, the middle capped with birdseye-bearing peritidal calcilutite, and the upper capped by a mottled exposure surface (Heckel and Watney, Stop 5A in Heckel et al., 1985; Heckel, 1988), which can be traced through several counties in east-central Kansas (Fig. 7B,8A). The upper one-third, informally termed upper Winterset, is separated from the lower part by a sparsely fossiliferous 1-foot shale, with a thin blocky mudstone at the base that may be a paleosol upon the underlying exposure surface. The upper Winterset unit here is a transgressive-regressive sequence with calcarenite at the base and locally at the top, and a thin gray moderately conodont-rich shale in the middle. Northward at a well exposed 27-foot thick reference section in the Kansas City area (Fig. 8A) in the quarry north of the cold storage plant along Inland Drive (near ctr N line NW NE sec 27, T11S, R24E) in Wyandotte County, the upper Winterset unit displays a dark sparsely fossiliferous, probably nearshore carbonate facies, and the underlying shale contains lenses of coal and shoreline carbonate above an exposure surface upon the lower Winterset unit.

South of the principal reference section along US 69 in Miami County, the Winterset Limestone Member thickens through 40 feet in Linn County and 50 feet in Bourbon and Allen Counties, to perhaps 60 feet in Neosho and northern Labette and Montgomery counties. Even though it therefore is quarried extensively throughout this region, no quarry known exposes the entire thickness. Reference sections of the thick Winterset include the quarries north of Cadmus (SE-NE sec 31, T19S, R23E) and south of Centerville (NW NE sec 20, T21S, R22E), and a nearby roadcut (W line NW SW SW sec 21) in Linn County; quarries above Tippie Creek (NW-SE-SE sec 17, T24S, R23E) and east of Bronson (SE-SE sec 6, T25S, R22E) in Bourbon County; a quarry northwest of Stark (SE-SE sec 12, T27S, R20E), roadcuts along US 59 and Ks Rte 39 between Stark and Chanute at Canville Creek (S line SW-SE-and along SW sec 14, T27S, R20E) and at Big Creek (N line NW-SE sec 22, T27S, R19E), and

FIGURE 8A

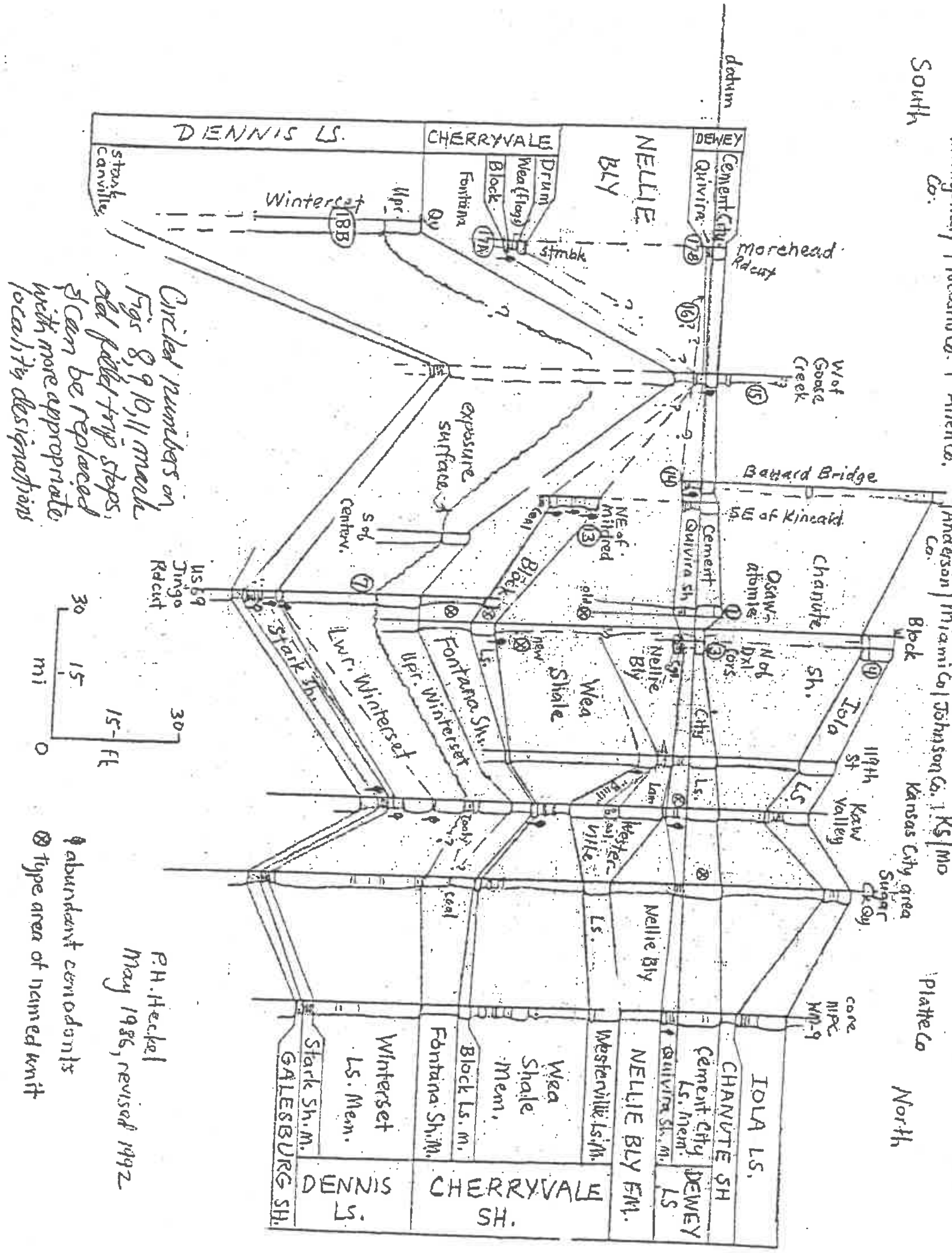
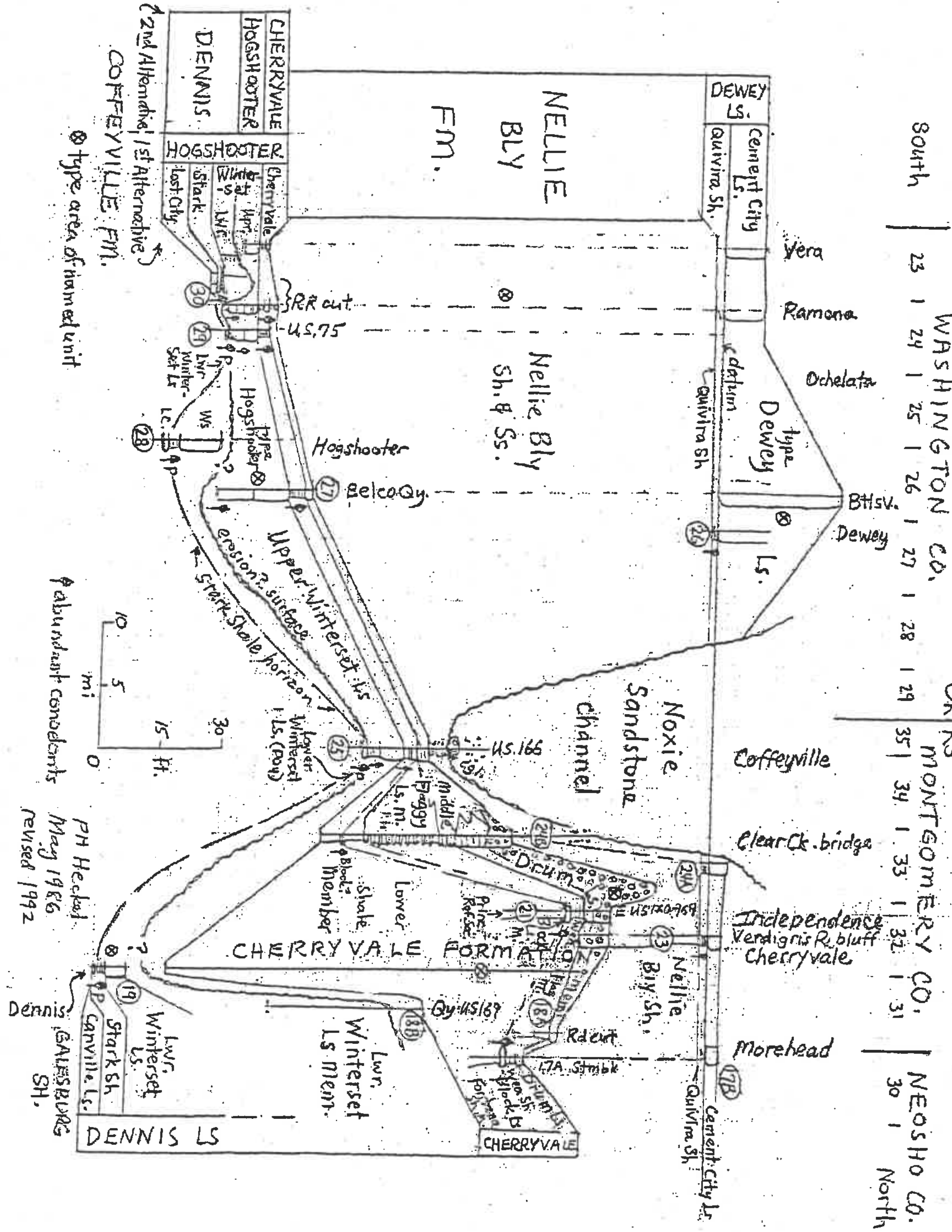


Figure 8.--Stratigraphic cross-section of middle Missourian strata (Dennis, Cherryvale, Dewey, Iola) from Kansas City area to southern Neosho County (A) and from there to southern Washington County, Oklahoma (B), showing stratigraphic control in measured sections and cores. Figure 8B also shows alternative possibility for slightly amended definition of Hogshooter Limestone in Oklahoma so that it could be used also for upper Winterset unit in Kansas. [The two parts of this figure were not used in KGS Bulletin 246]

FIGURE 8B



South
North
WASHINGTON CO.
OK
KS
MONTGOMERY CO.
NEOSHO CO.
DEWEY LS.
Cement City LS.
Quivira Sh.
NELLIE BLY FM.
CHERRYVALE
HOGSHOOTER
DENNIS
HOGSHOOTER
Cherryvale
Winter-set
Stark
Lost City
(2nd Alternative, 1st Alternative)
COFFEYVILLE FM.
⊗ type area of named unit
Vera
Ramona
Ochelata
type Dewey
Btlsv.
Dewey
Ls.
Quivira Sh.
RR cut
U.S.75
Nellie Bly Sh. & Ss.
Hogshooter
Belco Qy.
Upper Winterset Ls.
erosion? surface
Stark Shale horizon
Noxie Sandstone Channel
Coffeyville
US.166
Clear Ck. bridge
Drum
Independence
Verdigris R. bluff
Cherryvale
Nellie Bly Sh.
CHERRYVALE FORMATION
Lower Shale Member
Block
Middle
Quindaro
Morehead
Rd cut
Qy US169
Lwr. Winterset Ls Mem.
Lwr. Winterset Ls.
Stark Sh.
Canville Ls.
GALESBURG SH.
Dennis
DENNIS LS
Cement City Ls.
Quivira Sh.
abundant conodonts
30
15
ft.
10
5
0
mi
PH Heckel
May 1986
revised 1992

quarries north of Ks Rte 47 (SE-NE-SE sec 9, T29S, R19E) and near Urbana (SE sec 30, T28S, R19E), all in Neosho County; and 2 quarries north of Cherryvale, one south of the US 160-169 intersection (S« NW sec 22, T31S, R17E) and one just east of Drum Creek (near ctr N line NE sec 29, T31S, R17E) in northeastern Montgomery County. The shale separating the lower and upper Winterset units can be traced above the exposure surface at least to the Centerville region (Fig. 8A), and what may be the same shale is seen in the Stark quarry and in the US 160-169 quarry north of Cherryvale. Throughout much of this region, the lower Winterset unit shows a sequence of skeletal calcilutite grading upward to phylloid algal mound facies and capped by locally thick oolite. This oolite locally grades laterally into brachiopod-rich calcilutite at the quarry northwest of Stark, which lies in the synclinal feature along alignment 1 of Heckel and Cocke (1969). The upper Winterset unit grades southward to largely phylloid algal mound facies in Neosho County.

Along an ENE-WSW trending line (alignment 2 of Heckel and Cocke, 1969) across northern Labette and Montgomery counties, the Winterset algal mound facies thins abruptly southward as it grades into a non-algal skeletal calcilutite that ranges from about 7 to 10 feet thick (Fig. 8B). Small exposures of the top of the mound edge may be seen north of Cherryvale in southward-dipping skeletal-algal calcilutite in the roadcut on US 169 (NW SE SW sec 22, T31S, R17E) south of the US 160-169 guarry, and in the bed of Drum Creek just south of the bridge (NW-SW-SW sec 29, T31S, R17E) south of the Drum Creek quarry. The best exposure of thin Winterset south of the mound edge is at the Dennis Limestone reference section southwest of Dennis (ctr E line NE sec 21, T31S, R18E) where it is at least 5 feet of massive skeletal calcilutite to calcarenite with conspicuous fossils, overlying black Stark Shale. A different facies is well exposed in the nose of the Verdigris River bluff north of Coffeyville (SE-SW-SW sec 14, T34S, R16E) where 15 to 20 feet of interbedded skeletal calcilutite and shale overlie the thick Stark in this probable channel feature that is indicated by exposures of Winterset about 50 feet higher along strike (Cedar Bluff Camp, NE-SW-NW sec 14; old road down Big Hill, NW-SW-SW sec 23).

Elsewhere in southernmost Kansas, the Winterset Limestone is a thin-bedded skeletal calcilutite with conspicuous brachiopods and echinoderms and shale interbeds particularly toward the base. Here it directly overlies Galesburg sandstone to sandy shale, with a distinctive basal bed of skeletal calcarenite containing phosphate nodules. This bed is well seen in a reference section along the north side of US 166 west of Coffeyville (N line NW-NW-NW sec 5, T35S, R16E) where the phosphatic limestone is overlain by 3 feet of fossiliferous shale and 6 feet of shaly fossiliferous limestone (Fig. 8B). Phosphate nodules are seen in the basal Winterset at least from 6 miles northeast of Liberty (ctr E line SE-SE sec 35, T32S, R17E) to south of Coffeyville (shallow quarry at SE cor NE sec 9, T35S, R16E) where the nodules rest on top of Galesburg sandstone, and southward in many sections of typical Hogshooter Limestone in northern Oklahoma. Cronoble and Mankin (1965) referred to this basal phosphatic bed in Oklahoma as "lower Winterset" and the remaining thicker part as "upper Winterset".

The exact stratigraphic relations between the upper and lower Winterset units in Oklahoma and those described previously (separated by the shale resting on the exposure surface) in the thick sequence in eastern Kansas, are not definitely established, but preliminary observations suggest that the lower and upper units in each state are roughly equivalent. The basal phosphatic limestone bed constituting the lower Winterset unit in southernmost Kansas and Oklahoma also contains much skeletal material, glaucony, quartz grains, and abundant conodonts. Therefore it appears to be a residual lag deposit representing a long period of time during which glaucony formed while the thin lower beds (Stark Shale, Canville/Lost City Limestone, and top of the Galesburg sands) were winnowed of their finer clay, organic matter and carbonate mud, leaving behind phosphate nodules, conodonts, carbonate skeletal debris, and coarse quartz grains. This probably occurred in a relatively shallow marine environment developed southward after exposure of the thick lower Winterset unit northward in Kansas prior to the transgression that eventually brought deposition of the upper Winterset unit northward at least to west central Missouri.

The "reefs" described in the Winterset Limestone by Cronoble and Mankin (1965) near Ramona and Hogshooter, Oklahoma, overlie remnants of Stark Shale and have no phosphatic zone at their base. These "reefs", along with the channel-filling north of Coffeyville and the roadcut section southwest of Dennis, probably are remnants of the lower Winterset unit that were not winnowed during the lowstand, probably because of protection in the topographic low for the channel and perhaps because of greater initial thickness of the carbonate sediment mass in the "reefs". The reefs probably originally were local carbonate mud mounds deposited in places on the Stark surface during an early stage of lower Winterset deposition, in deeper water in view of their lack of phylloid algae, which are common northward on the shelf. These local deeper water mud mounds then protected the Stark Shale and underlying Canville/Lost City Limestone from the winnowing that formed the lower Winterset phosphatic bed elsewhere during the lowstand that exposed the top of the thick lower Winterset unit northward across eastern Kansas. Thus the upper Winterset unit above the phosphatic bed south of the mound edge in southernmost Kansas and northern Oklahoma probably is a basinal facies of the upper Winterset unit of the Kansas shelf. Its nature in Oklahoma is elaborated in the following discussion of the Hogshooter Limestone.

Hogshooter Limestone

As currently recognized by the Oklahoma Geological Survey (Fay et al., 1979), the Hogshooter Limestone overlies the Coffeyville Formation and underlies the Nellie Bly Formation in northern Oklahoma (Fig. 2). It was named by Ohern (1910) from exposures along Hogshooter Creek in T26N, R14E, east of Bartlesville in Washington County, Oklahoma. Oakes (1940a, p. 41) regarded the Hogshooter as substantially equivalent to the Dennis Limestone of Kansas (named in 1903), but he retained the name Hogshooter largely because of entrenched usage. He recognized it as comprising the same 3 members as the Dennis in parts of T25N to T26N and T27N in ascending order: thin Canville Limestone, black Stark Shale, thick Winterset Limestone, but he noted that in most places only the Winterset is present. He (p.44) also recognized the Lost City Limestone Member below the Winterset Limestone in western Tulsa (T19N) and adjacent counties. He regarded the Lost City Limestone as distinct from both the Winterset and Canville limestones, and probably time equivalent to both the Canville Limestone and Stark Shale. In a more detailed study of the Hogshooter Limestone, Cronoble and Mankin (1965, p. 106) denoted the type section in the west bank of Hogshooter Creek in SW-SE-SW sec 9, T26N, R14E. They removed the Canville, Stark and Lost City members from the Hogshooter and placed them in the underlying Coffeyville Formation because they regarded them as facies of the clastics that dominate the top of that formation. They also recognized two widespread bedded units in the Winterset Limestone Member, a lower thin phosphatic calcarenite, and an upper thicker calcilutite, and also 2 localized more massive "reefs", which they regarded as local facies of the bedded units.

Recent work has shown that the Canville and Lost City Limestone Members are equivalent because a gray facies of the Stark Shale, identified by its abundant and distinctive conodont fauna, was found by Niemann (1986) above the Lost City Limestone in its type area west of Tulsa (Prattville quarry, SW NW sec 21, T19N, R11E). Nevertheless, both names are retained because of ingrained and consistent usage in their respective type regions.

The basal sandy, phosphatic, glauconitic, conodont-rich skeletal calcarenite bed that constitutes the Lower Winterset unit averages 1 foot or less in thickness everywhere (Fig. 8B). It appears to be a residual lag deposit formed over a long period of time in a marine environment shallower than that of the underlying Stark Shale, when parts of the lower beds (Stark, Lost City/Canville Limestone, top of Coffeyville Formation) were winnowed of their finer material (organic mud, lime mud, and argillaceous mud) prior to induration, leaving the coarser material behind as a sheet deposit equivalent in age to at least the top of the thicker lower Winterset unit of eastern Kansas (see previous section on the Winterset Limestone). This bed is present everywhere at the base of the Winterset, except beneath the two "reefs" described by Cronoble and Mankin (1965): 1) at the railroad bridge over South Double Creek at Ramona and 2) in the streambed west of Hogshooter. This relationship suggests that these "reefs" are thicker remnants of an earlier pre-winnowing stage of lower Winterset deposition, which were not winnowed away (perhaps because they were deposited as local buildups), and which also protected the underlying Stark Shale and Lost City-Canville Limestone from removal during the later stage of lower Winterset deposition when the phosphatic calcarenite bed was forming elsewhere.

The Upper Winterset unit in northern Oklahoma ranges from 4 feet of shaly skeletal calcilutite in most places, to 8 feet of shale-parted calcarenite near the "reef" at Ramona; all facies contain conspicuous crinoids. In the Belco quarry 1 mile north of US 60 (SW sec 9, T26N, R14E) very close to the designated Hogshooter type section east of Bartlesville in Washington County, the

Upper Winterset attains about 20 feet in thickness, with moderately conodont-rich shale at the base and a phylloid algal mound (mentioned by Heckel and Cocke, 1969) at the top (Fig. 8B). Because this unit makes up almost the entire Hogshooter Limestone at this locality and represents a transgressive-regressive cycle of deposition that appears to be equivalent to the upper Winterset unit of eastern Kansas, this cycle is referred to as Hogshooter-upper Winterset in Figure 3.

At the top of the Hogshooter Limestone, a succession of about 1 to 3 feet of dark shale, locally with thin crinoidal limestones, was discovered by A.P. Bennison at several localities in northern Oklahoma (Fig. 8B). These include Ruthdale in sec 18, T27N, in Nowata County; the west wall of the Belco quarry east of Bartlesville above the main ledge of the Hogshooter algal mound; the area around Ramona farther south, where it is well exposed in the stream along US 75 (W line SW-NW-SE sec 16, T24N, R13E), and where it lies at the top of the calcarenitic "flank" beds just off the "reef" at the railroad bridge north of town (ctr N« SW-NE sec 28); and in a roadbed west of Vera (W of ctr S line SE sec 21, T23N, R13E). This dark shale bed and associated crinoidal limestones, in all localities analyzed, carry an abundant conodont fauna, which indicates that it is an offshore (core) shale of a succeeding marine cycle of deposition. This fauna is compatible with the abundant fauna of the Block-Wea sequence in the Cherryvale Formation in Kansas. This, in conjunction with the southward thinning of the entire Cherryvale sequence to 3 feet of flaggy calcilutite and 1 to 2 feet of underlying shale and skeletal calcilutite in the US 166 roadcut west of Coffeyville, suggests that the thin dark shale and crinoidal limestone sequence at the top of the Hogshooter Limestone in Oklahoma represents the distal basinal facies of the entire Cherryvale Formation of Kansas (Fig. 7B). This shale previously was not recognized as distinct from either the overlying Nellie Bly Formation or the Hogshooter in Oklahoma, and has been informally termed "New Harmony" by A.P. Bennison after the new name for the church at Hogshooter, but which is not shown on the most recent topographic map of the area. This unit probably should not be included within the Nellie Bly, which is mainly deltaic to terrestrial clastics, and which forms a distinct unit above the Cherryvale Formation in Kansas. It could be included within the Hogshooter Limestone as the Cherryvale Member. This procedure would expand the Hogshooter to encompass the more basinal marine facies of several cycles of major to minor scale, from the Dennis upward through the entire Cherryvale, representing a time when shoreline did not withdraw basinward any farther than southeastern Kansas.

An alternative for classifying the Hogshooter succession would be to recognize three formations: 1) the Dennis Limestone at the base, comprising the Lost City, Stark and Winterset Members (but including only the Lower Winterset unit of current usage); 2) the Hogshooter Limestone in the middle, comprising only the Upper Winterset unit of current usage (which is coincident with the type Hogshooter designated by Cronoble and Mankin, 1965); and 3) the Cherryvale Formation, comprising the dark shale and crinoidal limestones at the top (Fig. 7B,8B). This alternative would extend the name Hogshooter northward into Kansas in place of the upper Winterset unit of current usage there and explicitly recognize the importance of the exposure surface between the lower and upper Winterset units of Kansas as a formational boundary. This alternative, however, should await more definite confirmation of the correlation of the lower and upper Winterset units of Kansas with those respectively of Oklahoma. The ultimate disposition of nomenclature and classification of the Hogshooter succession rests with the Oklahoma Geological Survey.

LINN SUBGROUP

The Linn Subgroup overlies the Bourbon Subgroup and underlies the Zarah Subgroup, in the middle of the Kansas City Group. It comprises 4 formations, in ascending order: Cherryvale Formation, Nellie Bly Shale, Dewey Limestone and Chanute Shale. Nellie Bly and Dewey are northeastern Oklahoma names extended into Kansas as a result of the correction of the long-standing miscorrelation of the Dewey with the Drum Limestone of Kansas, which is now classified as a local member of the Cherryvale Formation. The Iola Limestone, formerly at the top of the Linn Subgroup, is transferred to the overlying Zarah Subgroup because it is stratigraphically more related to overlying formations.

The Linn Subgroup was defined by Moore (1948) as a shale-dominated unit distinct from the Bronson Subgroup and comprising the Cherryvale Formation Drum Limestone, Chanute Shale and Iola Limestone. The modifications made herein serve to increase the prominence of shale because of the removal of the Iola Limestone. The Linn Subgroup was "...named from Linn County, Kansas, which contains excellent exposures of all constituent units..." (Moore, 1949). No type section was given, and the exposures currently known in Linn County are now generally poor enough that reference sections of most units are available only nearby in Miami County where relief is greater in the valley of the Marais des Cygnes River and its tributaries.

The Linn Subgroup averages about 60 feet in thickness in the Kansas City area and thins northward to an average of about 40 feet in Iowa and Nebraska. Southward, it thickens to about 100 feet in southern Miami County and farther southward to perhaps as much as 200 to 300 feet in central Montgomery County where the lower Cherryvale, Nellie Bly, and particularly the Chanute thicken substantially as the latter two units become dominated by sandstone.

Cherryvale Formation

The Cherryvale Formation overlies the Dennis Limestone and is now recognized to underlie the Nellie Bly Formation throughout Kansas (Fig. 2B). The Cherryvale Shale was named by Haworth (1898) from escarpments in bluffs and mounds around Cherryvale in northeastern Montgomery County, and was recognized to apply to strata between the Dennis Limestone below and the Drum Limestone above by Haworth and Bennett (1908). Its usage in northeastern Kansas and northward (Fig. 7A) was stabilized by Moore (1948, 1949) as the Cherryvale Formation comprising 5 members, in ascending order: Fontana Shale, Block Limestone, Wea Shale, Westerville Limestone, and Quivira Shale, all named from northeastern

Kansas, except for the Westerville, which was named from Iowa. This correlation and classification of the Cherryvale Formation was based on the determination by Moore (1948, p. 2030) that the type Drum Limestone in southeastern Kansas correlates with the Cement City Limestone (named from Missouri), which overlies the Quivira Shale in the Kansas City area, rather than with the Westerville Limestone (the "Kansas City oolite") as believed by previous workers.

Recent discovery (by A.P. Bennison) of the Cement City Limestone and underlying Quivira Shale (confirmed by its distinctive conodont fauna) lying 20 feet above the Drum Limestone in its type area at Independence, Kansas (Fig. 8B), necessitates recorrelation and reclassification of the Cherryvale Formation and Drum Limestone in Kansas, and also of the Nellie Bly Formation and Dewey Limestone of Oklahoma, which had been considered their respective equivalents (Fig. 7A). This significant recorrelation places the type Drum Limestone of southern Kansas equivalent to the Westerville Limestone at Kansas City, and the type Cherryvale Formation equivalent to only the Fontana Shale, Block Limestone, and Wea Shale Members of northeastern Kansas (Fig. 8A,B), ironically as had been considered for some time by earlier workers (e.g., Hinds and Greene, 1915). One could limit the Cherryvale Formation to this sequence, and this would leave the Drum Limestone and Westerville Limestone as independent correlative formations above the Cherryvale, but not continuous along outcrop.

The complex facies relations observed between classic Cherryvale strata and the Drum Limestone in their type area in Montgomery County, however, suggest a preferred alternative, that of including both the Drum and Westerville limestones as upper members of the Cherryvale Formation in southern and northern Kansas, respectively (Fig. 7B). This would serve several beneficial purposes: 1) It would include two partly equivalent lithotopes (Drum limestone, Cherryvale shale) in the same formation; 2) It would eliminate the need for a formation (Drum-Westerville) that is absent along outcrop by nondeposition for about 70 miles from Miami to Neosho counties, thereby retaining all formational units as continuous along outcrop in Kansas and leaving only certain members as local units, 3) It would retain more of the currently recognized members within the Cherryvale Formation in the Kansas City area, as only the Quivira Shale but not the Westerville Limestone is removed; 4) It includes all members of a relatively complex intermediate-scale cycle of deposition (Fig. 3: Block Limestone, Wea Shale, Westerville-Drum Limestone) in the same formation, a precedent established by Moore (1936), which has facilitated depositional understanding of other dominantly marine units in the Missourian (e.g., Swope, Dennis, Iola). This last point would suggest exclusion from the Cherryvale of the basal Fontana Shale as a separate formation analogous to the Galesburg Shale below. However, because the Fontana grades southward into the bulk of the original type Cherryvale shale (as it represents a less extreme sea level drop than the Galesburg), this is deemed less desirable than retaining the Fontana in the Cherryvale Formation.

Thus the Cherryvale Formation, as revised herein, comprises 4 members in northeastern Kansas and northward, in ascending order: Fontana Shale, Block Limestone, Wea shale, and

Westerville Limestone (Fig. 7A, 8B). In east central Kansas, only the Fontana, Block, and Wea members are present, and none are well known in this area of poor exposure of this part of the sequence. In those parts of southeastern Kansas where the Block Limestone is recognized, the Cherryvale Formation comprises 4 ascending members: Fontana Shale, Block Limestone, Wea Shale, and Drum Limestone. Where the Block is not recognized the Cherryvale comprises an informal unnamed Lower Shale Member, an informal unnamed Middle Flaggy Limestone Member, and the Drum Limestone Member at the top (Fig. 7B, 8B). The base of the Cherryvale Formation everywhere is the top of the Winterset Limestone Member of the Dennis Limestone. The top of the Cherryvale Formation is the top of its Westerville and Drum Limestone Members where they are present. Where they are absent, the Wea Shale Member of the Cherryvale is overlain by the Nellie Bly Formation, a detrital unit newly recognized in Kansas in the lower part of what has been considered Quivira Shale Member, which is herein redefined to be limited to only its upper marine beds and classified with the Cement City Limestone Member in the Dewey Limestone (see later section). Thus the upper boundary of the Cherryvale Formation in east-central Kansas is difficult to place in the poorly exposed detrital sequence, unless one can identify a marine Drum-Westerville-equivalent shale, and place the Cherryvale-Nellie Bly boundary at its top.

No type section was originally given for the Cherryvale Shale beyond the escarpment in bluffs and mounds around Cherryvale. Therefore an excellent exposure of most of the upper part just two miles north of Cherryvale in the road ditch along E line SE-SE sec 32, T31S, R17E and particularly in the hillslope just south of the road intersection just north of the ctr E line of SE sec 32 is designated as the type section. There the entire 60-foot upper part of the thick Lower Shale Member is completely exposed, followed upward by the Middle Flaggy Limestone Member, only 4 feet thick in this area, and mapped by about 2 feet of Drum Limestone Member less well exposed at the top of the hill. An exposure of the top of the Winterset Limestone in the bed of Cherry Creek just to the south (SW-NW-NW sec 4, T32S, R17E) provides an estimate of about 35 feet of the covered lower part and about 100 feet for the entire Cherryvale Formation in this area, just south of the Winterset mound edge. A new roadcut 0.2 mile east of the US 160-169 junction, about 3 miles south of Cherryvale, along N line NE sec 31, T32S, R17E, affords an excellent exposure and principal reference section of the upper part of the Cherryvale Formation where the Block Limestone and Wea Shale Members as well as the Drum Limestone Member can be recognized.

The principal reference section for the Cherryvale Formation in northeastern Kansas is in a rill above the main quarry wall behind the transformer station at the north and of the cold storage plant quarries along Inland Drive (near ctr N line NW-NE sec 27, T11S, R24E) in Wyandotte County, which is accessible only with difficulty but exposes all four members. The Cherryvale Formation ranges from about 35 to 45 feet thick in the Kansas City area and northward through Missouri. It thins to an average of about 15 feet along the Iowa-Nebraska outcrop belt, where all 4 members are still recognizable in most places.

Fontana Shale Member.--The Fontana Shale overlies the Dennis Limestone (Winterset Limestone Member) and underlies the Block Limestone Member (Fig. 2, 7B,8A). It was named by Newell (in Moore, 1932; 1935) from exposures near Fontana in Miami County to apply to these strata, and it was included as the base of the Cherryvale Formation by Moore (1948, 1949). Its contacts are sharp with the overlying and underlying limestones. Typical exposures were given as roadcuts near ctr W line NW sec 36, T18S, R23E, about 1.5 miles north of Fontana and "at NE cor" (actually near ctr N line NE¬) sec 11, T18S, R23E, 1.25 mile west of Block, neither of which are well exposed today. The best exposure currently known, designated the principal reference section, is the US 69 roadcut along W line SW-NE sec 6, T19S, R25E, just south of the principal reference section of the Winterset Limestone in the US 69 roadcut by Jingo, 8 miles east of Fontana.

The Fontana Shale Member in its type area ranges from 12 to 18 feet of gray shale to mudstone with small scattered carbonate nodules, locally an iron-stained zone at the base, and scattered marine fossils in the upper part. Northward it thins to about 5 feet in the Kansas City area, where it consists of 3 feet of blocky mudstone overlain by 2 feet of shale with a fossiliferous sandstone just above the mudstone, in the Cherryvale reference exposure in the quarry north of the cold storage plant quarries along Inland Drive (near ctr N line NW-NE sec 27, T11S, R24E) in Wyandotte County. In Missouri, the Fontana Shale ranges from 5 to l5 feet of similar gray shale and mudstone with a local coal near the middle on the east side of Kansas City. Northward it thins to 0.4 to 2.5 feet of gray mudstone with carbonate nodules along the Iowa and Nebraska outcrop. In Nebraska the Fontana Shale has been misidentified as the higher Quivira Shale. Throughout this northern region, the lower Fontana mudstone is largely a paleosol developed on nearshore or terrestrial shale deposited during the lowstand of sea level that closed Winterset Limestone deposition (and the Dennis cyclothem), whereas the upper marine shale is the initial phase of the Cherryvale transgression (Reeves and Felton, 1992).

Southward from its type area in Miami County, the Fontana Shale Member is very poorly exposed and not well studied in east-central Kansas, and is identified mainly by the recognition of the bounding limestones. It is reported to reach perhaps 45 feet in thickness with interbedded sandstone in northern Allen County (Miller, 1969), and coal is exposed at the top in a creek bank (just SE of NW corner sec 33, T23S, R21E) there and nearby in southernmost Anderson County (roadditch at center W line sec 17, T23S, R21E). A roadditch exposure west of Goose Creek in southern Allen County (E line NE NE NE sec 26, T26S, R19E) suggests that the entire Cherryvale Formation has thinned to a 5-foot interval (Fig. 8A). Southward, in Neosho County, the Fontana Shale Member is reported to be about 15 feet of blocky gray shale with thin coal beds in T29S, R18E (Jungmann 1966). In southernmost Neosho County, the uppermost 7 feet of Fontana gray shale are exposed below the Block Limestone in a creek valley 2 miles east of Morehead (NW-NW-SW sec 32, T30S, R18E) where the Fontana merges southward with the main body of the original type Cherryvale shale. Southward, the Fontana

Shale Member is identified only where the overlying Block Limestone Member is identified, as at the new roadcut 0.2 mile east of the US 160-169 junction south of Cherryvale (N line NE sec 31, T32S, R17E), and 2 miles westward along US 160 (S line SW-SW sec 25, T32S, R16E), where only the upper 20 feet of a gray shale sequence perhaps 50 to 70 feet thick is exposed. Where the Block Limestone is not identified, the Fontana Shale Member merges largely with the Lower Shale Member of the Cherryvale Formation (see next section).

Lower Shale Member.--In those parts of Montgomery County where the Block Limestone is not recognized, the informal Lower Shale Member constitutes the lower part of the Cherryvale Formation (Fig. 2, 7B). Its base is a sharp contact on top of the underlying Winterset Limestone. Its top is the base of the overlying informal Middle Flaggy Limestone Member, where the contact is gradational and placed at the base of the lowest thin flaggy limestone bed.

The Lower Shale Member consists of unfossiliferous gray shale with scattered argillaceous carbonate concretions in a monotonous sequence about 95 feet thick at its principal reference section at the Cherryvale type section in the roadcut and hill north of Cherryvale. It thins southward to 15 feet in the west bank of the Verdigris River near ctr sec 28, T33S, R16E, north of the mouth of Clear Creek. Here, it carries a thin (<0.1 ft) impure skeletal limestone in the lower part, which contains echinoderms and conspicuous snails on the upper surface. This limestone also contains an abundant conodont fauna that suggests that it may be the southern featheredge of the Block Limestone. The Lower Shale Member is 8 feet thick between the Winterset Limestone and the Middle Flaggy Limestone Member in the old road down Big Hill north of Coffeyville (NW-SW-SW sec 23, T34S, R16E), and it thins southward essentially to disappearance between the top of the Winterset and the "fused" flaggy limestone unit in the US 166 roadcut west of Coffeyville (N line at NW cor sec 5, T35S, R16E).

The Lower Shale Member of the Cherryvale Formation (and the south end of the largely equivalent Fontana Shale Member) is a locally thick prodeltaic shale with a probable northeasterly source, suggested by the perhaps fluvial sandstones in the poorly exposed Fontana Shale in east-central Kansas. Its southward disappearance in southern Montgomery County is mainly by distal prodeltaic thinning away from the northerly detrital source.

Block Limestone Member.--The Block Limestone Member overlies the Fontana Shale Member and underlies the Wea Shale Member (Fig. 2, 7B, 8A). It was named by Newell (in Moore, 1932; 1935) from exposures of limestone well above the Winterset Limestone in the vicinity of Block in central Miami County, and it was grouped with other units in the Cherryvale Formation by Moore (1948). The type locality of the Block Limestone was designated by Newell (1935, p. 143) at the S line SW section 6, T18S, R24E, just east of the hamlet of Block. The top of the Block Limestone recently has been fairly well exposed in the ditch at ctr N line NW sec 7, T18S, R24E just across the road from the type locality, and the base is well exposed at another reference section in a streamcut along N line NW-NW sec 2, T18S, R23E, just 2 miles to the west-northwest.

The Block Limestone Member in its type region of Miami and northern Linn County averages 3 to 4 feet of dense gray skeletal calcilutite, generally with sharp contacts with shale above and below, a rather typical transgressive limestone for the Cherryvale cyclothem. It ranges up to 8 feet thick about 10 miles southwest of Block and about 2 miles southeast of Beagle (0.25 mile W of ctr W line sec 18, T19S, R23E, according to Newell, 1935, p. 133) probably the other typical exposure mentioned by Moore (1936), which is poorly exposed today. Northward the Block Limestone thins to about 1 foot in the Cherryvale reference section high in the quarry wall north of the cold storage plant along Inland Drive in Wyandotte County. The top of the Block Limestone along with the base of the overlying Wea Shale Member here and at the type Block locality carry an abundant conodont fauna, which contains the first appearance of good numbers of the deeply troughed idiognathodids, *Streptognathodus gracilis* and *S excelsus.*

Farther northward in Missouri and southern Iowa, the Block Limestone is generally 3 feet of dense dark skeletal calcilutite often with abundant fossils including fusulinids, brachiopods, echinoderms, and osagia-coated grains. In central Iowa it thins to less than 1 foot of dense bluish skeletal calcilutite above Fontana shale and mudstone. In Nebraska the Block is about 1 foot of skeletal calcarenite with mud pebbles at the Richfield P.W.A. quarry (near ctr S« N« sec 28, T13N, R12E) in Sarpy County, where it was named the P.W.A. Limestone Member of the Drum Formation by Condra (1949), which is a junior synonym of Block. The Block Limestone is a similar bed in the Amerada core (NAC) in Cass County, where it was included in the Westerville Limestone by Condra (1939), and it is absent in the Offutt core (NOC) in eastern Sarpy County, where fossiliferous shale assigned to the Wea Shale Member overlies Fontana mudstone.

Southward from its type region, the Block Limestone is poorly exposed and may be lenticular. In exposures around the Anderson-Allen County line east of Mildred, the Block ranges from about 1 foot of dense dark skeletal calcarenite (in the east creek bank just SE of NW corner sec 33, T23S, R21E) to perhaps 12 feet of locally quartz sandy, medium bedded, dense skeletal calcarenite (roadditch along W line NW-NW-SW sec 17, T23S, R21E), in both cases identified by its position above the coal-bearing top of the Fontana Shale and by its abundant conodont fauna (Fig. 8A). Southward the Block may be absent in the 5-foot Cherryvale interval in the roadditch (along E line NE-NE-NE sec 26, T26S, R19E) west of Goose Creek in southern Allen County, but it reappears in southernmost Neosho County 2 miles east of Morehead as 0.3 foot of dense skeletal calcarenite with abundant conodonts, below about 2.5 feet of Wea Shale with flaggy limestones overlain by the northernmost known, good definite exposure of Drum Limestone (Fig. 8A,B). In the two reference roadcuts south of Cherryvale (along US 160, S line SW-SW sec 25, T32S, R16E; 0.2 mile east of US 160-169 junction, N line NE sec 31, T32S, R17E) the Block Limestone is well exposed as about 1 foot of similar calcarenite with a similar abundant conodont fauna, below shale with limestone flags and above non-flaggy shale.

Southward, the Block may be identified within the Lower Shale Member as the thin limestone with conspicuous snails and abundant conodonts in the west bank of the Verdigris River north of the mouth of Clear Creek (near ctr sec 28, T33S, R16E). South of here the Block Limestone has not been identified, but a similar, though not as abundant, conodont fauna was obtained from shale at the top of the shaly Winterset Limestone succession in the U.S. 166 roadcut west of Coffeyville (N line NW-NW-NW sec 5, T35S, R16E; Fig. 7B). This may represent the Block/Wea interval, and it probably extends southward into Oklahoma as the shale bed at the top of the Hogshooter Limestone, which has been called "New Harmony" by A. P. Bennison.

South of its type area, the Block is a transgressive limestone above the fluvial to prodeltaic Fontana Shale in east central and southern Kansas, but unlike the typical skeletal calcilutite facies to the north (which resembles that of most other transgressive limestones), it is more lenticular and calcarenitic with abraded grains. This calcarenitic facies toward the south reflects long-term winnowing, perhaps due to the higher depositional topography on the locally thick detrital deposits of the underlying Fontana Shale Member in this region.

Wea Shale Member.--The Wea Shale Member overlies the Block Limestone Member and underlies the Westerville Limestone Member in northeastern Kansas, the Nellie Bly Shale in east-central Kansas and the Drum Limestone Member in southeastern Kansas (Fig. 2, 7B, 8A). It was named by Newell (in Moore, 1932; 1935) from Wea Creek in northeastern Miami County, and the name originally was specifically employed for shale between the Block Limestone below and the black shale bed of the higher Quivira Shale above. Moore (1948, 1949) grouped the Wea Shale with other members in the Cherryvale Formation, and he stabilized the name Wea to apply to the shale between the Block Limestone below and the Westerville Limestone above (Fig. 7A), suggesting usage of the term Wea-Quivira where the Westerville was absent and the two shales could not otherwise be separated, that is, in the absence of the black shale bed of the Quivira.

The recent recorrelation that recognizes the northward extension of the detrital Nellie Bly Formation between the Quivira Shale above, and the Drum Limestone and equivalent Westerville Limestone below (Fig. 7B), raises a problem with the typical exposures of Wea Shale listed by Newell (1935, i.e., SE cor sec 31, T16S, R24E; ctr E line sec 12, T18S, R22E) because both expose only the top of the detrital sequence below the black shale of the Quivira, and they therefore represent mostly, if not entirely, the Nellie Bly Formation. Therefore two new principal reference sections are selected for the Wea Shale Member in Miami County, both unfortunately poorly exposed, but each with the Block Limestone at the base. One is just above the type locality of the Block Limestone (along N line NE-NW sec 7, T18S, R24E) where the mostly unexposed Wea Shale interval is about 27 feet thick and is overlain by a brown sandstone (Newell, 1935, p. 144) that is presumably Nellie Bly. The other is two miles to the west-northwest (along E line just S of NE corner sec 3, T18S, R23E) where the base of the Wea consists of 1 foot of gray shale with a thin crinoidal limestone at the top, overlain by about 2 feet of siltier shale, but with an undefined top.

The Wea Shale Member is reported to be mainly greenish-gray shale in its type region, with various plant-bearing sandy beds toward the top, but these latter may well belong in the Nellie Bly Formation. The basal clayey Wea Shale dug out above the top of the type Block Limestone at the first principal reference section of the Wea (ctr N line NW sec 7, T18S, R24E) contains a very abundant conodont fauna. This confirms at least the lower part of the Wea as an offshore shale of the intermediate-scale Cherryvale cyclothem, but in which water depth did not become great enough to produce a thermocline and the resulting black shale facies. The most complete (though not easily accessible) reference exposure of the Wea Shale Member in northeastern Kansas is at the Cherryvale reference section (Fig. 8A) high in the quarry wall north of the cold storage plant along Inland Drive (near ctr N line NW-NE sec 27, T11S, K24E) in Wyandotte County, where it displays sharp contacts with both the underlying Block Limestone and overlying Westerville Limestone. Here the Wea is 7 feet of gray shale with two thin argillaceous limestone beds, one in the middle with abundant small brachiopods, and one near the base with sparse brachiopods and distinctive dark burrow mottling. Here also, the Wea Shale carries an abundant conodont fauna in the base, and thus appears to be simply a core shale, but an exposure 11 miles southward, along 119th St. at Tomahawk Creek (N line at NE cor sec 21, T13S, R25E) in Johnson County, shows at least 26 feet of gray, conodont-poor Wea Shale below a complete section of Westerville (and with Block Limestone reported by Newell, 1935 p. 104, about 4 feet further below). This succession shows a minor peak of conodont abundance at the Wea-Westerville contact, suggesting that the main body of thick Wea Shale here is a prodeltaic shale representing early regression, and that the Westerville Limestone resulted from a later minor transgression.

Northward in Missouri, the Wea Shale Member thickens to as much as 28 feet of dark gray shale with locally prominent thin beds, lenses and nodules of dark calcilutitic limestone, and a scattered but locally conspicuous fauna of brachiopods (particularly *Crurithyris*) in both rock types. It thins northward to an average of 10 feet in Iowa with more scattered thin beds and nodules of similar limestone, and local zones of abundant fossils, including other groups in addition to the brachiopods. Westward in Nebraska, the Wea Shale thins to 1 to 3 feet of fossiliferous shale, both in the Amerada core (NAC) where it was included in the Westerville Limestone by Condra (1939), and in the Richfield P.W.A. quarry, where it was named the Richfield Quarry Shale Member of the Drum Formation by Condra (1949), which is a junior synonym of Wea. Samples of this shale from both the Amerada core and the Richfield Quarry contain a moderately abundant conodont fauna that is compatible with that of the basal Wea in northeastern Kansas. The basal contact of the Wea Shale is normally sharp with the underlying Block Limestone in the northern region also, but the upper contact ranges from transitional to gradational, by alternation of shale and limestone beds, with the top of the Wea picked at the top of the thickest dark shale below the dominantly carbonate Westerville Limestone Member.

Although relatively dark in color in the northern region, the Wea is not a typical core shale because of its much greater thickness and the presence of many limestone beds in Missouri and Iowa. Both of these characteristics probably relate to a minor regression during Wea deposition that provided local environments of carbonate production in the face of periodic fine detrital influx.

Southward from its type region, the Wea Shale Member is very poorly exposed and essentially unknown in east central Kansas, particularly because it is difficult to distinguish from the overlying Nellie Bly Formation. One is tempted to suggest that the scattered sandstone beds and plant-bearing shale reported from the "Wea-Quivira" interval belong mostly, if not entirely, in the Nellie Bly, which is a more generally terrestrial sequence, whereas any marine deposits in the lower part belong to the Wea, but this presumes that the source of the Wea prodeltaic mud in Johnson County is from the east rather than from farther south along outcrop, which is not known. Theoretically, there should be a marine horizon at the top of the Cherryvale in east central Kansas that would be equivalent to the Westerville and Drum Limestones (Fig. 7B), which apparently are continuous in the subsurface (Edwards, 1987). Cores will be needed to work out the Cherryvale-Nellie Bly relations in this region of poor exposure.

Southward in southernmost Neosho County (creek valley east of Morehead, NW NW SW sec 32, T30S, R18E) and northern Montgomery County (roadcut 0.2 mile east of US 160-169 junction south of Cherryvale, N line NE¬, sec 31, T32S, R17E), the Wea Shale Member is 2 to 3 feet of gray shale with lenticular flaggy limestone beds, between the Block Limestone Member below, and the Drum Limestone Member in its type area, above (Fig. 8B). The Wea thickens westward in Montgomery County in 2 miles to at least 10 feet of otherwise similar flaggy shale in the roadcut along US 160 (S line SW SW SW sec 25, T32S, R16E). It thickens southwestward in 8 miles to perhaps nearly 45 feet along Clear Creek in section 28, T33S, R16E (estimated from Siebels, 1981, p. 39 and adding 15 feet for regional dip) above the more recently discovered thin possible Block Limestone in the bank of the Verdigris River near ctr sec 28. Where the Block Limestone is not identified, the Wea Shale merges with the Middle Flaggy Limestone Member of the Cherryvale Formation (Fig. 2, 7B).

In southern Kansas, the Wea Shale Member is relatively conodont-poor compared to the underlying conodont-rich Block Limestone, which represents the condensed interval ("core") of the Cherryvale cyclothem in this region. This, in conjunction with its flaggy lithology and local thickness changes south of Cherryvale, suggests that here the Wea Shale is largely a regressive deposit reflecting the interplay of distal prodeltaic influx and carbonate mud washed off a nearby shoal.

Middle Flaggy Limestone Member.--The informal Middle Flaggy Limestone Member of the Cherryvale Formation overlies the Lower Shale Member and underlies the Drum Limestone Member (Fig. 2, 8B) in those parts of Montgomery County where the Block Limestone Member is not recognized, and the Wea Shale Member is not defined. The Middle Flaggy Limestone

Member is about 4 feet of gray shale with several thin beds of calcilutite at the top of the hill in the Cherryvale stratotype north of Cherryvale (near ctr E line SE SE sec 32, T31S, R17E), where it overlies about 95 feet of Lower Shale Member. It thickens southward to perhaps 30 to 35 feet in scattered outcrops illustrated by Siebels (1981, p. 39, and adding 15 feet for regional dip) along Clear Creek in section 28, T33S, R16E where the lowest flags lie above only 15 feet of the Lower Shale Member (Fig. 8B). If the thin Block Limestone is correctly identified in the lower part of the Lower Shale Member here, then the flaggy limestones lie entirely within the Wea Shale Member. The upper 4 feet of flags here are well exposed and accessible at a reference section below the bridge over Clear Creek (W line SW-SW sec 28), where they consist of about one half argillaceous calcilutite flags, each from 0.2 to 0.3 foot thick, and one half essentially unfossiliferous shale. The top of the Middle Flaggy Limestone Member is picked at the top of the highest prominent shale bed here, just below the more wavy bedded Drum Limestone Member.

Southward the Middle Flaggy Limestone Member is exposed at a number of roadcuts in sections 3, 10, 15, 22 and 27, in T34S, R16E, north of Coffeyville, where complete exposures, however, are hard to find. The member aggregates a 12-foot succession along the road in ctr S« S« sec 22, where 6 feet of flags are overlain by about 0.5 foot of fossiliferous shale and capped by 5 feet of more knobby flags, all interbedded with shale. The upper part of the flag succession here may be equivalent to the Drum Limestone Member, as the typical Drum oolite facies disappears southward in section 33, T33S, R16E just south of Clear Creek, and the lower Drum beds at the Clear Creek bridge section are knobby beds of fine peloidal calcarenite, which may be a shoal-proximal facies of the flags elsewhere. Therefore, the entire 3 feet of dense, laminated, only slightly argillaceous calcilutite, which look like fused flags, above the Winterset Limestone and below shale and sandstone in the US 166 roadcut west of Coffeyville (NW cor sec 5 & NE cor sec 6, T35S, R16E), may be equivalent to most of both the Middle Flaggy Limestone and Drum Limestone members of the Cherryvale Formation (Fig. 8B), assuming that the horizon of the Block Limestone lies in the conodont-rich shale a short distance below. This fused flag unit is traced southeastward just above the Winterset Limestone, through a 3-foot exposure (along N line NW-NE-NE sec 16, T35S, R16E) to the Oklahoma border in the SE corner of the same section, south of which it appears to be locally eroded by later channeling.

Like the flaggy Wea Shale in this southern area, the Middle Flaggy Limestone Member of the Cherryvale Formation appears to represent an interplay between distal prodeltaic influx and fine limy slope deposits derived from a nearby carbonate shoal, probably associated with the locally thick Drum Limestone to the north around Independence. This shoal began shedding carbonate mud just after the Block-lower Wea transgression, and continued throughout the minor upper Wea regression and the minor Drum-Westerville transgression, until the post-Drum Nellie Bly regression brought in coarse terrestrial clastics over the entire region.

Westerville Limestone Member.--The Westerville Limestone Member overlies the Wea Shale Member and underlies the recently recognized Nellie Bly Formation in northeastern Kansas (Fig. 2). It now forms the top of the Cherryvale Formation from northeastern Kansas northward (Fig. 8A), and it is equivalent to the Drum Limestone Member, which now forms the top of the Cherryvale Formation in southern Kansas (Fig. 7B). The Westerville Limestone was named by Bain (1898) from a limestone exposure near Westerville, Iowa, which lies some distance above a limestone that was eventually determined to be the Winterset (Moore, 1936, p. 101). Its type locality, "on Sand Creek near Westerville" (which is in sec. 21, T70N, R27W, Decatur County, Iowa), has not been revisited to determine its exact identity, even considering all the "confusion in the classification and correlation of beds in this part of the section" (Moore, ibid.). Nevertheless, the name Westerville is well enough ingrained in the literature for the distinctive limestone above the Wea Shale in the Kansas City area, that it is retained in any case. The Westerville Limestone was grouped by Moore (1948, 1949) in the Cherryvale Formation as the limestone member between the Wea Shale Member below and the Quivira Shale Member above (Fig. 7A). However, the recent discovery that the Quivira Shale and superjacent Cement City Limestone overlie both the type Drum Limestone and superjacent Nellie Bly Formation in southern Kansas, means that certain beds in the base of the Quivira Shale in the Kansas City area belong to the Nellie Bly, and the Westerville Limestone is now known to be overlain by the Nellie Bly Formation in all places where the Nellie Bly is present (Fig. 8A).

The principal reference section of the Westerville Limestone Member in Kansas is along the north side of (I-70 about 0.7 mile west of 18th St. (NW-SE-NW sec 17, T11S, R25E) in Wyandotte County, but the base is well exposed only in the Cherryvale reference section high in the quarry wall north of the cold storage plant quarries along Inland Drive 4 miles to the west-southwest, where the upper Westerville is essentially inaccessible. Another good reference section for the Westerville Limestone Member is exposed 13 miles southward along 119th St at Mission Road (N line NE cor sec 21, T13S, R25E) in Johnson County.

The Westerville Limestone Member in the Kansas City area consists essentially of 3 units in ascending order: basal skeletal calcilutite (the "bull ledge" of local workers), middle oolite (the "Kansas City oolite" of older workers), and capping laminated calcilutite (Fig. 8A). The basal skeletal calcilutite ranges from about 8 feet thick at the principal reference sections along the Kansas River, westward in a few miles to about 10 feet of dominantly phylloid algal calcilutite mentioned by Heckel and Cocke (1969) near Holliday, and southward in 13 miles to 4 feet at the reference exposure on 119th St. The middle oolite bed is typically cross-bedded, fossiliferous, and lenticular. It ranges from less than 1 foot to about 6 feet thick in the principal reference exposure along I-70, from 1 to 3 feet thick in an exposure along Inland Drive (NW-SE-SE sec 22, T11S, R24E) northeast of the cold storage plant quarries, and it attains about 20 feet in Leawood at the state line (NW cor sec 35, T12S, R25E) as reported by Newell (1935). It is just as prominent and variable in thickness in Kansas City, Missouri, but it thins southward to about 0.2 foot of fine calcarenite at the reference exposure on 119th St. in Kansas. The capping barren laminated calcilutite is best shown along the I-70 reference section and nearby on Ks Rte 32, just west of the I-635 overpass, where it is about 10 feet thick. Westward and southward, this unit becomes shaly and thins to about 4 feet at the 119th St. exposure, where it is mainly shale with rubbly limestone nodules and a bed of fine peloidal calcarenite.

Thus, although quite variable, the Westerville Limestone Member in the Kansas City area displays the classic shallowing-upward sequence of open-marine through agitated shoal to peritidal deposits characteristic of regressive limestones, and it is considered the northern regressive limestone of the Cherryvale cycle. Nevertheless, its base appears to represent a minor transgression (Fig. 3) following the upper Wea prodeltaic shale wedge, which is supported by the moderate abundance of conodonts at the contact of the two units at the 119th St. exposure. The upper peritidal deposits appear to grade southward into shale that could be classified as Nellie Bly Formation at the 119th St. exposure. This shale represents a wedge of detrital sediment that penetrated a carbonate tidal flat and later underwent some degree of pedogenesis to form the rubbly carbonate nodules. Southward, the Westerville Limestone is absent, probably by lateral replacement of the top by Nellie Bly Formation and probably also by gradation of the lower part into a marine shale that one might expect to find in the poorly exposed Wea-Nellie Bly shale succession, where carbonate facies were not established during the minor transgression because of greater detrital influx at this time in east-central Kansas. The isolated exposure of conglomeratic "Westerville" reported by Newell (1935) in east-central Miami County (W line NW-SW-NW sec 7, T18S, R25E) probably belongs in the Nellie Bly Formation even though it may consist of material eroded from the Westerville Limestone (Edwards, 1987).

Northward in northern Missouri and southern Iowa, the Westerville Limestone Member ranges from 8 to 14 feet of shaly skeletal calcilutite generally grading upward to more calcarenitic facies, typically with abundant osagia-coated grains, and often very rubbly in the top. In central Iowa it thins to 2 to 6 feet of primarily osagia-grain calcarenite, locally with distinctive dark pebbles in the top, and apparently was identified as the Drum Limestone (Hershey, et. al. 1960), which in fact is its southern Kansas equivalent. In Nebraska the Westerville is about 10 to 12 feet of shaly limestone, often calcarenitic upward and also with dark pebbles at or near the top. At the Richfield PWA Quarry, this unit was regarded as the upper and major part of the Drum Limestone, which included the Richfield Quarry Shale and P.W.A. Limestone Members (Condra, 1949) below, now known to be the Wea Shale and Block Limestone Members of the Cherryvale Formation respectively.

Drum Limestone Member.--The Drum Limestone Member overlies the Wea Shale Member and the Middle Flaggy Limestone Member of the Cherryvale Formation and is now known to underlie the Nellie Bly Formation in southern Kansas (Fig. 2, 7B, 8). It was named by Adams (1903) from Drum Creek near Independence in Montgomery County, and the name became stabilized to apply to the predominantly oolitic limetone (and underlying calcilutite) exposed just east of Independence, with typical exposures along S line sec 28, T32S, R16E and in the quarry in NW sec 4, T33S, R16E (Moore, 1936). Exposures close to these are readily accessible today (e.g., US 160 roadcut along N line NW-NE¬, sec 33, T32S, R16E), but do not readily afford a complete sequence with bounding strata above and below. Therefore the new roadcuts starting 0.2 mile east of the US 160-169 junction south of Cherryvale and 1.5 mile east of Drum Creek are designated as the principal reference section of the Drum Limestone Member. The first roadcut (along N line NE sec 31, T32S, R17E) exposes complete Drum Limestone and underlying flaggy Wea Shale, Block Limestone and upper Fontana Shale members of the Cherryvale Formation, and the roadcut 0.2 mile eastward (along S line SE-SE sec 30) exposes nearly complete Drum Limestone along with overlying Nellie Bly Formation.

Although several earlier workers had correlated the Drum Limestone with the Westerville Limestone in the Kansas City area, largely on the basis of the oolite facies common to both, others (particularly Moore, 1936, 1949) insisted that the Drum, specifically its lower calcilutitic unit, correlated northward with the Cement City Limestone of the Kansas City area and southward with the Dewey Limestone of Oklahoma (Fig. 7A). This correlation resulted in the inclusion of the Cement City as a member of the Drum Limestone in the Kansas City area and northward, and in the recognition of the Dewey Limestone as the lower member of the Drum in southern Kansas. It stood until A.P. Bennison (1985) discovered the Cement City Limestone and underlying black Quivira Shale in a position 20 feet above typical Drum Limestone in its type region along a ravine into the Verdigris River (just N of ctr S line NE sec 19, T32S, R16E) on the north side of Independence, Kansas. This discovery, along with recognition of the Quivira Shale at the base of the type Dewey Limestone near Dewey and Bartlesville in Oklahoma, has caused a significant recorrelation that necessitates a major change of classification of middle Missourian units (Fig. 7).

First, type Drum Limestone is equivalent to neither the type Cement City Limestone nor the type Dewey Limestone; therefore, classifying either of them as members of the Drum is invalid. The Dewey Limestone, Cement City Limestone and Quivira Shale are recognized as parts of the same major marine unit, which herein is classified as the Dewey Limestone comprising the Cement City Limestone and Quivira Shale Members (see later section).

Second, the type Drum Limestone near Independence lies below both the Quivira Shale and its underlying terrestrial shale and sandstone, which is the northward extension of Nellie Bly Formation clastics of northern Oklahoma. Therefore the Drum Limestone is equivalent to the Westerville Limestone of the Kansas City area, which underlies the type Quivira Shale. There, however, the Quivira has included thin terrestrial mudstone and coal in its base in places, which are now regarded as a further northward extension of the Nellie Bly Formation (see later section). Even though the Drum and Westerville Limestones are not laterally continuous along outcrop, they do appear to be continuous in the subsurface (Edwards, 1987), and the base of both seem to reflect a minor transgression that interrupted the regressive phase of the Cherryvale cycle (Fig. 3). Rather than suppressing the junior name (Drum), both names are retained because they have been in common use for some time for well known units in southeastern and northeastern Kansas, respectively.

Third, for reasons developed under the discussion of the Cherryvale Formation, the Drum Limestone is now included as the capping member of the Cherryvale Formation in southeastern Kansas, which is consistent with treatment of the Westerville Limestone as the capping member of the Cherryvale Formation in northeastern Kansas (Fig. 7B). Moreover, evidence of lateral facies relations between the Drum Limestone and the Middle Flaggy Limestone Member of the Cherryvale (presented later) supports inclusion of the Drum in the Cherryvale Formation from a depositional perspective as well.

Fourth, the reduction in rank of the Drum Limestone to a member reduces its previously recognized members to beds (lower: calcilutitic Dewey/Cement City; upper: oolitic Corbin City). Because the upper oolite unit is extremely local and adequately designated by its lithology alone, the name Corbin City is abandoned. For similar reasons, no replacement is deemed necessary for the misapplied names Dewey and Cement City for the lower unit of the Drum. The conglomeratic limestone formerly included in the Corbin City Member is actually a local basal bed of the higher Chanute Shale that consists of eroded fragments of Dewey and Cherryvale lithologies. At its principal reference section, the Drum Limestone Member consists of 2 feet of skeletal calcilutite overlain by 3 to 4 feet of cross-bedded oolite (Fig. 8B). This sequence thickens eastward in 0.2 mile to over 4 feet of calcilutite overlain by 6.5 feet of oolite, with 2 feet more of 3 lenticular beds of oolite extending upward into the overlying shale. A small "patch reef" of bryozoan, brachiopod and coral-bearing calcilutite projecting 4 feet upward into the oolite at this section is a feature that may account for the disconformable contact with 5 feet of relief reported by Moore (1936, p. 106) between the two units of the Drum near Cherryvale. The Drum Limestone thins northward through 4 feet north of Cherryvale, where 3 feet of stromatolite-bearing skeletal calcilutite is overlain by 1 foot of oolite in a roadcut (along S line SE-SE-SW sec 28, T31S, R17E), to 1.5 feet along Ks. Rte 37 (E line SE-SE-NE sec 4, T31S, R17E) to just 1 foot of skeletal calcilutite/calcarenite at the reference section in the creek valley east of Morehead (NW NW-SW sec 32, T30S, R18E) in southernmost Neosho County, which currently is its northernmost known good exposure (Fig. 8A).

Westward the Drum Limestone Member thickens to perhaps 60 feet of mainly oolite, characteristically oomoldic, in prominent exposures along the Verdigris River south of the US 160 bridge just east of Independence, and in the cement plant quarries just to the south (N« sec 5, T33S, R16E). Southward the Drum thins to about 14 ft at the reference section in the road ditch on the south side of Clear Creek (W line NW-SW-SW sec 28, T33S, R16E) where it is oolite grading downward into thin wavy-bedded peloidal calcarenite resting on more evenly bedded shale-parted flags of the Middle Flaggy Limestone Member. Although the lower contact of the Drum Limestone here is placed at the base of the more wavy-bedded limestone above a prominent shale parting, a section about 1 mile to the east-southeast (W line NW-SW-NW sec 34) shows a more gradational contact from oolite downward through fine peloidal calcarenite to typical middle Cherryvale flags. This also is the southernmost currently known exposure of obvious, though fine grained and non-oomoldic, oolite. Southward all the limestone at this horizon is flaggy and is included within the Middle Flaggy Limestone Member of the Cherryvale, but the knobby flags in an old quarry (in SE-SW sec 22, T34S, R16E) 2 miles north of Coffeyville show zones of peloidal calcarenite in the calcilutite matrix, suggesting that the top of the flags unit here is equivalent to the base of the Drum Limestone northward (Fig. 7B, 8B). Thus although the lower contact of the Drum Limestone Member is sharp over shale to the north, it is laterally gradational with the increasingly limy Middle Flaggy Limestone Member to the south, lending further support to inclusion of the Drum Limestone as a member in the Cherryvale Formation.

The Drum Limestone Member appears to be a local, but complex, laterally variable carbonate buildup, with both reefy and oolitic facies generated on thicker parts of the Cherryvale prodeltaic shale in the north. The oolite migrated southwestward into a paleotopographic low, as indicated by its dominant cross-bedding direction (Stone, 1984) and by recent coring (Feldman and Franseen, 1991). The flaggy slope facies also migrated southward, as shown by increasingly coarser peloidal material from the northern shoal appearing upward in the flag sequence in this direction. A minor transgression, suggested by somewhat increased conodont abundance at the Wea-Drum contact in the principal reference section south of Cherryvale (and having a counterpart in the basal Westerville Limestone to the north), may have initiated the major period of shale-free Drum carbonate production, but the flags below suggest that earlier buildups may have already developed nearby. The later regression that brought in Nellie Bly clastics terminated oolite formation earlier in some areas than in others, resulting in the tongues and lenses of oolite occurring in shale above the main body of Drum oolite.

Nellie Bly Formation

The Nellie Bly Formation is now recognized in Kansas (Fig. 2, 7B) overlying the Cherryvale Formation (Drum Limestone, Westerville Limestone, or Wea Shale Member) and underlying the Dewey Limestone (black Quivira Shale Member). The name Nellie Bly was applied by Gould (1925, based on an unpublished manuscript by Ohern, 1914) to shale and sandstone above the Hogshooter Limestone and below the Dewey Limestone, exposed along Nellie Bly Creek in sections 28, 29, 32 and 31 (sic; 33?), T24N, R13E (Oakes, 1940a), just southwest of Ramona in Washington County, Oklahoma. In its type region in T24 and T23N, the Nellie Bly ranges from 115 to 180 feet of sandy shale grading upward to sandstone. It thins northward to about 80 feet of a similar sequence in T28N, where its top and the overlying Dewey Limestone were removed by post-Dewey erosion, and the resulting channel was filled with sandstone (Noxie) of the lower part of the overlying Chanute Shale (Fig. 8B). Flaggy limestones that are not seen farther south were reported in the lower Nellie Bly Formation on the Kansas border (near ctr N line sec 14, T29, R15E) by Oakes (1940a), who felt that they probably correlate with similar flaggy beds north of Coffeyville, Kansas. These are now known to be the Middle Flaggy Limestone Member of the Cherryvale Formation and to include the southern equivalent of the Drum Limestone Member at the top of the Cherryvale.

Because of the long-standing miscorrelation of the type Dewey Limestone of Oklahoma with the type Drum Limestone of southern Kansas (Fig. 7A), the Nellie Bly Formation has been considered to be the southern equivalent of the Cherryvale Formation (Moore, 1948, p. 2031). The recent discovery by A.P. Bennison of Dewey-equivalent Cement City Limestone and black Quivira Shale 20 feet above the Drum Limestone in its type area along the Verdigris River just north of Independence, Kansas, in conjunction with the recognition that the Middle Flaggy Limestone Member of the Cherryvale Formation around Coffeyville contains the southern equivalent of the Drum Limestone in its top, means that the 20 feet of shale and sandstone between the Drum and Dewey Limestones at Independence, rather than the Cherryvale Formation below the drum, is the northward extension of the Nellie Bly Formation (Fig. 8B). Recognition of the thin unit of flaggy limestone on the Kansas-Oklahoma border as the Cherryvale Formation, lying below the terrestrial Nellie Bly, emphasizes the important stratigraphic relations clarified by the recorrelation. Therefore, the lower boundary of the Nellie Bly Formation in Kansas is placed at the top of the Cherryvale Formation (Fig. 7B). This is relatively straightforward where the upper member of the Cherryvale is limestone (Drum, Middle Flaggy Member, or Westerville, although some lateral gradation is recognized in places, as elaborated in previous sections). Thus for consistency, the thin Cherryvale-equivalent dark shale and limestone in Oklahoma should be included within the underlying Hogshooter Limestone rather than within the overlying Nellie Bly Formation (or perhaps eventually could stand alone, as elaborated in the previous section on the Hogshooter Limestone).

In southern Kansas, the principal reference section for the Nellie Bly Formation consists of about 20 feet of shale-parted sandstone grading upward into sandy shale along the Verdigris River and a small tributary (just N of ctr S Line NE sec 19, T32S, R16E) on the north side of Independence. Southward the Nellie Bly has been largely removed in places by post-Dewey erosion, and the channel filled with younger sandstone (Noxie) of the lower Chanute Shale (Fig. 8B). Even where the Dewey Limestone still remains in erosional outliers (overlooked by earlier workers; see later section for localities), the entire shale and sandstone sequence of the Nellie Bly was previously included in the lower Chanute. Where limestone conglomerate in the lower Chanute, which consists largely of eroded and redeposited fragments of Dewey Limestone, was noted around Coffeyville by earlier workers (e.g., Moore, 1936, p. 106), it was considered erroneously as part of the Corbin City Member (now abandoned) of the Drum Limestone. Recognized now as basal Chanute Shale, this conglomerate delineates the top of the Nellie Bly Formation in places where it is present. Where both the conglomerate and the Dewey Limestone are missing (as in most of T33, T34 and T35S), the Nellie Bly Formation is difficult to distinguish from the Chanute Shale.

Northeast of Independence, where both the Dewey Limestone and the Drum Limestone have been traced into southern Neosho County by A.P. Bennison, the Nellie Bly Formation occupies the approximately 30-to 50-foot interval between them. In this area the Dewey had apparently been overlooked by previous mappers, and so here too the Nellie Bly had been included in the lower Chanute Shale. North of the northernmost definite Drum Limestone exposure in southern Neosho County, the Drum may be largely absent, and so the Dewey Limestone was misidentified as the Drum, and the Nellie Bly Formation would have been included in the upper part of the Wea-Quivira interval of the Cherryvale Formation. Scattered reports of thin sandstones and sandy shale in this generally poorly exposed interval across east-central Kansas probably refer mainly to the Nellie Bly. In better exposures in Miami County, the Nellie Bly probably encompasses most if not all of the upper sandy beds (Fig. 8A), often with plant fossils, originally assigned to the Wea Shale, and includes near the top a maroon shale bed in some places and a thin local coal in others (Miller 1966).

Throughout southeastern Kansas and Oklahoma, the Nellie Bly Formation represents fluvial to deltaic sediment deposited during and after the regression of the sea that closed the Cherryvale marine cycle. Therefore the conglomeratic limestone in eastern Miami County (S of ctr W line NW sec 7, T18S, R25E) regarded as Westerville Limestone by Newell (1935) and possibly consisting of eroded fragments of Westerville, more appropriately belongs in the Nellie Bly Formation (Edwards, 1987).

In the Kansas City area where the Westerville Limestone is present, the Nellie Bly Formation has been included in the base of the Quivira Shale Member. It is absent in some places where the Quivira is thin and rests directly upon the top of the Westerville, as in much of the long roadcut along I-70 in N« sec 17, T11S, R25E. The Quivira Shale has been revised to exclude the heterogeneous beds below the gray to black, clayey to fissile shale beds at the top (and the thin local limestone that directly underlies them in places), and is now grouped with the Cement City Limestone as a member of the Dewey Limestone (Fig. 7B). The upper contact of the Nellie Bly Formation with the revised Quivira Shale Member is one of marine, often black shale of the Quivira, or thin marine limestone where present, above Nellie Bly terrestrial mudstone or sandstone, much like the contact between the black Stark Shale Member of the Dennis Limestone above the Galesburg Shale where the Canville Limestone Member is absent. Where present in most of the Kansas City area (Fig. 7A), the Nellie Bly Formation is from less than 1 foot to several feet of gray to tan to locally reddish mudstone, typically with calcareous nodules, and locally containing a thin coal. A good reference section of 0.5 foot of gray Nellie Bly blocky mudstone is exposed above the Westerville Limestone along Ks Rte 32 just west of the landfill entrance (ctr W« SE« SE« sec 12, T11S, R24E) in Wyandotte County. It probably represents largely a paleosol developed during subaerial exposure of the Westerville Limestone.

Just southeastward in Cass County, Missouri, the Nellie Bly Formation includes the 25- to 30-foot thick Belton Sandstone and overlying nodular limestone, underclay, coal, and sandstones, which were assigned by Gentile (1983) to the overlying Quivira Shale. Northward the Nellie Bly Formation ranges from 3 to 14 feet of gray shale to mudstone, locally with reddish mottling and locally with an underclay and thin coal at the top. It thins to 2 to 4 feet in Iowa and Nebraska

(Fig. 6) where it is largely a blocky mudstone often overlain by a thin coal. In both states the Nellie Bly has been misidentified as the Chanute Shale with the Thayer coal bed, because the overlying Dewey Limestone (with the black Quivira Shale Member) had been misidentified as the higher Iola Limestone (with the black Muncie Creek Shale Member).

Dewey Limestone

The Dewey Limestone is now recognized in Kansas as a formation that comprises the Cement City Limestone Member at the top, and the Quivira Shale Member at the base; the Dewey overlies the Nellie Bly Formation and underlies the Chanute Shale (Fig. 2, 7B). The Cement City Limestone previously had been miscorrelated with, and included as a member within, the Drum Limestone of southern Kansas. The Quivira Shale previously had been included as the top member of the Cherryvale Formation in northeastern Kansas (Fig. 7A), because of this miscorrelation.

The Dewey Limestone was named by Ohern (1910) from exposures in the old cement plant quarry (sec 26, T27N, R13E) east of Dewey in Washington County, Oklahoma. Oakes (1940a) traced the Dewey from a locality in Nowata County about 2 miles east of Wann and 6 miles south of the Kansas border (near ctr sec 13, T28N, R14E) southward through the Dewey-Bartlesville area, to the north part of T16N, R10E, a few miles southwest of Kellyville in Creek County southwest of Tulsa. He also indicated that the Dewey is probably equivalent to the Belle City Limestone of central Oklahoma, even though the two units apparently are not continuous along outcrop. From exposures both in the Dewey Limestone 2 miles southwest of Kellyville (quarry on hillside in SW-NE sec 28, T17N, R10E) and in the Belle City Limestone northwest of Sasakwa (Dolese Quarry in E« sec 24, T6N, R6E) in Seminole County, 70 miles to the south, a thin shale within the limestone sequence yields conodonts characteristic of the Quivira Shale Member, thus confirming these correlations to the south.

Northward from the locality near Wann, however, the Dewey Limestone was largely removed by pre-Chanute erosion across T29N in Oklahoma and in most parts of T35, T34 and T33S in Montgomery County, Kansas, (Fig. 8B). The principal reference section for the Dewey Limestone in southeastern Kansas is an excellent (though not readily accessible) outcrop in a ravine in the west bluff of the Verdigris River (just N of ctr S line NE sec 19, T32S, R16E) on the northern outskirts of Independence, Kansas. This exposure includes both the Cement City Limestone Member and underlying black Quivira Shale Member, totaling 5 feet in thickness, and resting upon 20 feet of shale and sandstone (Nellie Bly Formation) above typical Drum Limestone (Fig. 8B) in its type area. The discovery of this exposure by A.P. Bennison corrected the longstanding miscorrelation of the Cement City Limestone with the Drum Limestone. Moreover, the discovery of conodont faunas characteristic of the Quivira Shale in this black shale at Independence, and also in black and gray shale at the base of the type Dewey Limestone in Oklahoma, corrected the long-standing miscorrelation of the Dewey Limestone with the type Drum Limestone in Kansas and also confirmed the correlation of the Dewey with the Cement City Limestone of the Kansas City area, which had been made by previous workers.

Therefore both the Dewey and the Cement City Limestones are removed from the Drum Limestone of the old Kansas classification (Fig. 7A). Because the beds now known to be Quivira Shale had been included as the "middle shale member" within the Dewey Formation in the Tulsa area of Oklahoma by Oakes (1952), the most reasonable way to deal with the revision of nomenclature necessitated by the recorrelation is to recognize the Dewey Limestone as a formation comprising the Cement City Limestone and Quivira Shale as members throughout the entire Midcontinent, and also to recognize the Drum Limestone as a member of the Cherryvale Formation below (Fig. 7B). A local lower limestone member of the Dewey is recognized in the Tulsa area of Oklahoma, where it was informally termed Wekiwa limestone by A.P. Bennison. A lower limestone also is recognized at places in northwestern Missouri and central Iowa, where it has been named informally Pammel Park limestone bed by Heckel and Pope (1992). Thus the Dewey Limestone is basically a classic Kansas-type cyclothem recording a major transgression and regression of the Midcontinent sea (Edwards, 1987), differing from others mainly in the local, lenticular nature of the transgressive limestone and in the more frequent lateral gradation of black shale into gray shale facies in the Quivira Shale Member along the outcrop and subcrop belt.

Critical outcrops of the Dewey Limestone in southern Kansas above the level of the type Drum Limestone were overlooked by previous workers, thus contributing to the miscorrelation of the Dewey with the Drum in spite of Ohern's (1910) belief that the Dewey lay stratigraphically above the Drum. Many of these outcrops have been discovered recently by A.P. Bennison, e.g., on a small rise back of the motel on US 160 on the eastern outskirts of Independence (NW-NW-NW sec 32, T32S, R16E), around a hill southeast of the Drum Limestone quarries (in ctr N« N« sec 9, T33S, R16E), and in a roadcut east of Montgomery County State Park (along S line SE-SE-SW sec 17, T33S, R16E), where the black Quivira Shale is exposed eastward in the ditch. The position of the latter two exposures as outliers within the large Chanute sandstone-filled channel complex across southernmost Kansas (T33-35S) and northernmost Oklahoma (T29N) is shown by sandstone at the horizon of the Dewey Limestone just west of the roadcut exposure (along S line SW-SE-SW sec 17) and by masses of probable Dewey-derived limestone in a shale and sandstone succession just above the level of the Drum Limestone quarries about 1 mile west of the hill exposure (along W line SW cor SE sec 5, T33S, R16E).

Exposures of more conglomeratic limestone near this horizon above the Drum-equivalent flaggy limestone member of the Cherryvale Formation west of Coffeyville were known to earlier workers, but they were considered (erroneously) to be part of the Corbin City Member (now abandoned) of the Drum Limestone (Moore, 1936, p. 106). Current exposures of conglomeratic limestone are known along roads in this area (south of ctr E line NE sec 18, T35S, R16E; both east and north of SW cor sec 6, and west of NE cor sec 6, T35S, R16E) the latter along US Rte 166 west of Coffeyville, and on the west side of the old quarry (NE-NE-NW sec 33, T33S, R16E) southeast of the Clear Creek bridge. All appear to represent accumulations of Dewey-derived and probably some Cherryvale flag-derived material in Chanute channels.

North of Independence, A.P. Bennison discovered overlooked exposures of Dewey Limestone (with Quivira Shale) well above typical Drum Limestone northwest of Cherryvale (along N line NE-NW-NW sec 1, T32S, R16E; and at SE cor sec 25, T31S, R16E) in northeastern Montgomery County; 2.3 miles east of Morehead (along N line at NW cor sec 5, T31S, R18E) in northernmost Labette County, and about 2 miles north of Morehead (along ctr E line SE-SE sec 23, T30S, R17E), in southwesternmost Neosho County.

Northward across east-central Kansas to the Kansas City region, the Dewey Limestone had been mismapped as the Drum Limestone, which may become lenticular and pinch out northward in Neosho County, thus facilitating the jump in stratigraphic level. Good reference sections of Dewey (Fig. 8A) in eastern Kansas include the roadditch west of Goose Creek (E line NE-NE-NE sec 26, T26S, R19E) in southern Allen County; the creek bed at US 59 (near NE cor sec 2, T24S, R20E) west of Bayard in northern Allen County; the streambank southeast of Kincaid (SW-SW-SE sec 7, T23S, R21E) in Anderson County; the roadcuts 1 mile east of Osawatomie (S line SW SE NE sec 12, T18S, R22E) and 1 mile west of Somerset (N line NW-NE-NE sec 6, T17S, R24E) in Miami County; and along the north side of I-70 between 18th St and Park Road exits (across N« sec 17, T11S, R25E) in Wyandotte County. In the Kansas City region, the Dewey Limestone comprises the type Quivira Shale and the type Cement City Limestone as its members and totals an average of 12 feet in thickness.

Farther northward throughout Missouri, Iowa and Nebraska (Fig. 6), the Dewey Limestone ranges from 7 to 14 feet in thickness. It comprises the Quivira Shale and Cement City Limestone Members and includes in the Quivira a local basal limestone bed in cores MPC, MBC and MRC in Missouri, and in both core and outcrop in Madison County, Iowa. Along the Iowa and Nebraska outcrop, the Dewey has long been misidentified as the Iola Limestone and its component members, the Raytown Limestone and Muncie Creek Shale, and locally in Madison County, Iowa, the basal Paola Limestone as well. The recorrelation of these strata is based on lithostratigraphic tracing of units northward through the long cores in Missouri and southern Iowa to the near-surface cores and outcrops in central Iowa and Nebraska (Fig. 6); it is confirmed by identification of the characteristic conodont fauna of the Quivira Shale (which is distinct from that of the Muncie Creek Shale Member of the Iola Limestone) in the shale at this horizon in all the Missouri cores, in both Nebraska cores (NAC, NOC), in two Iowa cores (IBC, IMC), and in an outcrop previously identified as Iola/Muncie Creek, south of Pammel State Park in Madison County, Iowa (SW-NW sec 22, T75N, R28W). Thus all exposures previously referred to as Iola Limestone in Iowa and Nebraska are actually Dewey Limestone.

Quivira Shale Member.--The Quivira Shale is now recognized as the lower member of the Dewey Limestone in Kansas. It overlies the Nellie Bly Formation and underlies the Cement City Limestone Member (Fig. 2, 7B). It was named in Moore (1932) and formally described by

Newell (1935) from former exposures below the dam at Quivira Lake (near SW cor sec 32, T11S, R24E) in Wyandotte County on the western outskirts of Kansas City. Because it lies below the Cement City Limestone, which then was correlated with the Drum Limestone, it was understandably considered by Moore (1948, 1949) to be at the top of the Cherryvale Formation in the Kansas City area (Fig. 7A). Now that the Drum is known to correlate with the Westerville Limestone, which underlies the Quivira Shale in its type region, the Quivira is therefore removed from the Cherryvale Formation.

Because sandstone and shale of the Nellie Bly Formation are now known to lie above the type Drum Limestone and below the type Dewey Limestone, and because the Dewey Limestone includes marine beds now known to be Quivira Shale in the Dewey type region in Oklahoma, and is now regarded as including the Quivira Shale as a member across the Midcontinent, the terrestrial strata more properly assignable to the Nellie Bly Formation are now removed from the lower part of the Quivira Shale where they have been included in much of the Kansas City area and northward. Thus the tan blocky mudstone, often with calcareous nodules, that usually forms the base of the shale sequence between the Westerville and Cement City Limestones and locally is capped with a thin coal, are assigned to the Nellie Bly Formation rather than to the Quivira Shale in the Quivira type area. This removes roughly the lower half of the original type section from the Quivira (based on nearby sections measured by Newell, 1935, p. 86, 89). Because of poor exposure of the older described sections, the principal reference section of the Quivira Shale Member is now designated in a good accessible exposure along the north side of Ks Rte 32 just west of the landfill entrance (ctr W« SE-SE sec 12, T11S, R24E) in Wyandotte County, about 6 miles from Quivira Lake, and where it is underlain by 0.5 foot of Nellie Bly mudstone. Another good exposure is along the north side of Inland Drive (ctr W line SE-NW sec 23, T11S, R24E) 2 miles to the southwest. In some places the terrestrial Nellie Bly Formation was not developed on top of the underlying Westerville Limestone, and the marine Quivira Shale lies directly upon the Westerville, as in part of the Dewey Limestone reference section along I-70 between the 18th St. and Park Road exits (N« sec 17, T11S, R24E).

The Quivira Shale Member, as revised herein, ranges from 3 to 5 feet of gray to black marine shale with small phosphatic nodules, scattered macrofossils and abundant conodonts in its type area in the Kansas City region. It contains a thin limestone locally at the base, but generally its lower contact is one of medium to dark gray marine shale overlying lighter gray or locally tan to maroon Nellie Bly mudstone with calcareous nodules, and is rather diffuse in most exposures. The conodont fauna, which is generally most abundant in the black facies, is subdominated there by the genera *Idiognathodus*, *Streptognathodus* and *Gondolella*. It is characterized by the abundance of a distinctive large-lobed morphotype of *I. magnificus*, which has allowed ready recognition of the Quivira Shale among the several dark shales traceable along the Midcontinent outcrop. This has been most useful in confirming the correlation of the Quivira-Cement City sequence with the type Dewey Limestone of Oklahoma, in recorrelating the strata misidentified as Iola Limestone in Iowa and Nebraska with the Dewey (Fig. 6), and in recorrelating the type Drum Limestone with the Westerville at the top of the Cherryvale Formation rather than with the Cement City and Dewey Limestones (Fig. 7).

Northward in Missouri, Iowa, and Nebraska, the Quivira Shale Member ranges from 2 to 4 feet of gray shale with a black facies occupying roughly the lower half of the sequence, particularly in the more northern region, where (in Iowa and Nebraska) it had been misidentified as the Muncie Creek Shale Member of the Iola Limestone. A basal limestone ranging from 0.5 to 2 feet of skeletal calcilutite is present locally in Missouri (cores MPC, MBC, and MRC on Fig. 6) and in Madison County, Iowa, where it is prominent in exposures around Pamme Park. It has been named informally the Pammel Park limestone bed from this area by Heckel and Pope (1992). This limestone is rarely present and very thin in Kansas.

Southward from its type area, the Quivira Shale Member is well exposed only rarely below the ledge-forming Cement City Limestone. Where observed, the Quivira ranges from 2 to 5 feet of gray shale with about 1 foot of dark gray clayey to black fissile shale at the base (Edwards, 1987). A good reference section is in the roadcut 1 mile east of Osawatomie (S line SW-SE NE sec 12, T18S, R22E) in Miami County, where the Quivira and its basal contact with terrestrial shale of the underlying Nellie Bly Formation is exposed in a rill at the east end of the cut. Other Quivira reference exposures are in the roadcut 1 mile west of Somerset (N line NW-NE-NE sec 6, T17S, R24E) in Miami County, where it can be dug out, in a creek bank southeast of Kincaid (SW-SW-SE sec 7, T23S, R21E) in Anderson County, where it carries large limestone concretions that contain ammonoids, and in the creek beneath the US 59 bridge near Bayard in Allen County. The Quivira Shale is very poorly exposed southward in Allen and Neosho Counties, but it reappears as about 2 feet of mostly black fissile phosphatic shale in Montgomery County at exposures mentioned previously under discussion of the Dewey Limestone.

An exposure of about 3.5 feet of mostly black fissile shale resting on limestone and overlain by several feet of Chanute sandstone, with a rusty-stained, perhaps erosional contact, 3 miles east of Chanute near Greenwood Cemetery (south stream bank in NE cor SE-NE sec 26, T27S, R18E), was considered to be the Stark Shale Member of the Dennis Limestone by previous workers, who thus regarded the Chanute as having eroded out the entire Drum (Dewey) and Cherryvale Formations and Winterset Limestone Member of the Dennis (which is quite thick in this area). Recent recognition of black Quivira Shale in southeastern Kansas, in conjunction with the old report by J.M. Jewett (KGS stratigraphic files) of definite Stark Shale, Canville Limestone and Galesburg Shale 3 miles to the southeast at an old ford across the Neosho River (N« NE sec 8, T28S, R19E) about 30 feet lower in elevation, and possibly an additional 90 feet below (from regional dip) the black shale exposed at the Greenwood Cemetery locality, suggests that the black shale beneath the sandstone east of Chanute is Quivira; so far, not enough well preserved conodonts have been released from the leached but refractory shale to confirm the correlation. If it is Quivira Shale, then the Chanute sandstone has eroded out only the Cement City Limestone at this locality. The identity of the underlying limestone, which is only partially exposed in the creek bed, is unknown, but it resembles the Winterset, suggesting that the black shale itself rests in a channel that cut out the entire Nellie Bly and Cherryvale Formations, a situation that is not unreasonable considering the thin 5-foot Cherryvale-Nellie Bly interval in the roadditch west of Goose Creek (E line NE NE NE sec 26, T26S, R19E) about 9 miles to the northeast.

The Quivira Shale in Oklahoma ranges from 0.2 to 1 foot of black fissile shale in the Dewey-Bartlesville area (Edwards, 1987), and thickens southward to several tens of feet in the Tulsa region where it is mostly gray shale becoming darker toward the base where it contains phosphate nodules and ammonoids. A thin basal bed of limestone was informally termed Wekiwa Limestone by A.P. Bennison from a locality west of Tulsa. This name should apply to only the uppermost, nonsandy bed of the sequence of thin calcareous strata referred to as "lower Dewey" by Oakes (1952), because the remainder are interbedded with sandstones and are more appropriately included in the underlying Nellie Bly Formation. Southward at the quarry southwest of Kellyville in Creek County and in the Belle City Limestone exposed in the Dolese quarries northwest of Sasakwa in Seminole County, the Quivira Shale, identified by its distinctive conodont fauna, is thinned down again to 1 to 2 feet.

Throughout its extent from Iowa to Oklahoma, the Quivira Shale Member is a typical offshore shale for the Dewey cyclothem deposited within or below a pycnocline during sea-level highstand, but it has a somewhat more lenticular black shale facies than do other major cycles. This may reflect more local underlying topographic variation than the more regional features, such as underlying deltas, algal mounds or the Bourbon arch, that apparently affected other major cycles that display more regionally discontinuous black facies.

Cement City Limestone Member.--The Cement City Limestone is now recognized as the upper member of the Dewey Limestone throughout Kansas. It overlies the Quivira Shale Member and is overlain by shale and sandstone of the Chanute Shale (Fig. 2). It was named by Hinds and Greene (1915) from exposures in the cement plant quarry at Cement City, northeast of Kansas City in Jackson County, Missouri, and has long been well known above the dark Quivira Shale throughout the Kansas City region. The Cement City Limestone was previously correlated with, and classified as a member of the Drum Limestone (Fig. 7A), but the discovery by A.P. Bennison of Cement City Limestone and Quivira Shale 20 feet above the Drum in its type region near Independence in southern Kansas necessitates the removal of the Cement City from the Drum Limestone. Moreover, the recognition of the Quivira Shale in the base of the type Dewey Limestone of northern Oklahoma leads reasonably to the inclusion of the Cement City and Quivira as members of the Dewey Limestone (Fig. 8B).

The Cement City Limestone Member in its type region averages about 8 feet of wavy-bedded skeletal calcilutite with conspicuous horn corals in the upper part. This is overlain locally by up to 1 foot of skeletal calcarenite, a shallowing-upward sequence typical of regressive limestones. Both lower and upper contacts are sharp with underlying and overlying shale. A good accessible reference section is along the north side of Kansas Rte 32 just west of the I-635 overpass (SW-SE-SW sec 7, T11S, R25E) in Wyandotte County, where the overlying Chanute Shale is well exposed. Another is along the north side of Inland Drive (near ctr W line SE-NW sec 23, T11S, R24E) where the underlying Quivira Shale is well exposed. Both adjacent units are well exposed with the Cement City in the reference section for the entire Dewey Formation in northeastern Kansas along the north side of I-70 (across N« sec 17, T11S, R25E) just 1 mile east of the K-32 exposure, and the entire sequence is most accessible along the westbound exit ramp to Ks Rte 32 (E« NE-NE sec 18), which is designated the principal reference for the Cement City Limestone Member in Kansas. The Cement City thins southward in the Kansas City region to about 6 feet thick in the Mission Road exposure at 119th Street (W line NW cor sec 22, T13S, R25E) just east of Tomahawk Creek in Johnson County.

Northward in Missouri, the Cement City Limestone Member ranges from 5 to 10 feet of generally shaly calcilutite to oncolitic and fusulinid calcarenite in two of the cores (MBC, MRC). In Iowa it is generally 9 to 10 feet of shaly skeletal calcilutite grading upward to calcarenite and locally capped by laminated calcilutite with shale-filled fractures in the top, a classic shallowing-upward sequence to subaerial exposure at the top. In Nebraska it ranges from 8 to 13 feet of similar but less shaly limestone. In both Iowa and Nebraska, the Cement City Limestone has long been misidentified as the Raytown Limestone Member of the Iola Limestone, the next higher major cyclothem.

Southward from its type region around Kansas City (Fig. 8A), the Cement City Limestone Member thins to about 2 to 5 feet of brownish-weathering skeletal calcilutite with conspicuous white crinoid columnals in most exposures throughout east central to southeastern Kansas, where it generally has been misidentified as the Drum Limestone. One to several feet of capping skeletal calcarenite are known locally in Miami and Linn Counties and were generally misidentified as the Corbin City Member (abandoned) of the Drum Limestone. Reference sections of the Cement City Limestone include a roadcut northwest of Drexel Corners (W line NW-SW-NW sec 7, T18S, R25E) where it is only 2 feet thick, and the roadcuts 1 mile east of Osawatomie (S line SW-SE NE sec 12, T18S, R22E) and 1 mile west of Somerset (N line NW-NE-NE sec 6, T17S, R24E) where it has the calcarenite bed at the top, all in Miami County; the streambank southeast of Kincaid (SW-SW-SE sec 7, T23S, R21E) in Anderson County; in the creek where it forms a small falls west of the US 59 bridge near Bayard (NE-NE-NE sec 2, T24S, R20E) in northern Allen County; in the roadcut west of Goose Creek (along E line NE-NE-NE sec 26, T26S, R19E), where it is grayer and appears to contain clasts, in southern Allen County. The Cement City only recently has been discovered in the Drum Limestone type area in Montgomery County, where it is exposed at the principal reference section for the Dewey Limestone in southeastern Kansas above the Drum Limestone in the ravine in the west bluff of the Verdigris River north of Independence (just N of ctr S line NE sec 19, T32S, R16E). It is also exposed at the more accessible roadcut northeast of Montgomery County State Park (along S line SE SE-SW sec 17, T33S, R16E) where it is cut out just to the west by Chanute sandstone in this area of general channeling and removal, and in other exposures in this region located in the section on the Dewey Limestone.

Southward in Oklahoma, the Cement City Limestone constitutes the main mass of the Dewey Limestone in its type area around Dewey and Bartlesville (Fig. 7B), where it forms a phylloid algal mound complex up to 30 feet thick mentioned by Heckel and Cocke (1969) and described in more detail by Edwards (1987). Here it shoals upward to subaerial exposure at the top, indicating that the typical regressive sequence extended at least this far south along outcrop. Southward the Cement City Limestone thins to a few feet above thickened Quivira Shale as the upper Dewey Limestone of Oakes (1952) in southern Osage and Tulsa Counties. Its equivalent is 16 feet thick as the top of the Belle City Limestone in the Dolese quarry northwest of Sasakwa (E« sec 24, T6N, R6E) in Seminole County.

Chanute Shale

The Chanute Shale is now recognized as the shale and sandstone formation lying above the Dewey Limestone (Cement City Limestone Member) and below the Iola Limestone (Paola Limestone Member) (Fig. 2). The Chanute Shale was name by Haworth and Kirk (1894) from exposures around Chanute in northwestern Neosho County. The stratigraphic extent of the unit was stabilized by Moore (1936) to the beds between the Drum Limestone below and the Iola Limestone above. He recognized, however, that the base of the Chanute Shale is erosional in many places in southern Kansas, where it therefore lies directly upon older units. In view of the recent recognition 1) that the type Drum of southeastern Kansas had been miscorrelated both southward with type Dewey Limestone of northern Oklahoma and northward with type Cement City Limestone of the Kansas City region, 2) that type Drum is actually older, correlating northward with the Westerville Limestone below the Cement City and southward probably with the top of the Hogshooter Limestone below the Dewey, and 3) that the Nellie Bly Formation between the Hogshooter and the Dewey Limestones in Oklahoma extends northward between the Drum and the Dewey Limestones in southern Kansas (Fig. 7), then the basal beds of the Chanute Shale in the type region of the Drum Limestone in southernmost Kansas probably belong to the Nellie Bly Formation. However, because the Dewey and Cement City Limestones are correlative, their miscorrelation with the Drum Limestone led to practical application of the term Chanute Shale in both Oklahoma and east central to northeastern Kansas to strata extending from the Dewey Limestone to the Iola Limestone, and this situation obtains in the Chanute type area in northern Neosho County. Thus the only area that the previously defined Chanute Shale has included strata that are now known to be Nellie Bly is Montgomery and adjacent parts of Neosho, Labette and Wilson counties, Kansas. Because the Dewey Limestone is now recognized across most of this area, it is most reasonable to redefine the base of the Chanute Shale in its type region at the top of the Dewey (Cement City Limestone Member), thereby retaining the name Chanute for the same strata as currently recognized in both northern Oklahoma and east central to northeastern Kansas.

The only precisely listed (but mislocated) exposure of those given as typical for the Chanute Shale by Moore (1936) was "in SE sec 33, T26S, R18E" in Allen County, 3 miles north of Chanute, where Miller (1969) noted that a 20-foot thick section measured by N.D. Newell extends from the "Drum Limestone" to the Iola Limestone and contains the Thayer coal. This section was recently rediscovered about 1 mile to the east along center S line SE-SE sec 34, T26S, R18E, where it is only poorly exposed now but includes both overlying (Paola) and underlying (Cement City) limestones, and therefore is regarded as the type section of the Chanute Shale. A better exposure of the upper Chanute occurs at the underpass of new US 169 over the old highway 1.3 miles westward in SE-SW-NE sec 33, T26S, R18E, where at least 17 feet of sandy micaceous shale with thin sandstone beds are well exposed below the Iola Limestone. Supplementing the type section is a partly exposed 65-foot section of dominantly sandstone near Greenwood Cemetery, 3 miles east of Chanute, extending southward along E line SE-NE sec 26, T27S, R18E from the top of the probable Quivira Shale (see previous section) in the creek bed at ctr E line NE sec. 26, to the base of the Iola Limestone at the top of the hill just south of ctr E line sec 26. This section spans the Chanute interval where it is thicker and dominated by sandstone.

Near the middle of the Chanute Shale in its type region of southeastern Kansas is the Thayer coal bed (Fig. 2), named by Adams (1896) from exposures around Thayer in Neosho County. The Thayer coal has been used to divide the Chanute Shale into two members, the Noxie sandstone below, named by Moore et al. (1937), from exposures around Noxie (NW cor sec 30, T29N, R15E) in northern Nowata County, Oklahoma, and the Cottage Grove sandstone above, named by Newell (in Moore 1932; 1935) from Cottage Grove Township (south half of T26S, R18-19E) in Allen County, Kansas. Because of the notorious lenticularity and diachroneity of sandstone bodies in the Pennsylvanian, these units are no longer considered formal members of the Chanute Shale in Kansas, but the names are retained in an informal sense to refer to sandstone bodies in the lower and upper Chanute respectively, in their respective type areas in southern Kansas.

The lower Chanute, below the Thayer coal bed, was reported (Miller, 1969) as about 13 feet mainly of shale with an underclay at the top at the type section north of Chanute, and it ranges from about 6 to 27 feet northward to the Kansas City area. Most of this unit is shale also in Linn County (Seevers, 1969), but sandstone occurs locally in Allen and Miami counties (Miller, 1966, 1969), and maroon shale occurs in the base in northern Linn, Miami, and Johnson counties (Schoewe, 1944). Marine fossils occur in the base in Wyandotte County. Southward from Chanute, the lower unit thickens to as much as 88 feet or more in Montgomery County (Schoewe, 1944), where the added thickness is largely made up by Noxie sandstone, but it is not known how much of this might include strata belonging to the underlying Nellie Bly Formation in places where the Dewey Limestone was removed by erosion.

Where the Dewey Limestone has been eroded, the base of the Chanute Shale is marked at least locally by deposits ranging from sandy, rubbly calcarenite to massive beds of calcirudite composed largely of debris eroded from the Dewey Limestone. Exposures of the calcarenite are known southeast of Independence (along W line at SW cor SE sec 5, T33S, R16E) and south of Dearing west of Coffeyville (near ctr W line SW-NW sec 31, T34S, R16E; and near ctr S line SW-SW sec 6, T35S, R16E). Exposures of the conglomerate are known in the same region (near ctr W line SW SW sec 6, along old highway S line SW-NE-NE sec 6, and along new US 166 near ctr N line NE-NE sec 6, T35S, R16E) west of Coffeyville, and along the west side of an old quarry between Coffeyville and Independence (NE-NE-NW sec 33, T33S, R16E). Clasts in the conglomerate include skeletal calcilutite, fossil fragments, oolite, dense calcilutite, shale, pieces of wood, and occasional phosphate nodules. They represent material derived from the Cement City and Quivira Members of the Dewey Limestone, the Drum oolite, and possibly the Cherryvale flags, as well as debris from the old land surface. This bed has been misidentified as the Corbin City Member (abandoned) of the Drum Limestone (e.g., Moore, 1936). The conglomerate is reported to attain 20 feet in thickness just south of the Oklahoma border (near NE cor sec 15, T29N, R15E) according to Oakes (1940a), who also reported it at other localities around Noxie.

The Thayer coal bed once was mined in parts of southern and east central Kansas and was studied in detail by Schoewe (1944), who reported it to reach a maximum of 2.4 feet thick in Montgomery County, thinning through 1 foot in Linn County to no more than a streak in the Kansas City region. Most exposures that he described from strip mines are now badly slumped, but exposures have been recently observed (or previously illustrated) along US 169 north of the river bridge east of Osawatomie (SW sec 1, T18S, R22E) in Miami County, in a road ditch 2 miles south of Beagle (W line NW cor sec 23, T19S, R22E) in northern Linn County, at the old Dunbar strip mine (SW sec 21, T29S, R17E, illustrated by Schoewe, 1944) in Wilson County, in a roadcut 5 miles east of Sycamore (ctr S line SE sec 23, T31S, R16E), and a roadcut south of Coal Creek on the Independence-Dearing road (E line NE-NE-SE sec 24, T33S, R15E) in Montgomery County.

The upper Chanute, above the Thayer coal, was reported (Miller, 1969) to be 7 feet of sandstone (Cottage Grove) at the type section in southernmost Allen County, north of Chanute. This unit thickens northward to 15 to 30 feet in most of Linn and Miami counties where it remains largely sandstone. In Allen and Wilson counties it contains thin coal beds above the Thayer coal, near the top (Schoewe, 1944). In Miami County (US 169 roadcut north of river bridge east of Osawatomie in SW sec 1, T18S, R22E) and Linn County (south of Beagle; see above), a thin dark limestone with scattered fossils occurs in the base of this unit just above the Thayer coal, and A.P. Bennison reports a marine limestone at about this horizon just west of US 59 south of the Dewey Limestone locality at Bayard bridge (near ctr E line NE sec 2, T24S, R20E) in Allen County. These suggest a marine horizon just above and thus probably responsible (by transgressive ponding) for the Thayer coal. However, Schoewe (1944, p. 97-98) reported mainly sandstone or shale above the Thayer coal, without mentioning fossils in the many localities he studied, so the existence of the mid-Chanute marine horizon shown on

Figure 3 is not well documented. The upper Chanute unit thickens southward from the type area to over 70 feet in Wilson County and as much as 160 feet in Montgomery County (Schoewe, 1944), where it and the lower Chanute unit form an outcrop belt several miles wide, which displays many partial exposures of thin- to thick-bedded shale-parted sandstone.

The Chanute Shale (Formation in Oklahoma) thins southward in Oklahoma largely by the loss of the Noxie sandstone at the edge of its channel complex in the base of the lower unit in T28N. The entire Chanute Formation ranges from 15 to 35 feet of shale and sandstone through the Dewey-Bartlesville region, where all three units are still recognized (Oakes 1940a). Oakes (1952) reported the Thayer coal as far south as T21N in southern Osage County, and he reported the Chanute Formation to be about 40 feet of shale and sandstone in western Tulsa county.

Northward in the Kansas City region, the Chanute Shale ranges from about 6 to 15 feet thick and reportedly contains a thin coal streak in places. At a good reference section for northeastern Kansas along Ks Rte 32 just west ofthe I-635 overpass (SW-SE-SW sec 7, T11S, R25E) in Wyandotte County, the Chanute consists of about 10 feet of sandy shale grading up to thin-bedded sandstone. Northward in Missouri, Iowa and Nebraska, the Chanute Shale ranges from 4 to 15 feet of mudstone with local calcareous nodules and local reddish color in the base, and fossils toward the top in places just below the Iola Limestone. In Iowa and Nebraska, the Chanute has long been misidentified as the higher Lane Shale largely because of misidentification of the underlying Dewey and overlying Iola limestones as the two next higher marine formations, the Iola and Wyandotte limestones respectively.

Throughout most of its outcrop extent, the Chanute Shale represents a variety of sand-rich fluvial, alluvial and other terrestrial environments. Probable paleosols were developed throughout in the northern region, but only locally beneath the Thayer coal (Schoewe, 1944) and on top of the Dewey Limestone in Kansas. Prodeltaic deposits probably dominated in parts of northeastern Kansas where the underlying Dewey (Cement City) Limestone shows no evidence of subaerial exposure at the top, and marine fossils occur in the base of the Chanute. Chanute rocks formed during the general lowstand of sea level following the major regression that terminated Dewey Limestone deposition and preceded the major Iola marine transgression.

ZARAH SUBGROUP

The Zarah Subgroup overlies the Linn Subgroup, underlies the Lansing Group, and forms the top of the Kansas City Group. It comprises 4 formations, in ascending order: Iola Limestone, Liberty Memorial Shale, Wyandotte Limestone, and Lane Shale. The Iola Limestone is transferred upward from the top of the underlying Linn Subgroup because of closer stratigraphic relations to Zarah strata above, where it serves equally as well as marker datum for structural mapping at the boundary between the two subgroups. The Liberty Memorial Shale is an old Missouri name revived and extended into Kansas as a result of correction of a longstanding miscorrelation of the type Lane Shale of Kansas with this unit. The Wyandotte Limestone and Lane Shale are modified in stratal content as a result of this same recorrelation, but together comprise the same strata that originally were included in the middle to upper part of the Zarah Subgroup.

The name Zarah was taken from the village of that name (Moore, 1949) in northern Johnson County (SW-NE sec 14, T12S, R23E) now engulfed in the Kansas City suburbs. No type section was given, but an essentially complete exposure of the subgroup 3 miles to the northeast on either side of the ramps connecting southbound I-435 with Holliday Drive (E« NW sec 6, T12S, R24E) is designated type section of the Zarah Subgroup as well as principal reference section for most of its constituent units.

The Zarah Subgroup locally attains thicknesses of 150 feet in the Kansas City area where carbonate units form local buildups and shale units form local deltaic lobes (Crowley, 1968). Northward, the subgroup thins to about 50 feet in Iowa and Nebraska as the shales thin substantially. Southward, the Liberty Memorial Shale disappears, the Wyandotte Limestone thins as it comes to rest on the Iola Limestone, and the Zarah Subgroup comprises mainly the Iola Limestone and Lane Shale totaling an average of about 100 feet throughout most of southeastern Kansas.

Iola Limestone

The Iola Limestone overlies the Chanute Shale and is now recognized to underlie the Liberty Memorial Shale in the Kansas City region (Fig. 2) and to underlie the Wyandotte Limestone in most of east-central and southeastern Kansas. The Iola previously was considered to underlie the Lane Shale throughout Kansas (Fig. 9A), but recent recognition that the Argentine Limestone Member of the Wyandotte Limestone descends over the southward pinchout of the shale called Lane at Kansas City to directly overlie the Iola Limestone below the type Lane Shale in western Miami County (Fig. 9B), necessitates renaming of the shale between the Iola and Wyandotte limestones in the Kansas City region. The name applied to this shale is Liberty Memorial, originally proposed by Clair (1943) from a locality in Kansas City, Missouri (see later section).

The Iola Limestone was named by Haworth and Kirk (1894) for the prominent limestone underlying the town of Iola in east-central Kansas, and its correlation northward and southward was stabilized by Moore (1936, 1949). The type section listed by Moore in the cement plant quarry on the south side of Iola (NE sec 2, T25S, R18E) still suffices, but it is now recognized that the interbedded shale and limestone beds (from the 1.3-foot-thick shale of Mitchell, 1981, upward) above the top of the main thick bed of quarried limestone, belong to the overlying Liberty Memorial Shale and Wyandotte Limestone (Fig. 9B). The Iola Limestone is subdivided into 3 members in ascending order (Fig. 2): thin Paola Limestone, thin black or gray phosphatic

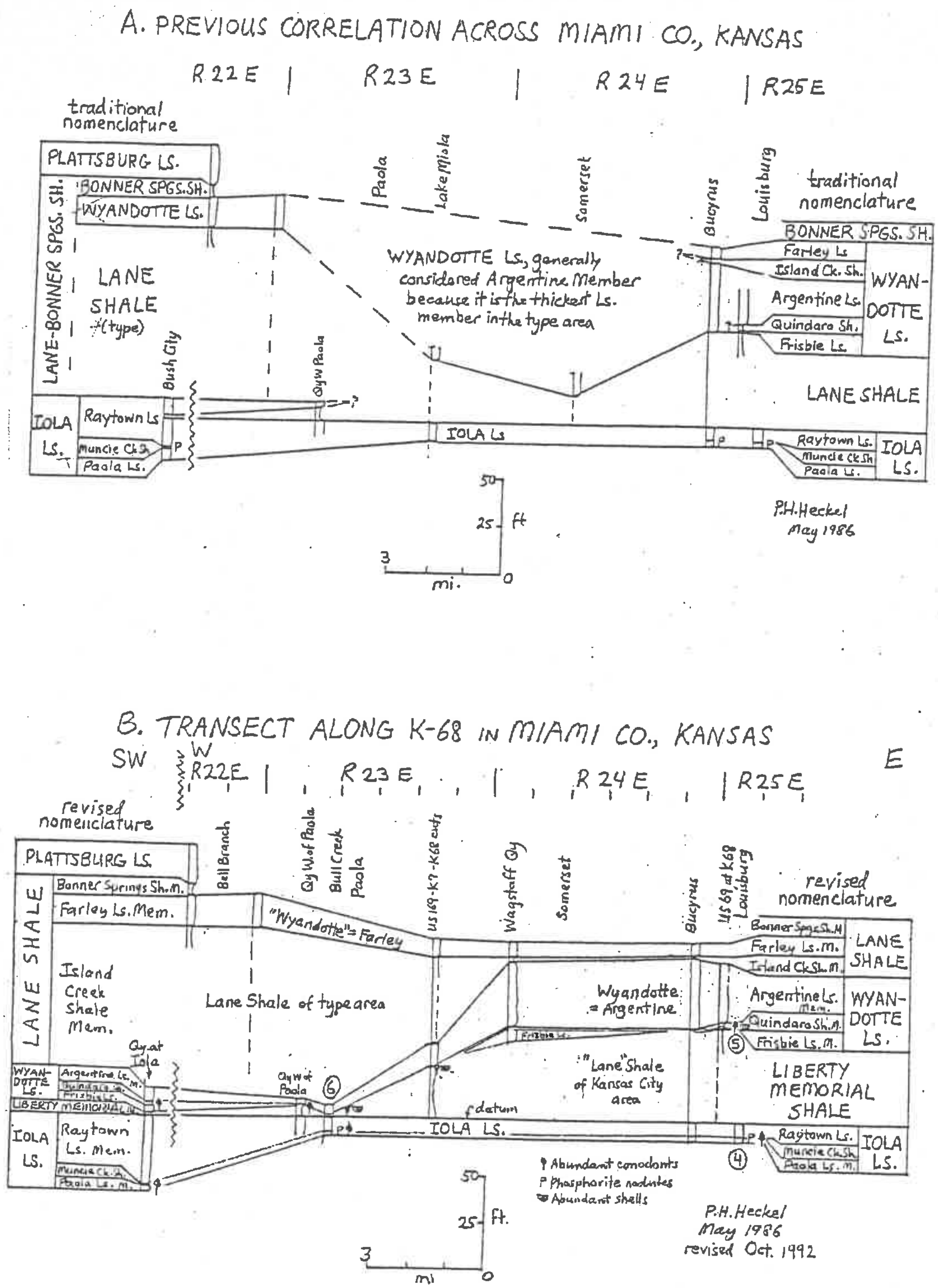


Figure 9.--Comparison of previous correlation, nomenclature and classification (A) of upper middle Missourian strata (Iola, Liberty Memorial, Wyandotte, Lane) in Miami and nearby counties, Kansas, with revised nomenclature and classification (B) mandated by correction of miscorrelation of Farley Limestone in western Miami county with entire Frisbie-Argentine-Farley succession in northeastern Miami County and northward, and of type Lane Shale of western Miami County with type Liberty Memorial Shale of Kansas City area. [This figure was modified to become Figure 28 in KGS Bulletin 246]

Muncie Creek Shale, and thick Raytown Limestone. These members are recognized throughout the entire outcrop belt, typifying the Iola as one of the major cyclothemic limestone formations denoted by Moore (1936, 1949).

Good complete reference sections of the Iola Limestone showing all three members in Kansas include the following, from north to south: west end of the roadcut along Ks Rte 32 just west of I-635 overpass (SW-SE-SW sec 7, T11S, R25E) in Wyandotte County; east side of the road south of Blue River at Redel (NE-SE-SE sec 16, T14S, R25E) in Johnson County; new roadcut just east of the US 169 underpass east of Paola (NE-NW-NW sec 22, T17S, R23E) in Miami County; east side of the US 59 roadcut at Katy Lake 3 miles north of Moran (ctr W line NW sec 13, T24S, R20E) in northeastern Allen County; the cement plant quarry south of Humboldt (SE sec 9, T26S, R18E) in southwestern Allen County; the cement plant quarries along Ks Rte 39 west of Chanute (along quarry road in NW-NE sec 24, T27S, R17E) in Neosho County; roadcut and bluff west of Chetopa Creek (S line SE-SW-SE-SW sec 16, T29S, R17E) in Wilson County. The complete section described by Mitchell (1981) beneath the west end of the Mill Street bridge in Neodesha (SW-SE-SE sec 20, T30S, R16E) has been largely covered by bridge reconstruction.

Southward the Iola Limestone extends at least to the area west of Tulsa, Oklahoma, (e.g., railroad cut south of Arkansas River near ctr SW sec 10, T19N, R10E) where all three members are still well defined, and the upper member is termed Avant Limestone Member. Northward the Iola Limestone extends through Missouri to Iowa and Nebraska (Fig. 6) where likewise all three members are well defined. Along the northern outcrop belt in Iowa and Nebraska, however, the Iola has long been misidentified as the higher Wyandotte Limestone, and its three members accordingly misidentified as the Frisbie Limestone, Quindaro Shale and Argentine Limestone, respectively.

<u>Paola Limestone Member</u>.--The Paola Limestone overlies the Chanute Shale and underlies the Muncie Creek Shale Member (Fig. 2). It was named by Newell (in Moore, 1932; 1935) as the basal member of the Iola Limestone from a type exposure located in a composite section from a railroad cut to the top of a shale pit in SW sec 9, T17S, R23E (Newell, 1935, p. 125) at the north edge of Paola in Miami County, Kansas. An exposure along a new road just east of the US 169 underpass on the east side of Paola (NE-NW NW sec 22, T17S, R23E) provides a good principal reference section.

The Paola Limestone Member is about 1.5 to 2 feet of dense skeletal calcilutite in its type area. It is remarkably uniform along outcrop, a typical transgressive limestone, and generally is more calcarenitic to locally quartz sandy at the base (Mitchell, 1981). The Paola thickens southward to about 4 feet southeast of Bush City (roadcut on E line just S of NE cor sec 30, T21S, R21E) in Anderson County, then thins to about 2 feet in Allen County where it is well exposed in the US 59 roadcut at Katy Lake, and to 1 foot in Neosho County where it is well exposed along the quarry road just south of the Ks Rte 32 overpass west of Chanute. The

Paola maintains this thickness where it becomes sandier southward in Wilson County above sandier beds at the top of the Chanute, as reported by Mitchell (1981) west of the bridge over Chetopa Creek and formerly under the Mill Street bridge in Neodesha. Southward it is 1.5 feet thick in an increasingly slumped exposure in the road ditch east of Stony Point northeast of Tyro (near ctr S line SW-SE sec 29, T34S, R15E) in southern Montgomery County. Southward the Paola Limestone is traced into Oklahoma as 1 to 3 feet of sandy limestone in Washington County (Oakes, 1940a) and is recognized at least as far south as a railroad cut on the south side of the Arkansas River (near ctr SW sec 10, T19N, R10E) west of Tulsa.

Northward from its type area, the Paola Limestone Member thins through 1.5 feet in Johnson County (roadcut south of Blue River at Redel) to about 1 foot in the Kansas City area, where it is well exposed along a Ks Rte 32 roadcut about 0.5 mile west of the landfill entrance (NE-SE-SW sec 12, T11S, R24E) in Wyandotte County. Northward in Missouri and southern Iowa, it ranges from about 0.7 to 1.5 feet of locally argillaceous skeletal calcilutite. Along the northern belt of outcrop in Iowa and Nebraska, the Paola Limestone is 0.5 to 1 foot of dense skeletal calcilutite, which has long been misidentified as the Frisbie Limestone Member of the higher Wyandotte Limestone.

Muncie Creek Shale Member.--The Muncie Creek Shale is the thin laterally persistent shale that separates the Paola Limestone Member below from the Raytown Limestone Member above (Fig. 2), with generally sharp contacts. It was named by Newell (in Moore, 1932;1935) as the middle member of the Iola Limestone from exposures near Muncie Creek on the western outskirts of Kansas City in Wyandotte County. As it was reported as typically exposed no more definitely than "in the bluffs between Muncie and City Park" by Moore (1936), a good exposure in this area at the west end of the roadcut along Ks Rte 32 west of the I-635 overpass (SW-SE-SW sec 7, T11S, R25E) serves as the principal reference section.

The Muncie Creek Shale Member is about 3 feet thick in its type area, where it consists of roughly one-half black fissile shale in the middle, underlain and overlain by thinner beds of dark gray shale in the base and top, a typical offshore core shale of a major cyclothem. Another easily accessible exposure is along the southbound I-435 offramp at Holliday Road (NW-NE-NW sec 6, T12S, R24E) in northernmost Johnson County about 5 miles to the southwest, where the underlying Paola Limestone, however, is normally obscured by slump. The black fissile shale contains phosphate nodules, often with conspicuous conularids. It also contains an abundant conodont fauna, which includes several species of Idiognathodus, but not the conspicuously large-lobed morphotype of I. magnificus that characterizes the Quivira Shale below in the Dewey Limestone, and it contains far fewer Gondolella than occur in the Quivira.

Northward in Missouri, the Muncie Creek Shale Member ranges from 2 feet up to 7 feet in some cores and contains the persistent 1 to 2 feet of black phosphatic shale generally at the base. In Iowa and Nebraska it ranges from 1 to 5 feet thick, with black fissile shale forming the lower one-half of thicker sections and nearly all of the thinner sections. In this northern outcrop region the Muncie Creek Shale Member has long been misidentified as the Quindaro Shale Member of the Wyandotte Limestone above, in spite of the fact that the Quindaro is observed to be only gray to dark gray in its type area in the Kansas City region. The recorrelation of the Iola Limestone with the "Wyandotte" Limestone of the northern outcrop belt is based both upon lithostratigraphic tracing of beds through the cores from northwestern Missouri and southwestern Iowa and upon the conodont fauna of the Muncie Creek Shale. This fauna contains several elements not found in the younger Quindaro Shale in its type region in Kansas City, and it also is distinct from that of the older Quivira Shale, which was formerly misidentified as the Muncie Creek Shale in the north.

South of Kansas City, from central Johnson County to northern Neosho County, the Muncie Creek Shale Member thins to a range from 0.1 to 0.5 feet, entirely of gray shale with abundant and conspicuous phosphate nodules, and carrying the same abundant conodont fauna as does the black facies to the north. Good reference sections (located under discussion of the Iola Limestone) include the roadcut south of the Blue River at Redel in eastern Johnson County, where the Chanute Shale is much thicker than to the north in the Kansas River valley; the new roadcut east of the US 169 underpass east of Paola in Miami County; the US 59 roadcut at Katy Lake north of Moran in Allen County, where an old quarry at the north end of the roadcut exposes the underlying top surface of the Paola Limestone littered with phosphate nodules remaining from the thin, readily washed-out Muncie Creek Shale; and the west side of the quarry road just south of the Ks Rte 39 overpass west of Chanute in Neosho County. Southward in Wilson and Montgomery Counties, the Muncie Creek Shale thickens to 1 to 3 feet with the black fissile phosphatic facies again developed. The best exposure remaining in this area is in the bluff along the north side of the road west of Chetopa Creek in eastern Wilson County.

Southward in Oklahoma, the Muncie Creek Shale Member is traced readily by virtue of its conspicuous abundant phosphate nodules (Oakes, 1940a). It is as thin as in Kansas across northern Washington County (T29-26N), but thickens southward beneath the thickening Avant (=Raytown) Limestone Member to about 20 feet west of Ramona and 30 feet west of Tulsa. In the thicker exposures only the lower 2 to 3 feet are dark gray and carry the phosphate nodules, along with abundant fossils including ammonoids and conodonts.

The Muncie Creek Shale was deposited in the deepest water during maximum inundation of the Iola marine cycle, as is indicated by its extreme lateral persistence with abundant phosphate nodules and the same abundant conodont fauna along the entire outcrop belt. The absence of black fissile facies across east-central Kansas may reflect the underlying topographic high of the Bourbon arch (Price et al., 1985), and also the thicker development of Chanute Shale, over which water did not remain deep enough during this particular inundation for sufficient time to establish a thermocline long enough to prevent oxidation or storm-wave winnowing of organic matter in this condensed interval.

Raytown Limestone Member.--The Raytown Limestone Member overlies the Muncie Creek Shale Member (Fig. 2), forms the top of the Iola Limestone, and represents the regressive limestone of the Iola cyclothem. The Raytown underlies the Liberty Memorial (formerly Lane) Shale in northeastern Kansas and underlies the Wyandotte Limestone where the Liberty Memorial is absent, in much of east-central and southeastern Kansas. The Raytown Limestone was named by Hinds and Greene (1915) from exposures around Raytown on the east side of Kansas City, Missouri, and it was recognized as the upper member of the Iola Limestone by Newell (in Moore, 1932; 1935). A good accessible principal reference section for northeastern Kansas is the roadcut on the southbound I-435 offramp at Holliday road (NW-NE-NW sec 6, T12S, R24E) in northern Johnson County, and another good section is along Ks Rte 32 west of the I-635 overpasses in Wyandotte County.

The Raytown Limestone Member in its type area averages about 7 feet thick and consists mainly of skeletal calcilutite with conspicuous phylloid algae in the lower part and a yellow and gray mottling that gave rise to the quarry term "calico bed". At the base of the Raytown Limestone throughout the Kansas City area in Kansas, is a distinctive bed of crinoid-dominated calcarenite, 0.1 to 0.5 foot thick, and separated from the main ledge by about 0.1 to 0.3 foot of gray fossiliferous shale. This calcarenite is composed only of unabraded, somewhat corroded invertebrate grains in an overpacked fabric with glaucony and abundant conodonts, and it stands in contrast to the abraded-grain calcarenites with algae that are often found at the tops of regressive limestones. It was interpreted by Heckel (1983) as a "deep-water" calcarenite formed by proliferation of invertebrates on the sea bottom after shallowing destroyed the thermocline responsible for the black facies of the underlying shale and oxygen returned to the bottom, but before resumption of algal lime mud production (and preservation) in the photic zone, which provided most of the matrix to the more common skeletal calcilutite facies.

Northward in Missouri, the Raytown Limestone Member ranges mostly from 6 to 11 feet of generally shaly skeletal calcilutite grading upward in places to skeletal calcarenite or birdseye-bearing calcilutite with shale-filled fractures at the top, a shallowing-upward sequence typical of regressive limestones. It thickens northward to 17 feet in the northernmost Missouri core (MNC on Fig. 6), and it ranges from 18 to 23 feet of locally shaly skeletal calcilutite generally grading upward through skeletal calcarenite to laminated and locally brecciated calcilutite at the top, in cores and along outcrop in Iowa and Nebraska. Here it has long been misidentified as the Argentine Limestone Member of the higher Wyandotte Limestone, perhaps because it is the thickest limestone in this part of the sequence here (Fig. 6), just as the type Argentine is the thickest limestone in the Kansas City area, where the Raytown Limestone is quite thin, like the lower Cement City Limestone in the northern outcrop, which has long been misidentified as the Raytown in the north.

South of the Kansas City area, the Raytown Limestone Member thickens through 12 feet in southern Miami County to nearly 40 feet in Allen and northwestern Neosho County (Mitchell 1981) where it forms the phylloid algal mound complex delineated by Heckel and Cocke (1969).

Throughout the area from central Miami County southward, higher beds of limestone are separated from the main thick bedded to massive Raytown Limestone by several inches to several feet of shale. These higher beds were classified with the Raytown by Miller (1966) and Mitchell (1981), but are now known to belong to the Wyandotte Limestone, based on abundant conodont faunas typical of the Quindaro Shale Member of the Wyandotte reported by Mitchell (1981) from these beds at several localities in Miami, Anderson, Allen and Neosho counties. The Raytown Limestone through this area grades southward from skeletal calcilutite to mainly phylloid-algae-dominated calcilutite ("moundrock") in Allen and Neosho counties and is capped by up to 1 foot of skeletal calcarenite in several localities.

Reference sections include the roadcut east of the US 169 underpass east of Paola, and also the Ks Rte 68 roadcut west of Bull Creek (ctr S line SE sec 29, T16S, R23E), where the Wyandotte Limestone with the conodont-rich Quindaro Shale Member at the base, directly overlies the Raytown, in Miami County; a roadcut south of Bush City (E line NE-NE-NE sec 30, T21S, R21E) where the basal 7 feet are exposed, and a quarry a little over 1 mile farther south (NE-NE sec 31) where Mitchell (1981) reported the upper 10 feet exposed with 1 foot of skeletal calcarenite at the top overlain by what is now known to be Wyandotte Limestone with the conodont-rich Quindaro shale at the base, in Anderson County; the US 59 roadcut at Katy Lake 3 miles north of Moran where the Raytown contains a lens of "algal sparite" lithology in the mound facies, at the type Iola Limestone quarry on the south side of Iola where it is the main quarried ledge and the mound facies is capped by 1 foot of skeletal calcarenite and overlain by 1.3 feet of conodont-poor (Mitchell, 1981) Liberty Memorial Shale (Fig. 9B), at the Humboldt quarry where it is the main quarried ledge also overlain by Liberty Memorial Shale, all in Allen County; and the new US 169 roadcut and quarries west of Chanute in Neosho County, where it is the main quarried ledge with large upright phylloid algal plant structures in the top and is directly overlain by the Wyandotte Limestone.

South of Chanute, the Raytown Limestone Member descends topographically as seen along US 169 on the west side of town (near ctr S line sec 19, T27S, R18E) and thins abruptly along alignment 1 of Heckel and Cocke (1969) to about 5 feet of nonalgal, locally fine sandy skeletal calcilutite, which apparently is a more basinal facies of this member above the recurrence of the black shale facies in the underlying Muncie Creek Shale Member. The most complete reference section remaining in this region is in the roadcut and bluff west of Chetopa Creek in Wilson County. This thin basinal facies of Raytown is traced in partial exposures throughout Montgomery County and across the Oklahoma border, probably with a thin but undetermined amount of Wyandotte shale and limestone at the top.

In Oklahoma the Raytown Limestone Member is known as the Avant Limestone Member, named by Ohern (1910) from a town in east-central Osage County. It remains thin (Oakes, 1940a) and basinal to the latitude of Ramona (southern T24N) where it thickens abruptly southward into the 40-foot-thick Avant algal mound complex (Heckel and Cocke, 1969) fronting the south side of the basin in a sort of symmetry with the south end of the Raytown mound complex at Chanute about 80 miles to the north. The Avant algal mound thins southward and grades into sandy limestone west of Tulsa (Oakes, 1952). Even though the name Avant has priority over Raytown, both names are retained because of consistent and ingrained usage in their respective type regions (see Moore, 1949).

Liberty Memorial Shale

The Liberty Memorial Shale is now recognized as the formation that overlies the Iola Limestone (Raytown Limestone Member) and underlies the Wyandotte Limestone (Frisbie Limestone, Quindaro Shale and Argentine Limestone members) in northeastern Kansas (Fig. 2) and locally in southeastern Kansas. The Liberty Memorial Shale was named by Clair (1943, Plate 1), presumably after the monument of that name in Penn Valley Park (SW sec 8, T49N, R33W) in Kansas City, Missouri, to apply to the shale from the top of the Raytown Limestone to the base of the Frisbie Limestone, a shale that was then erroneously considered to be the upper member of the Chanute Shale. Because this shale was later correlated with the Lane Shale (Fig. 9A), named in 1895 from exposures in western Miami County, Moore (1948) abandoned the name Liberty Memorial as a junior synonym. However, the recent recognition (Fig. 9B) that the Argentine Limestone and Quindaro Shale descend westward in central Miami County over the thinning shale originally named Liberty Memorial and extend southwestward upon the top of the Iola Limestone (Raytown Member) below the type Lane Shale, shows that the type Lane and the type Liberty Memorial are not correlative. Accordingly, the name Liberty Memorial Shale is reinstated for exactly the same strata to which it was originally applied.

The Liberty Memorial Shale is completely exposed at the I-435 southbound offramp to Holliday Road (NE-NW sec 6, T12S, R24E) in northern Johnson County, which is designated as the principal reference section for Kansas. Here it is 40 feet of gray shale with shaly thin-bedded sandstone toward the top, and a thin bed of fossiliferous limestone near the middle, which has yielded well preserved crinoids. It is similar elsewhere in northern Johnson and Wyandotte counties. Other than the thin zone with crinoids, the Liberty Memorial Shale is only sparingly fossiliferous. Its contacts are sharp with underlying and overlying limestones, but more diffuse where its sparsely fossiliferous shale is overlain by the more abundantly fossiliferous Quindaro Shale Member of the Wyandotte Limestone. In adjacent parts of Missouri the Liberty Memorial ranges from 7 to 61 feet thick and contains a channel sandstone in southwestern Jackson County (Clair, 1943, p. 24).

Northward in Missouri, the Liberty Memorial Shale ranges from 5 to 30 feet of silty micaceous shale (Fig. 6) with thin-bedded sandstone and locally a thin coal near the top. Farther northward it thins to 2 to 5 feet of silty shale and blocky mudstone, locally with reddish mottling, and in some places with marine fossils at the top (Heckel and Pope, 1992). In Iowa and Nebraska the Liberty Memorial has long been misidentified as the higher Island Creek Shale Member, formerly of the Wyandotte Limestone.

Southward from its type area, the Liberty Memorial Shale thickens locally to 70 feet in east-central Johnson County ("Lane shoal" of Crowley, 1969), then thins abruptly to less than 10 feet in a linear NE-SW trend across southeastern Johnson County ("interbank area" of Crowley, 1969). It then thickens somewhat to about 25 feet in the southeastern corner of Johnson County, and thins again to about 15 feet in eastern Miami County (Crowley, 1969, p. 8). Southwestward into western Miami County, the Liberty Memorial thins to disappearance as the Argentine Limestone and Quindaro Shale members of the Wyandotte Limestone descend to rest upon the top of the Raytown Limestone Member of the Iola Limestone. The best reference section in this region is the roadcut along new US 169-K7 just east of Lake Miola (from NE SE SW-to W line NW-SE sec 11, T17S, R23E) northeast of Paola, where 28 feet of gray Liberty Memorial Shale overlie the top of the Raytown Limestone and are overlain by about 1 foot of very fossiliferous Quindaro Shale, identified by its abundant conodont fauna with about 11 feet of Argentine Limestone above. Just 3 miles to the northwest, along Ks Rte 68 west of Bull Creek (ctr S line SE sec 29, T16S, R23E) north of Paola, the Argentine and Quindaro (similarly identified by its abundant conodont fauna) lie directly upon the Raytown Limestone, illustrating the westward pinchout of the Liberty Memorial Shale (Fig. 9B). Above the Argentine Limestone westward along Ks Rte 68 is the 100-foot-thick sandy lower Lane Shale in its type region, which is overlain by the Farley Limestone Member, considered the top member of the Wyandotte Limestone as originally defined. Thus the type Lane Shale is equivalent to the Island Creek Shale, which lies between the Argentine and Farley limestones in their respective type areas to the north, and not to the Liberty Memorial Shale below the Argentine Limestone and lower members of the Wyandotte Limestone in the Kansas City area.

Thin lobes and local pods of Liberty Memorial Shale extend southwestward from the main mass of shale. Exposures of shale formerly classified in the upper part of the Raytown Limestone Member in two quarries west of Paola (SE SE sec 7, T17S, R23E, where it is 4 feet thick; and near N line SE-SE sec 18, where it is 7 feet thick and illustrated by Miller, 1966, p. 16) represent a lobe of Liberty Memorial Shale extending beyond the pinchout exposed along Ks Rte 68, 3 miles to the north. Exposures of about 1.3 foot of conodont-poor shale classified in the upper Raytown Limestone by Mitchell (1981) at the type Iola quarry (NE sec 2, T25S, R18E) and probably also at the Humboldt Quarry (SE sec 9, T26S, R18E) both in Allen County, probably represent a local pod of Liberty Memorial Shale, as this shale is absent in the quarries west of Chanute and in the quarries in Anderson County, based on the information in Mitchell (1981).

The Liberty Memorial Shale in its type region around Kansas City is a deltaic to prodeltaic deposit, which extends southward from thin terrestrial deposits and paleosols in the north. Abrupt shifting of deltaic lobes in the Kansas City area probably was responsible for the limy bed with well preserved crinoids. The depositional topography of lobes and channels is preserved beneath the Wyandotte Limestone in this area because the sea withdrew no farther southward during regressive Raytown Limestone deposition than probably the northern outskirts of Kansas City before the Wyandotte transgression began, essentially ending further deltaic deposition of the Liberty Memorial and stranding lobes and pods of flood-borne mud above the Raytown Limestone, which were covered slowly by the sediment-poor, invertebrate-rich deeper water deposits of the lower Wyandotte. This "incomplete" regression was probably also responsible for the abrupt southern algal-mound front of the underlying Raytown Limestone at Chanute and the northern Avant Limestone algal-mound front at Ramona, Oklahoma, which are the basinward positions of the edge of prolific algal sediment production at the time that sea level rose and left the algae in darkness. The deeper quieter water also helped preserve the upright algal growth structures in the top of the Raytown Limestone at the southern end of its algal mound at Chanute.

Wyandotte Limestone

The Wyandotte Limestone overlies the Liberty Memorial Shale in northeastern Kansas and the Iola Limestone where the Liberty Memorial is absent in east-central to southeastern Kansas. The Wyandotte is now recognized to underlie the Lane Shale, specifically its basal Island Creek Shale Member in Kansas. The Wyandotte Limestone now consists of 3 members in ascending order: Frisbie Limestone, Quindaro Shale, and Argentine Limestone (Fig. 2). The Wyandotte Limestone was named by Newell (in Moore, 1932; 1935) from Wyandotte County, where it is prominent in the bluffs along the Kansas River, and Moore (1936) listed typical exposures in the cement plant quarries at the east edge of Bonner Springs (sec 28, T11S, R23E). The Wyandotte originally included two members above the Argentine: the Island Creek Shale, and the Farley Limestone at the top, partly because the limestone that was considered to represent the entire Wyandotte in western Miami and Franklin Counties had no shale beds to allow the original three limestone members (Frisbie, Argentine, Farley) to be separated from one another in that area (Newell, 1935, p. 59), and partly because the Farley Limestone was considered to be the top part of the typical cyclic limestone succession (the "super" limestone of Moore, 1936) in Missourian limestone formations.

Now that the Argentine Limestone and underlying members can be traced westward across central Miami County descending above the thinning Liberty Memorial Shale to rest upon the Iola Limestone below the type Lane Shale (Fig. 9B), it is apparent that the original type Lane Shale (now the lower part of the Lane) is equivalent, not to the Liberty Memorial Shale (which had been misidentified as Lane in the Kansas City area), but to the Island Creek Shale, which had been included in the Wyandotte. It also is apparent that the limestone called Wyandotte above the original type Lane Shale in western Miami and Franklin counties is only the Farley Limestone Member, which accounts for the absence of the Quindaro and Island Creek Shale members within it, and explains Newell's (1935, p. 60) observation that only it and the type Farley to the north, but not the Argentine, carry the distinctive brachiopod Enteletes. Because the original type Lane Shale, about 100 feet of largely terrestrial clastics, is the southern equivalent of the Island Creek Shale Member and intervenes between the middle and upper limestone members originally included in the Wyandotte, the Farley Limestone is a separate younger cycle of limestone deposition (as is true of some other "super" limestones of Moore's 1936 classification) and not part of the main cycle here regarded as Wyandotte. Therefore, the Island Creek Shale and Farley Limestone members are removed from the Wyandotte Limestone and recognized as members of a separate formation (Lane Shale) above the Wyandotte (Fig. 2, 9B). Because the type section of the Wyandotte Limestone designated by Moore (1936) in the cement plant quarry at Bonner Springs exposes mainly Farley and upper Argentine Limestone members and is not easily accessible, an excellent and accessible principal reference section is established just 4 miles to the east along the southbound offramp of I-435 at Holliday Road (NE-NW sec 6, T12S, R24E) where all three members remaining in the Wyandotte are well exposed.

Northward the Wyandotte Limestone can be traced through the cores in northern Missouri and southern Iowa to the Iowa-Nebraska outcrop (Fig. 6), where, because of the misidentification of the thickened Raytown Limestone as Argentine, the Wyandotte (Argentine Limestone Member) had been misidentified as the Farley Limestone. The Farley itself can be traced in the cores only to northern Missouri where it pinches out into shale. Southward the Wyandotte Limestone (as redefined) can be traced lying closely above the Iola Limestone from western Miami County southward (Fig. 9B) as a more basinal facies most of the way to the Oklahoma border. Reference sections of the entire Wyandotte in southeastern Kansas are well exposed at the type Iola Quarry (NE sec 2, T25S, R18E) in Allen County where all 3 members are differeniated, and in the new US 169 roadcut west of Chanute (E line NW sec 19, T27S, R18E) in Neosho County where they are not differentiated. The dark Quindaro Shale Member can be identified farther southward at least to southeastern Osage County, northwest of Tulsa.

The vertical succession of members of the Wyandotte Limestone (as redefined herein) forms a classic Kansas cyclothem in its type area: transgressive Frisbie Limestone, offshore Quindaro Shale, and regressive Argentine Limestone (Fig. 2,9B). The lack of a phosphatic black facies in the Quindaro Shale, coupled with the good development of all three members mainly in the Kansas City region, and the less obvious recognition of the conodont-rich zone in the Quindaro northward to the Iowa-Nebraska outcrop, indicates that the Wyandotte is a cycle of only intermediate scale (Fig. 3) rather than a major cyclothem as shown by Heckel (1986) prior to the discovery that the units thought to be Wyandotte Limestone in the north are really the Iola Limestone.

<u>Frisbie Limestone Member</u>.--The Frisbie Limestone is the basal member of the Wyandotte Limestone, lying above the Liberty Memorial Shale and below the Quindaro Shale Member (Fig. 2). It was named with this status by Newell (in Moore, 1932; 1935) from an outcrop just east of Frisbie ("near ctr N line," actually E line NE-NW¬, sec 17, T12S, R23E) in north-central Johnson County, which is now poorly exposed. Therefore, the principal reference section for the Frisbie Limestone Member is designated in the southbound offramp cut of I-435 at Holiday Road (NE-

NW sec 6, T12S, R24E), 5 miles to the east. The Frisbie is a dense skeletal calcilutite generally 1 to 3 feet thick with sharp upper and lower contacts, a typical transgressive limestone over much of Johnson and Wyandotte counties. Locally it reaches 5 feet in thickness, and at the principal reference section, the additional thickness is formed by small mounds of calcilutite containing large blades of phylloid algae, and surrounded by crinoid debris with calcisponges.

The Frisbie Limestone Member thins northward to 1 foot and less in Missouri outcrops, but is apparently differentiated northward only in core MNC in northern Missouri, where it is 3 feet of skeletal calcilutite beneath Quindaro Shale tentatively identified by a sparse but compatible conodont fauna. Northward, the Wyandotte members are not generally differentiated in Iowa and Nebraska, and the Frisbie Limestone is absent at the Stanzel Quarry west of Winterset, Iowa, where the Quindaro Shale and Argentine Limestone members are recognized (Heckel and Pope, 1992).

Southward from its type area in northern Johnson County, the Frisbie Limestone Member is not recognized above thin Liberty Memorial Shale in the "interbank" area (Crowley, 1969) across southeastern Johnson County, but reappears in the Stilwell bank area (of the higher Argentine and Farley limestones described by Crowley, 1969) in southeasternmost Johnson and eastern Miami Counties. In a good reference section along the southbound US 69 offramp at Ks Rte 68 (E line SE cor sec 25, T16S, R24E) just west of Louisburg, the Frisbie Limestone is one foot of shaly crinoid-rich skeletal calcarenite, and it is nearly 2 feet of similar limestone along old US 69 south of Louisburg (ctr W line SW-SW sec 5, T17S, R25E). In a quarry nearly 6 miles to the west (near ctr N« sec 30, T16S, R24E) 2 miles south of Wagstaff, the Frisbie comprises several feet of interbedded limestone and shale, illustrating some of the facies variation in this region of irregular depositional topography over the lobes and channels of the underlying Liberty Memorial prodeltaic shale. Southwestward around Paola, the Frisbie Limestone Member disappears, and the Quindaro Shale Member rests directly either upon the Liberty Memorial Shale, as along US 169 east of Lake Miola, or upon the Raytown Limestone Member, as along Ks Rte 68 west of Bull Creek. Exposures of Frisbie Limestone Member reported by earlier workers from the Wyandotte Limestone in western Miami and Franklin counties are now known to be the basal bed of the higher Farley Limestone.

In the thinner more basinal Wyandotte sequence in southern Kansas, the Frisbie Limestone Member is recognized only where the Quindaro and Liberty Memorial shales can be identified and are separated by limestone, as in the type Iola Quarry (NE sec 2, T25S, R18E) in Allen County, where nearly 4 feet of shale-parted skeletal calcilutite are assigned to the Frisbie. Elsewhere, either limestone was not deposited at this time, or it is grouped with the Argentine Limestone Member in an undifferentiated Wyandotte sequence. In Oklahoma, the Frisbie Limestone Member reappears as a thin 0.5-foot-thick argillaceous limestone lying below dark gray shale identified as Quindaro, in the roadcut south of the spillway by the new dam 4 miles west of Skiatook (E« SE sec 26, T22N, R11E) in southeastern Osage County northwest of Tulsa.

Quindaro Shale Member.--The Quindaro Shale overlies the Frisbie Limestone Member in northeastern Kansas and older units (Liberty Memorial Shale and Iola Limestone) southward, and it underlies the Argentine Limestone Member of the Wyandotte Limestone everywhere in Kansas (Fig. 2). It was named in this position by Newell (in Moore, 1932; 1935) from exposures at Boyne's Quarry (NW sec 30, T10S, R25E) in Quindaro Township in northeastern Wyandotte County, where it was reported to be 3 feet of tan to dark gray shale (Newell, 1935, p. 199). The Quindaro is about 0.4 foot of very fossiliferous dark gray shale about 10 miles southwestward at its principal reference section above the southbound I-435 offramp at Holliday Road, where it thins to about 0.1 foot as it drapes over the tops of the small mounds in the Frisbie Limestone. Here it carries an abundant conodont fauna that is distinct from that in the Muncie Creek Shale Member below in the Iola Limestone in that it is dominated by species of *Streptognathodus* and lacks *Gondella*. The contacts are usually sharp with overlying and underlying limestones. The Quindaro Shale is reported by O'Connor (1971) to range up to 7 feet thick to the west (NW-NE sec 25, T12S, R22E), but his report of 0.1 to 0.3 foot of dark shale overlain by several feet of gray shale with nodular limestone nearby suggests a gradational upper contact in that area.

Northward, the Quindaro Shale Member is 1 to 3 feet thick in outcrops in Missouri and was identified in core MNC in northern Missouri as 2 feet of dark gray shale with a sparse conodont fauna of similar generic composition to that in Kansas. Elsewhere in northern cores and along the Iowa-Nebraska outcrop belt, the Quindaro is so far differentiated from the rest of the Wyandotte only at the Stanzel Quarry west of Winterset, Iowa (SW NE sec 5, T75N, R29W) where it is 1 foot of dark gray fossiliferous shale with an abundant characteristic conodont fauna (Heckel and Pope, 1992). This sparsity of good development to the north, coupled with the lack of truly black phosphatic facies in Kansas, identify the Quindaro as a core shale of only an intermediate cycle of marine inundation.

Southward from its type region, the Quindaro Shale Member, like the underlying Frisbie Limestone Member, is not differentiated in the interbank area across southeastern Johnson county, but reappears southward and is exposed at several places in Miami County. Along the southbound US 169 offramp at Ks Rte 68 west of Louisburg (E line SE cor sec 25, T16S, R24E), it is about 1 foot of gray-brown very fossiliferous shale with conspicuous calcisponges. At the quarry south of Wagstaff, it is dark gray shale with inconspicuous fossils. The Quindaro Shale is about 1 foot of conspicuously fossiliferous, conodont-rich gray shale where it overlies Liberty Memorial Shale with a diffuse contact in the US 169 roadcut east of Lake Miola (E line NE cor SW sec 11, T17S, R23E) and in the quarry west of Paola (N line SE-SE sec 18, T17S, R23E), and also where it directly overlies the Raytown Limestone Member of the Iola Limestone along Ks Rte 68 west of Bull Creek (ctr S line SE sec 29, T16S, R23E) and in the quarry 3 miles southwest of Osawatomie (W« SW sec 20, T18S, R22E), as it delineates the westward pinchout of the underlying Liberty Memorial Shale in central to southwestern Miami County.

Southwestward across east-central Kansas, the Quindaro Shale Member has been identified in several places in the lower Wyandotte where it rests upon (or nearly upon) the top of the Iola Limestone, by means of its abundant conodont fauna reported in Mitchell (1981): quarries northeast and south of Bush City (SW-SE sec 33, T20S, R21E; NE-NE sec 31, T21S, R21E) in Anderson County, and the type Iola quarry (NE sec 2, T25S, R18E) in Allen County, where it rests upon a recurrence of the Frisbie Limestone Member. Elsewhere it is not differentiated from the Argentine Limestone Member where the conodont-rich horizon occurs in skeletal calcarenite beds in the basinal Wyandotte shaly limestone sequence above the Iola in southern Kansas, as is well exposed in the US 69 roadcut west of Chanute.

In Oklahoma, several localities of slightly darker shale collected in the lower part of the Wann Shale succession above the Iola Limestone by A.P. Bennison have yielded abundant conodont faunas that are compatible with that of the Quindaro Shale. These include an exposure southwest of Matoaka (W line NW-SW-SW-SW sec 1, T25N, R12E) south of Bartlesville, and a roadditch 3 miles west of Ramona (S line SW-SE NE sec 25, T24N, R12E), where it lies below a thick lenticular limestone that may be Argentine. The best and most easily accessible and currently most southerly known exposure of Quindaro Shale is 1.5 feet of dark gray shale, lying just above thin argillaceous limestone (assigned to the Frisbie), 22 feet above the top of the Avant Limestone in the roadcut south of the spillway of the new dam (E« SE sec 26, T22N, R11E) 4 miles west of Skiatook in southwestern Osage County, northwest of Tulsa.

Argentine Limestone Member.--The Argentine Limestone Member overlies the Quindaro Shale Member and underlies the Island Creek Shale Member of the Lane Shale as redefined in the Kansas City area, which correlates with the lower part of the type Lane Shale to the southwest (Fig. 2). The Argentine was named by Newell (in Moore, 1932; 1935) from an exposure near Argentine Station on the south side of Kansas City in Wyandotte County, as the middle member of the Wyandotte Limestone. Because the overlying shale, named Island Creek by Newell at the same time, is now known to correlate southward with the thick, largely terrestrial, original type Lane Shale in Miami County, the Island Creek Shale and overlying Farley Limestone Member are removed from the Wyandotte Limestone and placed in the redefined Lane Shale in order to retain the Wyandotte as a dominantly carbonate formation southward (Fig. 9B). Therefore the Argentine Limestone is now recognized as the upper member of the Wyandotte Limestone. The type exposure given by Newell (1935) is in a quarry south of 26th St. and Metropolitan Avenue (south of ctr N line sec 29, T11S, R25E), and an excellent principal reference section is designated 7 miles to the west above the southbound I-435 offramp at Holliday Road (NE-NW sec 6, T12S, R24E), where the base is easily accessible on the east side, and the top is accessible with care on the west side.

The Argentine Limestone Member ranges generally from 25 to 35 feet thick in its type region in the Kansas City area, where it holds up prominent bluffs. It is mainly skeletal calcilutite, with thin shale partings in the lower part and conspicuous phylloid algae in the upper part, which characterize the Kansas City bank area of Crowley (1969) of the phylloid algal mound complexes delineated by Heckel and Cocke (1969). The Argentine Limestone is capped in many places by up to 2 feet of skeletal calcarenite with abraded grains, completing the shoaling-upward sequence typical of regressive limestones. Contacts are generally sharp with both overlying and underlying shale, although O'Connor (1971 p. 17) reported a more gradational contact with the underlying Quindaro Shale Member in western Johnson County, where the lower several feet of Argentine are essentially shale with interbedded nodular limestone.

Northward in Missouri, the Argentine Limestone Member thins to 7 to 13 feet of shaly skeletal calcilutite in the 3 southern cores (MPC, MBC, MRC on Fig. 6) where it probably includes the 2 underlying Wyandotte members as well, because the Quindaro Shale has not yet been definitely identified. In the northernmost Missouri core (MNC) where the Quindaro has been identified, the Argentine as less than one foot of limestone, but the overlying shale contains thin interbeds of limestone attesting to a gradational upper contact in this area. Farther northward in Iowa and Nebraska (Fig. 6), the Argentine Limestone ranges from 3 to 11 feet of skeletal calcilutite, overlain in the thicker sections by oolite (core IMC) or by skeletal calcarenite capped by barren birdseye-bearing calcilutite (core IRC). In this area the lower two Wyandotte members are generally not differentiated, and the entire Wyandotte Limestone is assigned to the Argentine Limestone Member. In Iowa and Nebraska, this unit has long been misidentified as the Farley Limestone Member which appears to pinch out northward into shale in the subsurface around the Missouri-Iowa border, based on information available from the cores.

Southward from its type area, the Argentine Limestone Member thins to less than 10 feet of shaly skeletal calcilutite above thin Liberty Memorial Shale in the interbank area trending NE-SW across southeastern Johnson County (Crowley, 1969), then thickens abruptly to as much as 50 feet of largely phylloid algal calcilutite in the Stilwell bank area of southeasternmost Johnson and parts of adjacent counties (Crowley, 1969). It is largely the thickness and facies trends in the Argentine Limestone in relation to thickness trends in the underlying Liberty Memorial Shale (formerly Lane Shale) that allowed Crowley (1969) to delineate the carbonate bank trends in Johnson County, and his and O'Connor's (1971) lists of localities give a number of exposures for that area.

Southward in Miami County, the thick algal mound facies persists to the area around Louisburg where the top of the Argentine Limestone Member is well exposed with a calcarenite cap in the roadcut and creek bank 3 miles south of Bucyrus (N line NE-NW NW sec 12, T16S, R24E), and the base is well exposed along the southbound offramp from US 69 to Ks Rte 68 (E line SE cor sec 25, T16S, R24E). South of here the Argentine thins gradually above thinning Liberty Memorial in east-central Miami County. Five miles west of Louisburg, the Argentine Limestone thins more abruptly to about 10 feet and descends a slope exposed along Ks Rte 68, one mile north of Somerset (N line NW-NE-NE sec 32, T16S, R24E). This thinning may be into a small intermound channel between the Louisburg mound area and a local mound area northwestward around Wagstaff, which is well exposed in a quarry in E« NW sec 30, T16S, R24E, where the Argentine is 30 feet thick. Westward off the Wagstaff mound area, the Argentine Limestone descends well below the Farley Limestone (Arvidson, 1990). The westward- and southward-thickening shale between them becomes the original type Lane Shale (now lower Lane) west of Paola (Fig. 9B), confirming both the correlation of the lower Lane Shale with the Island Creek Shale Member and the identity of the entire "Wyandotte" Limestone of western Miami County as the Farley Limestone Member alone. Good exposures of thin Argentine Limestone, identified by the underlying 1-foot-thick conodont-rich Quindaro Shale Member, above the westward thinning and pinchout of the Liberty Memorial Shale in the Paola area are: along the US 169 roadcut east of Lake Miola (E line NE-SW sec 11, T17S, R23E), where it is 11 feet thick above the 1-foot-thick Quindaro Shale and 28-foot-thick Liberty Memorial Shale; in the north quarry face (SE sec 18, T17S, R23E), where it is 3 feet thick above the thin Quindaro Shale Member and 7 feet of Liberty Memorial Shale and where all these beds were included in the top of the Raytown Limestone Member by Miller (1966) and Mitchell (1981); and the Ks Rte 68 roadcut west of Bull Creek (ctr S line SE sec 29, T16S, R23E), where the Argentine Limestone is 4 feet thick and rests with only the thin intervening Quindaro Shale Member upon the Raytown Limestone Member of the Iola Limestone.

Southwestward across east central Kansas, the Argentine Limestone Member is identified in a number of localities given in Mitchell (1981) lying just above the Iola Limestone and identified by the conodont-rich zone in the intervening Quindaro Shale Member or in limestone assigned to the Argentine where the Quindaro Shale is absent. In some places the Argentine Limestone is separated from the Raytown Limestone by a thin pod of Liberty Memorial Shale and development of the lower Wyandotte members (Frisbie Limestone, Quindaro Shale) as in the type Iola Quarry (NE sec 2, T25S, R18E). In others, the Argentine lies directly on the Raytown as in the Chanute area (US 169 roadcut, E line NW sec 19, T27S, R18E), and in still others just the Quindaro Shale intervenes as in the quarry south of Bush City (NE-NE sec 31, T21S, R21E). The Argentine Limestone in this more basinal region is mainly non-algal skeletal calcilutite around Bush City in Anderson county. It is argillaceous invertebrate skeletal calcarenite southward at Iola, Humboldt, and Chanute. It locally contains abraded grains and oolitic coatings in the upper part at Iola and Humboldt, and west of Humboldt in the bed of Owl Creek (SW-NE-SE sec 1, T26S, R17E), giving evidence for shoaling upward during regression over higher parts of the underlying Raytown algal mound even in this more basinal region. Farther southward, the Argentine Limestone is identified as the thin conodont-rich invertebrate calcarenite reported by Mitchell (1981) at the top of the thin Iola Limestone sequence formerly exposed below the Mill Street bridge in Neodesha (SW SE-SE sec 20, T30S, R16E) in Wilson County, and it may persist southward above thin Iola Limestone toward Oklahoma, although this is not definitely confirmed.

The thick lens of fossiliferous limestone above the Quindaro-equivalent shale horizon in the hill 3 miles west of Ramona in Washington County, Oklahoma, is probably at least partly equivalent to the Argentine Limestone Member. This local carbonate mound developed just north of, and basinward to, the north end of the more widespread Avant Limestone mound at the top of the underlying Iola Limestone. The Argentine Limestone is absent in the sandy shale and sandstone succession above the Quindaro Shale Member in the roadcut above the spillway of the dam west of Skiatook in Osage County.

Lane Shale

The Lane Shale overlies the Argentine Limestone Member (now recognized as the top of the Wyandotte Limestone), underlies the Plattsburg Limestone, and forms the top of the Kansas City Group. The Lane Shale now includes the Island Creek Shale, Farley Limestone, and Bonner Springs Shale as members in northeastern Kansas and northwestern Missouri where the Farley Limestone is present (Fig. 2). Where the Farley Limestone is absent in southeastern Kansas, the Lane Shale comprises all the strata that have been referred to as Lane-Bonner Springs Shale. Where the Farley Limestone is absent in Iowa and Nebraska, the Lane Shale is the unit that has been regarded there as only the Bonner Springs Shale.

The Lane Shale was named by Haworth (1895) from exposures near Lane in Franklin County, Kansas, and the name was considered by Newell (1935) and Moore (1936) to apply to the strata from the top of Iola Limestone to the base of the Wyandotte Limestone, with exposures in the river bluffs in S« sec 33, T18S, R21E, just west of Lane implied as typical by Moore (1936). Recent field work has shown that the limestone at the top of the Iola succession throughout this area of southeastern Franklin and western Miami counties is really the Argentine Limestone Member of the Wyandotte Limestone (see previous section) and what was formerly thought to be the entire Wyandotte Limestone in this same region is really only the Farley Limestone Member (Fig. 9B), which had been considered the upper member of the Wyandotte since the work of Newell (1935). Thus the original type Lane Shale is equivalent to the Island Creek Shale Member, formerly of the Wyandotte Limestone, as named by Newell (1935) from northwestern Wyandotte County.

To avoid inclusion of the thick type Lane Shale as a member of the Wyandotte Limestone, the Wyandotte is herein redefined to comprise only the Frisbie Limestone, Quindaro Shale and Argentine Limestone Members, and the Farley Limestone Member above is recognized as a separate unit. Furthermore, in view of the lenticularity of the Farley Limestone and the desirability of avoiding the cumbersome term Lane-Bonner Springs Shale in Iowa, Nebraska and southern Kansas where the Farley is absent, the name Lane Shale is herein expanded to include the Farley Limestone and overlying Bonner Springs Shale as members in northeastern Kansas and Missouri, just as it was recognized by Hinds and Greene (1915) based to some extent on miscorrelations, prior to the work of Moore (1936), which corrected some, but not all of the miscorrelations. This procedure also allows retention of the name Island Creek Shale as the lower member of the Lane Shale rather than abandoning it as a junior synonym of the original type Lane. The recognition of the Argentine Limestone Member southward at the top of the Iola Limestone succession has shown that the unit that has been called Lane Shale below the

Wyandotte Limestone (Frisbie, Quindaro, Argentine members) in the Kansas City area is not equivalent to the type Lane shale but is an older shale formation termed Liberty Memorial Shale (Clair, 1943) from a locality in that area (see previous section).

Because the Lane Shale in its type region of southeastern Franklin and western Miami counties, originally included only the lower shale member now recognized as the Island Creek, the type exposure given by Moore (1936), which is now slumped and heavily vegetated, is unsatisfactory. Also, complete exposures of the thick Lane Shale, now redefined to include the overlying Farley Limestone and Bonner Springs Shale members as well, are essentially unknown. Therefore, an interval along W line sec 28, T18S, R22E, in Miami County 5 miles northeast of Lane, from the top of the Wyandotte Limestone (exposed in the road at ctr W line NW sec 28, and lying directly upon the top of the Iola Limestone in the quarry in NW-SE sec 20 just to the northwest) up to the base of the Plattsburg Limestone (just north of SW corner sec 28) is chosen as the neostratotype of the Lane Shale. This interval is about 140 feet thick and contains the Farley Limestone Member exposed above the middle (W line SW-NW-SW sec 28), but the two shale members (Island Creek below, Bonner Springs above) are mostly covered. A better exposed reference section of the entire Lane as redefined herein is available along the east bluff of Turkey Creek 3 miles north of Rantoul (W line NW-NW sec 10, T17S, R21E) in eastern Franklin County, where the Farley Limestone, upper Bonner Springs Shale and most of the Island Creek Shale Member are fairly well exposed above the Iola Limestone mapped by Ball et al. (1963) in the creek near NE corner sec 9. The Iola is not well exposed now, but presumably includes the Wyandotte Limestone at the top.

Southward the Farley Limestone at the middle of the Lane Shale disappears near Greeley in northeastern Anderson County, and the undivided Lane Shale (formerly Lane-Bonner Springs Shale) extends southward as a 50- to 160-foot sandy shale sequence in the sides of the prominent escarpments held up by the overlying Plattsburg Limestone in eastern Anderson, north-central Allen and eastern Wilson Counties. As a result, most of the roadcuts ascending the escarpment expose only the upper (or Bonner Springs) part of the Lane Shale. A good reference section along the highway at Kincaid from the top of the bedded Wyandotte Limestone along the railroad underpass (SW corner sec 31, T22S, R21E) westward to the base of the Plattsburg Limestone (ctr S line SE SW sec 35, T22S, R20E) exposes a good sequence from near the middle of the Lane (S line SE SE sec 35, T22S, R20E) upward, including rippled sandstone near the top (ctr S line SW-SE sec 35) in southeastern Anderson County. The Lane Shale contains a zone of thin-bedded, fossiliferous micaceous flaggy sandstones reported by Miller (1969) along the Anderson-Allen County line, which may represent a southern facies of the Farley Limestone Member.

A good exposure of the lower (or Island Creek) part of the Lane Shale is provided by the bluff above the road east of Carlyle (N of SE cor sec 32, T23S, R19E) in northern Allen County. Southward the Lane thins to about 30 feet of gray shale above the thicker part of the Raytown Limestone algal mound at Iola, where it is exposed along the highway just south of town (SW cor sec 35, T24S, R18E) and at Humboldt, where it has been used for brick manufacture in a claypit (NW sec 34, T25S, R18E) just north of town. It thickens again to perhaps 160 feet in Wilson County south of the disappearance of the Raytown algal mound at Chanute, where the base of the shale is well exposed above the thin argillaceous Wyandotte Limestone in the new US 169 cut west of town (W line SE sec 19, T27S, R18E). A good reference exposure of the top of the Lane is present along the Ks Rte 47 cut about 1 mile west of Altoona (near NW cor sec 17, T29S, R16E) in Wilson County, where about 50 feet of gray shale contains a thin argillaceous fossiliferous limestone bed about 13 feet below the top. Other exposures include the bluffs along the road 2 miles north of Neodesha (SW-NW sec 6, T30S, R16E) and along Ks Rte 96 just west of Neodesha (near ctr N line sec 25, T30S, R15E) in southern Wilson County, and the bluffs 2 miles northwest of Sycamore (NE cor sec 15, T31S, R15E) and south of the bridge over Sycamore Creek (near ctr W line NW sec 10, T31S, R15E) in northern Montgomery County. Southward the Lane thins to perhaps 50 feet of poorly exposed gray shale as it merges with the lower part of the Wann Formation of northern Oklahoma.

Northward beyond the pinchout of the Farley Limestone Member north of core MNC near the Missouri-Iowa border (Fig. 6), the Lane Shale is not separated into its component members. The entire Lane ranges from 14 to 26 feet in the Iowa cores, where it consists of gray shale, often with subequal red mudstone, and sandy and coaly horizons near the top. It contains a fossiliferous zone below the middle in core IBC in southern Iowa, which may represent the horizon of the Farley Limestone. On the Iowa-Nebraska outcrop, the Lane Shale ranges from 8 to 17 feet of gray and red mudstone, which previously had been recognized as only the Bonner Springs Shale because of the lack of recognition of the northward pinchout of the Farley Limestone in the subsurface along the Iowa-Missouri border. Above this interval, the upper Missourian units of Iowa and Nebraska have been correctly correlated with the Kansas City succession for many years.

The Lane Shale in Iowa and Nebraska consists largely of terrestrial deposits that underwent paleosol development during the two lower stands of sea level between the Wyandotte and Plattsburg marine transgressions. In Missouri and northeastern Kansas, the lower Lane (Island Creek) is deltaic, the middle Lane (Farley Limestone) is a minor transgressive-regressive marine sequence, and the upper Lane (Bonner Springs) is largely terrestrial with paleosol development, but with early transgressive deposits of the Plattsburg cycle locally at the top. Southward the entire Lane appears to be more prodeltaic, and the thin limestone in the upper part around Altoona may represent a minor hiatal deposit formed when a delta lobe shifted away for awhile, then returned to deposit the top of the gray silty shale.

Island Creek Shale Member.--The Island Creek Shale overlies the Argentine Limestone Member and underlies the Farley Limestone Member, and it is now recognized as the lower member of the Lane Shale in Kansas (Fig. 2). The Island Creek Shale was named in this position, but as a member of the Wyandotte Limestone by Newell (in Moore, 1932; 1935) from

Island Creek in northwestern Wyandotte County. However, with more recent discovery that the underlying Argentine Limestone is traced southward beneath type Lane Shale (Fig. 9) to rest on top of the Iola Limestone in central Miami County (see previous sections), the Island Creek Shale is now recognized to be equivalent to the original type Lane Shale. In order to retain the Wyandotte as a dominantly carbonate formation and to simplify nomenclature of the Lane-Farley-Bonner Springs succession throughout Kansas and northward, the Wyandotte Limestone has been redefined to exclude the Island Creek Shale and Farley Limestone Members, and the Lane Shale has been redefined to include them as members along with the overlying Bonner Springs Shale.

The type section of the Island Creek Shale Member denoted by Jewett and Newell (1935) in a quarry in the NW corner of sec 11, T10S, R23E on Island Creek about 1.5 miles northwest of Wolcott in Wyandotte County is now covered, as are other localities given in that work. The Island Creek Shale interval is present between the prominant Argentine and lower Farley limestones in the Missouri River bluffs for nearly 4 miles from Island Creek past Wolcott to Pomeroy, and a good (though nearly inaccessible) exposure in this bluff above the spillway tunnel from Wyandotte County Lake (near ctr S« SE sec 18, T10S, R24E) is the closest known exposure to the type section. In the Wolcott area, the Island Creek is about 40 feet of gray sandy shale, but it thins southward through 20 to 10 feet in the rest of Wyandotte County to a few feet or less in Johnson County, particularly over thicker parts of the algal mound complexes in the Argentine Limestone (Crowley, 1969). Several exposures are listed by Crowley (1969) and O'Connor (1971). Newer exposures include an accessible principal reference section in the cut hillside above the southbound onramp from Holliday Road to I-435 (ctr E« NW sec 6, T12S, R24E) in northern Johnson County, where it is 5 feet of sandy micaceous shale, and in the road ditch just south of the large quarry east of US 69, 4 miles north of Stilwell (S line SW-SE sec 18, T14S, R25E) in southeastern Johnson County, where it is about 8 feet of fossiliferous shale interbedded with limestone.

Northward in Missouri, the Island Creek Shale Member thins from 35 feet of shale capped by sandstone on outcrop in Platte and Clay counties (Howe, 1986) to 15 feet of gray shale below the northernmost identified Farley Limestone in core MNC near the Iowa border (Fig. 6). Northward beyond the Farley Limestone pinchout, the Island Creek Shale is not separated from the overlying Bonner Springs Shale. It is represented in the lower part of the undivided Lane Shale in Iowa and Nebraska where the entire succession of gray and red mudstone previously had been considered only the Bonner Springs Shale because the northward pinchout of the Farley Limestone was not recognized.

Southward from its type region in Wyandotte and Johnson Counties, Kansas, the Island Creek Shale Member remains thin into northeastern Miami County, where it is only 2 feet thick above the Argentine algal mound in the Wagstaff quarry (near ctr N« sec 30, T16S, R24E). Southwest of here, off the south end of the underlying Argentine mound complex above the southwestward thinning Liberty Memorial Shale, the Island Creek Shale thickens abruptly to an interval about 45 feet thick between the Farley Limestone exposed along Ks Rte 68 (N line NW-NW-NE sec 35, T16S, R23E) and the descending top of the Argentine Limestone exposed along the northward offramp of US 169 to Ks Rte 68 (W line SW-NW-NE sec 35) just to the southwest (Arvidson, 1990). Westward, the Island Creek thickens further to about 70 to 110 feet in western Miami and eastern Franklin County, where it is the unit that was originally considered the type Lane Shale, but which is now regarded as the lower member of the Lane for reasons given previously. In this region the Island Creek consists mainly of gray silty micaceous shale with sparse fossils in the lower part (Ball et al., 1963) and plant-bearing sandstone in the upper part. Partial exposures of the upper part are found below the prominent bluff-forming Farley Limestone Member at several places, e.g., along Ks Rte 68 northwest of Paola (S line SW-SW sec 26, T16S, R22E), along the road between Osawatomie and Rantoul (near ctr S line sec 28, T17S, R22E) and along the road on the east bluff of Turkey Creek 3 miles northeast of Rantoul (W line NW-NW and W line NW-SW sec 10, T17S, R21E).

The Island Creek Shale Member represents two deltaic sequences in northeastern Kansas and adjacent Missouri. One delta was centered in northwestern Missouri with a possible northeasterly source, and extended into the type Island Creek area of Wyandotte County, Kansas. The other was centered in the type Lane area of western Miami and eastern Franklin counties with a probable southeasterly source, and extended southward largely as prodeltaic deposits toward Oklahoma. Both deltas thinned greatly as they lapped onto the thicker Argentine Limestone algal mound complex of the Kansas City region centered around Johnson County, Kansas, but did not totally terminate carbonate deposition on some of the higher areas, where fossiliferous shale and thin limestones formed at this time. Both delta complexes formed late during the Argentine regression and succeeding lowstand when they prograded the shoreline into east-central Kansas and northwestern Missouri, but left some of the higher Argentine mounds in shallow marine water in the Kansas City region. Northward, paleosols developed during most of Island Creek deposition in Iowa and Nebraska.

Farley Limestone Member.--The Farley Limestone overlies the Island Creek Shale Member and underlies the Bonner Springs Shale Member in northeastern Kansas and northwestern Missouri, and is now recognized as the middle member of the Lane Shale (Fig. 2). The Farley Limestone was named by Hinds and Greene (1915) as the middle part of the Lane Shale from exposures near Farley in Platte County, Missouri, just across the Missouri River from Leavenworth County, Kansas, but it was included as the top member of the Wyandotte Limestone by Newell (1935). However, with the discovery that the original type Lane Shale correlates with the Island Creek Shale underlying the Farley Limestone, rather than with the older shale (now called Liberty Memorial) that underlies the base of the Wyandotte Limestone (Fig. 9) around Kansas City, the Farley is now regarded as a separate unit with a different stratigraphic trend that is independent of the Wyandotte Limestone (as revised herein to comprise only the Frisbie, Quindaro and Argentine Members). Therefore, the Farley Limestone is returned as a member to the Lane

Shale as Hinds and Greene (1915) first recognized it. The Farley Limestone is present only in northwestern Missouri and northeastern Kansas, and it grades both northward in Iowa and Nebraska, and southward in east-central Kansas, into the undivided Lane Shale.

The Farley Limestone Member in its type region northwest of Kansas City comprises 3 units: lower limestone, middle shale, and upper limestone, which are well shown as distinct beds in the Missouri River bluff above the good (but nearly inaccessible) exposure of the Island Creek Shale above the spillway from Wyandotte County Lake (near ctr S« SE sec 18, T10S, R24E). The principal reference section chosen for the Farley Limestone in Kansas is accessible above the southbound onramp from Holliday Road to I-435 (ctr E« NW sec 6, T12S, R24E), where the lower Farley limestone is 4 feet of algal calcilutite capped by 4 feet of skeletal calcarenite, the middle Farley shale is 6 feet of gray shale with sandy beds in the top, and the upper Farley limestone is 9 feet of algal-skeletal calcilutite.

Northward in Missouri, the Farley Limestone Member averages about 15 feet thick, but ranges from 5 to 30 feet on outcrop. The lower Farley Limestone unit consists of a variable thickness of oolite, overlain by the middle Farley shale with a coal horizon near the top, and capped by several feet of upper Farley osagia-grain calcarenite. The Farley Member thins northward from 24 to 7 feet in the Missouri cores, where it includes a variety of lithologies. These include an oolite sequence bisected by the middle Farley shale in the south, and skeletal calcilutite, birdseye-bearing calcilutite and oncolitic beds, all becoming shalier toward the north, where the sequence grades entirely into shale near the Iowa border (Fig. 6). A brachiopod-bearing shale within the Lane succession in one of the southern Iowa cores (IBC) may represent the horizon of the Farley Limestone Member.

Southward in the Kansas City region, Crowley (1969) showed that the lower Farley Limestone unit is generally 5 to 10 feet of oolite to skeletal calcarenite thickening locally to 20 to 25 feet of phylloid algal moundrock in the Olathe area of central Johnson County and in the Stilwell area of southeastern Johnson County, above thick Argentine algal mounds with only thin intervening Island Creek Shale. The middle Farley shale is 10 to 12 feet thick in a southward-extending lobe across east-central Wyandotte into east north-central Johnson County, which thins to disappearance in southwestern Johnson County. The upper Farley Limestone unit consists mainly of a phylloid algal mound facies nearly 7 feet thick in the Stilwell area and reaching 20 feet thick near Bonner Springs, both fringed by skeletal calcarenite facies (several localities are given in Crowley, 1969). Lateral intergradation of shale with both Farley limestone units, described for the lower Farley unit by J.W. Harris (in Heckel et al., 1985, p.32) on the east side of Bonner Springs (roadcut east of Rte K-7 in NW-NE-SE sec. 29, T11S, R23E) shows that the units recognized in the Farley Limestone Member should remain informal.

Southwestward into western Miami County, the entire Farley Limestone Member is 10 to 16 feet of skeletal to algal calcilutite, which was thought to represent the entire Wyandotte Limestone (Fig. 9A) by earlier workers, who sometimes described a lower massive bed as "Frisbie" and the rest as "Argentine", units that now are known to lie below the 100-foot-thick lower Lane (Island Creek) Shale in this region. Good exposures of the Farley Limestone are along a road and stream cut southeast of Antioch (S line SW-SE SE sec 26, T15S, R22E) and two places along Ks Rte 68 (S line E of SW cor sec 26, T16S, R22E; and S line SE sec 25, just to the east, where oolite occurs at the base). Southwestward in Franklin and northern Anderson and Linn counties, the Farley Limestone locally attains 40 feet in thickness where it consists largely of phylloid algal mound facies, capped in places by locally oolitic to osagitic skeletal calcarenite. Many exposures are given in Ball et al. (1963), listed under all members of the Wyandotte (their "Island Creek" may be a recurrence of the middle Farley shale). Among the more accessible exposures are along roads north of Rantoul (ctr W line NW-NW sec 10, T17S, K21E; SE corner and ctr W line sec 8, T17S, R21E); along roads (SE corner NE sec 12, T18S, R21E; ctr E line NE-SE sec 17, T18S, R21E; SE-NE-SE sec 9, T19S, R21E), and in quarries (NW-SW sec 21, T18S, R21E; ctr S line SW sec 36, T18S, R20E; NW-NW-and NW-SW sec 23, T19S, R21E) north, west and south of Lane. Southwestward from a line extending from north central Franklin (Ball et al., 1963, p.9) across northeastern Anderson into northwestern Linn County, the Farley Limestone pinches out into the thick sequence of undivided Lane Shale. Fossiliferous flaggy sandstone reported by Miller (1969) along the Anderson-Allen County line may represent the Farley interval in this thick detrital sequence.

Because of its limited lateral extent relative to most other Missourian limestones, in conjunction with its lack of a conodont-rich horizon, the Farley Limestone Member is considered to be only a minor cycle of transgression (Fig. 3). A relatively small sea-level rise stymied Island Creek delta formation across northeastern Kansas and northwestern Missouri long enough to establish a variety of carbonate facies, all in fairly shallow water, before stillstand allowed detrital penetration to form the middle Farley shale, particularly toward the north. The lateral persistence of the upper Farley Limestone unit above the rather persistent deltaic middle Farley shale, in conjunction with the delineation of the middle Farley shale as a single lobe by Crowley (1969) with a coaly horizon at the top in Missouri, suggests that the upper Farley limestone unit resulted from another minor transgression as shown on Fig. 3.

Bonner Springs Shale Member.--The Bonner-Springs Shale overlies the Farley Limestone Member where it is present in northeastern Kansas and northwestern Missouri, underlies the Plattsburg Limestone (Merriam Limestone Member), and is now recognized as the top member of the Lane Shale (Fig. 2). South and north of the Farley Limestone pinchout, in southeastern Kansas and in Iowa and Nebraska respectively, the Bonner Springs Shale Member is not separated from the underlying Island Creek Shale Member, and the entire sequence is the undivided Lane Shale. The Bonner Springs Shale was named by Newell (in Moore, 1932; 1935) from exposures at the cement plant quarry northeast of Bonner Springs (W« sec 28, T11S, R23E) in southwestern Wyandotte County (Jewett and Newell, 1935). Because of limited access to the quarry, the principal reference section is chosen just to the west in the roadcut along Rte K-7 in SW-SE-NE sec 29. Another good reference section is 4 miles to the east along I-435 (W line NW-SE sec 6, T12S, R24E) just south of the northbound offramp to Holliday Road. The name still refers to the same beds to which it originally was applied, with the recognition that it is now a member of the Lane Shale along with the underlying Farley Limestone and Island Creek Shale members, which are no longer members of the Wyandotte Limestone.

The Bonner Springs Shale Member at its principal reference section is 21 feet of gray micaceous shale that includes 3 feet of argillaceous sandy conglomeratic limestone containing invertebrates and plant fragments at the top, separated from the Merriam Limestone Member by a thin shale bed. In its type area, the Bonner Springs ranges from a few to 30 feet of gray to tan shale with local sandstone, and in many places with a zone of reddish mudstone near the top. At the reference section along I-435, it is 25 feet of gray shale with a limestone/shale pebble-filled channel up to 3 feet thick cutting into the upper red mudstone, and across the highway along the southbound lane, a calcareous paleosol is prominent at the top. More variation is exposed in the I-70--I-435 interchange (SW sec 12, T11S, R23E) where the northeastern loop shows the Bonner Springs Shale Member to be about 15 feet of cross-bedded sandstone with conspicuous channel cutting, whereas the southwestern loop shows it to be about 25 feet of gray sandy shale capped by the reddish zone, and thinning northwestward to 3 feet of brachiopod-bearing gray shale.

Northward in Missouri, the Bonner Springs Shale Member is 11 to 40 feet of gray micaceous shale and mudstone with lenticular sandstones and a thin local coal at the top. Farther northward the Bonner Springs Shale becomes reddish, and north of the Farley Limestone pinchout, it merges with the underlying Island Creek Shale Member to form the 14 to 26-foot undivided Lane Shale, a sequence of gray shale and red mudstone with sandy and coaly horizons near the top. Along the Iowa-Nebraska outcrop belt, the Lane ranges from 8 to 17 feet of gray and red mudstone, which, prior to recognition of the northward pinchout of the Farley Limestone in northern Missouri, was considered only the Bonner Springs Shale.

Southward from its type area, the Bonner Springs Shale Member thins to about 1 foot at the Loring Quarry (NW-SW sec 13, T12S, R22E) in southeasternmost Leavenworth county above the Bonner Springs algal bank area of Crowley (1969) in the upper Farley Limestone. Southeastward in Johnson County, the Bonner Springs Shale ranges from 10 to 30 feet of shale and mudstone with local sandstones throughout, and earthy, fossiliferous conglomeratic limestones near the top, which have been confused at times with the calcarenitic lower part of the overlying Merriam Limestone Member of the Plattsburg Limestone. These limestones may be depositionally related to the lower Merriam, and are classified with the Bonner Springs Shale only when they are argillaceous and separated from the Merriam Limestone by a conspicuous shale. The Bonner Springs Shale Member thickens to 80 feet in the interbank area of Crowley (1969) across southeastern Johnson County where it may include the middle Farley shale at the base, and where it is mainly gray shale with a thin coal overlain by sandstone near the top. Many exposures in this area were described by O'Connor (1971).

Southwestward in Miami and Franklin counties, the Bonner Springs Shale Member ranges from a few to 45 feet thick and is largely gray to reddish mudstones with local sandstones. Most exposures described by Miller (1966) and Ball et al. (1963) are now covered. Reference sections in this area include a roadcut 2 miles south of Rantoul (E line N of SE cor sec 32, T17S, R21E) where the upper 21 feet expose the red zone about 15 feet below the top, a quarry 2 miles north of Lane (NW-SW sec 21, T18S, R21E) where the lower 30 feet expose thin-bedded rippled sandstone in the lower 10 feet and the red zone 25 feet above the base, and a roadcut 4 miles west of Lane (NW cor sec 12, T19S, R20E) where the upper 41 feet expose thick-bedded sandstone in the lower part. South of the pinchout of the Farley Limestone in northeastern Anderson County, the Bonner Springs Shale Member is not separated from the underlying Island Creek Shale Member, and the undivided Lane Shale extends southward as a roughly 50- to over 100-foot sequence of sandy shale described previously.

The Bonner Springs Shale Member represents a variety of terrestrial deposits in northeastern Kansas with reddish paleosols becoming dominant northward. These formed as the sea regressed and terminated Farley Limestone deposition. They are overlain in places around Kansas City by reworked nearshore marine deposits related to the overlying Plattsburg transgression. Southward the Bonner Springs becomes deltaic in southern Franklin County and prodeltaic farther southward as it merges with the rest of the Lane Shale.

LANSING GROUP

The Lansing Group overlies the Kansas City Group and underlies the Pedee Group (reinstated) in Kansas (Fig. 2). It is a dominantly limestone group comprising three formations in ascending order, Plattsburg Limestone, Vilas Shale, and Stanton Limestone as it has in the past. It is newly modified, however, by removal of the Rock Lake Shale and South Bend Limestone members from the Stanton Limestone and their elevation to formation status and grouping with the overlying Stranger Formation in the Pedee Group. This is because of the closer depositional relationship of the South Bend Limestone with the overlying Stranger Formation than with the Stanton Limestone (as redefined; see later sections).

The Lansing Group was named as a formation by Hinds (1912) from Lansing in Leavenworth County, Kansas and was stabilized as a group by Moore (1932, 1936) to apply to the Plattsburg through Stanton Limestone interval. These two limestones together form a prominent traceable escarpment southward through Anderson County where the Vilas Shale thickens and splits the Lansing Group outcrop into two escarpments farther south, each corresponding to one of the two limestone formations. Because no type section was originally given, an excellent principal reference section providing a complete exposure of all the formations and members of the entire Lansing Group (as redefined) is designated in the Ks Rte 7 roadcut on the northeast side of Bonner Springs (W line SE-NE sec 29, T11S, R23E) about 12 miles south of Lansing.

The Lansing Group is about 70 feet thick in northeastern Kansas, thinning northward to about 40 feet along the Iowa-Nebraska outcrop. It thickens southward to nearly 200 feet in places in southern Kansas where both limestone formations contain thick phylloid algal mound complexes in southern Wilson and northern Montgomery counties (Harbaugh, 1959; Heckel and Cocke, 1969).

Plattsburg Limestone

The Plattsburg Limestone overlies the Bonner Springs Shale Member of the Lane Shale and underlies the Vilas Shale throughout Kansas and adjacent states (Fig. 2). This unit was named by Broadhead (1865) from Plattsburg in Clinton County, Missouri. Its correct correlation in Kansas was stabilized by Moore (1936). The Plattsburg Limestone is subdivided into 3 members in ascending order: generally thin Merriam Limestone, thin tan to dark gray Hickory Creek Shale, and thick Spring Hill Limestone, which are recognized throughout most of the outcrop belt. These members characterize the Plattsburg as a cyclothemic limestone of Moore (1949), but because the Hickory Creek lacks the black fissile phosphatic shale facies typical of major cyclothems and is not differentiated on outcrop in western Iowa (Heckel and Pope, 1992), the Plattsburg is considered a cycle of intermediate scale (Fig. 3).

The principal reference section for the Plattsburg Limestone in northeastern Kansas overlies that for the Bonner Springs Shale Member in the roadcut along Rte K-7 on the east side of Bonner Springs (SW-SE-NE sec 29, T11S, R23E) in Wyandotte County, where all 3 members are well exposed. Other complete reference sections are the roadcut on the east (northbound) side of I-435, just south of the offramp for Holliday Road (along ctr W line SE sec 6, T12S, R24E) in northern Johnson County, the roadcut on US 169 near Spring Hill (near ctr S line SE-SE sec 10, T15S, R23E) in southern Johnson County, and along Rte K-68 (ctr N line sec 32, T16S, R21E) in eastern Franklin County. The Plattsburg Limestone averages about 20 feet thick in this area but ranges from 10 to 28 feet.

Northward, the Plattsburg Limestone maintains this general thickness and 3-member subdivision along outcrop in Missouri, thinning northward in the subsurface to about 8 feet in the Platte River Valley of Nebraska, where the 3 members are still recognizable (Fig. 6). It thins to as little as 3 feet of argillaceous limestone in rare exposures in southwestern Iowa, where the members are not differentiated (Heckel and Pope, 1992).

Southward from the Kansas City area, the Plattsburg Limestone maintains its 3-member subdivision where it holds up prominent escarpments from eastern Anderson to eastern Wilson counties in Kansas. It thickens locally to about 50 feet in Anderson County and to nearly 100 feet in southern Wilson County. Most of the additional thickness appears as phylloid algal-mound complexes in the Spring Hill Limestone Member described by Harbaugh (1959) and Heckel and Cocke (1969), but the lower two members also vary in thickness more than do the homologous members in most other cyclothems. The principal reference section for the Plattsburg Limestone in southeastern Kansas is the roadcut along Rte K-47 just west of Altoona (near NW cor sec 17, T29S, R16E) in Wilson County, where all 3 members are well exposed, but the Spring Hill Limestone Member is only about 20 feet thick there, in the intermound region between the two outcropping algal mound complexes.

South of the southern algal mound complex, the Plattsburg Limestone is traced readily near the foot of the prominant Stanton Limestone escarpment to the vicinity of Table Mound, northwest of Independence in central Montgomery County. Here the entire formation has thinned to about 10 feet of argillaceous limestone and fossiliferous shale along the road just south of the east end of the Elk City dam (near ctr W« sec 9, T32S, R15). South of here, the Plattsburg is rarely exposed, but small exposures of limestone (member uncertain) in the road up the hill 2 miles west of Jefferson (just E of SW cor sec 5, T34S, R15E) and along the north side of US 166, 1 mile east of Tyro (S line SE NE NE sec 6, T35S, R15E, and incorrectly mapped as Iola Limestone by Heckel, 1975a) allow the formation to be traced into Oklahoma near the middle of the Wann Formation.

In northern Oklahoma, the Plattsburg Limestone is known in several exposures as a few feet of fossiliferous shale, identified on the basis of its general stratigraphic position (Fig. 10) and the compatible abundant conodont fauna recovered from the shale (Hickory Creek). In three good exposures, the shale lies between two thin argillaceous limestones, thus displaying the same 3-member sequence as in most of Kansas: 1) along the road up the hill 6 miles south-southwest of Bartlesville and 3 miles northwest of Ochelata (near ctr S« sec 15, T25N, R12E), 2) along Rte 0-11 about 1 mile south of Wolco (NE-SE SE« SE« sec 75, T24N, R11E) both in eastern Osage County, and 3) along the south side of the new road to Crystal Bay marina south of Rte O-20 (W line NW NE sec 21, T22N, R11E) in southern Osage County. Other exposures of fossiliferous shale that probably belong to the Plattsburg interval are mentioned under the discussion of the Hickory Creek Shale Member.

Merriam Limestone Member.--The Merriam Limestone overlies the Bonner Springs Shale Member of the Lane Shale and underlies the Hickory Creek Shale Member (Fig. 2). It was named by Newell (in Moore, 1932; 1935) from Merriam in Johnson County, Kansas, as the basal member of the Plattsburg Limestone. Problems with the original type section designated by Moore (1936) were resolved by O'Connor (1971), who designated a reference section nearby in the northeast loop of the I-35--U.S. 50 interchange (SE-SW-SE sec 12, T12S, R24E), which was under construction in March 1990. Therefore, the principal reference section of the Merriam Limestone Member is designated at the principal reference section for the Plattsburg Limestone in Kansas along the east side of Rte K-7 at Bonner Springs.

At the K-7 section, the Merriam Limestone Member is 3.5 feet thick, and consists of two distinct subequal limestone units. The lower limestone unit is calcarenitic and conspicuously fossiliferous, with clams (including myalinids and pectinids), snails, brachiopods, and osagid grains. It is separated from about 3 feet of noticeably more argillaceous conglomeratic, calcarenitic limestone in the top of the Bonner Springs Shale by a thin bed of shale. The upper limestone unit of the Merriam is dense skeletal calcilutite with brachiopods, echinoderms, bryozoans and fusulinids, and a burrowed upper surface. This two-part subdivision is recognized in most exposures in northeastern Kansas. The lower calcarenitic unit ranges from less than a foot up to 9 feet in thickness and is conspicuously sandy, conglomeratic, oolitic and cross bedded in some of the thicker exposures (e.g., southwestern loop of I-70--I-435 interchange, NE SW-SW sec 12, T11S, R23E in Wyandotte County, and along the north side of Rte K-68, S line SW-SE sec 27, T16S, R21E in Franklin County, illustrated by Ball et al., 1963, p. 15). The upper calcilutite unit is more uniform, averaging 1 to 2 feet in thickness over the same area, often with an earthy zone at the top that appears gradational with the overlying shale. This vertical sequence signifies deposition initially in agitated shallow water, followed upward by quiet deeper water deposition with only marine burrowing disturbing the diastemic surface at the top, a deepening-upward sequence that illustrates the transgressive nature of the Merriam Limestone as one of the better examples among Pennsylvanian cyclothems.

Northward, the Merriam Limestone Member ranges generally from 1 to 3 feet thick on outcrop in Missouri and Nebraska and 0.5 to 9 feet in the subsurface. It is mainly skeletal calcilutite that becomes more argillaceous in Iowa, where it is not differentiated on outcrop.

Southward from northeastern Kansas, the lower Merriam Limestone unit is well exposed in a spectacular new roadcut on Rte K-31 west of Garnett on the east bluff of Cedar Creek (W« SW-NW sec 23, T20S, R19E) in Anderson County, where it ranges from 4 to 7 feet of osagitic skeletal calcarenite overlain by up to 6 feet of fossiliferous shale that thins to disappearance eastward along the north side of the cut beneath the 1-foot thick upper Merriam calcilutite unit. It is possible that the lower Merriam calcarenite unit may be confused with, and perhaps related to, the calcarenitic beds in the upper Bonner Springs Shale.

Elsewhere, the entire Merriam Limestone Member is mainly skeletal calcilutite, essentially the upper unit of the Kansas City region. It averages about 1 to 2 feet thick through Anderson and Allen counties where it contains a conspicuous fauna of calcisponges. The Merriam Limestone Member is 3 feet thick in a good exposure along U.S. 59 about 1 mile west of Kincaid (S line SE-SW sec 35, T22S, R20E). It thins southward to less than one foot and becomes lenticular beneath the thickening Hickory Creek Shale Member in Wilson County, where it is well exposed at the Plattsburg Limestone reference section along Rte K-47 west of Altoona. Southward the Merriam is argillaceous fossiliferous limestone in the bluff northwest of Sycamore (near NE cor sec 15, T31S, R15E) and at the Plattsburg Limestone reference sections mentioned previously south of the Elk City dam on the northwest side of Table Mound near Independence in Montgomery County, Kansas, and in eastern and southern Osage County, Oklahoma.

Hickory Creek Shale Member.--The Hickory Creek Shale overlies the Merriam Limestone Member and underlies the Spring Hill Limestone Member in the Plattsburg Limestone (Fig. 2). It was named in this position by Newell (in Moore, 1932; 1935) from Hickory Creek near Peoria in eastern Franklin County. Because the typical exposures listed by Moore (1936) in roadcuts in SE sec 1, T17S, R20E were concealed by slump, Ball et al. (1963) described a roadcut along

Rte K-68 just east of Hickory Creek (near ctr S line sec 29, T16S, R21E) about 2 miles to the northeast as typical. The principal reference section is the best current exposure here, along the south side of K-68 (N line NE cor NW sec 32), where the Hickory Creek is about 0.6 foot of fossiliferous shale, dark gray in the lower half, with an abundant fauna of small brachiopods and crinoids.

Northeastward in the Kansas City area, the Hickory Creek Shale Member retains this general character, but ranges from 0.2 to 2 or 3 feet in some exposures. Good reference sections are the Plattsburg reference sections along Rte K-7 at Bonner Springs in Wyandotte County, along northbound I-435 just south of the Holliday Road offramp, and along U.S. 169 near Spring Hill in Johnson County. Locally the color becomes dark gray, as is seen in a slightly thicker development above a topographic low in the Bonner Springs Shale in the southwestern loop of the I-70--I-435 interchange (NE-SW-SW sec 12, T11S, R23E) in Wyandotte County. The Hickory Creek Shale carries an abundant conodont fauna, dominated by distinctive species of Streptognathodus, and which marks it as the core shale of the Plattsburg cyclothem. Apparently water depths did not become deep enough to maintain a thermocline that inhibited bottom oxygenation long enough to produce the anoxic black facies during this general time of sediment starvation.

Northward, the Hickory Creek Shale Member is generally 0.5 to 1.5 feet of gray to dark gray shale, with abundant conodonts recovered from cores in northwestern Missouri and southern Iowa. On outcrop in Nebraska it becomes more calcareous and carries a sparser fauna of conodonts. It is not differentiated on outcrop in southwestern Iowa (Heckel and Pope, 1992).

Southward from its type area, the Hickory Creek Shale Member remains less than 1 foot of fossiliferous gray shale through Anderson and Allen Counties (e.g., the K-31 cut west of Garnett on the east bluff of Cedar Creek, W« SW NW sec 23, T20S, R19E; the U.S. 59 roadcut 1 mile west of Kincaid, S line SE SW sec 35, T22S, R.20E). Farther south in Wilson County, it thickens to about 5 feet of extremely fossiliferous gray-brown shale in the Plattsburg reference section in the K-47 roadcut west of Altoona, where calcisponges and small corals become conspicuous along with crinoids, brachiopods and bryozoans. Southward it thickens further to about 40 feet of similarly fossilifereous shale with dipping lenses and beds of shaly skeletal limestone in the old shale pit at Brickton (SW sec 7, T31S, R16E) north of Sycamore in northern Montgomery County, where it may be in part a slope facies of the south end of the overlying Spring Hill algal-mound complex. Southward, the Hickory Creek thins to 9 feet of extremely fossiliferous shale in the Plattsburg reference section near the foot of Table Mound just south of the Elk City dam near Independence, and it is found southward at several localities in northern Oklahoma. One is about halfway up the mound just northwest of Wann (NE SW-SE sec 9, T28N, R14E) in northern Washington County, where the Hickory Creek is several feet of dark gray fossiliferous shale with abundant conodonts and ammonoids. Three more are the previously mentioned Plattsburg sections in eastern and southern Osage County, where the

Hickory Creek is about 2 to 3 feet of fossiliferous shale with abundant conodonts between two argillaceous limestones.

Spring Hill Limestone Member.--The Spring Hill Limestone, the upper member of the Plattsburg Limestone, overlies the Hickory Creek Shale Member and underlies the Vilas Shale (Fig. 2). It was named by Newell (in Moore, 1932; 1935) from Spring Hill in southern Johnson County, where Moore (1936) designated the type locality in a railroad cut along ctr E line sec 14, T15S, R23E. Because this is not a complete section, the principal reference section is designated along the east side of US 169 on the northwest outskirts of Spring Hill (near ctr S line SE-SE sec 10, T15S, R23E). Other complete reference sections for the Spring Hill Limestone Member in this region are the Plattsburg Limestone reference sections along Rte K-7 at Bonner Springs in Wyandotte County, along the east (northbound) side of I-435 just south of the offramp to Holliday Road in northern Johnson County, and along the south side of Rte K-68 above the type Hickory Creek Shale in eastern Franklin County.

In its type region of northeastern Kansas, the Spring Hill Limestone Member ranges from 8 to 23 feet and averages about 15 feet in thickness. Roughly the lower one third to one-half is rather uniform diverse skeletal calcilutite with thin shale partings, and locally prominant brachiopods including Enteletes. The middle part is generally calcarenite, typically skeletal and often with osagid coatings, but locally oolitic. The upper part is calcarenitic in some places, but in others it displays a few feet of argillaceous calcilutite and thin impersistant shales with locally conspicuous fossils, including fusulinids, bryozoans, myalinid clams, and a prominent zone dominated by the brachiopod Composita. This is for the most part a shallowing-upward sequence characteristic of a regressive limestone.

Northward, the Spring Hill Limestone Member is 10 to 20 feet thick in Missouri, where it maintains the tripartite subdivision with the top becoming more distinctively laminated calcilutite with fenestral fabric, vertical rooting structures and few fossils, representing peritidal facies and subaerial exposure. Shale beds become quite prominent in places in subsurface cores, suggesting facies relations with the overlying Vilas shale. The Spring Hill Limestone thins to 7 feet in Nebraska where it displays a shallowing-upward sequence from skeletal to laminated calcilutite.

Southward from the Kansas City area, the Spring Hill Limestone Member thickens to as much as 45 feet in Anderson County, where the upper three quarters become massive phylloid algal mound facies capped locally by calcarenite. Parts of this mound complex are exposed in roadcuts and old quarries along U.S. 59 north and south of Garnett, and in bluffs along the valley of Cedar Creek west of Garnett. Roadcut exposures on US 59 include W line S of NW cor section 6, T20S, R20E, and just S of ctr sec 6, T21S, R20E, and the quarries are in SE sec 12, T20S, R19E, along US 59. A good accessible exposure is along Rte K-31 on the west bluff of Cedar Creek (NE NW NE sec 22, T20S, R19E), where the capping calcarenite is 11 feet thick. Southward in Allen and northern Wilson counties the Spring Hill Limestone thins by loss of the algal mound complex at the top to about 20 feet of increasingly shaly, bedded skeletal calcilutite, essentially the lower part of the northern development, with increasing prominence of calcisponges in the diverse fauna. This is well seen in the Plattsburg reference section along Rte K-47 west of Altoona. Just north of here along the Verdigris valley, a 1- to 3-foot thick bed of distinctive marine pisoids (ooids up to several mm in diameter) forms the top of the Spring Hill, which at present is only poorly exposed in obscure outcrops.

Just 2 miles south of the Altoona roadcut, the Spring Hill Limestone Member thickens abruptly into another phylloid algal mound complex, which covers essentially the southern half of Wilson County. It forms much of the escarpment from Altoona to Sycamore and also the bluffs along the Fall River between Fredonia and Neodesha. The best exposures are in the quarry (NW sec 18, T30S, R16E) on the northwest edge of Neodesha, and in the roadcut along Rte K-96 (along ctr S line sec 23, T30S, R15E) 2 miles west of Neodesha. In this roadcut, the mound complex is about 60 feet thick (above the lower calcisponge-rich facies), with massive crystalline "algal sparite" (Heckel and Cocke, 1969) overlain by irregularly bedded calcilutite with local lenses and pockets of fossils, grading upward into shaly calcilutite containing diagenetic "spar spots" toward the top, and capped by 4 feet of cross-bedded calcarenite. This capping zone of calcarenite is oolitic along the Fall River (N line S« NW sec 23, T29S, R14E) just southwest of Fredonia, and pisolitic in northeastward-dipping exposures in NE sec 3, T29S, R15E northwest of Altoona, where it appears to become the pisolite bed in the Verdigris valley capping the thin offmound Spring Hill facies there.

Southwestward from the K-96 roadcut west of Neodesha, the shales within the upper Spring Hill Limestone thicken at the expense of the limestones, such that the upper Spring Hill grades laterally into the overlying Vilas Shale, as seen 3 miles southward (along ctr N line NE sec 11, T31S, R15E) in Montgomery County where only a tongue of calcarenite remains above the massive crystalline mound facies and the sponge-rich calcilutite downhill to the west. South of the southernmost exposure of mound facies in the Sycamore Quarry (SW NW sec 24, T31S, R15E) 2.5 miles farther south, the remaining lower beds of the Spring Hill grade into shale and thin to the less than 1 foot of shaly limestone seen above the Hickory Creek Shale Member at Table Mound (just south of the Elk City dam) and at the three previously mentioned Plattsburg Limestone localities in eastern and southern Osage County, Oklahoma.

Vilas Shale

The Vilas Shale overlies the Plattsburg Limestone (Spring Hill Limestone Member) and underlies the Stanton Limestone (Captain Creek Limestone Member) in Kansas and adjacent states (Fig. 2). It was named by Adams (1898) from Vilas in northeastern Wilson County, and Moore (1936) noted that it was typically exposed in sec 30, T27S, R17E just north of the village. Because there are no good accessible exposures there today, two reference sections are chosen in the vicinity of Altoona several miles to the southwest. The principal reference section exposes much of the middle and upper parts of the Vilas Shale along US 75 about 4 miles north of Altoona in 2 cuts separated by a small valley along W line SW-NW sec 22, T28S, R16E. Here it is overlain by basal Captain Creek Limestone Member in the northern cut, and the Plattsburg Limestone is exposed south of the southern cut just north of the southwest corner of section 22, giving a total thickness of about 100 feet for the Vilas Shale at this locality. The other reference section is just above the Plattsburg Limestone reference section along Rte K-47 about 1 mile west of Altoona near the northeast corner of sec 18, T29S, R16E, where the lower part is particularly well exposed, but the entire thickness is only about 25 feet because the overlying Stanton Limestone is developed in a topographically low marine channel facies in this area.

The Vilas Shale in its type area above the intermound facies of the Spring Hill Limestone Member is mainly rather uniform, gray silty micaceous shale with sparse marine fossils visible in fresh cuts, mostly small clams and snails with occasional brachiopods and echinoderm pieces. Contacts are abrupt but comformable with limestones above and below. The Vilas thins gradually northward to about 30 feet in northwestern Allen County, where it contains a zone of maroon mudstone (Miller, 1969). It thins to less than 1 foot of gray shale above the Spring Hill algal mound complex in Anderson County, as exposed in a quarry west of U.S. 59 north of Garnett (NW-NE sec 1, T20S, R19E) and in the quarries along US 59 just to the south (SE sec 12). It thickens westward in the Rte K-31 cut on the west bluff of Cedar Creek (N« NW-NE sec 22, T20S, R19E) where it consists of 3 to 5 feet of blocky mudstone overlain by 1 foot of barren argillaceous calcilutite and capped by 3 to 5 feet of slumped gray shale.

Northward, above thinner bedded facies of the Spring Hill Limestone Member in northeastern Kansas, the Vilas Shale thickens to a range of 5 to 30 feet of gray shale with local argillaceous calcilutite beds and sandstone bodies in many of the thicker sections. Some of the sandstones in the middle to lower part contain plant fossils. Sandstones in the upper part contain marine fossils and locally are quite calcareous, as seen in the quarry in SE-NW sec 7, T17S, R22E in western Miami County, and in the roadcut along Rte K-10 east of Kill Creek (SE sec 33, T12S, R22E) in western Johnson County. Fossiliferous sandstone at the top of the Vilas was referred to as the "Naish limestone or sandstone" by Moore (1932 p. 87,97) from a locality in the bluffs along the north side of the Kansas River in Wyandotte County, but this name is no longer in use. Complete sections of Vilas Shale are exposed above the Plattsburg reference sections along Rte K-68 (N line NW-NW-NE sec 32, T16S, R21E) in eastern Franklin County where it is 9 feet thick, and along Rte K-7 at Bonner Springs (SW-SE-NE sec 29, T11S, R23E) in Wyandotte County, where it is 22 feet thick with sandstone in the middle and top, and also below the type Captain Creek Limestone along the gravel road just north of Rte K-10 (N SE-SE-SW sec 3, T13S, R21E) in eastern Douglas County, where it is 16 feet thick with sandstone below the middle.

Northward (Fig. 6), the Vilas Shale maintains this variable thickness, ranging from 2 to 20 feet in Missouri, from 3 to 33 feet in Iowa, and thinning to 6 to 8 feet in Nebraska. The thicker sections are silty gray shale grading upward to sandstone, and the thinner sections usually are blocky mudstone overlain by sparsely fossiliferous, locally calcareous shale. The lower part of the mudstone is red on outcrop in western Madison County, Iowa (Heckel and Pope, 1992).

Southward from its type region in northern Wilson County, the Vilas Shale thins locally beneath the Stanton channel west of Altoona, and becomes even thinner regionally above the southern Spring Hill algal mound complex in southern Wilson County. In the Rte K-96 roadcut 2 miles west of Neodesha (near ctr S line SE-SW sec 23, T30S, R15E), the Vilas is two feet of gray shale above the calcarenite cap of the Spring Hill mound. It is overlain by several feet of interbedded shale and limestone with conspicuous blades of well-preserved phylloid red algae, which is now considered the base of the Stanton Limestone, the Benedict bed of the Captain Creek Limestone Member (see later section). Southward the Vilas Shale thickens greatly to about 80 to 100 feet in the face of the prominent Stanton-capped escarpment and its outlier Table Mound in north-central Montgomery County. A large part of this thickening is by southward facies change of the upper part of the Spring Hill Limestone mound complex into the lower Vilas near the Wilson-Montgomery County line, as described under the Spring Hill Limestone Member. A fairly well exposed nearly complete reference section of lower Vilas Shale is exposed along the road up the northwest side of Table Mound (E« SW sec 9, T32S, R15E), and the upper part is well exposed above the road down the south side of Table Mound (W« NE-SE sec 16, T32S, R15E). The Vilas Shale contains beds of thin-bedded shaly sandstone near the top in Montgomery County, mapped by Heckel (1975a) near Bolton and Tyro, and these become more prominent southward beneath the thinning Captain Creek Limestone (and its Tyro Oolite bed) as the Vilas merges southward with the upper part of the Wann Formation in northern Oklahoma.

The Birch Creek Limestone of east-central Osage County, Oklahoma, appears to lie within the interval of the Vilas Shale in the upper part of the Wann Formation. The Birch Creek Limestone was named by Bowen (1918) from exposures of a sparsely fossiliferous dolomitic limestone in bluffs on the north side of Birch Creek (near east line of SE sec 25, T24N, R10E) 2 miles south of Barnsdall. Because this locality is now submerged beneath a reservoir, the principal reference section is in a railroad cut about 1.5 miles to the northeast (NW-NW-SW sec 20, T24N, R11E). This distinctive unit has been traced by A.P. Bennison northward (roadcut near ctr S« SE sec 9, T24N, R11E) to a position below the exposure of the Eudora Shale Member of the Stanton Limestone along Rte 0-123 northeast of Barnsdall, and eastward (along Rte 0-11 south of Wolco near ctr E« SE-NE sec 25, T24N, R11E) to a position above the exposure of Plattsburg Limestone along Rte 0-11 just 0.6 miles to the south. It has been traced by Bennison southward to a roadcut along Rte 0-20 (near ctr W« SE-SW sec 13, T22N, R10E) below the position of the Eudora Shale just below the Wildhorse Dolomite in exposures about 3 miles to the west, and above the position of the Plattsburg Limestone along the road into Crystal Bay Marina about 3 miles to the east.

The distinctive lithology of the Birch Creek Limestone is not definitely known north of T24N in east-central Osage County, even though it had been miscorrelated with higher beds at the Kansas-Oklahoma border by Oakes (1940a). Because the base of the Birch Creek Limestone was used by Oakes (1959) to define the boundary between the Wann Formation below and the Barnsdall Formation above, it is suggested that this boundary be moved upward to the more widely traceable horizon at the base of the Stanton Limestone in Oklahoma (see next section) so that the Wann Formation of Oklahoma (named by Ohern, 1910, from exposures near Wann 6 miles south of the Kansas border on the Washington-Nowata County line) will be the exact equivalent of the Lane-Vilas interval of Kansas.

The Vilas Shale represents deposits of the lowstand of sea level between the Plattsburg and Stanton transgressions, interrupted by a minor transgression represented by the Birch Creek Limestone of northern Oklahoma and possibly by the upper part of the Spring Hill Limestone mound complex in southern Wilson County, Kansas, which grades laterally into the Vilas Shale (see previous section). The thick sparsely fossiliferous Vilas shales with thin sandstones elsewhere in southern Kansas (and in a southern Iowa core, IBC) represent prodeltaic deposits. The thinner shales with local sandstones in northeastern Kansas probably represent alluvial deposits overlain by nearshore marine beds associated with the Stanton transgression. The thin blocky mudstones noted locally in northeastern Kansas, and more generally northward in Iowa and Nebraska, are paleosols developed during withdrawal of the sea from this region.

Stanton Limestone

The Stanton Limestone overlies the Vilas Shale and is now recognized to underlie the Rock Lake Shale in Kansas (Fig. 2). It was named by Swallow and Hawn (1865) from exposures near the settlement of Stanton in Stanton Township in western Miami County, and the name became attached to the limestone formation above the Plattsburg Limestone elsewhere in eastern Kansas and northwestern Missouri. When Newell (1935) discovered that because of misidentification at the Stanton type locality of the then unrecognized "Wyandotte" (Farley) Limestone as Plattsburg and thus realized that the original type Stanton unit was really Plattsburg Limestone, he pragmatically chose to retain the name Stanton for the higher unit, to which it was commonly applied. Subsequently Moore (1936) designated typical exposures in roadcuts near SE cor sec 3, T13S, R21E in eastern Douglas County about 25 miles to the north. A better exposure of the complete Stanton Limestone about 2.5 miles eastward along the westbound onramp from Edgerton Road to Rte K-10 (NE-SE SE sec 36, T12S, R21E) in westernmost Johnson County now serves as the principal reference section. Another complete section is in the Rte K-7 roadcut at Bonner Springs (NW-SE-NE sec 29, T11S, R23E) in western Wyandotte County. A nearly complete section, lacking only the top of the upper limestone member (Stoner), along Rte K-68 (S line at SE cor sec 30, T16S, R21E) in eastern Franklin County is the best exposure currently known in the original type area.

The Stanton Limestone now comprises three members in ascending order: Captain Creek Limestone Member, dark gray to black Eudora Shale Member, and Stoner Limestone Member, which represent the classic transgressive-regressive sequence of a Kansas cyclothem. The Rock Lake Shale and South Bend Limestone, formerly included as members at the top of the Stanton are now recognized as separate formations. This is because the South Bend Limestone is a separate marine cyclothem that is completely developed in Nebraska, where it is now recognized as consisting of 3 named beds (Pabian and Strimple, in press), which are raised in rank to members in Kansas; and the Rock Lake Shale represents disconformable low-stand deposits that are distinctive and widespread enough to be recognized as a separate formation, as is consistent with stratigraphic practice lower in the Missourian sequence.

The Stanton Limestone averages between 25 and 35 feet in thickness throughout its type region in northeastern Kansas. Northward, it retains its distinctive three-member subdivision to the northern limit of outcrop (Fig. 6), thinning to an average of 25 feet in Missouri, 22 feet in Nebraska and 20 feet in Iowa. Two exposures in central western Madison County and in central western Cass County, Iowa, had long been misidentified as the younger Virgilian Oread Limestone until study of the conodont fauna in the black shale showed it to be Eudora instead of Heebner (von Bitter and Heckel, 1978).

Southward from its type region, the Stanton Limestone holds up a readily traceable escarpment as it thickens to about 40 feet in western Allen and eastern Woodson counties, 50 to 60 feet across central Wilson County and up to 95 feet in a nearly completely exposed reference section in a roadcut (W« NE to SE-NW sec 7, T32S, R15E) west of the Elk City dam at Table Mound in central Montgomery County. Most of the thickening occurs as phylloid algal mound facies in both limestone members. A named bed, Benedict Limestone (Heckel, 1975b), is recognized at the base of the lower member in Wilson County.

In Woodson and Wilson counties and adjacent parts of Allen and Neosho counties, the Stanton Limestone displays a system of three contemporaneous channels up to nearly 1 mile wide, one transecting mainly southeastern Woodson County, another joining it along the Allen-Neosho and Woodson-Wilson County line, and the longest transecting Wilson County for at least 22 miles from linear outliers between Altoona and Earlton westward to Fredonia (Heckel 1975b, p. 45). These channels are oriented westward to southwestward and connect with a basinal offmound area of Stanton in the shallow subsurface of northwestern Wilson County. All 3 members are recognized changing to nonmound facies as they descend into these channels, indicating that the channel facies formed coevally with the mound facies, but on topographically lower, pre-existing channels in the Vilas prodeltaic complex. Parts of two channels are filled with younger Rock Lake and South Bend strata. The roadcut along Rte K-47 (N« NW-NE sec 18, T29S, R16E) about 2 miles west of Altoona provides a complete reference section for the Stanton Limestone in the Wilson County channel. Elsewhere in this part of Kansas only partial exposures are available, and the better of these are described under the individual members. Northwest of the channel/mound/basinal area of northwestern Wilson County, the Stanton

Limestone is brought up in the centers of Rose dome around section 18, T26S, R16E in southern Woodson County, and of Silver City dome around section 6, T27S, R15E on the Woodson-Wilson County line, where quarries expose the lower member (Captain Creek) in mound facies.

South of the roadcut west of Elk City Dam, the Stanton Limestone thins southward (Fig. 10), to about 20 feet in southern Montgomery County, as the lower limestone member (Captain Creek) thins, and the upper limestone (Stoner) grades into fossiliferous shale that is classified largely with the intervening shale (Eudora). Three named limestone beds and one siltstone bed are recognized in this area: Tyro Oolite, which is equivalent to the Captain Creek Limestone Member; Timber Hill Siltstone and Bolton and Rutland limestones, which are equivalent to the Stoner Limestone Member (Heckel, 1975a). The Tyro Oolite bed extends a short distance into northern Oklahoma, and the overlying Eudora Shale Member is recognized on the basis of its dark color, phosphate nodules, and its distinctive conodont fauna at several localities in northern Washington County where it had been mapped in the upper part of the Wann Formation by Oakes (1940a).

The Eudora Shale Member also is recognized farther southward on a similar basis at four localities in eastern and southern Osage Counties. These are mapped in the Barnsdall Formation, named by Oakes (1951) with a type area east of Barnsdall in T24N, R11E (Oakes, 1959), where two of the exposures are located. Thus the Stanton Limestone is equivalent to at least part of the Barnsdall Formation, which has been thought to overlie the Wann Formation unconformably. The boundary between the Wann and Barnsdall Formations had been placed by Oakes (1959) at the base of the Birch Creek Limestone, which is now known to lie within the interval of the Vilas Shale (see previous section) below the Stanton Limestone. However, the Birch Creek Limestone had been miscorrelated northward with both the Tyro Oolite bed of the Captain Creek Limestone Member of the Stanton and with the stratigraphically higher, conglomeratic Little Kaw Limestone Member of the South Bend Limestone in northern Washington County (T29N) by Oakes (1940a). Heckel (1975a) corrected the resulting miscorrelation of the South Bend Limestone with the Tyro Oolite, but incorrectly assumed that the South Bend horizon was closer to the horizon of the type Birch Creek Limestone, and thus included the entire Stanton Limestone (including the then-included Rock Lake Shale) in the top of the Wann Formation, as Oakes (1940a) had done in northern Washington County. Because the type Birch Creek Limestone is unknown north of T24N, and therefore does not provide a mappable boundary in the northern five townships of Oklahoma, (Fig. 10), it is suggested that the base of the lowest unit of the Stanton Limestone (Tyro Oolite bed, Captain Creek Limestone Member, Eudora Shale Member) that is present in a particular area should define the Wann-Barnsdall formational boundary in Oklahoma. This procedure would stabilize the Wann Formation as the exact Oklahoma equivalent of the Lane, Plattsburg and Vilas formations, and the Barnsdall Formation as the exact equivalent of the Stanton, Rock Lake, and South Bend formations, although with the correlation of its upper boundary left uncertain for the present time.

Captain Creek Limestone Member.--The Captain Creek Limestone overlies the Vilas Shale, underlies the Eudora Shale Member, and forms the base of the Stanton Limestone (Fig. 2). It was named by Newell (1935) from Captain Creek east of Eudora in eastern Douglas County, and Moore (1936) designated exposures on Captain Creek and in a roadcut near SE cor sec 3, T13S, R21E as the type locality. Recent road construction has provided a better exposure nearby along the gravel road just north of Rte K-10 (N« SE-SE-SW sec 3) to serve as the principal reference section. Another good exposure is the principal reference section for the entire Stanton Limestone along the westbound onramp to Rte K-10 from Edgerton Road (NE-SE-SE sec 36, T12S, R21E) just 2 miles eastward in westernmost Johnson County. The Captain Creek Limestone Member contains two distinctive named beds in southeastern Kansas, the Benedict Limestone bed (Heckel, 1975b) at the base in Wilson, Woodson, and Allen counties, and the Tyro Oolite bed (Heckel, 1975a) at the south end in southern Montgomery County.

The Captain Creek Limestone Member in its type region in northeastern Kansas averages about 5 to 8 feet thick and consists mainly of medium-bedded skeletal calcilutite with a diverse marine biota including conspicuous brachiopods (especially *Enteletes*), fusulinids and large blades of phylloid algae. Thin calcarenite occurs locally at the base. It is a characteristic transgressive limestone above the terrestrial to nearshore Vilas Shale, although it is generally thicker than other Missourian (and Virgilian) transgressive limestones in Kansas. Good exposures of Captain Creek Limestone are found also in the Stanton Limestone reference section along Rte K-7 at Bonner Springs in Wyandotte County, and along Rte K-68 (N line NW-NE sec 32, T16S, R21E) in eastern Franklin County.

Northward, the Captain Creek Limestone Member remains skeletal calcilutite to the northern limit of outcrop as it thins through 4 to 2 feet in Missouri to 1 to 0.5 foot along the Nebraska-Iowa outcrop. In Iowa it had been misidentified as the younger Virgilian Leavenworth Limestone Member of the Oread Limestone in exposures in western Madison County and western Cass County, until analysis of the conodont fauna of the overlying black shale showed it to be Eudora rather than Heebner (von Bitter and Heckel, 1978).

Southward from its type region, the Captain Creek Limestone Member thickens gradually through Anderson County, where it is 10 feet thick in the roadcut just north of Pottawatomie Creek (W line NW-SW-NW sec 4, T20S, R19E) 5 miles northwest of Garnett, and through Allen County, where it is 13 feet thick in the US 54 roadcut (along S line SE-SE sec 25, T24S, R17E) 4 miles west of Iola. Here it consists mainly of increasingly algal-rich skeletal calcilutite with a calcarenite bed at the base. Southward the Captain Creek Limestone holds up the prominent Stanton escarpment as it thickens through 20 to 30 feet in southern Woodson and Wilson counties and attains 50 feet in central Montgomery County, where it also forms the caprock on

Table Mound northwest of Independence. Throughout this area it is thick-bedded to massive phylloid algal-dominated calcilutite with large patches of sparry calcite and rusty weathering dolomite, which has been informally termed "moundrock". This has been exposed extensively in quarries (e.g., SW-SW-SE sec 3, T26S, R17E due west of Humboldt, and SW sec 13, T26S, R15E southwest of Rose, in southern Woodson County; SW-SE-SE sec 17, T27S, R16E south of US 75 east of Wilson County State Lake, exposed more accessibly just to the west along the spillway west of the dam, 1.5 mile southeast of Buffalo; NE-SE sec 2, T28S, R15E, 1 mile northeast of Benedict; W« sec 19, T29S, R15E, south of Fredonia in Wilson County). It is also well exposed at the top of the Rte K-96 roadcut west of Neodesha (S line SW SE SW sec 23, T30S, R15E). The Captain Creek Limestone thins abruptly as it descends into the channel system in this region, as seen in the roadcut (W line NW-SW-SW sec 7, T29S, R16E) north of the K-47 cut west of Altoona, and grades into 1 to 3 feet of non-algal, skeletal calcilutite at the east end of the Stanton reference section in the K-47 cut (see Heckel, 1979, p. 34-35).

In Montgomery County, much of the upper part of the Captain Creek Limestone Member is a distinctive "algal sparite" facies (Heckel and Cocke, 1969) consisting mainly of large crystals of brownish calcite and patches of rusty-weathering ferroan dolomite, which often weather to vugs. This is exposed in extensive quarries in the top of Table Mound (sections 9 & 16, T32S, R15E), but is best seen in the reference section along the roadcut west of Elk City dam (ctr W« NE sec 7, T32S, R15E) where the top displays small skeletal calcarenite-filled channels, which delineate the south end of the thick mound complex in this area. Southward the Captain Creek thins rather abruptly to about 5 feet of algal calcilutite with calcisponges in the U.S. 160 roadcut (S line NW-NE sec 36, T32S, R14E) 5 miles west of Independence. Farther southward, the Captain Creek grades into 1 to 2 feet of yellowish weathering sponge-rich calcilutite, mapped by Heckel (1975a), and still partly exposed along the road just east of Walker Mound (N line NW-NE-NE sec 5, T33S, R15E) and in upended blocks in the hog lot (E line at NE cor sec 23, T33S, R14E) northwest of Bolton. This bed overlies a few feet of poorly exposed fossiliferous shale and about 1 foot of oolite, which has been exposed along the road east of Walker Mound and in a roadcut 2 miles southward (near ctr N line NW-NW sec 16, T33S, R15E).

The Benedict Limestone bed is a distinctive unit at the base of the Captain Creek Limestone Member in Wilson, Woodson, and Allen counties, named by Heckel (1975b) from Benedict in Wilson County. Its type section is along the road just south of the creek (NE-NE-NE sec 10, T28S, R15) on the northeast outskirts of town, where it is 4 feet of dense oolitic skeletal calcarenite with conspicuous brachiopods (*Punctospirifer, Composita*) and large-scale low-angle cross bedding, overlain by 2 feet of sparsely fossiliferous marine shale. This oolitic facies occurs in several other exposures at the base of the Captain Creek around Benedict (e.g., in roadditch on W line SW-NW-NE sec 26, T28S, R15E, where it is 1 foot thick, 3 miles to the south) and northeastward toward Buffalo along the northwestern rim of the Stanton algal-mound tract. Eastward, at the falls in the spillway to Wilson County State Lake (SW-SW-SE sec 17, T27S, R16E), the Benedict bed consists of 2 to 3 feet of oolite surrounding large shale-cored stromatolite heads about 1 foot in diameter (discovered by F.W. Wilson), with no overlying shale separating it from the main body of the Captain Creek. This displays the facies gradation of the Benedict bed eastward into a zone of large stromatolite heads, which characterize the bed, along with local lenses of brachiopod-bearing calcarenite, across most of the mound tract from central Wilson County (e.g., roadcut along W line SW-NW-SW sec 14, T28S, R16E, east of US 75 north of Altoona) to western Allen County (e.g., US 54 roadcut 4 miles west of Iola). Large blades of red algae occur around stromatolites associated with brachiopod shell hash in the Benedict bed along the Wilson County channel (along Rte K-47, S line SW-SW-SE sec 10, T29S, R15E) 3 miles west of the Altoona roadcut. Thus, the nearly 10-foot sequence of interbedded shale and calcilutite with conspicuous blades of red algae above the thin Vilas Shale at the K-96 roadcut west of Neodesha (and found in scattered exposures for 3 miles to the southwest) is also included in the Benedict bed near near its south end. Although Wagner (1961) included this unit in the top of the underlying Vilas Shale, I include it in the Captain Creek Limestone Member because it forms an integral part of the deepening-upward transgressive carbonate sequence of that member of the Stanton Limestone. The Benedict bed may be equivalent to the basal oolite of the Captain Creek around Walker Mound in central Montgomery County, but is separated from it for 12 miles along outcrop.

The Tyro Oolite bed forms the south end of the Captain Creek Limestone Member in southern Montgomery County. It was named by Heckel (1975a) from the village of Tyro with a type section in the abandoned quarry in NW-SW-SE sec 30, T34S, R15E just west of Stony Point, about 1 mile northeast of town. Here the base is covered, but the Tyro is at least 15 feet of cross-bedded, rust and tan-mottled oolite capped by a thin (<0.1 ft) layer of skeletal calcilutite beneath dark Eudora Shale, illustrating the deepening-upward sequence of the transgressive Captain Creek Limestone Member. The Tyro Oolite extends from exposures along the creek valley near ctr W line sec 6, T34S, R15E, and capping the hill west of Jefferson in SE cor sec 6, southward along the low escarpment to Tyro (exposures given in Heckel, 1975a), around the mass of hills southeast of Tyro, westward as an inlier along Hafer Run, and southwestward across the Oklahoma border just west of SE cor. sec 15, T35S, R14E. The Tyro is traced through several exposures a little over 2 miles into northern Washington County, Oklahoma, to the top of a shale bank near ctr S line SW-SE sec 21, T29N, R13E and along the road on W line NW-NW sec 27, same township. The Captain Creek Limestone Member reappears as less than 1 foot of brown dolomitic limestone at 2 localities northeast of Barnsdall in east central Osage County, and as a brachiopod-rich bed at the Rte O-20 locality in southern Osage County, all of which are located under discussion of the Eudora Shale Member.

Eudora Shale Member.--The Eudora Shale overlies the Captain Creek Limestone Member and underlies the Stoner Limestone Member in the middle of the Stanton Limestone (Fig. 2). The

Eudora Shale was named by Condra (1930) from exposures near Eudora in eastern Douglas County, and Moore (1936) listed the type locality as a roadcut near NE cor sec 4, T13S, R21E. Because this is now poorly exposed, the principal reference section now is designated above that of the Captain Creek Limestone Member along the gravel road just north of Rte K-10 (N« SE-SE-SW sec 3) just one mile to the southeast. Another good exposure is at the principal reference section for the entire Stanton Limestone, the roadcut along the westbound onramp from Edgerton Road to Rte K-10 (NE-SE-SE sec 36, T12S, R21E) three miles to the east in westernmost Johnson County. Other accessible exposures are the Stanton reference section along Rte K-7 at Bonner Springs in Wyandotte County, and along Rte K-68 (S line at SE cor sec 30, T16S, R21E) in eastern Franklin County.

In its type area of northeastern Kansas, the Eudora Shale Member ranges generally from 5 to 8 feet thick. It consists of a thin layer of dark gray shale at the base, overlain by 2 to 3 feet of black fissile shale with nodules and laminae of phosphorite, and capped by gray shale in the upper half, a classic core shale succession for the Stanton cyclothem. The gray facies carries sparse marine invertebrates including brachiopods and crinoid pieces. The black facies carries scattered inarticulate brachiopods and conularids, and an abundant fauna of conodonts, including the first appearance of 2 species, *Idiognathodus simulator* and *Streptognathodus firmus*, which provide confirmation of the lithic correlation of the Eudora Shale and Stanton cyclothem along outcrop and allow identification of the Eudora interval in the shale and sandstone-dominated sequence of northern Oklahoma.

Northward (Fig. 6), the Eudora Shale Member maintains this character, averaging 5 feet in thickness through Missouri and thinning gradually to about 3 feet in Iowa and 2 feet in Nebraska, where it is exposed in several quarries along the Platte River valley. In Iowa, it had long been misidentified as the black Heebner Shale Member of the younger Virgilian Oread Limestone at two outcrop localities (streambank in SW-SW-NW sec 7, T75N, R29W, south of Rte 92 near Stanzel in western Madison County; and east bank of Nishnabotna River upstream from a small falls in SW-NW sec 15, T75N, R37W, just southwest of Lewis in western Cass County) until analysis of the conodont fauna (von Bitter and Heckel, 1978) allowed it to be identified correctly as Eudora Shale.

Southward from its type region, the Eudora Shale Member thins to 2 feet in the roadcut just north of Pottawatomie Creek (W line NW-SW-NW sec 4, T20S, R19E) 5 miles northwest of Garnett and to less than 1 foot in several quarries 2 miles westward along Iantha and Pottawatomie Creeks in north central Anderson County (e.g., NE-NE sec 12, T20S, R18E). The Eudora retains its black shale facies at least as far south as the west bank of Cedar Creek just north of the railroad bridge (NW-SE-NE sec 17, T21S, R19E) 2 miles east of Mont Ida in central Anderson County, where it is about 3 feet thick. Southward the Eudora Shale loses the black facies above the thickening Captain Creek algal mound facies, where it consists (in sparse exposures) of only 1 foot or less of gray fossiliferous shale, which carries small phosphate nodules and which is identified as Eudora by its abundant and distinctive conodont fauna

(Wood, 1977). Exposures that are still accessible include the quarry just south of Piqua (NW-SW sec 34, T24S, R17E) and the western quarry on Rose dome (SW sec 13, T26S, R15E) in Woodson County, and the quarry south of U.S. 75 east of Wilson County State Lake (SW-SE SE sec 17, T27S, R16E). The Eudora Shale thickens and regains its black facies, however, as it descends into the channels that transect the mound tract in this area. Exposures of this facies include the north side of the east end of the Rte K-47 roadcut (NE NW NE sec 18, T29S, R16E) 2 miles west of Altoona in the Wilson County channel, a roadditch on the Wilson-Woodson county line (ctr N line NW-NE sec 3, T27S, R17E) in the County Line channel, and black facies was brought up in cores from the Woodson County channel. The Eudora Shale is missing in places on the mound edge along the channels (e.g., Altoona north roadcut, W line NW-SW-SW sec 7, T29S, R16), but its position is marked by the sharp contact of massive Captain Creek algal calcilutite overlain by basal Stoner calcarenite, which contains conodonts typical of the Eudora (Wood, 1977). The thicker sections of interbedded fossiliferous shale and limestone that have been reported as "Eudora" on the mound tract in Wilson and northern Montgomery counties (e.g., Heckel, 1975a) actually belong in the lower part of the overlying Stoner Limestone Member.

South of the mound tract in central Montgomery County, the Eudora Shale Member thickens greatly and regains its black phosphatic facies at the base, as the underlying Captain Creek Limestone Member thins and the overlying Stoner Limestone Member grades southward into the upper gray fossiliferous part of the Eudora Shale. The Eudora Shale is 70 to 75 feet of gray shale at Walker Mound (NE sec 5, T33S, R15E) and along U.S. 160, where a roadcut (S line NW-NW sec 36, T32S, R14E) exposes the top 20 feet with a molluscan fauna of snails and clams passing upward to a fauna of brachiopods, bryozoans, and echinoderms. The top of the Eudora Shale in this area is defined at the base of two named limestone beds (Rutland, Bolton) and a siltstone bed (Timber Hill) that are assigned to the Stoner Limestone Member, or, where they are absent, at the base of the lowest sandstone in the overlying Rock Lake Shale. The black facies of the Eudora Shale has been exposed at Walker Mound (in road ditch N line NW NE NE sec 5, T33S, R15E), in a road (near ctr N line SE SW sec 6, T34S, R15E) west of Jefferson, and above the type Tyro Oolite in the old quarry northeast of Tyro. The entire Eudora Shale thins gradually southward across southern Montgomery County, through 18 feet (along W line NW SW sec 6, T34S, R15E) west of Jefferson, to 2 feet in the Tyro Quarry. It carries ammonoids in the upper part in some exposures in this area (e.g., S line at SW cor sec 31, T33S, R15E), and it carries an extremely diverse invertebrate fauna at the Tyro Quarry (Malinky, 1980).

Southward in Oklahoma (Fig. 10), the Eudora Shale Member is exposed in the hill along U.S. 75 (W line SW-NW sec 10, T28N, R13E) 1.5 miles north of Copan, where it is again a thick gray fossiliferous shale south of the Rock Lake sandstone complex of southern Montgomery County. Elsewhere in northern Washington County, the Eudora black shale facies is exposed in the hillsides (near ctr N line NW-SE-SW sec 13, T27N, R12E; and just north of SW cor sec 13) west-northwest of Dewey, the former confirmed by its conodont fauna. Southward in east central Osage County, in the type area of the Barnsdall Formation northeast of Barnsdall, two exposures of gray Eudora Shale above Captain Creek Limestone discovered by A.P. Bennison (along east side of Rte 0-123 in SW-NW-SE sec 5, T24N, R11E; and along west side of road southeast of Dog Thresher Creek in SE-NW-NE sec 3, T24N, R11E) are confirmed by the distinctive conodont fauna. The 25 feet of gray shale below the Wildhorse Dolomite in the small outliers just north of Rte 0-20 (SW-NE-NW sec 21, T22N, R10E) and 2 miles northward (SE-SE-SE sec 4, same township) in southern Osage County also belong to the Eudora Shale based on the conodont fauna. Because all the Osage County localities have been mapped in the type Barnsdall Formation whereas the Washington County localities of Eudora Shale were mapped by Oakes (1940a) in the upper Wann Formation in its type area, the recognition and correlation of the Eudora interval across this region means that the Barnsdall is equivalent to the upper Wann as presently mapped, even though Oakes (1951) thought that the Barnsdall unconformably overlies the Wann. The most reasonable resolution to this problem is to recognize the Stanton Limestone-equivalent strata currently mapped as upper Wann in northern Washington County as the northern extent of the Barnsdall Formation (Fig. 10), and to redefine the Wann-Barnsdall contact at a traceable horizon at the base of the Stanton Formation (see previous sections on Vilas Shale and Stanton Limestone).

Stoner Limestone Member.--The Stoner Limestone is now recognized as the top member of the Stanton Limestone, overlying the Eudora Shale Member and underlying the Rock Lake Shale (Fig. 2), which is now considered a separate formation. The Stoner Limestone was named by Condra (1930, p. 11) from the Stoner farm northwest of South Bend in Cass County, Nebraska, and its correlation into Kansas was accepted by Moore (1949) to replace the local name Olathe Limestone introduced by Newell (1935) from quarries at the west edge of Olathe in Johnson County. The principal reference section for the Stoner Limestone Member in Kansas is the same as that for the entire Stanton Limestone, along the westbound onramp from Edgerton Road to Rte K-10 (NE SE SE sec 36, T12S, R21E) in western Johnson County. Another good exposure is at the top of the Rte K-7 cut at Bonner Springs in Wyandotte County.

The Stoner Limestone Member in northeastern Kansas ranges from 12 to 18 feet thick. It consists mainly of thin to medium wavy bedded skeletal calcilutite with a diverse fauna, overlain in places by up to 3 feet of calcarenite, often with osagid grains and capped by a rubbly zone, generally sparsely fossiliferous calcilutite, which locally appears nodular to brecciated and contains probable rooting structures. This is a classic shallowing-upward vertical sequence that marks the Stoner as the regressive limestone of the Stanton cyclothem with evidence of subaerial exposure at the top. The Stoner Limestone is extensively quarried in this region,

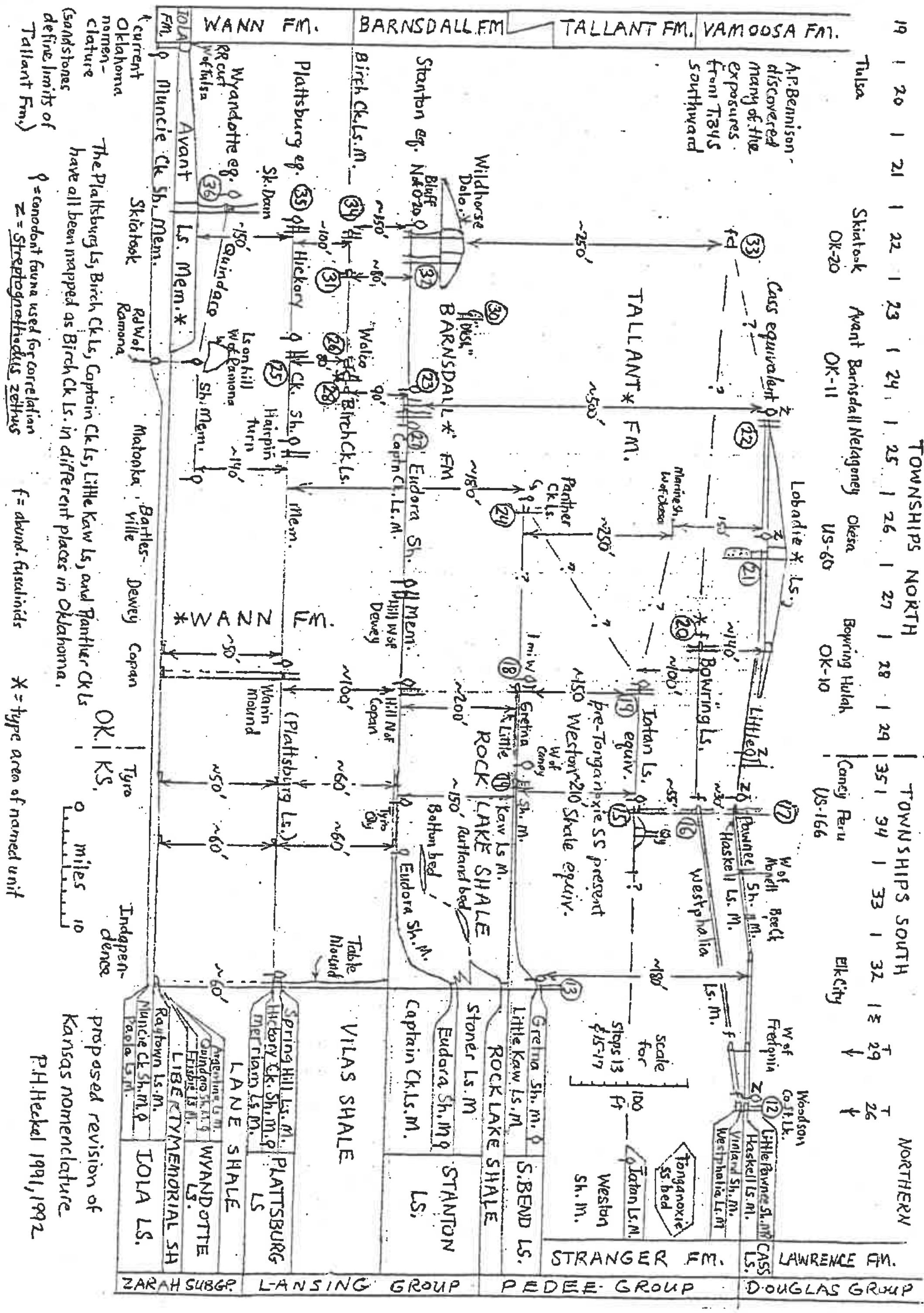


Figure 10.--Correlation cross-section of upper Missourian (Iola to Stranger) and basal Virgilian (Cass) strata from Kansas into northern Oklahoma, showing stratigraphic control of measured and estimated (~) sections and abundant conodont faunas (tailed diamond symbols). [Some information from this figure was used in making Figure 33 in KGS Bulletin 246]

particularly around Olathe (e.g., SE sec 23, T13S, R23E; SE sec 9, T14S, R23E) and Edgerton (NW sec 8, T15S, R22E) in Johnson County, around Eudora (e.g., NE sec 4, and SE-SE sec 15, T13S, R21E) in eastern Douglas County, and around Ottawa (e.g., S« sec 6, T17S, R20E) in Franklin County.

Northward, the Stoner Limestone Member retains its shallowing-upward character through northwestern Missouri, and it thickens to about 25 feet in its type area in the Platte River valley of Nebraska where it is extensively exposed in quarries. Here it contains two named beds in the lower part: the Dyson Hollow Limestone bed, named by Condra (1949, p. 32), about 1 to 2 feet thick at the base; and the overlying Kiewitz Shale bed, named by Condra (1927, p. 42, 55) about 2 to 3 feet thick, which contains a particularly abundant and diverse invertebrate fauna. Eastward in Iowa, the Stoner Limestone is about 18 feet thick with with a similar sequence shallowing upward to calcarenite and an exposure surface, but with very shaly limestone throughout the middle in western Madison County (Heckel and Pope, 1992). Here it had been misidentified as the higher Plattsmouth Limestone Member of the Virgilian Oread Limestone before study of the conodonts in the underlying black shale (von Bitter and Heckel, 1978) identified it as Eudora rather than Heebner.

Southward from northeastern Kansas, the Stoner Limestone Member thickens to at least 32 feet in the bank of Cedar Creek (at the railroad crossing, NW SE NE sec 17, T21S, R19E) east of Mont Ida in central Anderson County. Here the base is a 2.5 foot ledge of calcilutite, the lower part is fossiliferous shale and shaly thin bedded skeletal calcilutite, and the top is 10 feet of more massive phylloid-algal calcilutite with a calcarenite cap. This variation of the shallowing-upward sequence is traced through generally poor or incomplete exposures southward to the Stanton Limestone reference section in the roadcut west of Elk City dam (SE-SE-NW sec 7, T32S, R15E) in central Montgomery County, where the Stoner is about 40 to 45 feet thick. The shaly lower part is generally poorly exposed in the plateau held up by the massive Captain Creek Limestone Member, and had previously been referred to as "Stoner-Eudora" or "Eudora" (e.g., Heckel, 1975a), but it is now considered definitely part of the Stoner Limestone Member. It is still exposed at the quarry south of Piqua (NW-SW sec 34, T24S, R17E) in eastern Woodson County, in the quarry on Silver City Dome (SE-NW sec 6, T27S, R15E) in central northernmost Wilson County, in the top of the quarry south of US 75 east of Wilson County State Lake (SW-SE-SE sec 17, T27S, R16E) where the basal beds are a distinctive invertebrate calcarenite, and above the black Eudora Shale at the east end of the Rte K-47 cut west of Altoona in the Wilson County channel.

The upper Stoner phylloid algal mound facies is well exposed at the reference section west of Elk City dam in central Montgomery County, and along Rte K-96 (ctr S line SE sec 22, T30S, R15E) just west of the long Plattsburg-Captain Creek roadcut west of Neodesha, and in a quarry just to the west (NE-NW sec 27, T30S, R15E), in southern Wilson County. The upper Stoner mound facies grades into cross-bedded skeletal calcarenite up to about 15 feet thick in the Wilson County channel, which is well exposed in the Rte K-47 roadcut (S line N« NW-NE sec 18, T29S, R16E) west of Altoona, along the north side of the large quarry (NE sec 24, T29S, R14E) just south of Fredonia, and also caps the linear outlier in sections 23, 24, 28, 29 & 32, T28S, R17E, east of Altoona. The upper Stoner also grades into skeletal calcarenite along the northwestern rim of the Stanton Limestone mound tract from Fredonia to northeast of Buffalo, where it is well exposed along US 75 (near ctr E line SE sec 6, T27S, R16E) north of Buffalo in northern Wilson County. South of the reference roadcut west of the Elk City Dam in central Montgomery County, the Stoner Limestone grades southward into greatly thickened Eudora Shale as the upper mound facies pinches out (outlier in NW NW-SE sec 22 T32S, R14E), and three partly equivalent named beds represent the Stoner Limestone Member above the Eudora Shale Member and below the Rock Lake Shale in southern Montgomery County (Fig. 10).

The Timber Hill Siltstone bed, 2 to 4 feet thick, named by Heckel (1975b, p. 17) from a type section in a roadcut (near ctr W line NW sec 25 T32S, R14E) on the east side of Timber Hill, extends across the southern part of T32S to cap Walker Mound in NE sec 5, T33S, R15E. The Rutland Limestone bed, up to 8 feet thick, named by Heckel (1975a, p. 17) from a type section in an old quarry (near NE cor sec 2, T33S, R14E) in Rutland Township, is a cross bedded skeletal-algal calcarenite that overlies the Timber Hill Siltstone bed just to the north and extends a couple of miles southward into section 12, T33S, R14E. The Bolton Limestone bed, 1 to 4 feet thick, named by Heckel (1975a, p. 18) from a type section in a railroad cut (near ctr S« NW-NW sec 36, T33S, R14E) 2 miles southwest of Bolton, is mainly skeletal calcarenite with ooids and conspicuous brachiopods and crinoids. It extends from the NW sec 23, T33S, R14E, southward into northern T34S, R15E, where it is well exposed in a roadcut (along W line SW-NW SW of section 6) on the road to Tyro.

In Osage County, Oklahoma (Fig. 10), the Wildhorse Dolomite, named as a limestone by Greene (1918), overlies shale now recognized to be Eudora in the hill north of Rte 0-20 in SW-NE-NW sec 21, T22N, R10E. Assuming that its contact with this shale is conformable, it is equivalent to the Stoner Limestone Member.

PEDEE GROUP

The Pedee Group is reinstsated in Kansas to comprise the Rock Lake Shale, South Bend Limestone, and Stranger Formation at the top of the Missouri Supergroup. The term Pedee Group was applied by Moore (1932) from Pedee Branch (a stream near Weston in Platte County, Missouri) to the strata above the Lansing Group and below the Douglas Group (as both were then recognized). The term was discarded when O'Connor (1963) included its two constituent units (Weston Shale and Iatan Limestone) in the base of the Douglas Group when the Missourian-Virgilian boundary was lowered from the base of the Tonganoxie Sandstone to the top of the South Bend Limestone (see discussion under Stranger Formation).

Because the Missourian-Virgilian Stage (and Missouri-Virgil Supergroup) boundary is now raised to the base of the Haskell Limestone Member of the Cass Limestone at the top of the

Stranger Formation, the Douglas Group (of which Stranger has been the lower part) is split in half. The name Douglas Group is now confined to the upper part remaining in the Virgil Supergroup and comprising the Cass Limestone and Lawrence Formation as constituent units. The lower (now Missourian) part of the former Douglas Group (the Stranger Formation) and the underlying South Bend Limestone and Rock Lake Shale (which are removed from the Stanton Limestone and raised in rank to formations) are now grouped into a revised and greatly expanded Pedee Group consisting dominantly of shale, rather than added to the Lansing Group, which consists dominantly of limestone. Thus the reinstated Pedee Group still separates the Lansing from the Douglas Group, although with greatly revised boundaries.

The principal reference section for the Pedee Group in Kansas is designated at the type section of the Stranger Formation in SE sec 3, T12S, R21E, 2 miles north of Linwood in Leavenworth County, where the top of the Stoner Limestone Member of the Stanton Limestone is exposed along E line NE-SE sec 3, and the base of the Haskell Limestone is exposed near ctr S line sec 3. Because the Rock Lake Shale and South Bend Limestone are quite thin (2 to 10 feet) in most of northeastern and east-central Kansas, the thickness of the Pedee Group is about 110 feet, little more than that of the Stranger Formation (see later section). In Montgomery County near the Oklahoma border where the Rock Lake Shale thickens, however, the Pedee Group may reach as much as 350 feet in thickness.

Rock Lake Shale

The Rock Lake Shale overlies the Stoner Limestone Member, now recognized as the top of the Stanton Limestone, and underlies the South Bend Limestone, specifically the Little Kaw Limestone Member (Fig. 2, 11) The Rock Lake Shale was named by Condra (1927, p. 59) from a quarry near Rock Lake in Sarpy County, Nebraska, and the name was accepted by Moore (1949) to replace the local name Victory Junction Shale applied by Newell (1935) to this unit in northeastern Kansas, which was classified as a member of the Stanton Limestone. The Rock Lake Shale and overlying South Bend Limestone are now removed from the Stanton Limestone because they represent a widespread disconformity with terrestrial deposits that followed the end of Stanton marine sedimentation, and a distinctly later marine episode of deposition, respectively, and they are traceable as separate units across all of Kansas and adjacent states to the northern limit of outcrop.

The Rock Lake Shale in its type area in the Platte River Valley of Nebraska is 3 to 6 feet of red to gray blocky mudstone, which is a paleosol described in detail by Joeckel (1989). Both upper and lower contacts are disconformable with marine limestones. Although generally poorly exposed eastward in Iowa, the Rock Lake is 10 feet of gray blocky mudstone with a thin coal near the top in northeastern Adair County (Heckel and Pope, 1992). The Rock Lake varies southward from 1 to 16 feet of gray shale in Missouri, where it contains various amounts of sandstone.

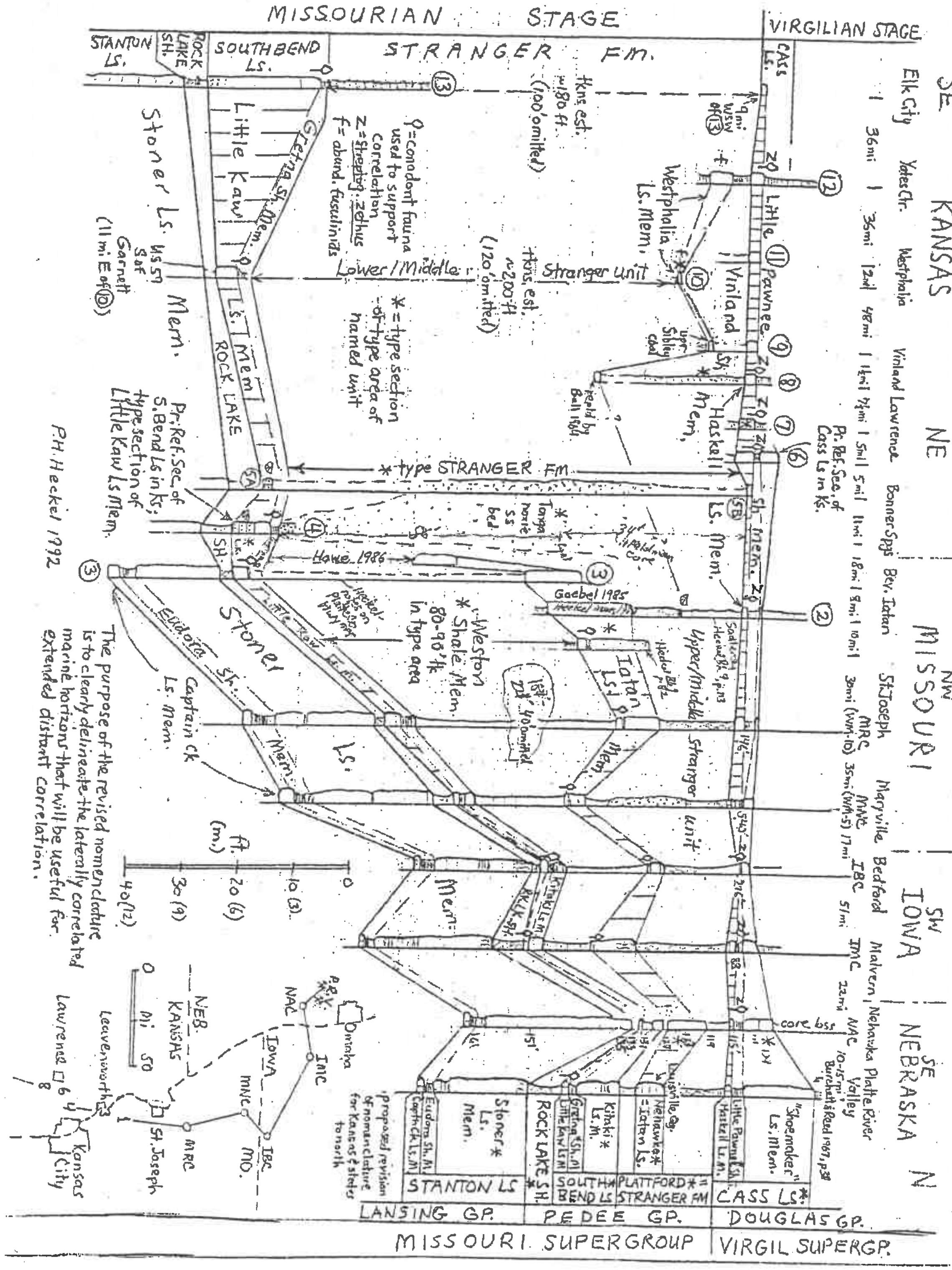


Figure 11.--Stratigraphic cross-section of upper Missourian (Stanton through Stranger) and basal Virgilian (Cass) strata from eastern Kansas through Missouri to Iowa and Nebraska, showing measured sections, cores (held by respective state geological surveys), and abundant conodont faunas upon which correlation is based. [This figure was modified with information from Figure 10 above to become Figure 33 in KGS Bulletin 246]

The principal reference section for the Rock Lake Shale in northeastern Kansas is in a roadcut along the east side of Rte K-7 (near ctr W line NW sec 8, T11S, R23E) about 3 miles north of Bonner Springs in western Wyandotte County. Here it is 6 feet of gray micaceous shale with thin sandstone beds, overlain with abrupt contact by calcareous fossiliferous sandstone, which is included in the base of the overlying Little Kaw Limestone Member of the South Bend Limestone. In the roadditch east of Coleman Creek (near ctr S line SE-SE sec 15, T13S, R21E) 2 miles southeast of Eudora in eastern Douglas County, the Rock Lake Shale comprises 3 feet of blocky mudstone overlain by 5 feet of interbedded sandstone and sandy shale, which thickens northward to 9 feet of dominantly noncalcareous sandstone in the adjacent quarry. Elsewhere in northeastern Kansas, the Rock Lake Shale ranges from 1 to 15 feet, with sandstone making up most of the thicker sections. Sandstones in the Rock Lake generally are noncalcareous, friable and unfossiliferous, which distinguishes them from hard marine calcareous and conglomeratic sandstone locally in the base of the overlying South Bend Limestone. The thinner sections of Rock Lake Shale are mainly gray mudstone that locally contains coaly horizons. In this region the Rock Lake Shale is developed both as paleosols and alluvial deposits with fluvial channels.

Southward the Rock Lake Shale is quite thin and poorly exposed in most of Franklin, Anderson, Allen, Woodson and Wilson counties. Where reported, the thin facies is 1 to 3 feet of locally sandy and locally limy, gray mudstone overlying brecciated limestone at the top of the underlying Stoner Limestone Member in a quarry south of Princeton (SE-NE sec 23, T18S, R19E illustrated by Ball et al., 1963, p 21) in Franklin County, 0.5 foot of gray mudstone in the US 169 roadcut (near NE cor sec 36, T21S, R19E) east of Welda in Anderson County, and 2 feet of gray mudstone grading laterally into plant-bearing sandstone along the Verdigris River at the low-water bridge southwest of Benedict (near ctr S« NE-NE sec 16, T28S, R15E) in central Wilson County.

The Rock Lake Shale thickens substantially, however, as fillings of channels in the underlying Stoner Limestone. In a locality northwest of Garnett (NW-NW-NE sec 5, T20S, R19E) in Anderson County, the Rock Lake consists of up to 15 feet of calcareous shale with a remarkable biotic succession reflecting the fresh to brackish to marine transition of the early South Bend transgression preserved in a small pre-existing channel that was not filled by sandstone (Reisz et al., 1982). Gray to brown Rock Lake sandstone with interbedded shale up to at least 50 feet thick fills the length of the larger Woodson County channel developed in the Stanton Limestone. These strata are well exposed in a roadcut in a hill south of Owl Creek (ctr S line SW sec 34, T25S, R17E) and south-southwestward in road ditches (S line SW sec 3, T26S, R17E; E line sec 9) for a couple of miles, and also 8 miles southwestward along the creek (near ctr S line sec 27, T26S, R16E) northeast of Buffalo, where their identity as Rock Lake is confirmed by the overlying South Bend Limestone at places in the south bank of the creek. Reddish brown Rock Lake sandstone up to 5 feet thick overlies Stoner calcarenite at places along the axis of the Wilson County channel (e.g., SW cor sec 7, T29S, R16E along Rte

K-47, just west of the main Altoona roadcuts), and it fills small side channels cut into the Stoner Limestone mound facies north of the channel in roadcuts 3.5 miles westward along K-47 (near ctr S line sec 9, T29S, R15E), 2.5 miles east of Fredonia.

In Montgomery County, the Rock Lake Shale comprises 2 feet of gray blocky mudstone (now poorly exposed) overlain by 2 feet of sparsely fossiliferous sandstone in the Stanton Limestone reference roadcut (SE-SE-NW sec 7, T32S, R15E) west of the Elk City dam. It thickens southward to 10 to 12 feet of mudstone above the Timber Hill Siltstone bed of the Stoner Limestone Member around the east side of Timber Hill (near ctr W line NW sec 25, T32S, R14E), then thickens further, above thinning Eudora Shale Member by addition of up to 100 feet of mainly sandstone. Nearly 20 feet of this cross-bedded reddish brown sandstone is well exposed along US 160 (near ctr S line SE sec 28, T32S, R14E) between Elk City and Independence. This unit was termed informally the Onion Creek sandstone body by Heckel (1975a, p. 27) from its extensive exposure along Onion Creek just to the south, especially along the road between sections 14 and 15, and 22 and 23, T33S, R14E. This and other bodies of sandstone in the Rock Lake Shale exposed southward in T34S and T35S, R14E were shown by Moussavi-Harami and Brenner (1984) to be a series of delta lobes from a northwestward flowing river, which are partly equivalent to the upper part of the Stoner Limestone (and the upper part of the thick Eudora shale in central Montgomery County) as well as to the Rock Lake Shale northward. The base of the Rock Lake Shale in this area is defined at the base of the lowest sandstone bed (which lies at different horizons, including just above thin dark basal Eudora shale at the Tyro Quarry). The Rock Lake Shale may aggregate a total thickness of 150 feet northeast of Caney. It consists throughout this region of massive brown sandstones separated by sandy shale, thin-bedded rippled sandstone and fossiliferous oolitic sandy limestone horizons, which reflect the nearshore marine environments into which the delta lobes prograded. These sandstones pinch out southward a short distance into Oklahoma, where the Rock Lake merges with the top of what had been mapped as the Wann Formation in northern Washington County by Oakes (1940a), but may more properly be assigned to the Barnsdall Formation (see previous section on the Stanton Limestone).

South Bend Limestone

The South Bend Limestone overlies the Rock Lake Shale and underlies the Stranger Formation in Kansas (Fig. 2, 11). The South Bend Limestone was named by Condra and Bengston (1915, p. 23) from exposures near South Bend in Cass County, Nebraska, and the name was accepted by Moore (1949) to replace the local name Little Kaw Limestone applied by Newell (1935) to the top member of the Stanton Limestone in Kansas. The South Bend Limestone is now removed from the Stanton and recognized as a separate formation in Kansas because it represents a distinctly later marine unit that is traceable from southern Kansas to the northern limit of outcrop in Iowa and Nebraska (Fig. 6), and is disconformably separated from the Stanton marine unit by terrestrial deposits of the Rock Lake Shale. Moreover, the type

South Bend Limestone in Nebraska represents a complete cyclothem with a basal transgressive limestone, overlying offshore shale, and capping regressive limestone, which have been named individually as beds by Pabian and Strimple (1993). Only the transgressive limestone and offshore shale are known to be present in Kansas where they are raised in rank to members. Of these, only the limestone is well exposed, and it is herein termed the Little Kaw Limestone Member, reinstating the old name of Newell (1935) for exactly the same strata to which it was originally applied.

The South Bend Limestone in its type area, along the Platte River valley in Nebraska, is about 9 feet thick (Fig. 11). The basal bed of limestone ranges from 0.5 to 1 foot of transgressive skeletal calcilutite, which is the exact depositional equivalent of the entire South Bend Limestone in Kansas, the Little Kaw Limestone, a name accepted by Pabian and Strimple (1993). The overlying offshore shale bed (termed Gretna by Pabian and Strimple, 1993) ranges from 0.2 to 1 foot thick and contains in addition to small invertebrates, an extremely abundant fauna of conodonts, which allows this unit to be recognized as the sediment-starved offshore (core) shale of the South Bend cyclothem.

The discovery of the same abundant conodont fauna in the base of the shale overlying what was previously considered the entire South Bend Limestone in Kansas identifies the Kansas South Bend as representing only the basal transgressive limestone of the Nebraska South Bend (Fig. 11). This means that the top of the South Bend Limestone as previously recognized in Kansas is distinctly older than the top of the type South Bend Limestone in Nebraska. This is an important distinction because the Missourian-Virgilian chronostratigraphic stage boundary has been defined as the top of the South Bend in Kansas since the report by O'Connor (1963), and has been assumed to be at the top of the South Bend in Nebraska (e.g., Burchett and Reed, 1967), a situation that is no longer tenable. (As explained in another section of this report, the Missourian-Virgilian boundary is being raised to the top of the overlying Stranger Formation for biostratigraphic reasons, which resolves this problem).

The upper limestone bed of the South Bend Limestone in Nebraska (named Kitaki by Pabian and Strimple, 1993) is 7 to 8 feet of skeletal calcilutite grading upward into oolite and skeletal calcarenite, and contains a shale bed near the middle that is locally sandy and up to 3 feet thick. This shallowing-upward sequence is characteristic of a regressive limestone that was penetrated by a small lobe of detrital sediment. The entire transgressive-regressive sequence of the South Bend Limestone is recognized elsewhere only in well logs and cuttings in southeastern Nebraska (Pabian and Strimple, 1993) and in cores in southwestern Iowa and northernmost Missouri (Fig. 11). Only partial exposures of the South Bend are so far known in Iowa (e.g., above the Rock Lake Shale in northeastern Adair County:Heckel and Pope, 1992). The basal member of the South Bend (Little Kaw Limestone) is recognized from Nebraska to northernmost Oklahoma and is the only limestone member of the South Bend known on outcrop in Missouri, Kansas and Oklahoma.

The principal reference section for the South Bend Limestone in Kansas is the roadcut along the west side of Rte K-7 at the intersection in NW-SW-NW sec 8, T11S, R23E, 0.4 mile south of the US 24-40 interchange, and about 3 miles north of Bonner Springs in western Wyandotte County. Here both the Little Kaw Limestone Member and the overlying Gretna Shale Member are well exposed and are overlain abruptly by 2 feet of conglomeratic sandstone, the basal deposit of the local Tonganoxie Sandstone bed of the overlying Stranger Formation (Fig. 11). Both members of the South Bend Limestone are exposed in a roadcut along US 59 about 5 miles north of Lone Elm (E line N of SE cor sec 6, T22S, R20E) in Anderson County, but the upper contact is not exposed. The principal reference section for the South Bend Limestone in southeasternKansas is the top of the roadcut west of Elk City dam (SW-SE-NW sec 7, T32S, R15E) northwest of Independence in Montgomery County, where both members are well exposed and the Greta Shale Member is overlain with more gradational contact by sandy shale of the Lower/Middle unit of the Stranger Formation (Fig. 11). The South Bend Limestone merges southward with the upper part of the Barnsdall Formation as mapped by Tanner (1956) in northeastern Osage County, Oklahoma (Fig. 10).

The Panther Creek Limestone, named by Roundy et al. (1922) from exposures along the valley of Panther Creek in T25-26N, R12E in east-central Osage County, was also mapped by Tanner (1956) in the Barnsdall Formation. It is stratigraphically higher than the type Birch Creek Limestone, (Fig. 10), with which Oakes (1940b) had correlated it, but it does not appear to correlate with the Captain Creek Limestone Member at the base of the Stanton Limestone because the overlying shale lacks the distinctive conodonts characteristic of the Eudora Shale in localities both southward as well as northward. The Panther Creek Limestone thus may possibly be equivalent to the South Bend Limestone, but this is not confirmed, as the conodont fauna of the associated shale in a roadcut (SW-SW-NE sec 24, T26N, R11E) and streambed nearby (ctr N line SW-NE sec 25) in the type region, is relatively sparse and nondiagnostic, although compatible with that found in the South Bend Limestone.

Little Kaw Limestone Member.--The Little Kaw Limestone is the basal member of the South Bend Limestone. It overlies the Rock Lake Shale and underlies the Gretna Shale Member of the South Bend Limestone (Fig. 2), which lies at the top of the South Bend in Kansas, where the upper (Kitaki) limestone member of the South Bend is absent. The Little Kaw Limestone was named by Newell (1935) from Little Kaw Creek in southern Leavenworth County about 2 miles southwest of Bonner Springs. Because the four typical exposures given in Moore (1936) are not exposed now, the type section is designated at the roadcut along the west side of Rte K-7 at the intersection in NW-SW-NW sec 8, T11S, R23E, 0.4 mile south of the US 24-40 interchange and about 3 miles north of Bonner Springs. This is also the principal reference section for the South Bend Limestone in northeastern Kansas and is positioned roughly among all the old typical exposures of the Little Kaw Limestone in western Wyandotte County. Here the Little

Kaw Limestone Member is 6 feet thick, comprising 3 feet of skeletal calcilutite with conspicuous brachiopods, crinoids and fusulinids, overlying 3 feet of calcareous sandstone with scattered marine fossils, including brachiopods and myalinid clams. Contacts are abrupt with both overlying and underlying shales.

Elsewhere in this area, the basal sandy beds of the Little Kaw Limestone Member are locally conglomeratic and locally merely a sandy zone in the base of the calcilutite, as in the roadcut south of the quarry at Coleman Creek (ctr S line SE-SE sec 15, T13S, R21E) in eastern Douglas County. The fossiliferous, limy, conglomeratic nature of the sandy beds at the base of the little Kaw Limestone readily distinguish them from the underlying, more nondescript, friable and unfossiliferous sandstones locally interbedded in the Rock Lake Shale. These distinctive beds mark the position of the South Bend marine flooding surface in generally poor exposures across most of eastern Kansas. The vertical sequence of laterally variable limy sandstone grading upward into more uniform, diversely skeletal calcilutite at the top, marks the Little Kaw Member as the transgressive limestone of the South Bend cyclothem.

Northward the Little Kaw Limestone Member retains this character on outcrop in Missouri, except where it was cut out locally by erosion preceding deposition of the younger Tonganoxie channel sandstone. At Beverly in Platte County, Missouri (hillside southeast of Rte M-92, E« NW-NE sec 31, T53N, R35W), the shaly top of the Little Kaw Limestone Member contains an abundant conodont fauna marking the upward transition to the offshore Gretna Shale Member, which is covered by slump at this locality. Farther northward, the Little Kaw thins to the 0.5- to 1-foot bed of skeletal calcilutite already described at the base of the South Bend Limestone along the Nebraska outcrop in the Platte River valley (Fig. 11).

Southward from its type area, the Little Kaw Limestone Member is poorly exposed above thin Rock Lake Shale some distance back from the top of the prominent Stanton Limestone escarpment in Franklin, Anderson, Woodson, and Wilson counties. Where seen, the Little Kaw ranges up to 4 feet thick, dominantly of skeletal calcilutite in cuts along U.S. 59, 4 to 5 miles north of Lone Elm (W line SW-SW sec 8 and W line at SW cor sec 5, T22S, R20E) in Anderson County, and it displays its characteristic trangressive sequence nearby with oolitic sandy beds at the base in the US 169 roadcut (near NE cor sec 36, T21S, R19E) 2 miles northeast of Welda. Large brachiopods and clams dominate the basal beds in places. Meekellids are conspicuous along the road south of East Buffalo Creek (W line NW-NW-SW sec 33, T26S, R16E) and at the east end of the bridge 1 mile to the northeast (ctr N line NE-NE sec 33) in southern Woodson County. Derbyiids are conspicuous in conglomeratic sandstone along Rte K-96, 1.5 mile west of the long Neodesha roadcut (S line near SW cor sec 22, T30S, R15E) and in oolite 1 mile westward (S line near SW cor sec 21), and myalinids are conspicuous in sandy conglomeratic limestone at the low-water bridge (ctr E« NE sec 16, T28S, R15E) across the Verdigris River southwest of Benedict in Wilson County.

The Little Kaw Limestone Member becomes mainly fossiliferous conglomeratic limy sandstone in the Wilson County channel (see discussion under Stanton Limestone), where it is exposed in the quarries southwest of the K-47 roadcut (NE-NW sec 18, T29S, R16E) west of Altoona, and it thickens to at least 15 feet westward in exposures south of Fredonia (e.g., NE cor sec 24, T29S, R14E), and in the northwest part of the large quarry just to the south (near ctr NE sec 24). The position of the Little Kaw Limestone Member above the thick sandstones in the Woodson County channel allows them to be identified as belonging to the Rock Lake Shale.

Southward, the Little Kaw Limestone Member thickens substantially into northern Montgomery County, where it is well exposed at the South Bend reference section in the roadcut about 1 mile west of the Elk City dam in S« SE-NW sec 7, T32S, R15E. Here the Little Kaw is about 20 feet thick. The basal 4 feet consist of fossiliferous sandy limestone, which is oolitic and cross-bedded on the south side of the cut and interbedded with sparsely skeletal calcilutite on the north side. This unit grades upward into massive to thick-bedded skeletal calcilutite with blades of phylloid algae, but with invertebrates increasing toward the top, the entire sequence reflecting the characteristic deepening-upward sequence of the member. Westward 5 miles in another good reference exposure in the quarry west of US 160, just south of the Elk River bridge (N« NE-SW sec 17, T32S, R14E) south of Elk City, the upper part above the basal sandy beds thickens to about 20 feet of massive phylloid algal mound facies in the north wall. This thins to about 13 feet of medium bedded skeletal calcilutite in the south wall, thus delineating the edge of the algal mound complex. The thick algal facies of the Little Kaw Limestone Member is also well exposed along the Elk River 1 mile westward at the old iron bridge (ctr W« NE sec 18, T32S, R14E), and in a quarry just to the south (W« SE sec 18).

From here, the Little Kaw Limestone Member thins abruptly southward in 2.5 miles from 25 feet in the Elk River quarry to about 4 to 5 feet of yellowish-weathering skeletal calcilutite with conspicuous calcisponges among the diverse fauna, and with sandy to conglomeratic beds at the base, exposed along US 160 on both sides of Coon Creek (ctr S« SW-SE¬, and near SE corner, sec 28, T32S, R14E). Farther southward, this distinctive unit is traced through southwestern Montgomery County (Heckel, 1975a), separating Rock Lake sandstone and shale below from Stranger shale and sandstone above (Fig. 10). The Little Kaw Limestone is traced across the Oklahoma border as 3 feet of fossiliferous sandy conglomeratic limestone in the west bluff of Little Caney River (near SW cor sec 14, T35S, R13E, into ctr N« N« NW sec 13, T29N, R12E) in northernmost Washington County. Southwestward 6 miles, about 1 foot of fossiliferous conglomeratic calcareous sandstone along Rte O-10 (S line SE-SE sec 4, T28, R12E) lies stratigraphically below shale in the ditch east of the hill to the west (SW-SW sec 4) containing an abundant conodont fauna compatible with that of the Gretna Shale Member of the South Bend Limestone, and may represent the currently southernmost known exposure of the Little Ka Limestone Member.

At the Kansas-Oklahoma border, the Little Kaw Limestone was mapped by Oakes (1940a) as the Birch Creek Limestone, which currently defines the top of the Wann Formation. Because the type Birch Creek Limestone south of Barnsdall, Oklahoma, appears now to lie below the horizon of the Eudora Shale and is not known north of T24N about 30 miles south of the Kansas border (Fig. 10), the basal bed of the Stanton Limestone (Tyro Oolite, Captain Creek Limestone or Eudora Shale) is considered to mark the top of the Wann Formation more consistently (see previous section). Thus the Little Kaw Limestone Member merges with the upper part of the overlying Barnsdall Formation in Oklahoma, which is where the Rte O-10 locality mentioned above was mapped by Tanner (1956).

Gretna Shale Member.--The Gretna Shale Member of the South Bend Limestone overlies the Little Kaw Limestone Member everywhere; it underlies the Kitaki Limestone bed of the South Bend Limestone in Nebraska and adjacent area, but it underlies the Stranger Formation in Kansas and adjacent parts of Missouri (Fig. 2,11). The lower contact is generally sharp over limestone. The upper contact is sharp where the overlying unit is limestone or sandstone, but is diffuse where the overlying unit is shale; it is placed at the base of the lowest thin sandstone/siltstone bed where present in the base of the Stranger Formation, recognizing that it is at slightly different levels in different places. The Gretna Shale Member was named as a bed by Pabian and Strimple (in press) from a type exposure at the former Gretna Fish Hatchery (NE« SW sec 12, T12N, R10E) 8 miles south of Gretna, Sarpy County, Nebraska. It ranges from 0.2 to 1 foot of fossiliferous shale with abundant conodonts in Nebraska. It is rarely exposed in Kansas, but has been identified in a few critical reference sections (Fig. 10,11), which have allowed the deciphering of the stratigraphy of the South Bend Limestone.

The Gretna Shale Member is well exposed at its principal reference section in Kansas at the stratotype of the Little Kaw Limestone Member along the west side of Rte K-7 at the intersection just south of the US 24-40 interchange north of Bonner Springs in Wyandotte County. Here it consists of 0.6 foot of fossiliferous gray shale with crinoids brachiopods, bryozoans and abundant conodonts, and it is overlain by the basal conglomeratic sandstone bed of the Tonganoxie Sandstone with erosional contact. It is partly exposed above the Little Kaw Limestone Member in the US 59 roadcut 5 miles north of Lone Elm (E line N of SE cor sec 6, T22S, R20E) in Anderson County. The Gretna Shale Member is well exposed above the thick Little Kaw Limestone Member on the north side of the reference roadcut west of the Elk City Dam in Montgomery County, where it is about 0.3 foot of fossiliferous shale with similar invertebrates and abundant conodonts, and is overlain by thin beds of argillaceous sandstone. From here, it thickens southward above the thinning Little Kaw Limestone. It contains ammonoids in the fence-line ditch south of the house on US 75 north of Caney (NW-SW-NW sec 6, T35S, R14E) where the Little Kaw is exposed in the driveway. In the road ditch and adjacent exposure 3 miles southwestward in southeastern Chautauqua County (near ctr SE-SW sec 10, T35S, R13E) 2 miles west of Caney, the Gretna Shale is about 20 feet of gray shale with brachiopods, crinoids, clams, snails, and ammonoids, and with abundant conodonts in certain horizons. Similar shale with a similar conodont fauna was collected by A.P. Bennison in a ditch along a hill just south of Rte O-10 (SW-SW sec 4, T28N, R12E) in northeastern Osage

County, Oklahoma, above fossiliferous calcareous sandstone nearby, which may represent the Little Kaw-Gretna succession of the South Bend Limestone.

Depositionally, the upper limestone unit (Kitaki) of the South Bend Limestone was swamped by largely prodeltaic detrital influx along the entire Kansas outcrop, leaving only various thicknesses of offshore shale of the South Bend cycle, that is, the Gretna Shale Member, above the basal Little Kaw Limestone Member. The lack of black phosphatic shale facies in the Gretna Shale marks the South Bend cyclothem as the result of an inundation of intermediate scale (Fig. 3). Because of the thinness and generally diffuse upper boundary of the Gretna Shale Member in Kansas, it is mapped with the base of the overlying Stranger Formation.

Stranger Formation

The Stranger Formation overlies the South Bend Limestone (Gretna Shale Member) and underlies the Haskell Limestone Member of the Cass Limestone in Kansas (Fig. 2,10,11). Although previously classified as Virgilian, the Stranger is now considered Missourian for biostratigraphic reasons explained earlier, and it now forms the top of the Missouri Supergroup in Kansas. The Stranger Formation was named by Newell (in Moore, 1932, 1935) from exposures in the bluffs along Stranger Creek (E side sec 3, T12S, R21E) in southern Leavenworth County. As originally defined (see also Moore, 1936), the Stranger extended from the base of the Tonganoxie Sandstone (generally some distance above the South Bend Limestone), to the base of the Ireland Sandstone (generally some distance above the Haskell Limestone). Because detailed work by Ball (1964) showed that these original formation boundaries were not the readily traceable widespread surfaces of disconformity that were originally envisioned, the boundaries of the Stranger Formation were revised to their current, more easily determinable positions (O'Connor, 1963).

As presently recognized in Kansas, the Stranger Formation consists mainly of shale, much of it sandy, with local masses of sandstone, several thin coals, and 2 thin limestones, only one of which is traceable along much of the outcrop. The Stranger ranges from about 100 feet thick in northeastern Kansas to about 200 feet thick locally in southeastern Kansas. Because of this substantial thickness, no single well exposed section of the entire formation is known. However, in the area of typical exposure designated by Newell (1935) the entire interval of the Stranger Formation can be delineated from just above the exposures of fossiliferous sandy limestone to calcareous sandstone in the base of the South Bend Limestone (Little Kaw Limestone Member) along ctr E line SE sec 3, T12S, R21E, up to exposures of Haskell Limestone in the road near ctr S line sec 3, just to the southwest. Good exposures of sandstone (Tonganoxie) within the Stranger are present along the north and west sides of the roads in adjacent NE-NE sec 10, T12S, R21E.

The Stranger Formation had been subdivided into 5 members in Kansas (O'Connor 1963; Ball, 1964) in ascending order: Weston Shale Member, Iatan Limestone Member, Tonganoxie Sandstone Member, Westphalia Limestone Member, and Vinland Shale Member. Although these members have been considered to constitute the entire thickness of the Stranger, only the upper two, Westphalia and Vinland, are readily traceable along most of the outcrop in Kansas (Fig. 2). The Tonganoxie Sandstone is well defined only in part of northeastern Kansas. The Iatan Limestone, which is named from Missouri, is traceable only a short distance into northeastern Kansas, and the Weston Shale, also named from Missouri, is well defined only where the Iatan is present. Both the Iatan and Weston were recognized previously as formations constituting the Pedee Group (Moore, 1932), which was considered Missourian prior to the revision reported by O'Connor (1963). South of the disappearance of the Iatan Limestone, Ball (1964) placed the Weston-Tonganoxie contact at the base of the lowest massive sandstone or lowest coal, whichever was lower. Stratigraphic problems with this definition, which will be elaborated under the individual units, make it more reasonable to recognize the Iatan Limestone and Weston Shale as members only where the Iatan is present, to recognize the Tonganoxie sandstone only as an informal unit and only where it is well defined in northeastern Kansas, and to leave the lower and middle Stranger strata below the Westphalia Limestone in east-central to southeastern Kansas an unsubdivided Lower/Middle Stranger unit of sandy shale with lenticular sandstones at various horizons (Fig. 2,11).

In Missouri, the strata that are equivalent to the Stranger Formation of Kansas have been classified in both the Pedee Group (comprising the Weston Shale and Iatan Limestone as formations) and the Stranger Formation. The latter includes the Tonganoxie Sandstone, Westphalia Limestone, Vinland Shale and Haskell Limestone at the top (as it had been in Kansas prior to the revision of O'Connor, 1963), all apparently as informal members and aggregating 15 to 20 feet in thickness (Searight and Howe, 1961). The Stranger as defined in Kansas attains about 120 feet in thickness in Missouri, but most of this thickness is in the Weston Shale.

In Iowa, the Stranger Formation as delineated in Kansas is poorly exposed and has been subdivided as in Missouri (Hershey et al., 1960). The Weston Shale, and Iatan and Haskell limestones are recognized in the Iowa cores (Fig. 6,11), where the entire sequence to the base of the Haskell ranges from 23 to 32 feet thick.

In Nebraska, the Stranger Formation had been treated as in Missouri by Condra (1949), but the more recent summary by Burchett and Reed (1967) shows the Stranger as now delineated in Kansas to be termed the Plattford Formation (originally named by Condra, 1927, from Plattford Township in western Sarpy County). It averages about 15 to 20 feet thick and consist of two unnamed shale members above and below the Nehawka Limestone Member (Fig. 11), which is now known to be equivalent to the Iatan Limestone (Ball, 1964; Goebel, 1985). The succession between the Iatan and Haskell Limestones north of the pinchout of the Westphalia Limestone is referred to herein as the Middle/Upper Stranger unit (Fig. 2,11).

In Oklahoma (Fig. 10), the Stranger Formation merges southward with the top of the Barnsdall Formation, the entire Tallant Formation, and base of the Vamoosa Formation (below the fossiliferous shale and thin limestone underlying the Labadie Limestone), as mapped by Tanner (1956) in northeastern Osage County.

Weston Shale Member.--The Weston Shale overlies the South Bend Limestone and underlies the Iatan Limestone Member in northern Leavenworth and Atchison counties in Kansas, and in Missouri, Iowa and Nebraska (Fig. 2,11). It was named by Keyes (1899, p. 300) from exposures near Weston in Platte County, Missouri. Ball (1964) proposed the type section in the Missouri River bluffs south of Beverly (SW-SE-NE sec 31, T53N, R35W) where it is 50 to 60 feet of gray silty shale with ironstone nodules and fossils toward the top. The Weston Shale thickens northward to 100 feet of very sparsely fossiliferous shale in Buchanan County and contains sandy beds in the upper part in a nearby core (MRC on Fig. 6,11) in Andrew County. It thins northward to about 15 feet of similar shale in cores (MNC, IBC) along the Iowa-Missouri border, and to 3 to 8 feet of fossiliferous shale in western Iowa cores (IMC, IRC). The Weston Shale is exposed in the Platte River Valley of Nebraska as 5 to 13 feet of dominantly red blocky mudstone, where it is classified as the lower unnamed member of the Plattford Formation. About 1.6 miles southward from its type section, the Weston Shale thins abruptly to only 15 to 25 feet of shale (Howe, 1986, p. 49) beneath an atypical conglomeratic facies of the Iatan Limestone. The Weston is only poorly exposed beneath the Iatan Limestone outcrop in northern Leavenworth County, Kansas.

The Weston Shale Member in its type area is largely a prodeltaic shale with the sediment source somewhere east of Buchanan and Andrew Counties, Missouri. Northward, it thins to a nearshore shale and eventually becomes a paleosol in Nebraska. Southward it thins to a distal prodeltaic facies beneath what may be a slope facies of the Iatan, south of which the stratigraphic relations of these units are obliterated by the erosional nature of the later Tonganoxie sandstone-filled channel (Fig. 11). The Iatan Limestone Member is unknown along most of the Kansas outcrop south of Leavenworth. Because the lower shaly facies of the lower Stranger Formation there, which was described by Ball (1964) as Weston Shale, is largely also prodeltaic to deltaic but derived from different, more southerly sources, much of it could be from lobes younger than, and thus stratigraphically higher than, the Iatan Limestone. Furthermore, because deltaic lobes typically grade upward into various delta front (e.g., distributary) sandstones, these sandstones by the criteria used by Ball (1964) for defining the Weston-Tonganoxie contact would be classified as Tonganoxie even if they were parts of lobes older than, and thus stratigraphically below the Iatan Limestone. As a case in point, if the crinoidal and algal limestone unit around Peru in Chautauqua County, Kansas, is correctly identified as Iatan, then the Iatan Limestone here overlies sandstones that crop out extensively eastward not far above the South Bend Limestone in many hills in southwestern Montgomery County, but would be classified as Tonganoxie by the criteria of Ball (1964). Therefore, the Weston Shale Member is now recognized only where the overlying Iatan Limestone Member is definitely identified, the Tonganoxie Sandstone is recognized only informally and only in its type area in northeastern Kansas, and the shale/sandstone sequence southward between the South Bend and Westphalia limestones is recognized only as undifferentiated Lower/Middle Stranger Formation (Fig. 11).

Iatan Limestone Member.--The Iatan Limestone overlies the Weston Shale Member and underlies the Middle/Upper unit of the Stranger Formation in northeastern Kansas (Fig. 2,11). It was named by Keyes (1899, p.300) from exposures near Iatan in Platte County, Missouri. Ball (1964) gave the principal reference section as the railroad cut at Iatan (near ctr sec 19, T54N, R36W), where the base is not exposed, but more complete sections are now available in quarries along the bluff 2 to 3 miles southeast of Iatan. The Iatan Limestone Member reaches a maximum thickness of about 18 feet in its type area and thins northward to 4 to 8 feet in the Iowa subsurface. It is about 5 feet thick in the Nebraska outcrop, where it has been called the Nehawka Limestone, named by Condra and Bengston (1915) from exposures near Nehawka in southeastern Cass County. The Iatan Limestone Member is known definitely in Kansas only in northern Leavenworth and southeasternmost Atchison Counties, where it is generally poorly exposed skeletal calcilutite with conspicuous phylloid algae.

Along much of its outcrop in Missouri and in the Missouri-Iowa subsurface (Fig. 6,11), the Iatan Limestone Member consists of 3 units: a thin basal transgressive skeletal calcilutite, overlain by a thin conodont-rich gray offshore (core) shale, overlain by a thicker regressive limestone consisting of skeletal calcilutite capped locally by calcarenite. Northward, the top of this regressive limestone unit grades into nearly barren calcilutite with shale-filled fractures and cavities interpreted as cryptokarst resulting from soil formation in the overlying Middle/Upper Stranger shale unit (Goebel et al., 1989). Southward, the Iatan becomes a phylloid algal mound facies in central Platte County, which thins and grades abruptly southward into a conglomeratic slope facies (Howe, 1986, p. 49) over the southward-thinning prodeltaic slope of the Weston Shale Member (Fig. 11). The Iatan Limestone has been recognized as an intermediate cycle of marine deposition by Heckel (1986). This marine horizon has been obscured by deltaic influx of southeasterly derivation along most of the Kansas outcrop, but Ball (1964) reported the Iatan Limestone appearing westward 20 to 40 miles in the subsurface in western Lyon, Greenwood and Elk counties.

A unit of crinoidal and phylloid algal limestone exposed around Peru in eastern Chautauqua County lies at the stratigraphic position of the Iatan Limestone Member (Fig. 10). It is well above definite South Bend Limestone mapped by Heckel (1975a) eastward in western Montgomery County, and below the probable Westphalia Limestone Member exposed in a roadcut 1 mile east of Peru (ctr W line SW sec 23, T34S, R12E). The probable Iatan-equivalent limestone unit consists of about 12 feet of phylloid algal calcilutite overlain by 1 foot of shaly crinoidal limestone in the old quarry 1 mile northeast of Peru (SW-SE-SE sec 10, T34S, R12E). It extends at least 2 miles southwestward to exposures along the creek on the west side of Peru, where it forms the bed on both sides of new US 166 (SW-NE-NW sec 21) and also the east bank south of old US 166 (near ctr E line SW-SW sec 16), where the thinned algal facies overlies 1 foot of fossiliferous shale and 1.5 feet of crinoidal limestone. The unit extends 3 miles eastward as about 1.5 feet of crinoidal limestone with a medial shale in exposures along new US 166 (NE-SE-SW sec 23, T34S, R12E) and along an abandoned segment of old US 166 (near ctr S« NW-SW sec 24, T34S, R12E) 2 to 3 miles west of Niotaze. An exposure of rubbly conglomeratic limestone along strike 5 miles north of Niotaze (SW-NW-NW sec 32, T33S, R13E) may represent a later reworked deposit of this unit. The conodont faunas of all the crinoidal limestones and shales are relatively abundant, and that from the new US 166 roadcut contains a form of *Strepognathodus* with incipient lobes that is found also in the thin core shale of the Iatan Limestone in Missouri. A similar conodont fauna occurs in 0.5 foot of shaly crinoidal limestone 10 miles to the south discovered by A.P. Bennison at the west end of the Hulah dam (SE-SE-SW sec 2, T28N, R11E) in northeastern Osage County, Oklahoma, which was mapped by Tanner (1956) in the Tallant Formation. This limestone lies well above the probable South Bend limestone and shale exposed along Rte O-10, about 4 miles eastward, and below the type Bowring Limestone, the probable Westphalia Limestone equivalent, just to the west, and thus also is probably equivalent to the Iatan Limestone Member (Fig. 10). The algal-crinoidal limestone unit near Peru now believed to be Iatan equivalent had been misidentified as Haskell Limestone by Ball (1964), but it lies about 70 feet below the Haskell Limestone and overlying Little Pawnee Shale, recently identified by its distinctive conodont fauna, in the new roadcuts along new US 166 1 mile east and 1 mile west of Peru (near ctr sec 22, and NE-NE sec 20, T34S, R12E).

<u>Undivided Lower/Middle Stranger Unit</u>.--South of the disappearance of the Iatan Limestone Member in northern Leavenworth County, the lower and middle parts of the Stranger Formation from the top of the South Bend Limestone (Gretna Shale Member) to the base of the Westphalia Limestone Member are not subdivided into formal members because there are no distinctive marker beds laterally traceable enough to effect a meaningful subdivision (Fig. 11). The Weston-Tonganoxie boundary described by Ball (1964; see also Ball et al., 1963) was explicitly at different stratigraphic horizons in different places, and the distinct possibility that sandstone that would be classified as Tonganoxie by his criteria underlies limestone that probably correlates with the Iatan equivalent in Chautauqua County (Fig. 10) renders the old member subdivision meaningless south of the southern limit of the type Tonganoxie sandstone bed in Douglas County.

The Lower/Middle Stranger unit thickens from about 100 feet in Franklin County southward to about 180 feet in southeastern Kansas. It consists mainly of silty to sandy micaceous shale with zones of ironstone nodules, and underlies the flat land in south-central Franklin, western Anderson and eastern Woodson counties. It contains lenticular bodies of shaly to massive sandstone, locally up to 40 feet thick in central Franklin County (e.g., Sand Hills southwest of Ottawa), one of which is well exposed in a shale pit south of Ottawa (NW sec 23, T17S, R19E).

Sandstones up to 20 feet thick occur at the top of this unit in southern Woodson County, and cap the conspicuous outliers, West Mound and South Mound, at Fredonia in Wilson County, where shale pits provide some of the few good exposures of the shale in this unit. Sandstones dominate much of this sequence in western Montgomery and eastern Chautauqua County, where exposures are available south of Elk City (along S line SW-SW sec 17, T32S, R14E; E line NE-SE sec 17, T33S, R14E), and on the east side of Timber Hill (E line SE sec 26, T32S, R14E) west of Independence. In most places the observed contacts between the sandstones an surrounding shale are gradational, which led Ball (1964) to doubt the existence of a widespread "Missourian-Virgilian" disconformity at this horizon. Southward into Oklahoma, the Lower/Middle Stranger unit merges mainly into the Tallant Formation (Fig. 10), named by Oakes (1951) from Tallant in east-central Osage County, and also into the basal part of the overlying Vamoosa Formation, named by Morgan (1924) from central Oklahoma.

Several thin coal beds are present in the upper part of the Lower/Middle Stranger unit in northeastern Kansas. One, the Sibley coal (Moore, 1936; later called Upper Sibley coal by Moore, 1949) named from exposures near Sibley (now Sibleyville, in sec 33, T13S, R20E) southeast of Lawrence, is traced from southern Douglas County northward into Platte County, Missouri, at the top of this unit just below the Westphalia Limestone. This coal attains 1.5 feet in thickness near Tonganoxie where it has been mined. It is currently exposed (but only 0.2 foot thick) just below the Westphalia Limestone in a roadcut (just east of ctr S line SE sec 12, T14S, R20E) 2.5 miles east of Vinland in Douglas County. Lower coal horizons (Lower Sibley, Blue Mound) have been reported in eastern Douglas County, and another (Ottawa coal) is known in central Franklin County, where it is exposed in the north wall of the shale pit southwest of Ottawa. Plant fossils are locally common and occasionally well preserved in shaly horizons associated with the sandstones and coals, as illustrated by Ball et al. (1963, p. 26) from localities south of Ottawa.

The Lower/Middle unit of the Stranger Formation in Kansas represents largely deltaic to shoreline/estuarine to alluvial deposits, in which the lower prodeltaic shales prevented regressive limestone deposition during the regressive phase of the underlying South Bend marine cycle. This was followed by distributary sandstones in many places, which are older than, and thus unrelated to the type Tonganoxie sandstone. The deltas that built out were inundated along present outcrop only locally by the succeeding Iatan marine transgression to form the lens of Iatan Limestone equivalent at Peru in Chautauqua County. The following regression brought the erosion of channels, and the deposition of more terrestrial alluvial and locally estuarine deposits (A.W. Archer, pers. commun., 1992), including the large channel-filling type Tonganoxie Sandstone in northeastern Kansas. Regression finally culminated in the paleosol surface upon which the Upper Sibley coal formed, ahead of the leading edge of the Westphalia transgression in that area.

Tonganoxie Sandstone bed.--The Tonganoxie Sandstone lies within the middle of the Stranger Formation in northeastern Kansas (Fig. 2). It was named by R.C. Moore in a 1934 chart (according to Moore, 1936) from exposures in the area east of Tonganoxie in Leavenworth County. The exact locations of the "good exposures" listed by Moore (1936) are not clear from the information given. Ball (1964) designated no type section, apparently as no complete section is known, but his measurement of an interval for the Tonganoxie Sandstone along US 24-40 (from S line SW-SE sec 1, T11S, R21E, to S line SE sec 3) 1 to 3 miles east of Tonganoxie, where several exposures are available (especially S line at SW cor & SE cor, SE sec 2) allow this transect to suffice as the principal reference section, with an exposure just to the east (ctr S line SE sec 6, T11S, R22E) added to display the distinctive large cross beds near the base of the unit.

Because of the notorious lenticularity of sandstone bodies at different horizons within shale-dominated formations such as the Stranger, the Tonganoxie Sandstone bed is no longer recognized as a formal member with implied lateral extent much distance from its type area. This obviates the problems inherent in delineating the Tonganoxie-Weston contacts at different horizons indicated in Ball (1964), and reemphasizes the lack of a regional traceable disconformity at the base indicated by Ball (1964), which led to removal of the Missourian-Virgilian boundary from the base of the Tonganoxie as reported by O'Connor (1963).

The Tonganoxie Sandstone occurs in an outcrop area from northeastern Douglas through southern Leavenworth, and northwestern Wyandotte Counties in northeastern Kansas, extending into southern Platte and Clay Counties in Missouri. This appears to be a southwestward-trending erosional valley about 20 miles wide (Lins, 1950), cutting locally into South Bend, Rock Lake and even Stanton strata. In this general area, the Tonganoxie consists in the lower part most conspicuously of ripple-laminated to thick-bedded micaceous sandstone up to 70 or 75 feet thick, with distinct trough-festoon cross bedding. It overlies lower Stranger shale or older units with a sharp, erosional and often conglomeratic base, which is well exposed at the principal reference section for the South Bend Limestone along the west side of Rte K-7 at the intersection just south of the US 24-40 interchange 3 miles north of Bonner Springs (NW-SW-NW sec 8, T11S, R23E). The Tonganoxie grades upward and laterally into thinner even to wavy bedded sandstone, shaly sandstone and eventually sandy micaceous to locally coaly shale, all with gradational contacts.

Traditionally the Upper Sibley coal bed, which is traced across this area, has been considered to be the top of the Tonganoxie Sandstone interval. By this definition, the upper Tonganoxie is mostly shale, and the entire interval was estimated by Ball (1964) to be 150 feet thick along US 24-40 east of Tonganoxie. A thin bed of sandstone just above the Iatan Limestone and below the coal in northwestern Platte County, Missouri, is considered to be the featheredge of the Tonganoxie (Searight and Howe, 1961). If so, it would fix the stratigraphic position of the Tonganoxie Sandstone in the middle of the Stranger Formation, even though it cuts down through the base of the Stranger in places (e.g., roadcut along US 24-40, S line SW-

SE sec 1, T11S, R22E, where it appears to be resting on the Rock Lake Shale just above the top of the Stoner Limestone Member). The Tonganoxie represents the coarse detrital filling of an alluvial valley eroded across northeastern Kansas during the low stand of sea level following the Iatan regression and prior to the Westphalia transgression.

Westphalia Limestone Member.--The Westphalia Limestone overlies the Lower/Middle unit of the Stranger Formation (which has the Upper Sibley coal at the top in northeastern Kansas) and underlies the Vinland Shale Member in Kansas (Fig. 2,10,11). It was named by Moore (1936) from Westphalia in western Anderson County. An exposure near one of the typical outcrops designated by Moore (ctr E line NE sec 20, T21S, R18E) 3 miles northeast of Westphalia is well enough exposed today to be considered the principal reference section. Here the Westphalia is 0.5 foot of fusulinid-dominated skeletal calcarenite. Because this and the other of Moore's typical outcrops (N line sec 12, T21S, R17E) had become poorly exposed, Ball (1964, p. 101) designated a roadcut several miles to the north (SW cor NW sec 19, T20S, R18E) as a "reference standard", but the closest exposure to this locality found recently, is in a streambank in SW-NW-SW sec 19, just to the south.

In its type region from Anderson to western Wilson County, the Westphalia Limestone Member ranges from 1 to 6 feet of massive to irregularly bedded, distinctively fusulinid-rich skeletal calcarenite, containing other skeletal debris such as crinoids and bryozoans, generally with osagid coatings. It is about 3 feet thick in a good exposure discovered by C.G. Maples 2 miles south of LeRoy (W of NE cor sec 16, T23S, R16E) in southeastern Coffey County. One of the best exposures of the Westphalia Limestone Member is in the spillway for Woodson County State Lake (SE-SW-NE sec 14, T26S, R14E) where it is about 4 feet thick in a succession that also exposes well the overlying units up through the shale overlying the Haskell Limestone. The Westphalia was recently exposed in a road ditch (S of ctr W line sec 19, T29S, R14E) 4 miles south of New Albany in Wilson County.

South of Wilson County, the Westphalia Limestone Member may be discontinuous, or at least largely undetected along outcrop. A recent exposure of sandy, crinoidal, fusulinid-dominated calcarenite discovered by A.P. Bennison in a roadcut (ctr W line SW sec 23, T34S, R12E) 1 mile east of Peru in Chautauqua County is probably the Westphalia Limestone, because it lies stratigraphically above the exposures of the crinoidal and algal limestone thought to be equivalent to the Iatan in this area, and below limestone and dark shale now known to be the Haskell Limestone and overlying Little Pawnee Shale, in new roadcuts along new U.S. 166, 0.5 and 2.2 miles to the west, on either side of Peru. The Westphalia Limestone was correlated southward by Ball (1964) with the Bowring Limestone, named by Tanner (1956) from exposures near Bowring (NE sec 16, T28N, R11E) in northern Osage County, Oklahoma, which also is rich in fusulinids. In support, the Bowring lies above strata (at the west end of Hulah dam) that contain a conodont fauna compatible with that of the Iatan Limestone, and below strata (Labadie Limestone) that correlate with the Haskell-Little Pawnee marine sequence (Fig. 10).

North of its type region, in poor exposures from northern Franklin County, Kansas, into Buchanan County, Missouri, the Westphalia Limestone Member is a thin lenticular, ostracode-rich, argillaceous, coaly, laminated calcilutite, overlying the Upper Sibley coal bed. It has been exposed at the type section of the Vinland Shale (S of ctr E line SE sec 2, T14S, R20E) in Douglas County, and nearby (near SW cor sec 15, T14S, R20E) where this facies attains its greatest reported thickness of 1.5 feet (Ball, 1964). Today it is well exposed along the paved road 2.5 miles east of Vinland (just E of ctr S line SE sec 12, T14S, R20E) overlying the thin Upper Sibley coal. The Westphalia Limestone is unknown in northernmost Missouri, Iowa and Nebraska in either cores or outcrop; thus it has presumably pinched out in that direction.

The Westphalia Limestone Member represents a minor cycle of transgression and regression (Heckel, 1986), which extended onto the shelf only as far as northern Missouri, and which ponded fresh water ahead of the leading edge to form the Upper Sibley coal. The ostracode-rich coaly calcilutite represents the restricted, perhaps largely lagoonal margin of this transgression, and the fusulinid calcarenite represents a more open marine shoal-water facies, perhaps subjected to storm wash and possibly derived from the more offshore skeletal calcilutite facies situated westward in the subsurface (Ball, 1971).

Vinland Shale Member.--The Vinland Shale overlies the Westphalia Limestone Member, and forms the top of the Stranger Formation (and the Missouri Supergroup) beneath the Haskell Limestone Member of the Cass Limestone in Kansas (Fig. 2,10,11). It was named by Newell (1935), after usage by J.M. Patterson in an unpublished thesis, from exposures near Vinland in eastern Douglas County. Its stratigraphic interval was stabilized by Moore (1936) who listed the type locality 2 miles northeast of Vinland in NW sec 12, T14S, R20E, which is now poorly exposed. Ball (1964) delineated the type section close by along the road at E line SE-SE sec 2, T14S, R20E.

The Vinland Shale Member at its type section is 26 feet thick with the upper 22 feet recently well exposed. Here it is mainly sandy micaceous shale with a sparse fauna dominated by ostracodes and foraminifers, capped by 5 feet of calcareous sandstone with brachiopods and other groups, particularly myalinid clams, at the top. It contains thin sandstone/siltstone beds toward the base from Douglas to Anderson counties. It thins southward to 2 to 6 feet thick in Woodson County, where the spillway to the State Lake (SE-SW-NE sec 14, T26S, R14E) provides a good reference exposure of 5 feet of conspicuously fossiliferous myalinid-bearing shale.

The Vinland Shale Member thickens southward again through 9 feet in Wilson County above the Westphalia Limestone Member, to 17 feet reported in eastern Chautauqua County (SW sec 4, T33S, R13E) by Ball (1964) with abundant myalinids at the top, but the base not exposed in an area where the Westphalia Limestone is not known. Southward along US 166 west of Peru (NE-NE sec 20, T34S, R12E), the Vinland Shale comprises 4 feet of fossiliferous shale with myalinids, above 10 feet of sandy shale to shaly sandstone with plant fossils overlying 28 feet of probably channel-filling sandstone, in a sequence that merges southward with strata classified in the lower part of the Vamoosa Formation in Oklahoma.

Northward from its type area in Douglas County, the Vinland Shale Member thickens to about 40 feet in Leavenworth county, then thins again to 4 to 14 feet in Atchison County. In this region it contains a persistent zone of septarian nodules in the middle that is traced from Franklin County northward into Missouri. Locally in Leavenworth and Atchison counties, the fossiliferous zone at the top becomes essentially an argillaceous shelly limestone. The Vinland Shale represents a minor regression after the Westphalia transgression, which allowed small detrital wedges to penetrate the shallow marine environment prior to the major transgression represented by the overlying Haskell Limestone.

Middle/Upper Stranger unit.--North of the disappearance of the Westphalia Limestone Member and Upper Sibley coal in northwestern Missouri, the Vinland Shale Member merges with the underlying shale above the Iatan Limestone Member to form a unit (Fig. 11) that has been considered the entire Stranger Formation in Missouri and Iowa, and the upper unnamed member of the Plattford Formation in Nebraska, but which is equivalent to only the middle and upper parts of the Stranger Formation as defined in Kansas. This Middle/Upper Stranger unit is 13 to 23 feet thick in Missouri with a blocky mudstone upon the Iatan at the base, a local sandstone in core MNC in the middle (which may or may not be equivalent to the Tonganoxie) and fossiliferous shale at the top. This unit ranges from 12 to 16 feet thick in Iowa cores where it is mostly reddish blocky mudstone, determined to be a well developed paleosol by Goebel et al. (1989), locally overlain by fossiliferous shale. It then thins westward to 5 to 11 feet of red blocky mudstone on the Nebraska outcrop.

VIRGIL SUPERGROUP

DOUGLAS GROUP

Cass Limestone

The Cass Limestone is now recognized in Kansas to include the Haskell Limestone Member at its base and to overlie the Stranger Formation, specifically the Vinland Shale Member (Fig. 2). The Cass underlies the Lawrence Formation as slightly revised by removal from it of the Haskell Limestone and the thin overlying members of the Cass Limestone recognized in Kansas. Even though the Cass Limestone is the basal formation of the Virgil Supergroup and also the base of the Virgilian Stage, a brief description of its stratigraphic classification is deemed necessary here to clear up minor problems with usage of the various names that have been applied to parts of the succession.

The Cass Limestone was named by Condra (1927, p. 41, 58) from exposures in northern Cass County, Nebraska, northwest of South Bend, where it is 12 feet thick. Later Condra (1949, p. 29) subdivided it into 3 members in ascending order: thin Shoemaker Limestone (as then redefined), thin dark Little Pawnee Shale, and thick Haskell Limestone (as then correlated from Kansas), which is a classic northern Midcontinent cyclothem sequence (Fig. 11). The Little Pawnee Shale is characterized by a black fissile phosphatic facies, which is traced in a thin, 2- to 6-foot-thick Cass Limestone succession through cores in southwestern Iowa and northwestern Missouri (Fig. 6). Because the Little Pawnee contains an abundant and distinctive conodont fauna that is found also in the base of the thick shale (Robbins) that overlies the type Haskell Limestone of Kansas (Fig. 11), the Haskell correlates with the basal member of the Cass Limestone in Nebraska, not the upper member (as recognized also by Ball, 1964). Recognizing that the basal member of the Cass Limestone is the Haskell Limestone displaces the name Shoemaker in Nebraska. Because the name Shoemaker Limestone was originally applied by Condra (1927) to the entire Cass Limestone interval near Nehawka, Nebraska, about 20 miles from the type Cass, it could now be applied reasonably to the upper thick limestone member of the Cass Limestone in Nebraska, to avoid introducing a new name into the succession. The use of Cass Limestone for just the upper limestone member of the sequence in Kansas (e.g., Ball, 1964; Ball, 1985) is inappropriate, as it applies to the entire limestone-shale-limestone sequence in Nebraska and should be used consistently in Kansas.

The Cass Limestone therefore is now recognized in Kansas to comprise 3 members in ascending order: Haskell Limestone at the base, Little Pawnee Shale above (at the middle in one known exposure, but at the top in all others), Shoemaker Limestone at the top in one exposure (preliminary, pending agreement by the Nebraska Geological Survey). The principal reference section for the Cass Limestone in Kansas is the roadcut along the north side of Rte K-32 (near ctr S line SW sec 13, T12S, R20E) in southwesternmost Leavenworth County, about 4 miles northeast of Lawrence and 6 miles west of Linwood. Here the Cass is about 7 feet thick with 3 feet of Haskell Limestone Member at the base, overlain by a little less than a foot of gray fossiliferous Little Pawnee Shale Member carrying the abundant distinctive conodont fauna, and capped by a little over 3 feet of Shoemaker Limestone Member (Fig. 11). In northern Oklahoma, identification of the Little Pawnee Shale Member beneath the type Labadie Limestone (named by Bowen, 1918, p. 45, from Osage County) indicates that the Labadie is the southern correlative of the Shoemaker Limestone and forms the top of the Cass Limestone in that area (Fig. 10).

Haskell Limestone Member.--The Haskell Limestone is removed from the Lawrence Formation and is now recognized as the basal member of the Cass Limestone in Kansas. It overlies the Vinland Shale Member of the Stranger Formation and underlies the Little Pawnee Shale Member of the Cass (Fig. 2,10,11). It is the transgressive limestone of the Cass major cyclothem. The Haskell Limestone Member was named by Moore (1932) from exposures near the Haskell Indian Institute in Lawrence, and the type locality was designated by Moore (1936, see Ball, 1964) at ctr N line NE sec 5, T13S, R20E, along 15th Street on the east side of town.

The Haskell Limestone Member at its type locality is 4 feet thick with a sandy limestone at the base overlain by an oolite and grading upward into skeletal calcilutite, forming a deepening-upward sequence characteristic of a transgressive limestone. Other accessible exposures in this area are at the type section of the Vinland Shale Member (ctr E line SE-SE sec 2, T14S, R20E), along the paved road 2.5 miles east of Vinland (ctr S line SW-SE sec 12), and along the road between Baldwin City and Douglas County State Lake (near NE cor sec 34, all in the same township). Although the lower contact is somewhat gradational at the type locality, it is generally distinct over shale, sandstone, or shaly limestone in most places. The upper contact is generally abrupt with shale.

Northward, the Haskell Limestone Member averages about 3 feet thick in Leavenworth County, where it is well exposed at the principal reference section of the Cass Limestone along Rte K-32, and where partial exposures of it mark the top of the type Stranger Formation between Linwood and Tonganoxie. The Haskell thins farther northward to 1 to 2 feet of crinoid-rich calcilutite along the Missouri outcrop. It is about 0.1 to 2 feet of shaly skeletal calcilutite in cores in the Missouri-Iowa subsurface and about 1 foot of shale-parted calcilutite on the Nebraska outcrop.

Southward from its type area, the Haskell Limestone Member is a remarkably uniform skeletal calcilutite, averaging about 2 feet thick and providing a good marker unit for the base of the Virgil Supergroup. It is well exposed in a roadcut (near ctr S line SW-SE sec 13, T21S, R17E) 2 miles north of Westphalia in Anderson County. The Haskell Limestone Member is best exposed in the spillway to Woodson County State Lake (SE-SW-NE sec 14, T26S, R14E), which serves as an important reference section and also is a candidate for the Missourian-Virgilian Stage boundary stratotype. The Haskell is also exposed along Rte K-96 (near SE cor SW sec 9, T28S, R14E in western Wilson County. It attains 6 feet in exposures nearby around New Albany (roadcuts between sections 11, 12, 13 & 14, and at SE cor sec 24, T29S, R13E) and thins southward to 0.3 foot of skeletal calcilutite in eastern Chautauqua County (near ctr E line NE-SE sec 22, T32S, R13E; and SW-NW sec 9, T33S, R13E), located by D.F. Merriam (pers. commun., 1990).

Southwestward the Haskell Limestone Member was recently discovered as 0.5 foot of argillaceous skeletal calcilutite by A.P. Bennison in new roadcuts along US 166, both east (near ctr sec 22) and west of Peru (NE-NE sec 20, T34S, R12E), where it is confirmed as Haskell by the distinctive abundant conodont fauna in the dark overlying Little Pawnee Shale Member. This unit is about 70 feet stratigraphically above the crinoidal limestone and lenticular algal limestone around Peru that was misidentified as Haskell by Ball (1964) and is now believed to be equivalent to the Iatan Limestone Member in the underlying Stranger Formation. The Haskell Limestone Member also has been identified as about 0.2 ft of argillaceous limestone below the Little Pawnee Shale Member in the roaditch exposure (ctr E line sec 32, T25N, R10E) discovered by A.P. Bennison, 2 miles south of Nelagony in east-central Osage County, Oklahoma.

Little Pawnee Shale Member.--The Little Pawnee Shale overlies the Haskell Limestone Member everywhere; it underlies the Shoemaker Limestone Member in Nebraska, Iowa, parts of Missouri, and at one locality in Kansas, and it underlies the Labadie Limestone Member in northern Oklahoma (Fig. 2). Elsewhere in Kansas, it underlies the Robbins Shale Member of the Lawrence Formation with a diffuse contact, just as the homologous Gretna Shale Member of the older South Bend Limestone underlies the basal shale of the Stranger Formation in Kansas. The Little Pawnee Shale was named by Condra (1949, p. 29) from Little Pawnee Creek in Saunders County, Nebraska, as the middle member of the Cass Limestone.

The Little Pawnee Shale Member in Nebraska is 1 to 2 feet of dark gray fossiliferous shale with a thin black laminar phosphatic shale zone in the middle. It is traced as 1 to 2 feet of dark gray shale, usually with a thin black phosphatic facies, through cores in southwestern Iowa and northwestern Missouri (Fig. 11). The Little Pawnee Shale carries an abundant conodont fauna that contains the first appearance of a distinctive lobed form resembling Streptognathodus zethus, which allows it to be identified where no black facies is present and has caused it to be traced at the top of the Haskell Limestone Member from Nebraska to southern Kansas, and southward below the Labadie Limestone of northern Oklahoma (Fig. 10).

The Little Pawnee Shale Member is recognized in Kansas as about 0.6 foot of fossiliferous gray shale, confirmed by the distinctive conodont fauna, between the Haskell and the Shoemaker Limestone members in the Rte K-32 cut (near ctr S line SW sec 13, T12S, R20E) northeast of Lawrence, which is regarded as its principal reference section in Kansas. Elsewhere in this area, it is about 0.2 foot of gray to dark gray fossiliferous shale with phosphatic nodules and a remarkable biota (discussed by Miller and Swineford, 1957) of fish remains, cephalopods and other invertebrates, as well as conodonts, and capped by a thin bed of iron hydroxide (goethite). Southward the Little Pawnee Shale Member is confirmed by its abundant conodont fauna just above the top of the Haskell Limestone in the Woodson County State Lake spillway (SE-SW-NE sec 14, T26S, R14E) where it lies at the base of the type Robbins Shale Member of the Lawrence Formation (Ball, 1964). Because of its thinness and generally diffuse upper contact with the Robbins, the Little Pawnee Shale would be mapped with the base of the Robbins Shale throughout this area.

Farther southward, the Little Pawnee Shale Member is well exposed as about 10 feet of dark gray shale above the thin Haskell Limestone Member, with a black zone near the base and the distinctive conodont fauna throughout several feet, in the new US 166 roadcuts both east (near ctr sec 22) and west of Peru (NE-NE sec 20, T34S, R12E) in Chautauqua County. It is partly exposed 5 miles southward in road ditches and cuts east and west of Elcado Cemetery just north of the Oklahoma border (SW-NE-NE sec 14; and NW-NE-NE sec 16, T35S, R12E), both discovered by A.P. Bennison and confirmed by the distinctive conodont fauna. Southward, the Little Pawnee is about 2 feet of dark gray shale (confirmed by conodonts) below the type Labadie Limestone along US 60 (NE-NW-SW sec 2, T26N, R10E) between Pawhuska and

Bartlesville in northern Osage County. At its southernmost known locality so far confirmed by the conodont fauna, the Little Pawnee Shale Member is 1 foot of gray fossiliferous shale between two shaly limestones in the roadditch about 2 miles south of Nelagoney (near ctr E line sec 32, T25N, R10E) in east-central Osage County.

The Little Pawnee Shale Member is the core shale deposited during the time of general sediment starvation at maximum transgression of the Cass cyclothem, but it was encroached early during regression by prodeltaic influx forming the thick Robbins Shale Member in most of Kansas.

Shoemaker Limestone Member.--The Shoemaker Limestone is now recognized to overlie the Little Pawnee Shale Member and form the top of the Cass Limestone in Nebraska, Iowa, Missouri and at one exposure in northern Kansas (Fig. 2). It underlies the Robbins Shale Member of the Lawrence Formation. The Shoemaker Limestone was named by Condra (1927, p. 73) from the Shoemaker farm and bridge near Nehawka in southeastern Cass County, Nebraska. Originally applied to the entire unit later recognized to be Cass Limestone, which was named at the same time, Condra (1949, p. 29) redefined the name Shoemaker to apply to only the basal beds of the Cass below the Little Pawnee Shale, because of the imputed (and incorrect) correlation of the upper limestone member of the Cass with the Haskell Limestone of Kansas. Because the type Haskell Limestone is now known by its position beneath the widely traceable, easily identified Little Pawnee Shale to be the lower member of the Cass Limestone, the name Shoemaker as revised by Condra (1949) is displaced. Because the name Shoemaker originally was applied to the entire Cass Limestone, it seems more reasonable to revise it again to apply to the upper, thickest limestone member of the Cass in Nebraska, rather than to introduce a new name into the many that currently grace the Midcontinent Pennsylvanian.

The Shoemaker Limestone Member in Nebraska ranges from 5 to 15 feet thick and consists mainly of skeletal calcilutite capped in places by calcarenite with oolitic and osagid coatings (Burchett and Reed, 1967, p. 62). This is a shallowing-upward sequence characteristic of regressive limestones. The Shoemaker thins to 1 to 3 feet of skeletal calcilutite in cores in southwestern Iowa and northwestern Missouri (Fig. 11), and is reported on outcrop (as Cass Limestone) from DeKalb to Platte counties, Missouri, by Ball (1985, p. 89).

The Shoemaker Limestone Member is known in only one outcrop in Kansas, at the principal reference section for the Cass Limestone in that state along Rte K-32 (near ctr S line SW sec 13, T12S, R20E) in southwestern Leavenworth County northeast of Lawrence, where it is about 3 feet of skeletal calcilutite. Elsewhere along the Kansas outcrop, it was apparently overwhelmed by early prodeltaic detrital influx of the Robbins Shale Member at the base of the overlying Lawrence Formation.

The Labadie Limestone overlies the Little Pawnee Shale Member in northern Osage County, Oklahoma, and underlies shale equivalent to the Lawrence Formation (but classified in the middle part of the Vamoosa Formation). Thus the Labadie is equivalent to the Shoemaker Limestone Member of the north. The Labadie Limestone was named by Bowen (1918, p. 45) from exposures at Labadie Point in sec 9, T26N, R10E (Clark, 1918). Ball (1964) designated a roadcut on US 60 (near ctr NW-SE sec 3, T26N, R10E) about 1 mile to the northeast as the principal reference section, where it is about 14 feet of dolomitized skeletal calcilutite. It thins southward to about 1 foot of rubbly argillaceous limestone above the Little Pawnee Shale Member in the roadditch 2 miles south of Nelagony (near ctr E line sec 32, T25N, R10E). Although the Wildhorse Dolomite exposed southward in T22N, R10E had been correlated with the Labadie Limestone, the conodont fauna collected in the shale below the Wildhorse in the outlier north of Rte 0-20 (SW-NE-NW sec 21, T22N, R10E) resembles that of the older Eudora Shale Member of the Stanton Limestone more than that of the Little Pawnee Shale Member. Thus the Wildhorse Dolomite is probably equivalent to the older Stoner Limestone, and not to the Labadie.

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