DEPOSITIONAL ENVIRONMENTS OF THE TONGANOXIE SANDSTONE MEMBER OF THE STRANGER FORMATION (UPPER PENNSYLVANIAN) IN NORTHEASTERN KANSAS

by

JACKI L. SPRIGGS

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Approved by:

Page C Twiss

Major Professor

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INTRODUCTION

Purpose of Investigation

Traditional environmental studies of Pennsylvanian sandstones utilized a fining upward, autocyclic approach, but ignored indirect controls by allocyclic (sea level) events. Recognition of climate change surfaces (Busch, 1984) within the Tonganoxie Sandstone Member (Figure 1) of the Stranger Formation of the Douglas Group (Virgilian Stage, Lower Pennsylvanian Series) has provided insight into environmental conditions of the "outside shale" of Heckel (1977).

The primary objectives of this study are: (1) to interpret depositional environments of conglomerate, sandstone, shale, mudstone, and coal from examination of sedimentary structures and vertical and lateral lithofacies relationships, (2) to provide detailed correlations of genetic surfaces (Busch, 1984) in northeastern Kansas, (3) to apply a T-R unit hierarchical approach to stratigraphic analysis of the "outside shale" member, (4) to determine the effects of local structural features on deposition of the Stranger Formation, and (5) to use Markov Chain analysis to test the PAC hypothesis (Goodwin and Anderson, 1985).

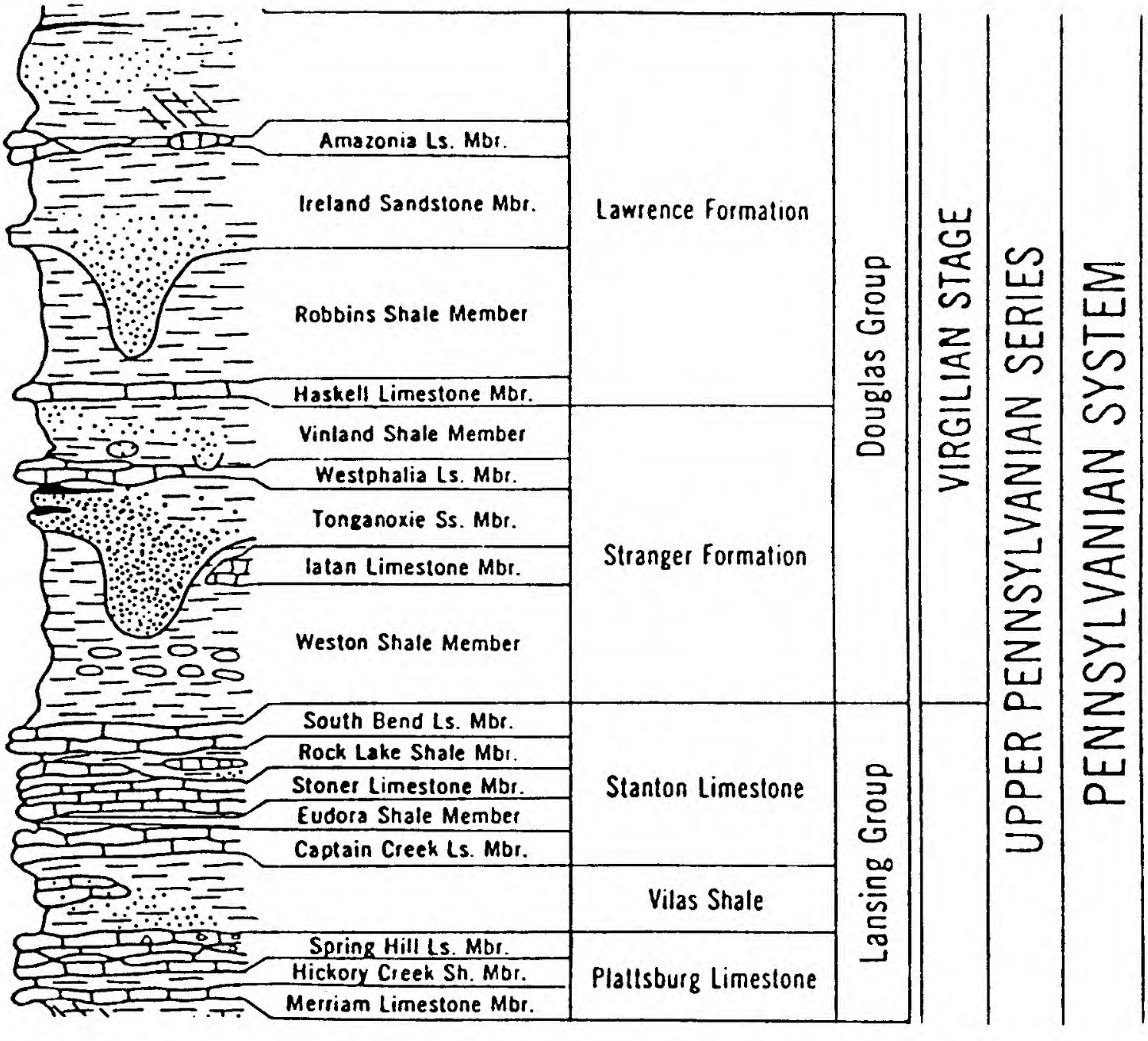


Figure 1. Stratigraphic column of part of the Kansas Pennsylvanian, showing study interval (adapted from Zeller, 1968).

Area of Investigation

Detailed studies of sedimentary structures and stratigraphic sections were limited to the outcrop belt within a six-county area of northeastern Kansas and northwestern Missouri (Figure 2). These counties are Platte, Leavenworth, Wyandotte, Douglas, Franklin, and Anderson Counties. Reconnaissance was conducted southward to northern Oklahoma. About 40 surface stratigraphic sections were examined along the outcrop belt of which 25 were described in detail. Appendix I contains the locations and descriptions of all stratigraphic sections which have not been described by previous authors. Appendix I also credits the authors who originally described these stratigraphic sections. A core furnished by the Kansas Geological Survey provided the most complete stratigraphic section of the Tonganoxie Sandstone in the study area.

Previous Work

The term cyclothem was introduced by Wanless and Weller in 1932 "to designate a series of beds deposited during a single sedimentary cycle of the type that prevailed during the Pennsylvanian Period" (1932, p. 1003). Cyclothems of Wanless and Weller (1932) consisted of eight specific lithofacies beginning with a disconformable sandstone and

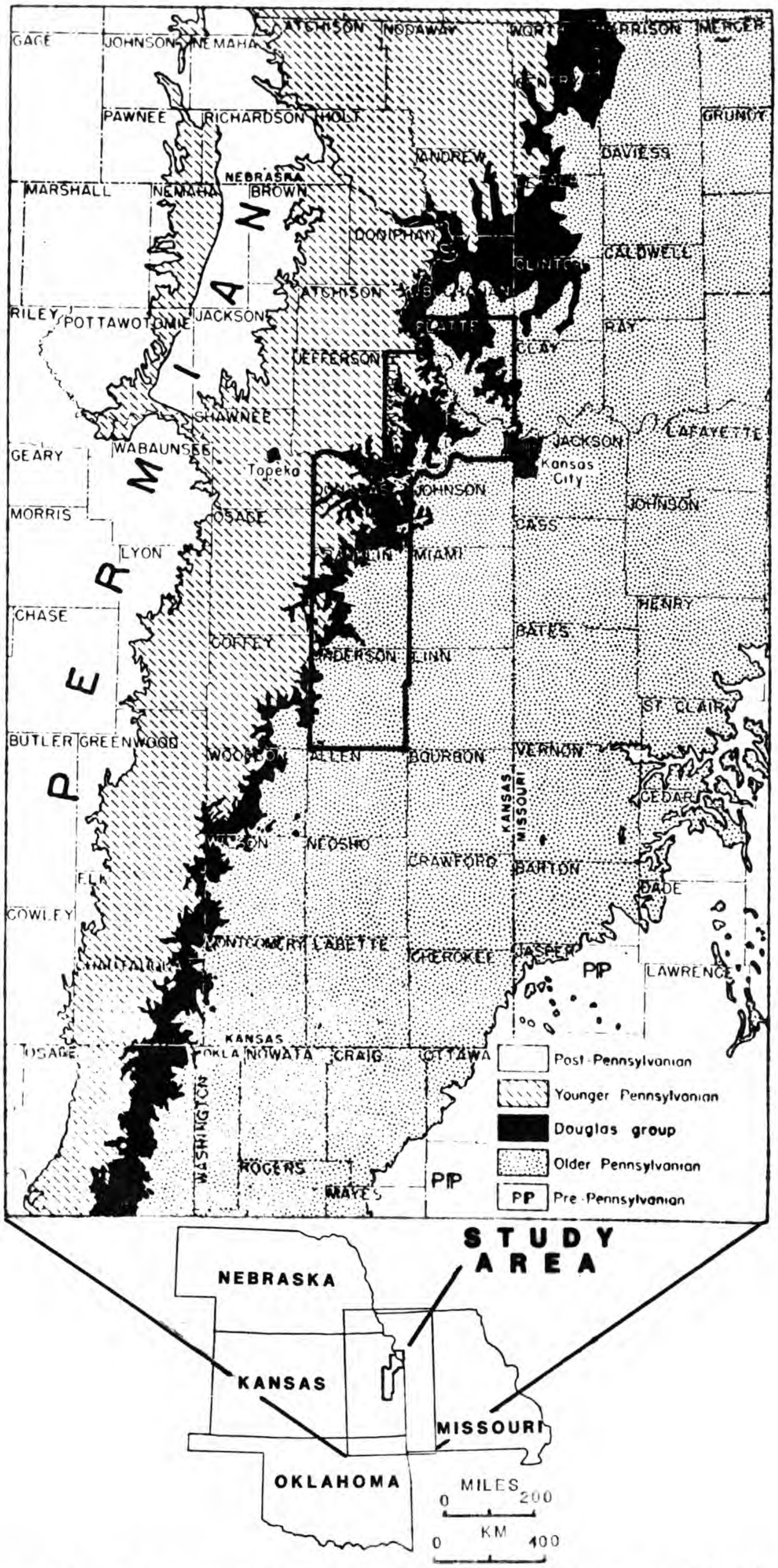


Figure 2. Outcrop of Douglas Group (from Moore, 1949).

ending with shale containing "ironstone" nodules and bands. Twenty years earlier, Udden (1912) had recognized the cyclicity of Pennsylvanian rocks, but commenced his cycles at the base of a coal seam representing his accumulation of vegetation stage. Heckel (1977, 1980) showed that Wanless-Weller (1932) cyclothems and Moore's (1936) megacyclothems were deposited in 400,000-year intervals representing a single transgressive-regressive period of time. Heckel's (1977, 1980) typical cyclothem contains two limestones separated by a black, phosphatic, fissile shale representing maximum transgression. This interval is bounded by outside shales which represent nearshore and continental conditions.

This study applies a punctuated aggradational cycle (PAC) approach to analysis of the Tonganoxie Sandstone in the Midcontinent. Goodwin and Anderson's (1985) PACs are upward shallowing units of sediment deposited between times of rapid sea level rise during which no net deposition occurred. These allocyclic transgressive-regressive (T-R) units are 1-5 meters thick and represent intervals of tens of thousands of years. PACs are sixth-order T-R units in the hierarchy of Busch and Rollins (1984) and Busch and West (1987). PACs can be grouped into larger-scale T-R units (Figure 3), about 5-30 meters thick, termed cyclothemic PAC sequences (i.e., fifth-order T-R units) by Goodwin and Anderson (1985). In contrast to cyclothems and megacyclothems which are lithostratigraphic units composed of

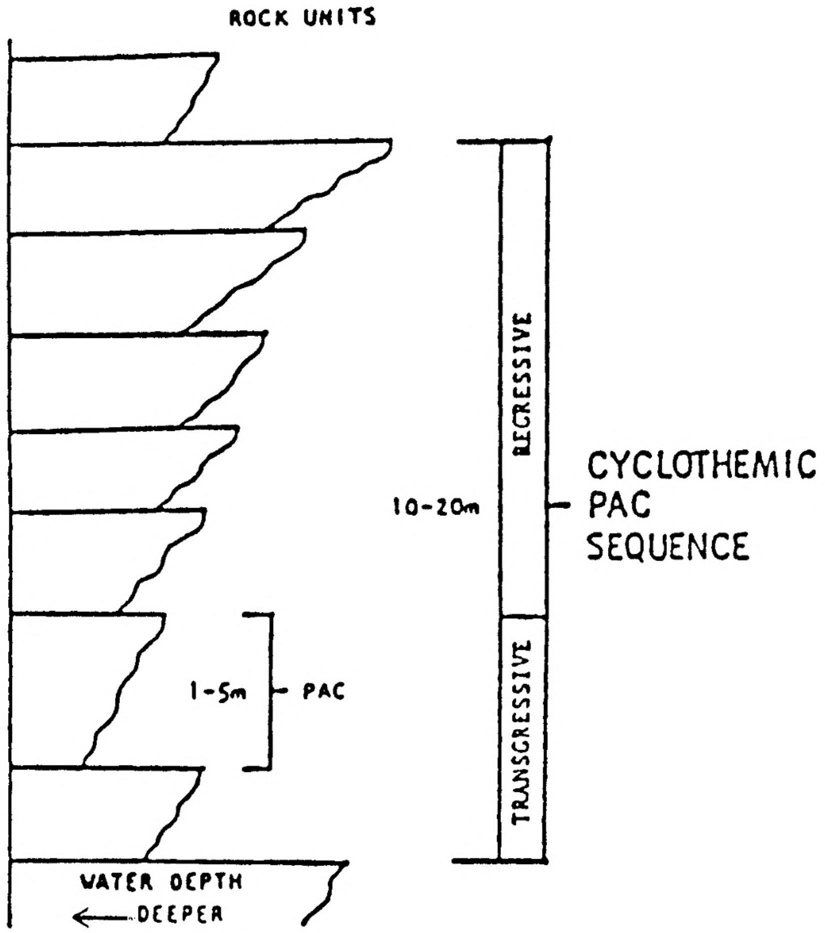


Figure 3. Concept of punctuated aggradational cycles, or PAC's, (sixth-order T-R units) and cyclothemic PAC sequences (fifth-order T-R units) (modified from Anderson and Goodwin, 1980).

rhythmic or cyclic repetitions of specific lithofacies, PACs and cyclothemic PAC sequences have genetic boundaries with lateral persistence. The T-R units are shown in Table 1 with respect to the first-, second-, third-, and fourth-order T-R unit hierarchical classification.

Table 2 shows the year and results of geologists who previously investigated the Tonganoxie Sandstone. Observations of these authors are credited and referred to in appropriate parts of the report.

Methods of Study

Most data for detailed correlations and interpretation of depositional environments were collected from field observations in the summer of 1984 and the following academic year. Selected stratigraphic sections were measured and described in detail (Figure 4), emphasizing sedimentary structures, bedding characteristics and genetic surfaces. Twenty-five outcrops were selected based on completeness of the Tonganoxie Sandstone, geographic spacing, lateral extent of each exposure, and the number of genetic surfaces.

Oriented samples were collected at vertical changes in lithology, color and bedding characteristics. Unweathered samples were collected where possible, but the Tonganoxie Sandstone is extremely weathered in outcrop; consequently,

HIERARCHY OF PERMO-CARBONIFEROUS T-R UNITS

BUSCH & ROLLINS, 1984 AND BUSCH, 1984	VAIL *et al.*, 1977	CHANG, 1975 AND RAMSBOTTOM, 1979	MOORE, 1936	GOODWIN AND ANDERSON, 1985	HECKEL, 1977 AND HECKEL, 1986	WANLESS AND WELLER, 1932
FIRST-ORDER 225-300 Ma	FIRST ORDER DEPOSITIONAL SEQUENCES					
SECOND-ORDER 20-90 Ma	SECOND ORDER DEPOSITIONAL SEQUENCES	SYNTHEMS				
THIRD-ORDER 7-13 Ma	THIRD ORDER DEPOSITIONAL SEQUENCES					
FOURTH-ORDER 0.6-3.6 Ma		MESOTHEMS				
FIFTH-ORDER 300-500 ka		CYCLOTHEMS	MEGACYCLOTHEMS	SHALLOWING PAC SEQUENCES	KANSAS CYCLOTHEMS; MAJOR CYCLES	CYCLOTHEMS
SIXTH-ORDER 50-130 ka			CYCLOTHEMS	PUNCTUATED AGGRADATIONAL CYCLES (PACs)	MINOR CYCLES	

Table 1. Hierarchy of Permo-Carboniferous T-R units with average periodicities (from Busch and West, 1987, in part after Busch and Rollins (1984).

NAME	YEAR	RESULTS
Patterson, J.	1933	Described the Douglas Group in Leavenworth and Douglas Counties
Moore, R.C., Elias, M.K., Newell, N.D.	1934	Applied the name Tonganoxie to the member previously called the Stranger Sandstone
Bowsher, A.L., and Jewett, J.M.	1943	Allochthonous littoral marine coals
Lins, T.W.	1950	Southwest-trending valley carved and filled by a low gradient river; northern and eastern source
Winchell, R.L.	1957	Correlated with subsurface "Stalnaker" sandstone using electric logs; deposited by filling in erosional basin by nearshore marine deposition in part
Sanders, D.T.	1959	Deposited in a southwest-trending river valley using isolith maps
Bower, Richard	1961	Deposited in a fluvial environment in northeastern Kansas and a tidal flat or shallow marine environment in southeastern Kansas using directional sedimentary structures; northern source
Hamblin, W.K.	1964	Detected rhythmic laminations using radiographic techniques
Ball, S.M.	1964	Mixed-environments principally controlled by proximity to the shoreline and influx of terriginous detritus; southern source
Bandel, Klaus	1967	Estuarine by description of isopod and limulid marks and trails
Minor, J.A.	1969	Fluvial, deltaic, tidal flat and shallow marine sequence; northern, southern and eastern source
Griffith, Gary Lee	1981	Fluvial depositional environment with a northerly source

Table 2. Previous investigations of the Tonganoxie Sandstone.

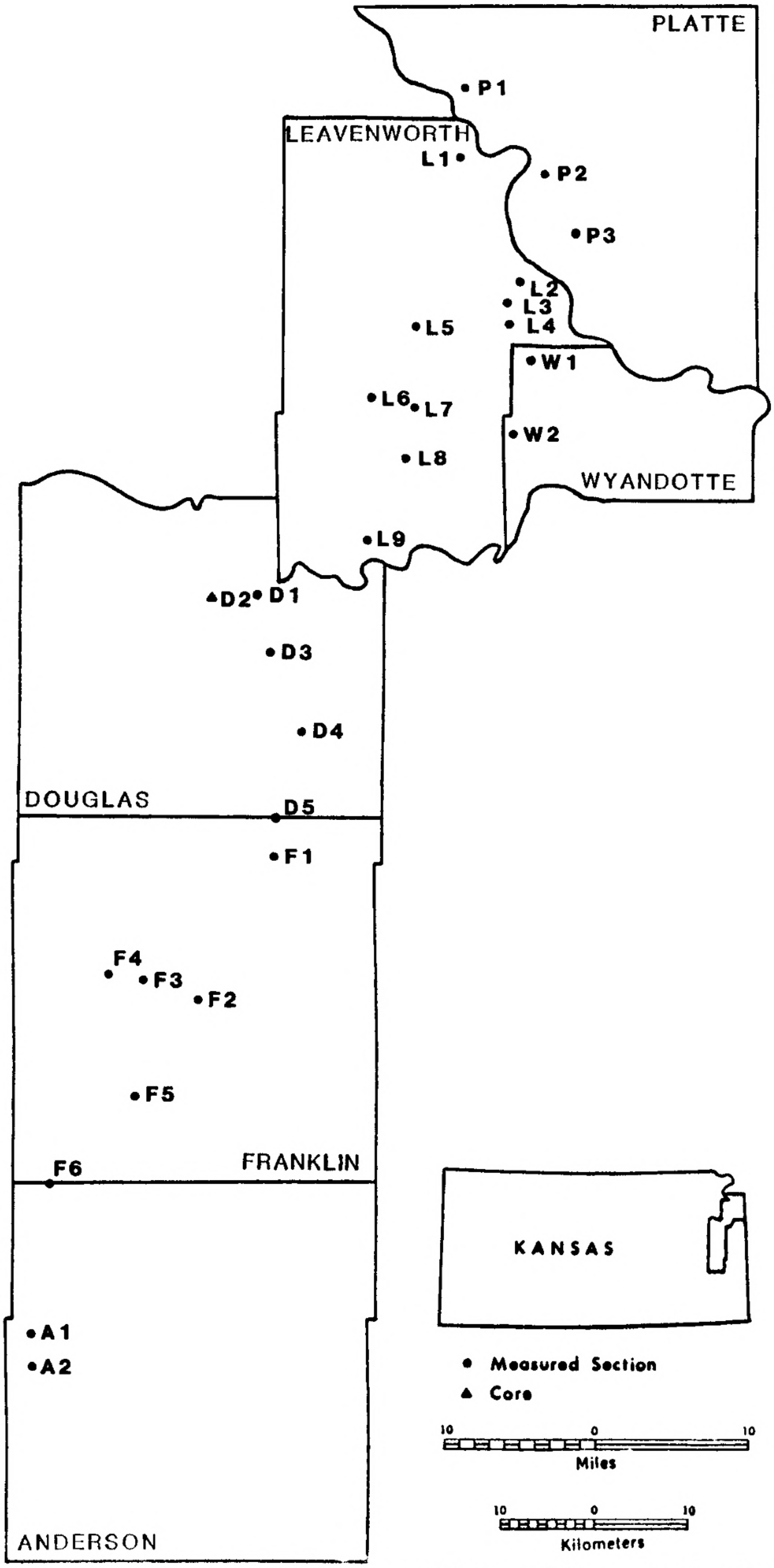


Figure 4. Localities of measured sections of Tonganoxie Sandstone used in regional study.

fresh sandstone samples are rare. Mineralogy, grain size, and sedimentary structures of all samples of each measured section were noted using megascopic and binocular microscope observation. Several samples of limestone and conglomerate were randomly slabbed perpendicular to bedding for determination of lithology, grain size, bedding characteristics, and fossil content. Eleven samples for thin section analysis were selected in an attempt to document lateral and vertical relationships of the Stranger Formation in northeastern Kansas. These thin section descriptions are reported in Appendix II. A core furnished by the Kansas Geological Survey provided information on diagenesis and total thickness. Descriptions and locations of stratigraphic sections are in Appendix I.

STRUCTURAL SETTING

The principal tectonic elements of the Midcontinent are in Figure 5. The southern margin of the northern Midcontinent is bordered by the Ouachita Mountains and Arbuckle Uplift which were created by Desmoinesian to Virgilian tectonism produced by continent to continent collision (Wickham, et al., 1976). The Canadian Shield, including the Wisconsin Highlands, is the chief tectonic constituent to the north. The Nemaha Uplift and Ozark Dome of the Midcontinent border the study area on the west and east, respectively.

The study area includes parts of the Forest City Basin, Schell City-Rich Hill Anticline, and Bourbon Arch. The Forest City Basin and Cherokee Platform were essentially filled and acting as a Midcontinent shelf by the time of Desmoinesian deposition (Heckel, 1985).

The rocks within the study area are structurally included in the Prairie Plains Monocline. These rocks dip slighty to the west-northwest from the Ozark Plateau (Jewett, 1941, p. 99). The general dip of the rocks in the study area is about 15-20 feet per mile to the west-northwest. Detailed study of the Tonganoxie Sandstone within this regional framework has provided additional information regarding conditions of deposition of the Douglas Group.

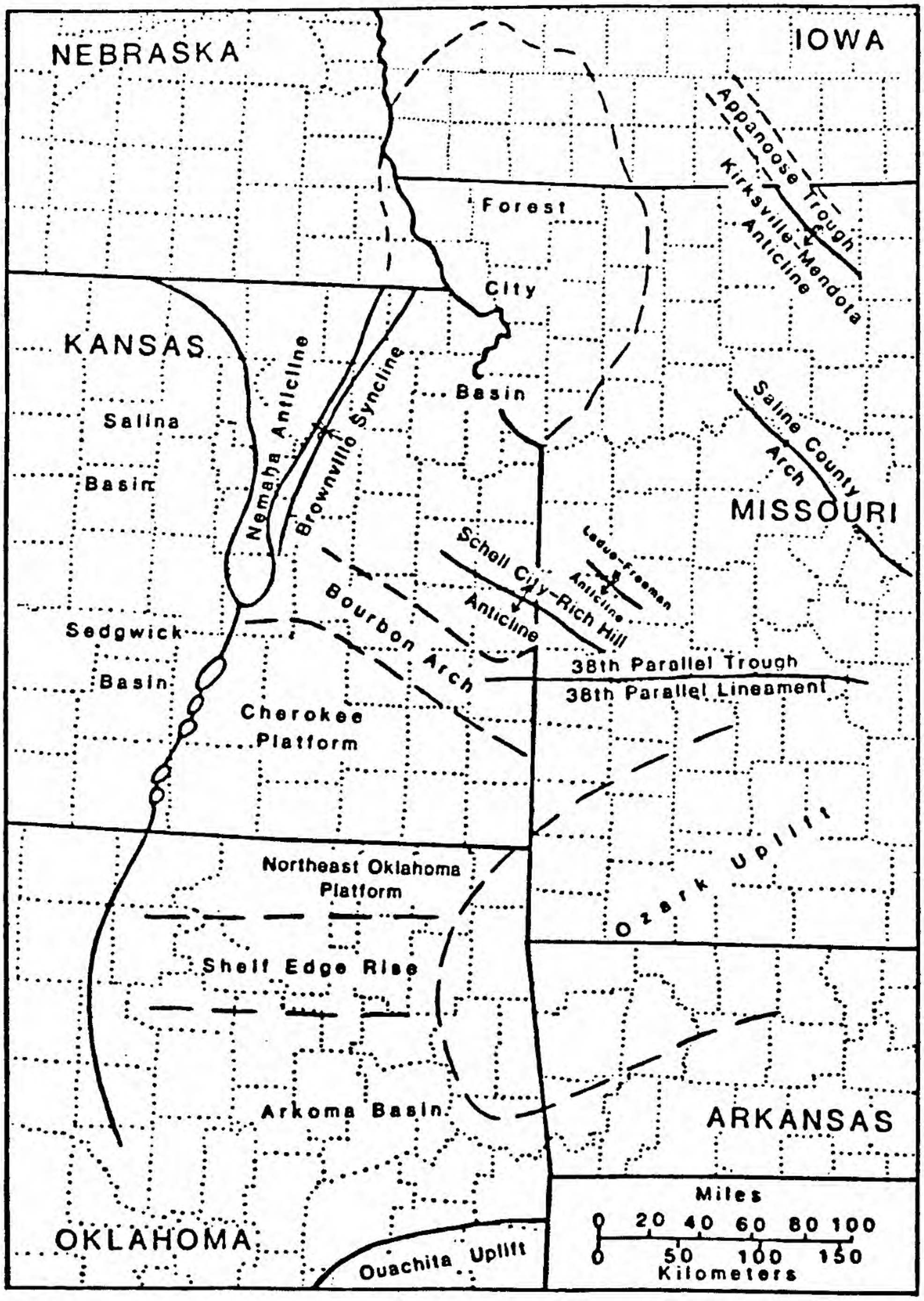


Figure 5. Principal tectonic elements in part of the Midcontinent (from Knight, 1985, p. 38).

STRATIGRAPHY

Douglas Group

The main outcrop belt of the Douglas Group (Virgilian Stage-Upper Pennsylvanian Series) extends from northwestern Missouri through eastern Kansas to northeastern Oklahoma (Figure 2). The Douglas Group (Figure 1) extends from the top of the Lansing Group to the base of the overlying Shawnee Group, and consists of the basal Stranger Formation and upper Lawrence Formation. The Douglas Group has been described by Ball (1964, p. 73) as "...a shale-sandstone wedge thickest to the south and southeast, thinnest to the north and northwest, and becoming a shale-limestone sheet in the northwesternmost part..." (Figure 6). Two admirable cross-sections of the Douglas Group along the outcrop belt produced by Bowsher and Jewett (1943) and Ball (1964) are shown in Figure 7 and Figure 8, respectively. These cross-sections show thicknesses, general lithologies, and local disconformities of all Douglas Group strata.

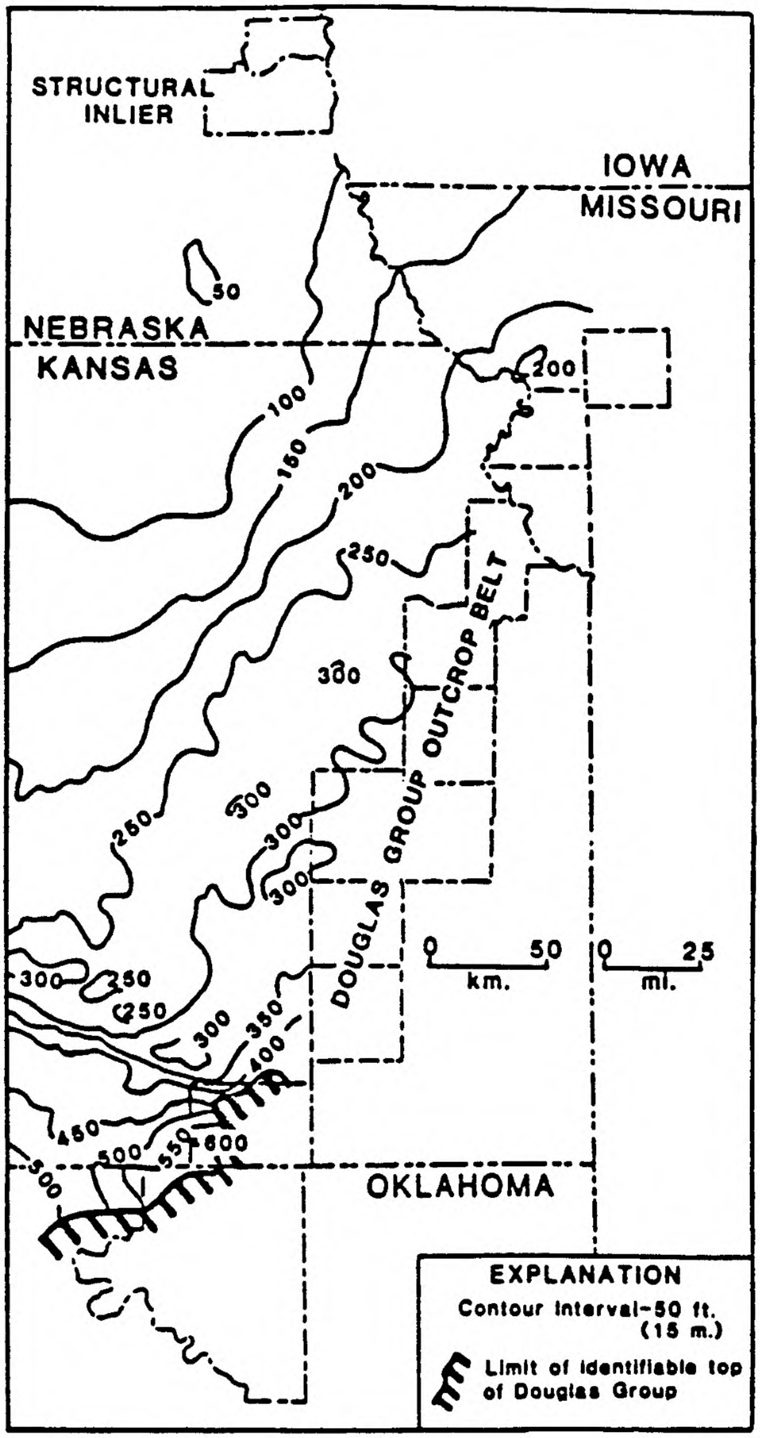


Figure 6. Isopach map of the Douglas Group (from Ball, 1985, p. 27).

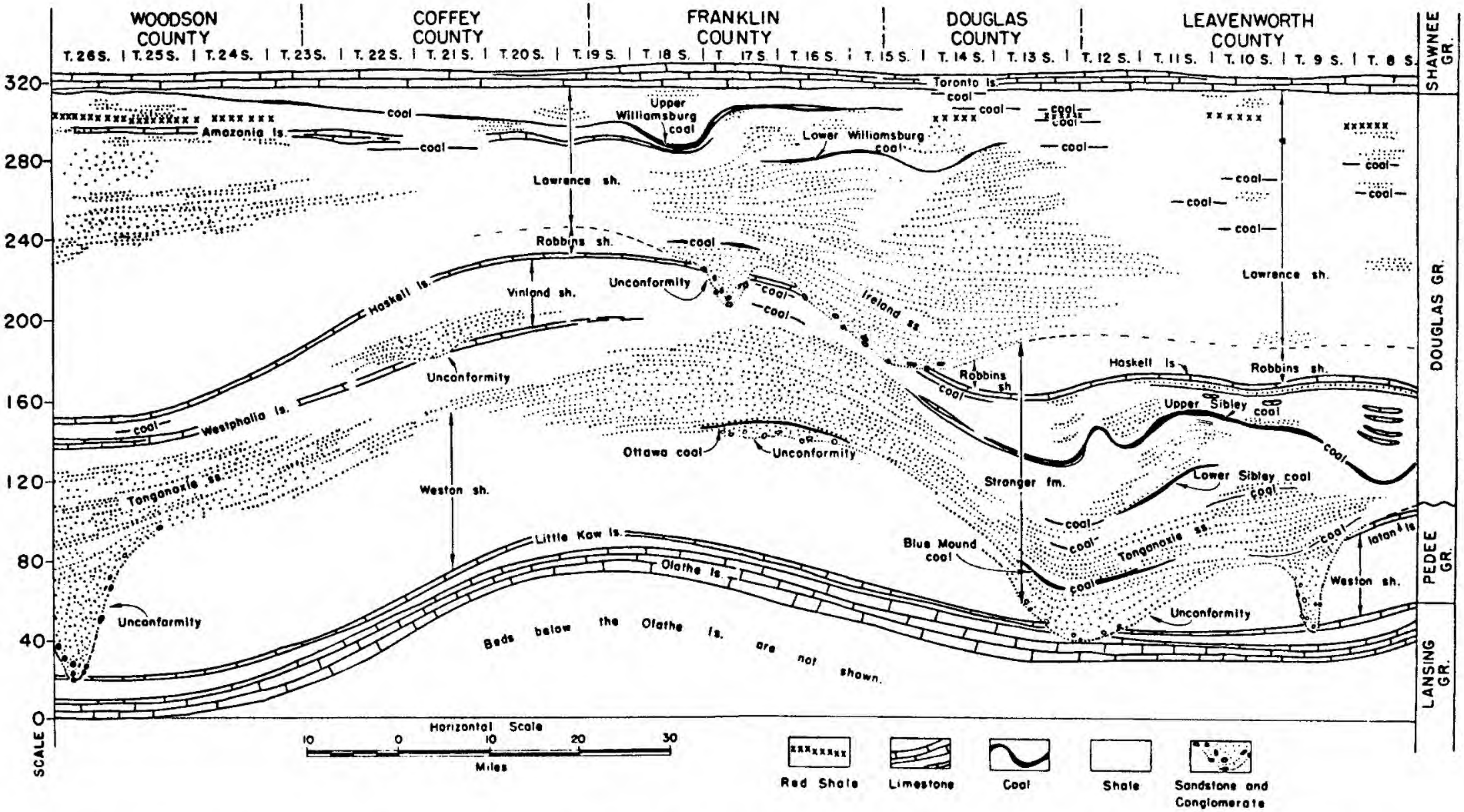


Figure 7. Diagrammatic cross section of the Douglas and adjacent rocks (from Bowsher & Jewett, 1943, pp. 30, 31).

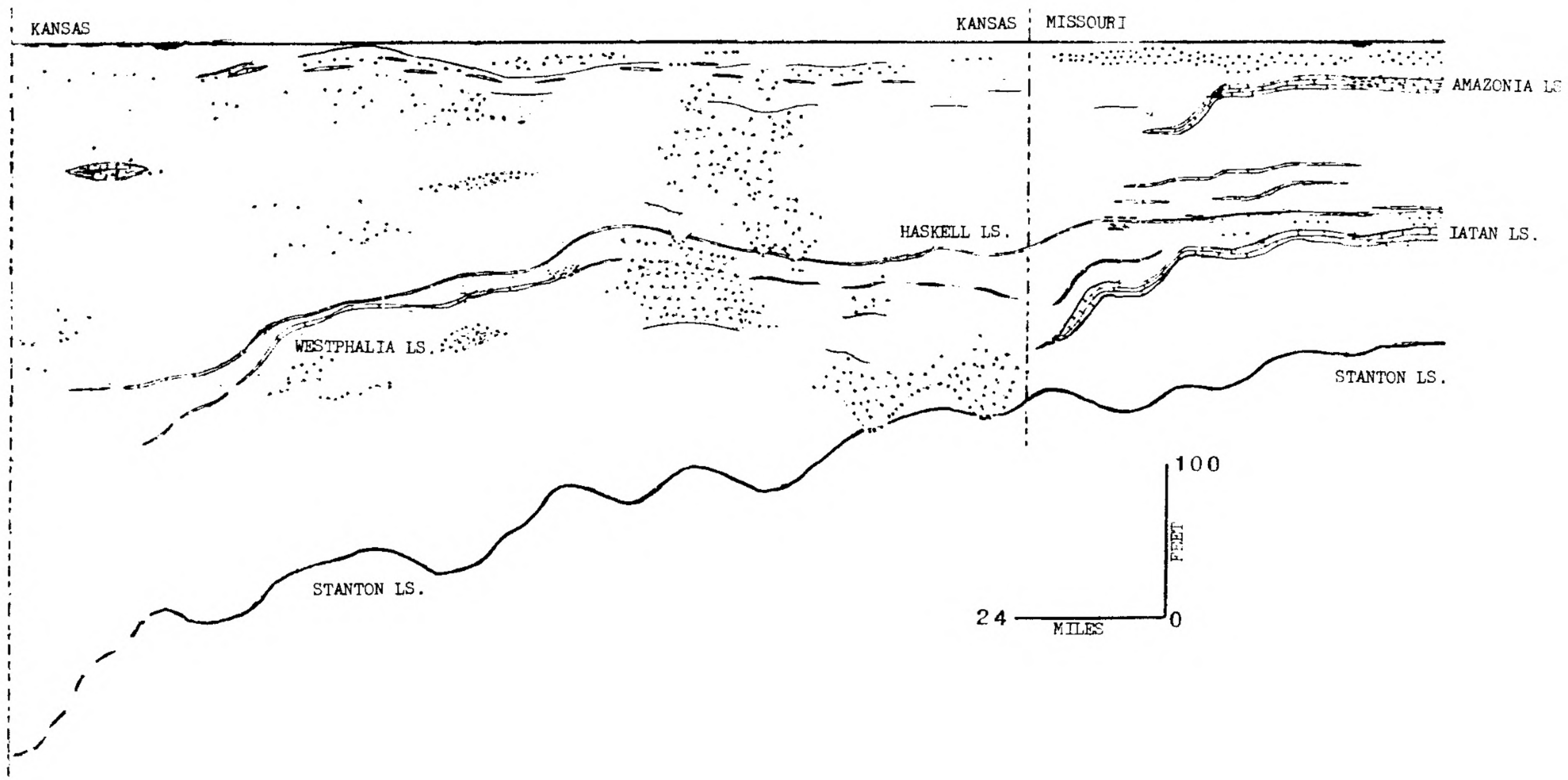


Figure 8. Diagrammatic cross-section showing Douglas Group rocks (from Ball, 1964, p. 71).

Stranger Formation

The Stranger Formation (Moore, et al., 1934) is the basal formation of the Douglas Group and contains, in ascending order, the following members: Weston Shale, Iatan Limestone, Tonganoxie Sandstone, Westphalia Limestone, and Vinland Shale.

Weston Shale

The Weston Shale Member was named by Keyes (1899, p. 300) for exposures in the Missouri River bluffs near Weston, Missouri. The base of this section marks the Missourian-Virgilian boundary. The Iatan Limestone Member bounds the Weston Shale north of approximately T. 10 S. near Leavenworth, Kansas. South of this latitude the Iatan Limestone is seemingly absent, and the upper contact of the Weston Shale has been placed in several stratigraphic positions including the base of: 1) the locally disconformable Tonganoxie Sandstone, 2) Ottawa coal, and 3) a concretionary bed. Ball, et al. (1963) regarded the Ottawa coal as the top of the Weston, but I believe the Ottawa coal is correlative with the Blue Mound coal (Figure 9); therefore, the Iatan base must be stratigraphically lower than the Ottawa coal. A calcareous, fossiliferous conglomerate below the Ottawa coal marks the basal Iatan

Limestone.

The unit is a blue gray and less commonly olive gray, fissile, silty in part, shale but highly variable in thickness and fossil abundance. Discontinuous stringers of clay-ironstone concretions are locally common. The overlying disconformity associated with downcutting by the Tonganoxie Sandstone is the predominant cause of the variable thickness that ranges from a featheredge to about 42.7 meters (140 feet)(Wagner and Harris, 1953). In Missouri, Howe and Koenig (1961, p. 106) noted that the Weston Shale "...thickens from 60 feet in Platte County to nearly 100 feet in Buchanan County and thence thins rapidly northward and westward to a thickness of only a few feet."

Disaggregation of Weston Shale samples and study of the washed residues was not attempted in this investigation; therefore, a meaningful statement about fossil abundance cannot be made. Ball (1964, p. 77) concluded that the member was more fossiliferous in its lower and upper parts at least locally, but was known to be fossiliferous in all parts in one place or another. Brachiopods, arenaceous foraminifers, crinoids, and bivalves are common, but bryozoans, echinoids, trilobites, ostracodes, gastropods, and ammonoids are also present. Although the abundance of fossils is variable, field observations suggest that fossils increase directly above the discontinuous stringers of clay-ironstone concretions. The abundance of fossils also increases at a ferruginous, osagid mixed-skeletal biomicrite locally developed about 5.2 meters (16.9 feet) above the top of the South Bend Limestone in Leavenworth County, Kansas.

Iatan Limestone

The Iatan Limestone Member was named by Keyes (1899, p. 300) for exposures in the Missouri River bluffs near Iatan, Missouri. There is no type section for the member; however, Ball (1964) proposed a standard reference section (NW cor., NE1/4, SW1/4, sec. 19 T. 54 N., R. 36 E.) at an exposure in a railroad cut near Iatan, Missouri. The Iatan has not been recognized by previous authors in outcrops south of latitude, 39°18'N, near Leavenworth, Kansas. This study indicates that a thin limestone and fossiliferous conglomerate at the top of the Weston Shale in Franklin and Anderson Counties, Kansas, are correlative with the Iatan Limestone in Leavenworth County, Kansas, and Platte County, Missouri. The thickness of the Iatan ranges from about 1.4 m. (4.5 ft.) in central Buchanan and west-central Dekalb Counties, Missouri, to about 5.3 m. (17.5 ft.) in Platte and southern Buchanan Counties, Missouri (Ball, 1964). The thickest stratigraphic sections of the Iatan Limestone consist of two distinct units differentiated by bedding and abundance of fossils. The lower unit ranges up to 4.5 m. (14.8 ft.), and predominantly consists of light, olive gray, recrystallized, algal biomicrudite that is irregularly interbedded and encloses masses of brownish gray, algal biolithite. This very thick, scarp-forming bed also contains few to abundant brachiopods, gastropods, fusulinids, crinoid columnals, and rare bryozoans, bivalves, and echinoids. Randomly-oriented linear masses of sparry calcite are interpreted as algal fronds, and are abundant and conspicuous in thin section and hand samples. Laminar algae, identified as Archaeolithophyllum (R.R. West), are irregularly arranged and form masses up to 3 cm. thick and reach lengths of 20 cm. Multi-layered, phylloid algae are seemingly attached to the micritic substratum, but extreme recrystallization prevents conclusive interpretations of relationships with the depositional surface.

The upper unit ranges up to 0.8 m. and consists of dusky yellow to light olive gray, medium calcirudite: recrystallized, fossiliferous, intraclast-bearing micrite. In contrast to the lower unit, the upper unit lacks the numerous sparry, algal fronds and consists of poorly sorted ferruginous-stained micrite intraclasts ranging from 2 mm. to 25 mm. The upper 2 to 3 cm. of this single, resistant, thick bed consists of coarse calcarenite: osagid, mixed-skeletal, intramicrosparite. The upper 2 to 3 cm. is finer and contains more skeletal fragments and a trace of quartz silt and very-fine sand. The skeletal debris consists of, in order of relative abundance, algae, brachiopods, crinoids, fusulinids, bryozoans, echinoids, osagid-coatings, bivalves, ostracodes, and trilobites.

The Iatan Limestone thins northward, and consists of interbedded calcareous shale or shaly limestone with a prominence of coated grains (Ball, 1964).

Tonganoxie Sandstone

The Tonganoxie Sandstone Member was named by Moore, Elias, and Newell (1934) for sandstone outcrops east of Tonganoxie in Leavenworth County, Kansas, and includes all strata between the top of the Upper Sibley coal and the Iatan Limestone Member. The Tonganoxie Sandstone rests disconformably on different members of the Stanton Limestone (Upper Missourian), Weston Shale and Iatan Limestone, and attains a maximum thickness of 38.6 m. (126.4 ft.). Although no complete surface stratigraphic sections are exposed in the northern part of the study area, the thickness was obtained from the core near Lawrence, Kansas. A minimum thickness of 3.2 m. (10.3 ft.) was measured in Platte County, Missouri. Variable development of sandstone causes the extreme thickness differences in the member. Lithologies, stratification, and T-R units of the Tonganoxie Sandstone Member will be discussed in detail subsequently.

Westphalia Limestone

The Westphalia Limestone Member was named for outcrops near Westphalia, Kansas, by Moore and Newell (in Moore, 1936, p. 150). The Westphalia Limestone contains two distinct facies. South of Franklin County to central Chautauqua County, the Westphalia Limestone is similar to the standard reference section (SW cor., NW1/4, sec. 19, T. 20 S., R. 18 E.) proposed by Ball (1964) which is a continuous, yellow brown to light brown, flaggy limestone that ranges from 0.3 to 1.5 m. thick. This facies is a fusulinid biomicrite that contains an abundance of fusulinids in both fresh and weathered samples. Other fossils include sparse to common productid brachiopods, bryozoans, crinoids, gastropods, echinoids, and osagid-coated skeletal grains. The upper part of this facies locally contains rhizoliths and vertical burrows. North of Anderson County, Kansas, to Buchanan County, Missouri, the Westphalia Limestone is a discontinuous, light gray to medium light gray limestone bed which weathers pale yellow brown that ranges from a featheredge to 0.5 m. (1.5 ft.). The northern facies is a thin-laminated, coaly, argillaceous, ostracode, high-spired-gastropod micrite. The abundance of fossils increases upward from the lower gradational contact with the Upper Sibley coal, whereas accumulation of fossil plants decreases upward. Several bedding planes contain unfragmented fossil plants and bark. The Westphalia Limestone is locally intercalated with the Upper Sibley coal. At locality P1, the Westphalia Limestone contains several undulating, thin stringers of coal (Plate 1). These stratigraphic relationships are important and striking characteristics of the northern facies.

Vinland Shale

The Vinland Shale Member was named by Patterson (1933, p. 17) for the section of shale between the top of the Upper Sibley coal and base of the Haskell Limestone. Ball (1964) proposed a road cut exposure at the center east line, SE1/4, sec. 2, T. 14 S., R. 20 E., as the type section. The predominantly shale section ranges up to 14.9 m. (48.9 ft.) within the study area, and predominantly consists of greenish gray, clayey to silty shale. Ball (1964, p. 114) concluded that the member consists of greenish-gray mudstone, argillaceous limestone, limestone septaria, arenaceous limestone, quartzose sandstone and siltstone, and negligible coal. Fossils of the Vinland Shale are dominated myalinid clams with a few ostracodes and arenaceous foraminifers (Ball, 1964). Ball (1964, p. 115) noted that algal-coated brachiopods and pelecypods occur in several Kansas exposures.

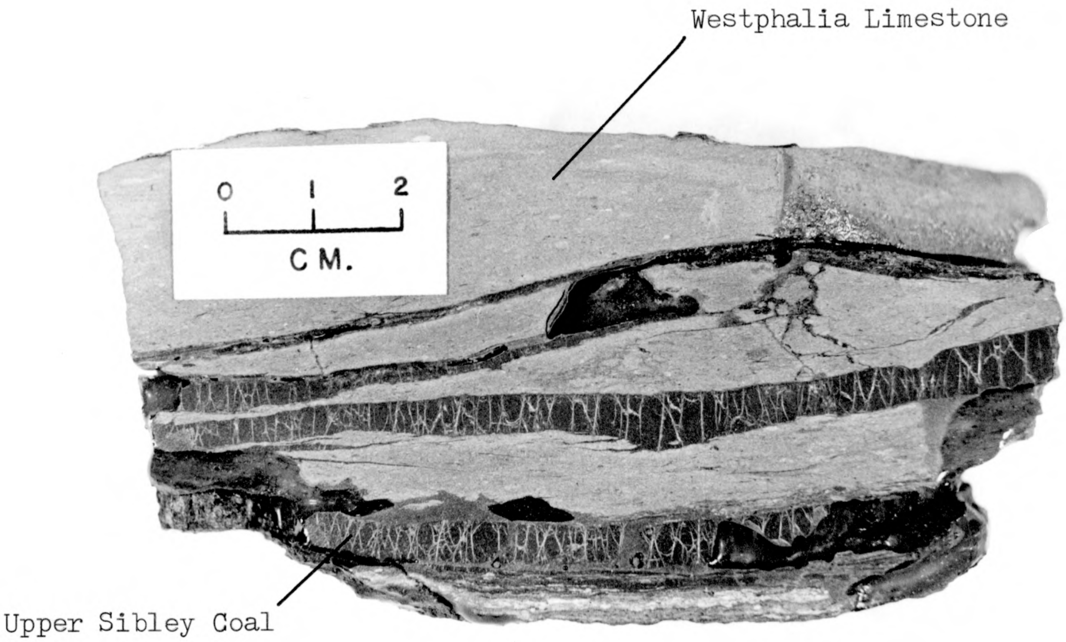


Plate 1. Interfingering of Westphalia Limestone and Upper Sibley Coal at locality P2, Platte County, Missouri (coal - dark gray, limestone - light gray).

LITHOLOGY OF THE TONGANOXIE SANDSTONE MEMBER

Conglomerate

Conglomerates are volumetrically important rocks of the Tonganoxie Sandstone. Ball (1964) described two types of limestone conglomerates, one quartzose and the other calcareous, and studied the later extensively. These conglomerates rest disconformably on limestones of the Stanton Formation, Weston Shale, and Iatan Member and attain a maximum thickness of 3.4 m. (11.2 ft.) at a recently exposed roadcut near Lansing, Kansas (Figure 10). The gravel fraction of these conglomerates is derived predominantly from the Stoner Limestone, South Bend Limestone, and Iatan Limestone. Although most conglomerates are basal to the Tonganoxie Sandstone, the quartzose conglomerate also occurs stratigraphically higher at the base of massive or cross-bedded sandstones where the member consists of a series of multi-stacked channels.

<u>Nearshore Limestone Conglomerate.</u>--The calcareous limestone conglomerate is a light gray, fine-sandy, pebble conglomerate classified as a calcareous, submature, fossiliferous, recrystallized sedrudite that ranges from a featheredge to 2.9 m. (9.5 ft.) thick. The gravel fraction consists of abundant limestone granules, pebbles, and cobbles; common to abundant invertebrate fossils; and rare

to common shale and mudstone granules and pebbles. The sand fraction consists of abundant very fine to coarse carbonate sand, sparse quartz sand, plant fragments, and mica flakes. The cement is predominantly sparry calcite. Ball (1964) noted the very close spacing of limestone pebbles, some of which were fitted together like puzzle pieces with larger pebbles wrapped around smaller ones with microstyolithic contacts. Grain size of the gravel fraction tends to decrease upward within planar to irregular, very thin to medium beds. Ball (1964) observed some cross-stratification within this conglomerate. This type of conglomerate is relatively unweathered and forms resistant ledges with platy to slabby splitting. Ball (1964) described straight to meandering tubular structures which cut across and pass through some limestone pebbles at a locality in Andrew County, Missouri, which he concluded were trace fossils probably referable to Repichnia (Hanteshel, 1962, p. W181). Although this conglomerate contains reworked and abraded brachiopods, echinoids, crinoids, fusulinids, and bryozoans, the trace fossils are apparently the only indigenous fossils. Lack of siliceous cement, overcrowding of grains and abundance of carbonate sand are diagnostic features of this conglomerate.

Fluvial Limestone Conglomerate.--The quartzose conglomerate is a moderate red brown, medium-sandy, pebble conglomerate: siliceous, ferruginous, and locally calcareous, submature, micaceous, recrystallized sedrudite that ranges from a featheredge to 3.4 m. (11.2 ft.) thick (Plate 2). The gravel fraction consists of abundant spheroidal to discoidal limestone, clay, and sandstone granules and pebbles, sparse to common wood fragments, and sparse invertebrate fossils. Invertebrate fossils include abraded and fragmented brachiopods, crinoids, echinoids, fusulinids, and bivalves which commonly occur incorporated in rock fragments. Conglomerates which do not rest disconformably on limestone tend to have a greater concentration of clay and sandstone clasts. The sand fraction consists of abundant very fine to very coarse quartz sand, sparse to common mica flakes and plant fragments, and rare fine to coarse carbonate sand. Siliceous and ferruginous cements are most common, but calcite is developed locally where the conglomerate rests disconformably on limestone. Grain size of the gravel fraction tends to decrease upward within planar to slightly undulating, very thin to very thick beds. Imbrication of discoidal limestone and clay pebbles is developed locally, and dip directions are in the approximate opposite direction of associated trough cross-bed azimuths. Conglomerates are rarely cross-bedded, but commonly interbedded with conglomeratic, cross-bedded sandstone. This type of conglomerate is extensively weathered but still forms resistant ledges. Recrystallized and dissolved grains, and

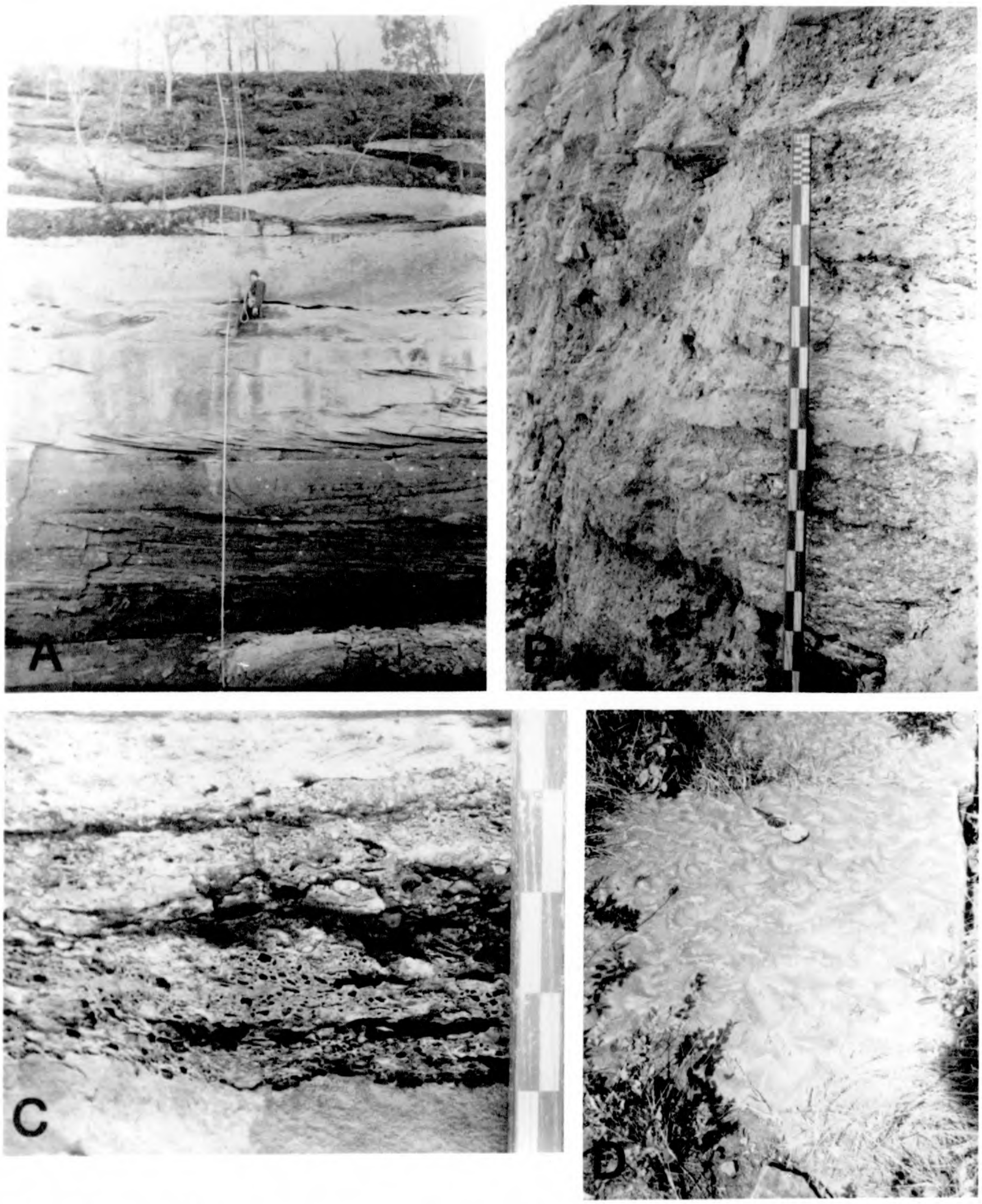


Plate 2. Sedimentary structures of the confined valley-fill facies of the Tonganoxie Sandstone Member: A) trough cross-beds, B) conglomerate, C) conglomerate, D) asymmetrical ripple marks. Scale: 1.5 meters with decimeter divisions.

light brown to moderate red brown color caused by the abundance of Fe-oxides as cement and stain are characteristic of this conglomerate. Extreme weathering may be attributed to overlying permeable sandstone, whereas the relatively unweathered, calcareous, limestone conglomerate is overlain by less permeable interbedded shale and siltstone.

Sandstone

Beds of sandstone of the Tonganoxie Sandstone Member are variable in thickness, texture, composition, and stratification. No complete surface section of the Tonganoxie Sandstone was observed in its type area, but the sandstone unit comprises approximately two-thirds of the Tonganoxie in the northeastern part of the study area where sandstone development is predominant. Sandstone is an inconspicuous part of the Tonganoxie Sandstone Member in the southern part of the study area.

Texture.--Although no mechanical analysis of sandstone samples was attempted, binocular observation and petrographic study of thin sections revealed important trends about texture. Samples of sandstone show a variety of textural trends that depend on stratification.

Generally, the predominant grain size of quartz particles is very fine to fine sand, but ranges from coarse silt to very coarse sand. Conglomeratic sandstones interbedded with conglomerates near the base of the Tonganoxie Sandstone (Figure 10) have the coarsest mean grain size (1.5 phi, medium sand). Trough cross-bedded and associated massive channel sandstones have a mean grain size of (2.5 phi, fine sand). Planar and ripple-marked, very thin beds tend to have the finest mean grain size (3.5 phi, very fine sand). Minor (1969) analyzed 19 samples for grain size and concluded the sandstones group about a mean of 3.0 phi (fine to very fine sand) and show moderate to moderately poor sorting, moderate to strong fine skewness and leptokurtic to very leptokurtic peakedness with sorting values increasing as mean grain size decreases because of greater mixing of sand and clay. Although these moment calculations are consistent with my observations of sandstones in the northern part of the study area, planar, very thin-bedded and massive sandstones of Franklin County, Kansas, tend to be moderately well- to well-sorted, quartzarenites.

Roundness of grains in Tonganoxie Sandstone samples is predominantly a function of the depositional agent and concomitant bed-form type. Generally, most quartz grains are subangular, but range from angular to rounded. Quartz grains from planar, very thin beds and massive beds in Franklin County, Kansas, show the greatest degree of rounding. These grains tend to be subrounded and rounded.

Cross-bedded and massive channel sandstones consist predominantly of subangular grains of quartz, but range from angular to subrounded. Many disaggregated samples of siliceous sandstone show an inaccurate concentration of angular grains because they break across quartz overgrowths.

Sphericity of grains is relatively uniform and apparently is not correlative with stratification type. Quartz grains range from subelongate to equant, but are primarily subequant. The quartz overgrowths also give inaccurate results about sphericity in disaggregated samples because breakage occurs across quartz overgrowths.

Composition.--The majority of samples of Tonganoxie Sandstone are quartzarenites, but some subarkoses do occur. Minor (1969, p. 76) concluded that the average composition is: quartz, 88 percent; feldspar, 5 percent; and rock fragments, 7 percent.

Quartz types, in order of decreasing abundance, are common, recrystallized metamorphic, schistose metamorphic, stretched metamorphic, and vein.

The predominant K-feldspar is orthoclase, but a few microcline and perthite grains are present. In most samples, plagioclase grains are less abundant than K-feldspar, and small extinction angles of albite twinning indicate that the composition is albite-oligoclase. Alteration of feldspars to clay minerals and water-filled vacuoles is extremely variable ranging from fresh to highly-altered.

The majority of rock fragments are shale and carbonized plant fragments of which many are stained with Fe-oxides.

Mica is conspicuous in outcrop, and ranges from one to five percent in most samples. Muscovite is dominant, but biotite does occur. Mica is distributed throughout sandstone samples, but is often concentrated with macerals on bedding planes.

Opaque and non-opaque heavy minerals were studied by Minor (1969), and he concluded most opaque grains are magnetite and ilmenite with traces of pyrite. Minor (1969, p. 77) determined that the Tonganoxie Sandstone consists of a rather mature assemblage of heavy minerals including: zircon (58%), tourmaline (15%), rutile (10%), anatase (7%), garnet (5%), apatite (4%), and traces of hornblende and kyanite giving a high ZTR index of 83 percent that suggests reworking of older sediments.

Cements of the Tonganoxie include quartz, calcite, Fe-oxides, and clay. All cement types are common, but Fe-oxides are prolific in outcrop except in tightly-cemented calcareous sandstones. Fe-oxides act as cement and impart a light brown to gray orange color to outcrops. Subsurface samples are light gray to medium light blue, and in thin section show less oxidation of clay and iron than outcrop samples. This corroborates an observation made by Sanders (1959, p. 147) that subsurface samples are nearly white and contain calcium carbonate cement. Although calcite locally acts as cement, the predominant cement in most samples is quartz overgrowths recognized by dust, vacuoles, and idiomorphic interlocking of adjacent overgrowths. Minor (1969, p. 55) recognized rhombic grid patterns of Fe-oxides and concluded they were deposited by meteoric Fe-bearing water after deposition of silica and calcite, respectively. Primary clay is often difficult to distinguish from secondary clay, but tends to increase on bedding planes. Secondary clay acts as cement translocating along pore linings after alteration of feldspars.

Shale

Shale is the predominant rock type in the southern part of the study area, and comprises most upper Tonganoxie strata where sandstone occurs. Shale in the northern part of the study area grades vertically from planar and rippled, very thin- to thin-bedded siltsone and sandstone, to silty shale, and finally clay shale. This gradational fining upward sequence is common in Leavenworth and Douglas Counties, Kansas. Upper bounding contacts are sharp and irregular where overlain by mudstone, and in many places gradational and increasing in carbonaceous matter upward where overlain by coal.

Shale of the upper Tonganoxie is light gray to medium gray with blue overtones. Bedding type commonly consists of planar, parallel, very thin to medium laminations separated by finely disseminated mica and macerals. Shale in Anderson County, Kansas, is pale olive to gray green with planar, parallel, very thin to thin laminations. This shale contains calcareous, sand intercalations and load casts.

Although the abundance of mica is variable, concentration of muscovite tends to decrease upward as grain size decreases. Carbonaceous matter and maceral content are also variable, but in many places increase abruptly tens of centimeters below coal or carbonaceous beds. A profusely carbonaceous shale containing an abundance of plant fossils occurs in lower strata of the Tonganoxie Sandstone in the core. This 46 cm. (1.5 ft.) thick shale bed is bounded by sandstone with Calamites logs abruptly increasing 60 cm. (2.0 ft.) below the shale-sandstone contact.

Several types of concretions occur within the shale unit including ironstone, clay-ironstone, septarian, sandstone, siltstone, and rare pyrite. Hollow and solid ironstone concretions are most common and occur individually and in discontinuous bands often below coal beds. Well-preserved Fe-oxide replaced Calamites logs also occur in the shale. Plant fossils are the only indigenous fossils observed in the shale, but Bowsher and Jewett (1943) found local concentrations of marine fossils in marginal shale layers at the base of the coal beds. Ball (1964) found a few ostracodes, arenaceous foraminifers, minute-spired gastropods, brachiopod valve fragments, and echinoid spines below the Upper Sibley coal and interpreted the ostracodes, foraminifers, and gastropods to be indigenous.

Mudstone

Mudstone is relatively rare volumetrically; however, its significance in environmental interpretations has been overlooked by previous authors. Mudstone occurs below all coal beds locally but develops extensively below the Upper Sibley coal and Westphalia Limestone ranging from a featheredge to 1.81 m. (5.9 ft.). Tonganoxie mudstones share several characteristics including sharp upper contacts, gradational lower contacts, very weakly to moderately developed horizons, root traces and mottles, bleached appearance of upper horizons, and lack of fissility. Four types of mudstones occur in the study area predominantly differentiated by color and soil structure.

The northern facies occurs in Leavenworth and Douglas Counties, Kansas, and generally contains a moderate olive brown lower horizon, and a light olive gray upper horizon overlain by a bituminous coal. This facies contains a few to common, distinct, fine to medium (2 to 15 mm.), gray orange to dark yellow orange mottles which increase in abundance in the upper horizon. A carbonaceous film is commonly associated with these limonitic mottles which are seemingly oxidized roots. The lower contact with laminated shale is diffuse, smooth to irregular, and differentiated by an upward decrease in bedding. The boundary between the horizons within the mudstone is gradual, smooth to irregular, and differentiated by a change in color and soil structure. The upper horizon is structureless with a bleached appearance, and plastic texture, whereas the lower horizon has a weakly developed, angular blocky structure. Both horizons contain a few randomly-distributed clay-ironstone concretions. The larger concretions nucleate on clay, whereas the smaller concretions containing more Fe-oxides nucleate on well-preserved plant fossils. A 10 cm. layer of small (1 cm. in diameter) ironstone concretions locally occurs at the base of one of these mudstones.

The mudstone below the Ottawa coal at locality F3 consists of a single, very light gray, very thin horizon. Unlike most Tonganoxie mudstones, this mudstone has a sharp lower contact because it rests on a well-indurated, undulatory, carbonaceous siltstone. A few, distinct, fine, carbonaceous root traces were identified near the upper contact of this mudstone. This mudstone is structureless, soft and has an extremely bleached appearance.

Although the lower contact was not observed, the mudstone below the Ottawa coal at locality F6 is moderately developed, and consists of three horizons differentiated by root traces, soil structure, and color. Root traces are preserved in all three horizons, but abundance decreases upward. These root traces are preserved as casts composed of calcite ranging from 2 to 6 cm. long and 0.2 to 3 cm. wide. Generally, these root traces taper downward, but have a relatively blunt apex. Small root traces taper downward to a relatively pointed apex. Several root traces were observed in a horizontal position perpendicular to the tapered root traces. The middle horizon contains common root casts which occur above a continuous zone of caliche nodules. These caliche nodules are very calcareous, well-indurated, and have a very irregular, bulbuous habit with a reddish-brown oxidized surface. Slabbed sections show ripped up and disturbed clasts of calcite with calcareous clay intersticies. The lower horizon is an olive green, structureless mudstone with a gradual to diffuse, smooth to wavy upper contact. The middle horizon is a medium blue gray mudstone; however, the cutans are gray black. These argillaceous skins differentiate the medium to coarse, subangular blocky soil structure. The size of the highly calcareous peds decreases upward, and the upper contact of the middle horizon is gradual to diffuse, smooth to wavy, and differentiated by a decrease in soil structure and a color change. The upper horizon is medium gray, structureless mudstone overlain by a black, bituminous coal. The upper contact is abrupt and smooth to wavy.

The mudstone below the Westphalia Limestone in Anderson County, Kansas, is structureless and very weakly developed. Generally, this mudstone is gray green with common dark yellow orange and red brown, distinct, fine to medium mottles. This mudstone contains common macerals.

Coal

The Tonganoxie Sandstone Member contains three horizons of bituminous coal beds that are named the Blue Mound, Lower Sibley, and Upper Sibley. The Ottawa coal which this study indicates is the time-stratigraphic equivalent of the Blue Mound coal crops out in Franklin County, Kansas. These coal beds are lenticular and range considerably in thickness in a short distance from featheredge smuts to 76 cm. (2.5 ft.). Bowsher and Jewett (1943) admirably studied and portrayed the distribution of the coal resources of the Douglas Group in Kansas (Figure 7). This cross-section accurately shows the lateral extent and lenticularity of the coal beds except that the Ottawa coal extends south to the Anderson-Franklin County line. All coal beds are restricted to the northern part of the study area and their absence south of Franklin County, Kansas, is a striking characteristic of Tonganoxie coals. Generally, the coals consist of planar, parallel, very thin to thin beds. Coals are commonly interbedded with clay and silt shales at both the lower and upper contacts and are more pure in the medial parts. Coal beds less than 15 cm. (0.5 ft.) are often interlaminated with carbonaceous shale throughout. Gradational lower contacts are common where coal overlies shale or siltstone; in many places plant fragments occur abruptly tens of centimeters below coal beds. Lower contacts are sharp where coal overlies mudstone, but upper contacts are gradational with few exceptions. Most coals grade upward into clay and silt shales; but in southern Platte, northern Leavenworth and southern Douglas Counties, Kansas, the Upper Sibley coal grades upward into the Westphalia Limestone (Figure 11) which is a coaly, argillaceous, ostracode, high-spired-gastropod micrite. At locality P1, the Westphalia Limestone is intercalated with several very thin to thin undulating coal stringers (Plate 1). Although I was unable to find this stratigraphic relationship at locality L1, Ball (1964) described a single intercalation of the Upper Sibley coal and Westphalia Limestone. Molds of tree trunks, stems, and leaves lying parallel to laminations are well-preserved throughout this limestone. Preservation of plant remains within bituminous coals and adjacent shale, siltstone, and sandstone is highly variable. Altered vegetal matter is unidentifiable within most coals, especially in the medial parts where thick coals become more pure. Adjacent shale, siltstone, and sandstone commonly contain compressed fragmentary, poorly preserved fossil plants parallel to bedding, but well-preserved tree bark, ferns and other foliage occur locally. Tree trunks and stumps (Bowsher and Jewett, 1943, Pl. 4B, p. 28) rooted in the Ottawa coal are preserved in an upright position of growth. Stalks of <u>Sphenophyllum cuneifolium</u> cut across three overlying siltstone beds (Bandel, 1967, p. 3). A list of the

Pennsylvanian plants preserved in the Tonganoxie is given by Cridland, Morris and Baxter (1963, p. 59).

STRATIFICATION OF THE TONGANOXIE SANDSTONE MEMBER

The Tonganoxie Sandstone Member contains several stratification types and sedimentary structures. Although bed configurations differ for different sediment sizes, the majority of sedimentary structures occur in very fine to medium sand; therefore, the few corresponding siltstone sedimentary structures have not been differentiated.

Cross-beds

Trough Cross-beds.--These sandstones are volumetrically the most important and generally occur near the base of the sandstone section just above the conglomerate zone. In east-central Leavenworth County, Kansas, (localities L3 and L4) trough cross-bedded, granular, medium sandstones are interbedded with medium-sandy, pebble conglomerates (Figure 10). Where the conglomerate zone is absent, trough cross-bedded sandstones rest disconformably on the Weston Shale or South Bend Limestone.

These sandstones are composed mainly of very fine- to medium-grained quartz sand. Grain size generally decreases upward within sets. The thickness of trough sets ranges from 0.1 m. to 2.8 m. with widths of less than 1 m. to 4 m. (Plate 2). Trough sets are commonly 1 m. to 3 m. long, but have been traced for over 16 m. Sets are differentiated within cosets by scoured reactivation surfaces which are approximately parallel and commonly associated with a thin conglomeratic lag. Concave upward foresets range from 0.5 cm. to 4 cm. thick, but generally are less than 1.5 cm. Most foresets are congruent and have tangential bases. Grain size decreases upward within foresets which commonly have shale, ironstone or sandstone granules concentrated along the base. The top of each foreset is invariably differentiated by very thin to thin laminae composed of clay, mica or macerals or a combination of these. These laminae are readily distinguishable in outcrop because of oxidation to darker colors than those of adjacent foresets.

Dip angles of cross-laminae at their steepest part are as much as 30 degrees, but more commonly range from 15 to 25 degrees. Low angle cross-beds are rare, but the upper parts of locality W2 (Wyandotte County, Kansas) contain dip angles from 2 to 10 degrees. The most common dip directions of trough cross-beds are south-southwest and southwest; however, azimuths in all quadrants were observed. Although the azimuths of cross-beds were measured and recorded when describing stratigraphic sections, they were not treated statistically because of previous paleocurrent studies by

Bower (1959) and Minor (1969). Paleocurrent measurements by Bower (1959) resulted in a grand arithmetic mean of 242 degrees with a main current system flowing to the southwest and less conspicuous southeast and northwest trends south of Franklin County, Kansas. The vector resultant of 219 measurements of trough cross-beds by Minor (1969) indicated a paleocurrent direction of 209 degrees with a variance of 4,939 (Figure 12).

Planar Cross-beds.--Although planar cross-beds within the Tonganoxie are rare and have not been described in previous studies, they are important in environmental interpretations. Planar cross-beds have only been positively identified in Franklin County, Kansas, at locality F5 (Plate 3).

These sandstones are fine-grained, siliceous, mature quartzarenites. Set thickness ranges from 30 to 45 cm., and sets are differentiated within cosets by attitude. Planar, parallel foresets range from 0.4 to 1 cm. thick and are angular based. The top of foresets are differentiated by moderate brown Fe-oxides.

Dip angles of cross-laminae range from 16 to 18 degrees. Herringbone cross-bedding with bimodal directions of foresets in adjacent sets was observed within one coset at locality F5. Directions of dip of herringbone cross-bedding are east-northeast and west-southwest with associated planar sets dipping east-northeast.

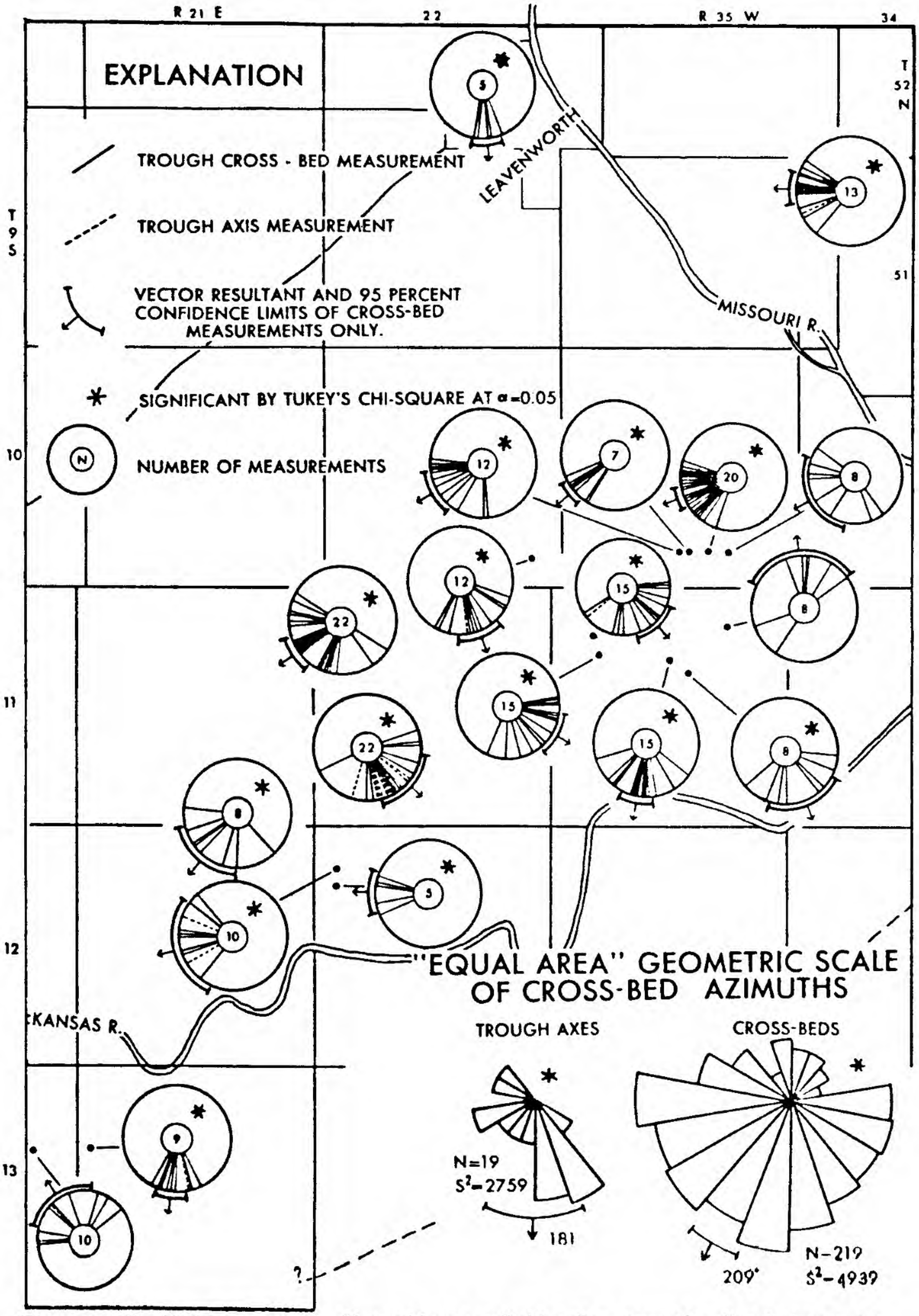


Figure 12. Paleocurrent directions of the Tonganoxie Sandstone as determined from cross-beds (from Minor, 1969, p. 38).

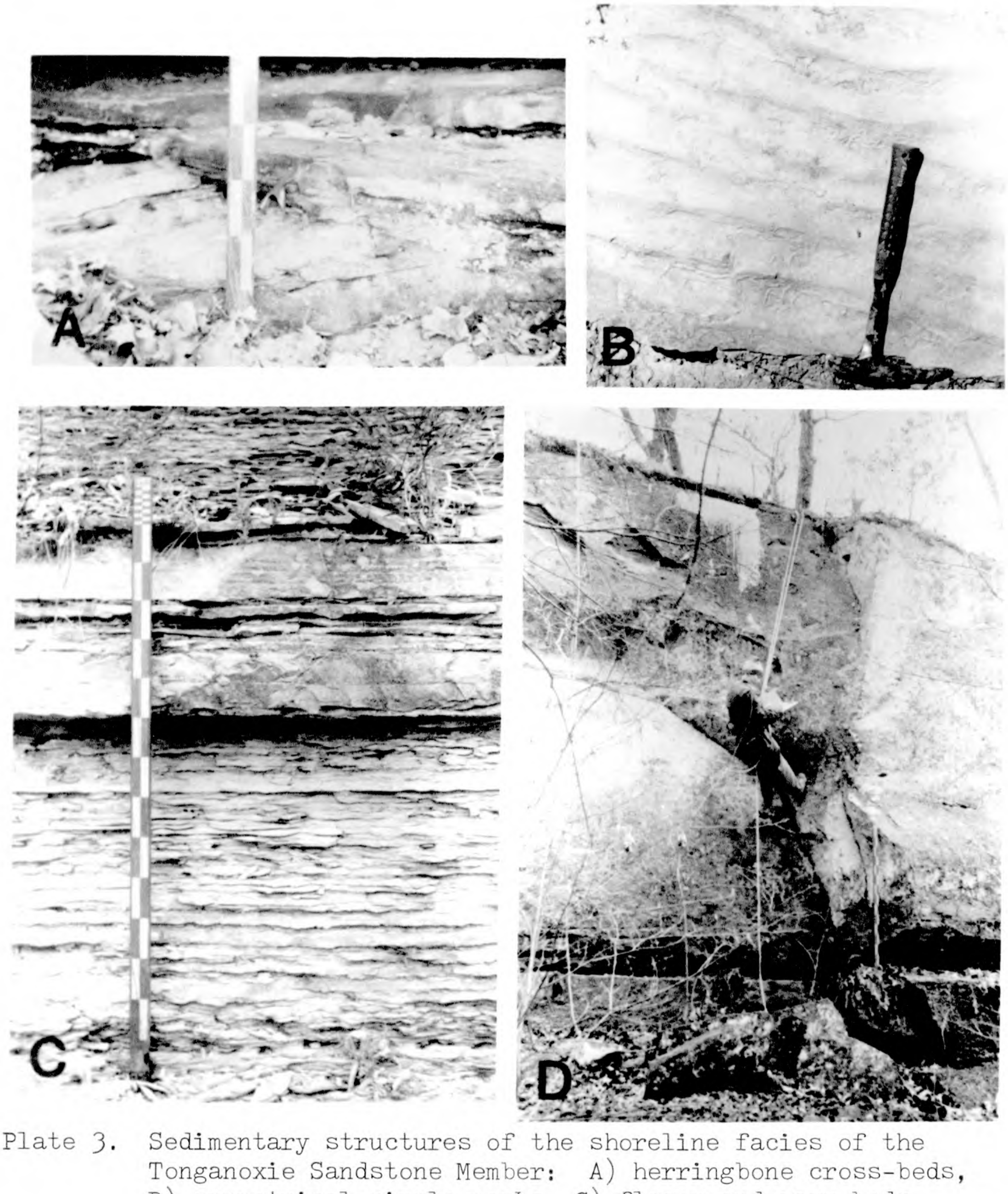


Plate 3. Sedimentary structures of the shoreline facies of the Tonganoxie Sandstone Member: A) herringbone cross-beds, B) symmetrical ripple marks, C) flaser and wavy beds, D) structureless beds. Scale: 1.5 meters with decimeter divisions.

Planar Beds

Planar beds are relatively rare within the Tonganoxie Sandstone, but are locally abundant in east-central Leavenworth and Franklin Counties, Kansas. Planar beds are produced in a wide range of sediment sizes and current velocities; therefore, interpretations of depositional conditions must often rely on associated bedforms. Two types of planar-bedded sandstones were delineated by associated sedimentary structures. The volumetrically more important planar beds which are designated type 1 are associated with flaser to wavy bedding and bioturbated, massive bedding. Type 2 planar beds are less abundant and are contained in sequences with conglomerates and trough cross-bedding.

Generally, type 1 planar beds are very fine- to fine-grained, siliceous, calcareous, mature quartzarenites. Type 1 planar beds are as much as 2.2 m. thick and are invariably composed of parallel, very thin to medium laminae that are predominantly differentiated by Fe-oxides with subordinate amounts of clay, mica and macerals; however, at locality L3 carbonaceous matter and mica are more abundant.

Generally, type 2 planar beds are fine- to medium-grained, siliceous, submature quartzarenites. Type 2 planar beds commonly decrease in grain size upward and contain clay and sandstone granules and pebbles at their base. Type 2 planar beds range from 10 to 22 cm. thick and are composed of parallel, thin to thick laminae differentiated by mica, clay, macerals or Fe-oxides or a combination of these. Tops of these planar beds in the subsurface are predominantly composed of macerals and mica.

Ripple-marked Beds

Ripple marks are relatively rare within the study area, but are locally abundant in the extreme lower and upper parts of the sandstone section. Reconnaissance south of the study area revealed that ripple-marked beds are the predominant bed form in Wilson County, Kansas. Most ripple marks in the study area were eroded away by subsequent downcutting. This disconformity is evident at locality P1 where rippled beds are juxtaposed with a channel where the ripples are eroded. Several types of ripple marks, including current ripples, wave ripples, and climbing ripples, occur in the basal part of the Tonganoxie at locality L3 where downcutting hasn't removed the basal beds. Current ripples were observed above the trough cross-bedded zone grading upward into lenticular beds and finally silty shale. Generally, rippled-marked beds are composed of coarse siltstone to fine-grained sandstone: siliceous, mature quartzarenites.

Asymmetrical Ripples.--Asymmetrical ripples are volumetrically the most important ripple marks in the study area (Plate 2). These bedforms are locally abundant in the basal part of the Tonganoxie and above the trough cross-bedded zone. The ripple-marked unit above the trough cross-bedded zone is usually less than 2.5 m. and consists predominantly of unidirectional current ripples. This unit commonly grades upward into ripple-marked, lenticular, very thin to thin beds. These asymmetrical ripples, up to 3 cm. high, generally have a linguoid shape, but asymmetrical ripples with highly sinuous crests were also observed. Cross-laminae which are concave upward with tangential lower contacts range from 1 to 4 mm. thick. Tops of cross laminae are differentiated by mica and macerals.

Several types of ripple marks occur in the basal beds of the sandstone section in east-central Leavenworth County, Kansas. Ripple marks at locality L3 are interbedded with planar, parallel laminations and flaser to wavy beds. These ripples are preserved as form sets and internal trough cross lamination. The ripple-marked unit consisting of asymmetrical ripples interbedded with shale is as much as 1.0 m. thick, whereas the thickest trough cross-laminated unit is 0.6 m. Most asymmetrical ripples at locality L3 have slightly sinuous crests with wavelengths ranging from 6 to 12 cm. and averaging 8 cm. The height of these ripples averages 1 cm., but ranges up to 4 cm. These ripples are commonly interbedded with symmetrical ripples and planar laminations. The trough cross-laminated zone contains concave upward, tangential, very thin to medium foreset laminae that are differentiated by mica, macerals or Fe-oxides. Foresets differentiated by Fe-oxides are more resistant. Sets of trough cross laminae were observed with opposing dip directions. Set thickness ranges up to 4 cm. and are bounded by planar, parallel reactivation surfaces.

Symmetrical Ripples.--These ripples are rare within the study area, but reconnaissance southward showed that symmetrical ripples are a common bedform in Wilson and southern Woodson Counties, Kansas. Symmetrical ripples were only positively identified in basal beds above the Weston Shale at locality L3 (Plate 3). Units containing symmetrical ripples are less than 1 m. thick and are interbedded with silty shale or slightly sinuous, asymmetrical ripples. These symmetrical ripples have rounded troughs and straight, continuous, peaked crestlines which commonly bifurcate. Symmetrical ripples have average heights and wavelengths of 1 and 7 cm., respectively. Most ripples are sinusoidal, and have congruent, slightly concave to straight, very thin to thin cross-laminae differentiated by macerals and mica. Cross-laminae show opposing dips and are generally less resistant than interbedded asymmetrical ripples with foresets differentiated by Fe-oxides. Symmetrical ripples have thin clay or coal drapes on the upper contacts of form sets.

Flaser to Wavy Beds

Flaser and wavy bedding occur in several parts of the sandstone section in east-central Leavenworth, northern Douglas, and Franklin Counties, Kansas. The thickest flaser unit which includes abundant wavy beds crops out in basal strata above the Weston Shale at locality L3 (Plate 3). A flaser-bedded sandstone between the Lower and Upper Sibley coals in Douglas County, Kansas, thins toward the north near the Douglas-Leavenworth County, Kansas, line. Flaser beds also occur above the trough cross-bedded zone grading upward into wavy beds and finally lenticular beds. Rare flaser beds are interbedded with structureless channel sandstones and conglomerates at locality L2. Strata of Franklin County, Kansas, contain abundant flaser beds predominantly concentrated in the lower and medial parts of the sandstone section.

Most flaser beds are composed of very fine- to fine-grained sandstones classified as siliceous, mature quartz-arenites; however, in Leavenworth County, Kansas, some sandstones contain more clay and are immature. The thickest flaser-bedded sequence located in Franklin County, Kansas, is 5.5 m. and contains interbedded planar laminations and planar cross-beds. Flaser beds in Franklin County, Kansas, form resistant ledges with flasers commonly differentiated by Fe-oxide rinds. Most flasers are composed of Fe-oxides concentrated in troughs, but a few unweathered beds have clay flasers with different amounts of macerals. Staining in troughs is generally the only stratification that can be differentiated in these bluffs. Flaser beds are commonly associated with wavy beds north of Franklin County, Kansas.

Wavy beds are interbedded with structureless, convoluted, and cross-laminated sandstones at locality L3. This sequence is 4.9 m. thick, but the thickest wavy-bedded unit is 1.6 m. thick. Individual wavy beds up to 5 cm. thick are composed of asymmetrical, sigmoidal, sinuous to three-dimensional ripples with clay drapes ranging from 0.2 to 1 cm. thick. These drapes are predominantly composed of clay, but a few beds contain an abundance of mica and macerals. Most wavy beds are out of phase and contain very thin to thin cross-laminae with common opposing dip directions. Cross laminae are differentiated by mica, macerals or clay or a combination of these.

Flaser- and wavy-bedded units commonly contain vertical burrows and horizontal trails. Vertical burrows have average depths and widths of 10 and 4 mm., respectively. The base of these burrows is bulbuous and adjacent disturbed laminae point downward. Horizontal trails are simple, straight to meandering, positive ridges up to 7 mm. in diameter concentrated on top of rippled beds. Flame structures and convolute bedding are commonly associated with flaser and wavy bedding and generally occur at the base of these sandstone sequences.

Structureless Beds

Structureless sandstones have no apparent sedimentary structures; however, a radiographic analysis by Hamblin (1964) revealed rhythmic alternations presumably caused by concentrations of heavy minerals. Two types of structureless sandstones were differentiated by associated bedforms.

Type 1 structureless sandstones are associated with conglomerates and trough cross-beds, and are locally abundant in Leavenworth County, Kansas. Generally, type 1 structureless sandstones are very fine- to medium-grained, siliceous, submature quartzarenites. Thickness of units is highly irregular ranging from a featheredge to 3.3 m. thick. These sandstones commonly have conglomeratic, disconformable, lower contacts which infrequently display channel forms. Conglomeratic lags are rarely imbricated and consist predominantly of discoidal, clay-ironstone clasts.

Type 2 structureless, coarse siltstones to fine-grained sandstones are predominantly siliceous, mature quartzsiltites and quartzarenites. These sandstones form resistant bluffs in Franklin County, Kansas, and are as much as 9.1 m. thick (Plate 3). Planar-laminated and flaser- to wavy-bedded sandstones are commonly interbedded with type 2 structureless sandstones.

Convolute Beds

Convolute bedding is rare within Tonganoxie strata. Although most convolute bedding occurs above shale sections, contorted and overturned cross-beds were observed within a. Sandstone sequence at locality W2.

Generally, convolute bedding occurs in very fine- to fine-grained, siliceous, submature quartzarenites, and commonly occurs in single beds up to 0.5 m. thick. Very thin to thin convolutions outlined by mica and macerals or hematite show different degrees of folding including upright cuspate forms with sharp anticlines to continuously curved laminations. Several beds show an upward increase in the intensity of disturbed lamination. Overturning occurs in both trough and low angle cross-beds and ranges from oversteepening to extensive deformation.

Sole Marks

Sole marks occur predominantly at the base of beds of conglomerate and sandstone. Although erosional structures are rare, both scour and tool marks are locally abundant in

Leavenworth County, Kansas. Deformational sole marks such as load casts and flame structures are also rare and occur in shale sections in Franklin and Leavenworth Counties, Kansas.

Flute casts and gutter casts are two types of scour marks observed at a few localities in the northern part of the study area. Ball (1964, p. 99) noted flute casts at the base of a 0.8 m. thick, slightly imbricated conglomerate at locality W2. These simple, parabolic, spindle-shaped, flute casts range up to 1 m. long and 0.4 m. wide and 0.1 m. deep. Most flute casts are symmetrical, highly elongate forms which have similar depths throughout the entire length of the flute. Gutter casts are associated with flute casts at the base of beds of conglomerate and sandstone beds at a few localities in Leavenworth County, Kansas. These longitudinal grooves are commonly up to 4 cm. wide and almost as deep. Most casts show symmetrical, U-shaped profiles and are commonly straight to slightly sinuous. A few gutter casts showed bifurcations with junctures pointing in similar directions as overlying trough cross-beds.

A few tool marks were tentatively identified, but were not positively differentiated from scour marks because associated tools were not found. Rare, isolated grooves and bounce marks which have more sharply defined shapes than scour marks were observed on bases of sandstone beds in Franklin and Leavenworth Counties, Kansas. Most tool marks are found on the bases of very thin to thin beds, whereas scour marks occur on the bases of thicker beds.

Most load casts and concomitant flame structures occur on the bases of very thin to thin sandstone beds in Anderson and Franklin Counties, Kansas. Load casts range up to 25 cm. in diameter, and are rounded, irregular-shaped balls of sand which commonly cover an entire bedding surface. A few isolated load casts occur at localities F6 and A1, but most casts are protrusions on lower surfaces of sandstone beds. Flame structures are commonly associated with load casts protruding from sandstone beds. Flame structures are composed of shale that has been squeezed upward in convex-upward, irregular-shaped wedges between load casts.

ENVIRONMENTS OF DEPOSITION OF THE TONGANOXIE SANDSTONE MEMBER

Conglomerates

The calcareous and siliceous limestone conglomerates occur in close association, both stratigraphically and areally; however, they represent different conditions of deposition. Ball (1964, pp. 294, 298) suggested that the origin of these conglomerates didn't differ appreciably and that they were deposits of marginal or mixed environments. Although the geometry of both conglomerates is vaguely known, associated rock types, fossil content, packing of grains, matrix type, and sedimentary structures indicate these conglomerates were deposited in different environments.

Nearshore Limestone Conglomerate.--The laminated to medium-bedded calcareous limestone conglomerate is a product of the upper part of the upper flow regime. This conglomerate predominantly crops out near the Iatan Limestone in the Missouri River bluffs in east-central Leavenworth County, Kansas, and west-central Platte County, Missouri. The thickest conglomerate rests disconformably on the Stoner Limestone at locality L2 and is overlain by interbedded conglomerate and shale which contains brachiopods with no evidence of reworking. Fossils within the conglomerate are extensively polished or fragmented or both. In Platte County, Missouri, this conglomerate rests on the Iatan Limestone or Weston Shale. Ball (1964, p. 352) noted this conglomerate questionably passes laterally into the Iatan Limestone south of locality P2 in the Missouri River bluffs. At locality P2 the calcareous limestone conglomerate contains lenses of fossiliferous shale and cut-and-fill stratification.

The overcrowding of grains with pebbles wrapped around one another indicates the carbonate wasn't totally lithified when reworked. Ball's (1964, p. 291) observation that trace fossils cut across and pass through limestone pebbles corroborates the conclusion that the Iatan Limestone wasn't completely consolidated at the time of erosion. The lateral passage of this conglomerate toward the north into the subtidal, marine environment represented by the Iatan Limestone indicates that the limestone conglomerate is a product of contemporaneous nearshore deposition. This is substantiated by the close areal and stratigraphic association toward the south with a nearshore sandstone section containing wave ripples and cross-lamination with an abundance of alternate opposing dips. The aforementioned fossiliferous shale interbedded with and incorporated within the conglomerate also indicates marginal marine deposition. Ball (1964, p. 298) noted that the limestone conglomerates show characteristics of beach gravels, but concluded this was improbable, and regarded them as deposits of marginal or mixed environments without elaborating on reasons precluding a beach gravel interpretation. Although the geometry of the calcareous limestone conglomerate is vaguely known, the facies relationships, abundance of carbonate sand, relative lack of quartz sand, overcrowding of grains with microstyolitic intergranular contacts, predominance of sparry calcite cement, presence of meandering horizontal burrows, and interbedding with fossiliferous shale indicates this conglomerate was deposited above effective wave base in a beach or nearshore environment.

Fluvial Limestone Conglomerate.--This conglomerate is a product of the upper part of the upper flow regime. The thickest conglomerate rests disconformably on the South Bend Limestone at locality W1 and is associated with trough cross-beds and structureless beds showing channel forms (Figure 11). Imbrication of flat-pebble clasts dipping in the opposite direction of associated trough cross-bed azimuths and channel forms with oriented Calamites logs indicate this conglomerate is a fluviatile deposit. Preserved channel margins are relatively rare, but were observed inclined to the depositonal horizontal with distinct erosional relief at localities P1, L4, and W1. Channel forms and channel margins truncating finer sediments are clearly a product of channelized flow. Although channeling is not restricted to fluviation, formation by turbidity currents, alluvial fans or submarine fans is improbable. Flute casts and gutter casts associated with the sharp erosional boundary at the base of this conglomerate are indicative of highly turbulent flow. This scoured surface represents the channel floor which has cut into pre-existing deposits. The magnitude of erosional relief along this disconformity has been a subject of debate. Ball (1964, p. 268) concluded that this disconformity is extremely planar, and stratigraphic relief was no more than structural relief shown by normal dips of strata within the study area. Ball's (1964, p. 87) conclusion was based on the stratigraphic relationship that the Tonganoxie was in contact with parts of the South Bend Limestone ranging through approximately seven feet of section in an eight- to nine-mile distance. This localized, planar disconformity would be expected when a resistant bed of rock in the path of a stream affected the ability of a stream to lower its channel, thus producing a local base level. Regionally, the disconformity at the base of the Tonganoxie rests on strata ranging from the Iatan Limestone Member to as low as the Captain Creek Member of the Stanton Formation. The depth of erosion was estimated by Lins (1950, p. 119) at about 80 to 100 feet by determining thicknesses of eroded formations and by measuring the maximum thickness of the Tonganoxie valley-fill. Ball (1964, p. 264) concluded that these estimates were based on invalid assumptions including zero pre-erosional dip, uniformity of deposition, and a valley-fill depositional environmental interpretation. Although the first two assumptions are probably correct, but difficult to prove, my observations corroborate a valley-fill interpretation of about 100 feet which corresponds to the depth of erosion. The poorly bedded conglomerate just above the erosional surface is interpreted as a channel lag deposit representing the deepest part of the channel. This conglomerate predominantly occurs at the base of the Tonganoxie but crops out stratigraphically higher at locality L4. At this locality, a series of conglomerates predominantly composed of clay, sandstone, and clay- ironstone clasts occur above erosional scours, and are interbedded with trough cross-beds and massive beds. Channels, imbrication, and associated bedding at this outcrop clearly show these conglomerates are channel lag deposits of multi-stacked channels. In summary, the siliceous limestone conglomerate shows several characteristics of fluvial deposits including basal flute and gutter casts, imbrication, associated channeling and trough cross-beds, and subjacent deep erosional scour. The relative lack of carbonate sand and cement and the predominant occurrence of fossils included in rock fragments also indicate the siliceous limestone conglomerate, unlike the calcareous limestone conglomerate, is a product of fluvial deposition.

Sandstones

Two types of sandstones occur in close association, both stratigraphically and areally; however, they represent different conditions of deposition. Although the geometry of both sandstones is vaguely known, associated rock types, texture, trace fossils, primary sedimentary structures, and stratification sequences indicate that these sandstones were deposited in different environments. The majority of sandstones in Leavenworth and Douglas Counties, Kansas, were deposited in a fluvial environment, whereas most sandstones in Franklin County, Kansas, are products of shoreline deposition.

Fluvial Sandstone.--This sandstone predominantly crops out in Leavenworth and Douglas Counties, Kansas, but thin basal sections also occur in Franklin County, Kansas. Generally, this sandstone overlies the conglomerate zone, and consists of trough cross-beds with subordinate planar, structureless, and rippled beds. Trough cross-bedding is a product of the upper part of the lower flow regime and is formed by the migration of three-dimensional subaqueous dunes. The dominance of larger-scale trough cross-beds in areas of deepest erosion indicates these large transverse bars migrated near the channel floor. These extensive deposits of trough cross-beds are located in the central part of the Tonganoxie valley (Lins, 1950) and mark the principal channel area.

Locally interbedded with trough cross-beds are planar beds (Figure 10) which are products of the lower part of the upper flow regime. Interbedding with conglomerates and gravelly trough cross-beds attests to high current velocities to form this type of horizontal stratification.

These planar beds are locally associated with structureless beds (Figure 10). This type of structureless or massive bedding commonly has a conglomeratic, disconformable lower contact which infrequently displays channel forms. Structureless bedding overlying channel margins and channel forms indicates that these homogeneous beds are a product of channelized flow. This homogenization may be primary in origin due to rapid deposition within the channel or because of water expulsion during compaction.

Although rippled beds are relatively rare in the fluvial sandstone facies, current ripples locally occur above the structureless and trough cross-bedded zones. Flaser and wavy beds also overlie the trough cross-bedded zone near the top of the sandstone section (locality D2) and grade upward into lenticular beds and finally silty shale. Rippled beds are a product of the lower part of the lower flow regime, and indicate that current velocities were low, but sufficient for traction transport. The occurrence of unidirectional ripples above structureless beds and trough cross-beds indicates diminishing flow velocities because of waning currents. The upward gradation from flaser and wavy beds to lenticular beds and finally silty shale also reflects waning currents and an increase of deposition from suspension.

The sedimentary structures, stratification sequences, and flow regimes indicate that these sandstones are clearly a product of fluviation. Although these sandstones are part of a fluvial system, it is difficult to classify the Tonganoxie Sandstone within the spectrum of fluvial types between braided and fine-grained meanderbelts. Distinguishing features of the Tonganoxie sandstones include: (1) dominance of large- to moderate- scale trough cross-beds, (2) slight upward fining grain size, (3) upward decrease in scale of troughs, (4) thin channel lag deposit, (5) organic silt and shale on top of sandstone, (6) interruption of sandstone deposition by carbonaceous shale or coal, (7) base of channel in contact with a variety of underlying facies including marine limestones, (8) high width/thickness ratio, and (9) relatively straight channels. These characteristics typify a confined valley-fill depositional model (Brown, Cleaves, Erxleben, 1973).

Confined valley-fill deposits fill valleys that eroded into underlying sediments and originate on alluvial plains because of a base-level change induced by an eustatic change in sea level. Minor sea level fluctuations prominently affect a low paleoslope causing a large base-level change.

Although these deposits usually fill small valleys, a larger base-level change would cause a channel to incise a larger valley resulting in a thicker fluvial deposit. An idealized valley-fill depositional model including a block diagram and vertical sequence is shown in Figure 13. The grain size vertical sequence of the idealized valley-fill depositional model (Figure 13) is similar to the SP log of the Tonganoxie Sandstone recorded at locality D2 (Figure 14). Both logs reflect a slight upward decrease in grain size with relatively abrupt deposition of a shale unit on top of the sandstone unit. Minor differences in the Tonganoxie SP log include the deposition of a carbonaceous shale within the sandstone, and deposition of a nearshore sandstone between the Lower and Upper Sibley coals in the post-fluvial sediments.

A generalized paleogeographic map (Figure 15) of the base of the Tonganoxie valley shows a ratio of 14 to 20 miles of valley width to a valley depth determined by thicknesses of eroded formations of 80 to 100 feet which suggests that the Tonganoxie River was near grade (Lins, 1950, p. 131). Sand units deposited within this shallow wide valley are multilateral, composed primarily of transverse bars and channel-fill. Laterally contiguous channel forms (Figure 10) attest to multilateral deposition. These channel forms and high width/thickness ratios of interbedded conglomerate, trough cross-beds and planar beds

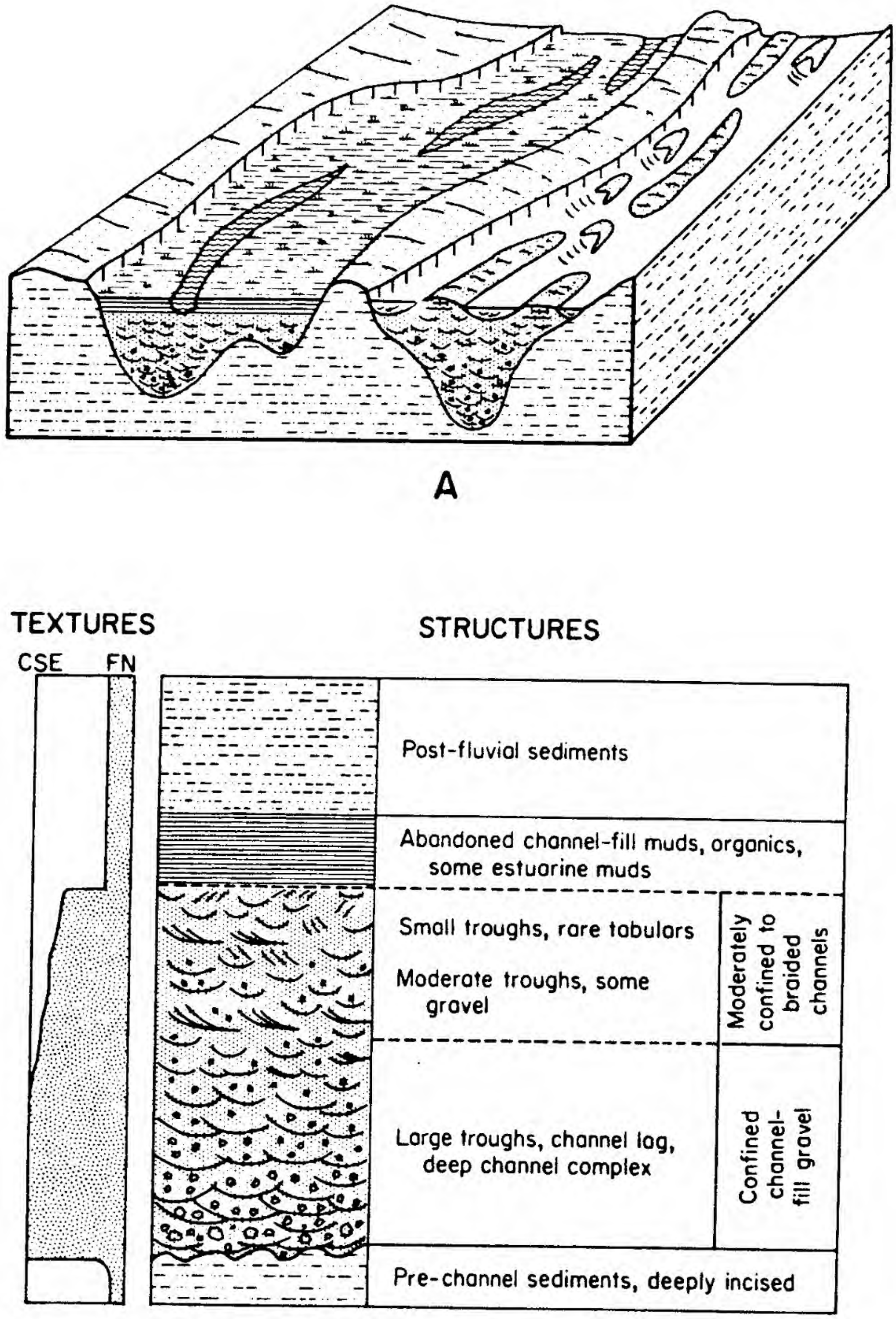


Figure 13. Depositional model of an idealized valley-fill fluvial system (from Brown, Cleaves, and Erxleben, 1973, p. 19). A. Block diagram showing nature of aggradational-fill deposits. B. Idealized vertical sequence.

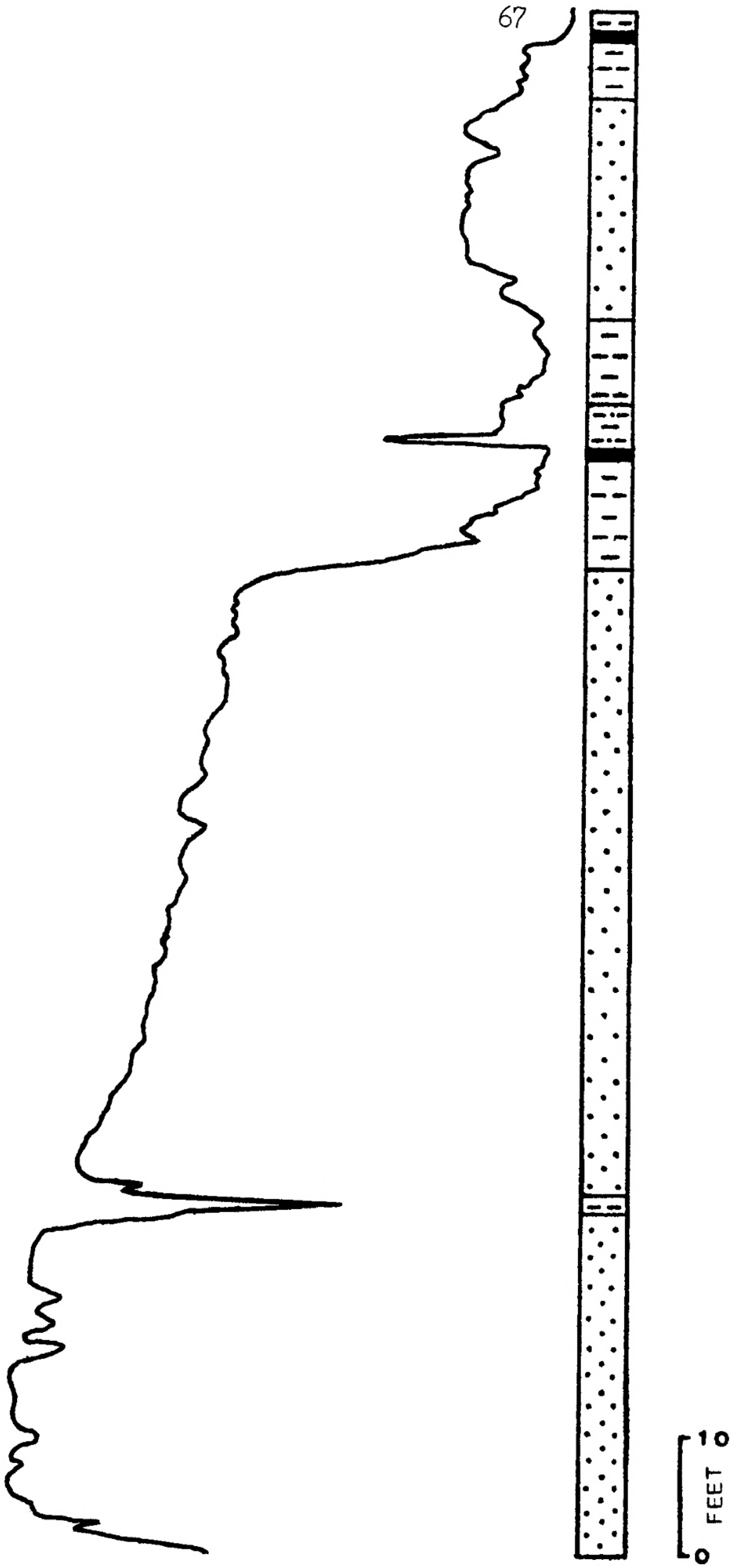
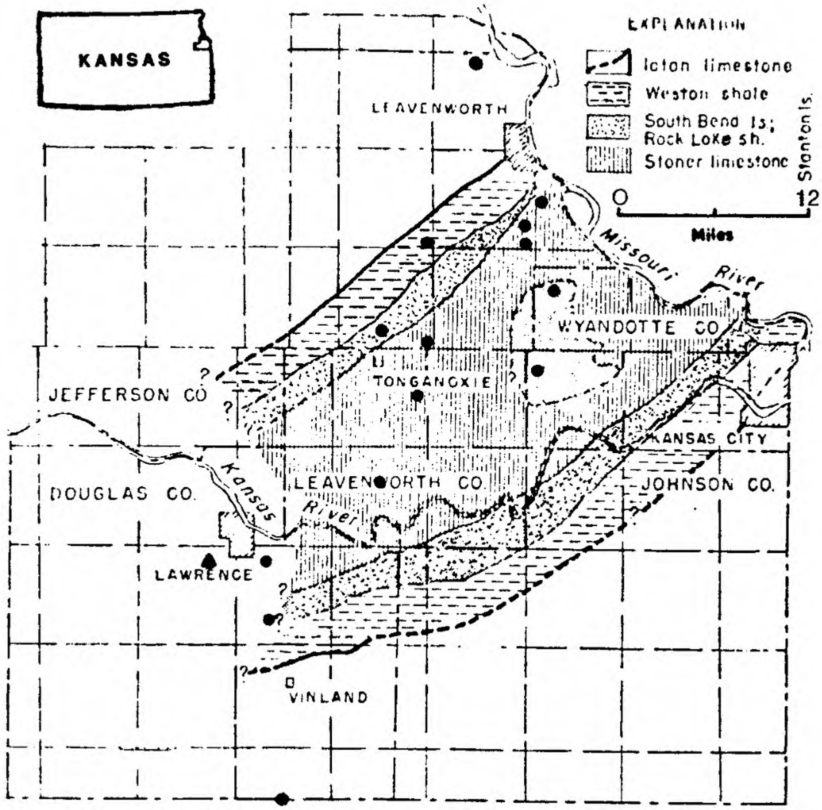


Figure 14. SP log of the Tonganoxie Sandstone Member at locality D2.



• Localities of stratigraphic sections used in this study.

▲ Locality of core used in this study.

Figure 15. Generalized geologic map of the disconformity at the base of the Tonganoxie Sandstone (from Lins, 1950, p. 118).

(Figure 10) indicate that the Tonganoxie valley was not carved and filled by a single meandering channel. Multi-stacked channels at locality L4 corroborate this conclusion. Occurrence of a thick shale below the lower Sibley coal in the center of the Tonganoxie valley indicates channel abandonment which also suggests multi-channel deposition. Gravel content, grain size, and scale of troughs decreases upward when the channels aggrade to a level where a significant decrease in flow confinement occurs. The thin, planar, and rippled beds overlying the trough cross-bedded zone in the upper parts of the valley-fill were deposited under diminished confined flow. The confined valley-fill depositional model predicts that the unconfined braided facies will spread beyond the limits of the buried valley, and that some channels will be abandoned before final filling (Brown, et al., 1973, p. 21). An abandoned channel that is filled with silty shale and mudstone at locality P1 overlies the Iatan Limestone on the divide area near the margin of the Tonganoxie valley. This abandoned channel that is beyond the limits of the Tonganoxie valley confirms the unconfined flow after final filling.

Directional sedimentary structures indicate that this river system flowed southwestward down the paleoslope. Paleocurrent measurements by Bower (1959) and Minor (1969) produced vector resultants of 242° and 209° respectively.

My observations and these measurements agree favorably and suggest an approximate valley trend of 230°. An isopachous map of the Tonganoxie Sandstone in the subsurface (Figure 16) also shows southwestward, channel-like trends in Douglas, Osage, and Coffey Counties, Kansas. These subsurface trends match the orientation of the Tonganoxie valley in outcrop. This southwestward trend is interrupted in northwestern Franklin County, Kansas, and diverted to the northwest (Figure 16). Directly south of this northwestward diversion of the channels in eastern Osage and central-western Franklin Counties, Kansas, is a northwest trending area containing no sandstone. A northwest-oriented thick sandstone section in eastern Osage and western Franklin Counties, Kansas, (T. 16 S., R. 17 E.; T. 16 S., R. 18 E.; T. 17 S., R. 17 E.) is located directly south of the area with no sandstone. Minor (1969) interpreted this sandstone as a valley from the east converging with the southwestward trending channels. The texture, composition, and sedimentary structures of this thick sandstone build-up indicate deposition in a shoreline environment rather than a fluvial system.

The southwest-oriented paleocurrent patterns indicate the source of the Tonganoxie Sandstone in northeastern Kansas was located to the northeast. Minor (1969, p. 77) concluded the Huronian metasedimentary rocks of the Wisconsin Arch and southwestern Canadian Shield in the

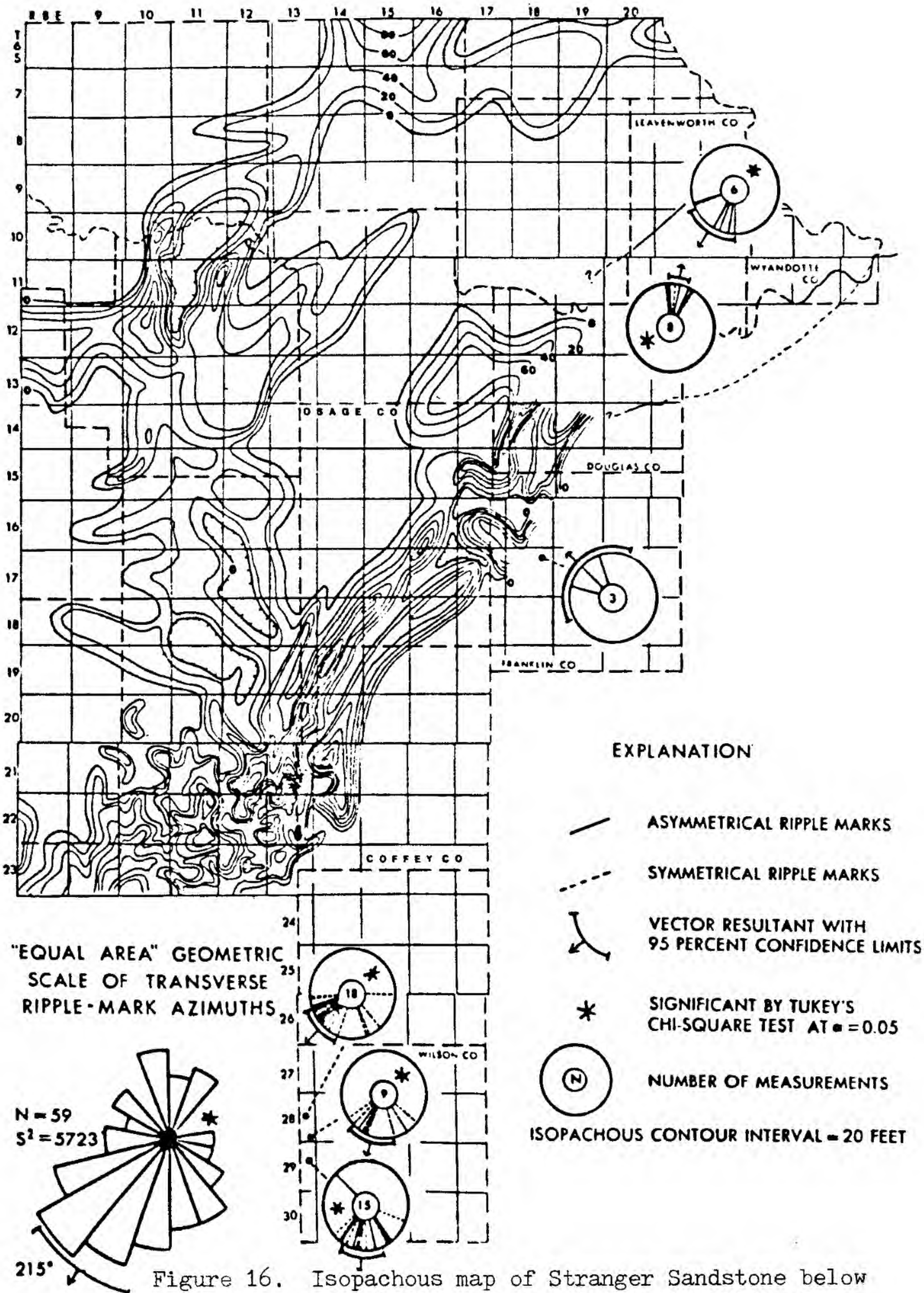


Figure 16. Isopachous map of Stranger Sandstone below Haskell Limestone and the direction of paleocurrents derived from ripple marks (from Minor, 1969, p. 41).

vicinity of Lake Superior may have been the source of the Tonganoxie Sandstone detritus. Ball (1964, p. 227) suggested the Arbuckle Mountains and Ozark Dome as source areas for the Douglas sandstones because they thicken to the south and southeast, and no quartz sand occurs to the north. Although the Arbuckle Mountains and Ozark Dome are the probable source areas of Douglas sandstones in Oklahoma and southern Kansas, a southern source is improbable for the Tonganoxie Sandstone in northeastern Kansas. The lack of sandstone in Nebraska and Iowa exposures does not preclude a northeastern source because the channel facies is a small part of a fluvial system. Exposures of the Tonganoxie Sandstone Member in Kansas and Missouri occur beyond the limits of the Tonganoxie valley, and contain no sandstone, but are obviously part of a fluvial system. I doubt that any geologist would argue for a southerly source area after examining the southwestward paleocurrent dispersal patterns in northeastern Kansas.

Shoreline Sandstone.--This sandstone crops out in east-central Leavenworth, and central Franklin Counties, Kansas. Most of these sandstones overlie the Weston Shale; however, at locality F4 this sandstone crops out above a fluvial sandstone. A shoreline sandstone also crops out between the Upper and Lower Sibley coals in Douglas County, Kansas. The shoreline sandstone consists of rippled beds, flaser and wavy beds, planar laminations, structureless beds, planar cross-beds, and convoluted beds. Most of these stratification types reflect deposition in the lower flow regime; however, planar beds are products of the lower part of the upper flow regime. Convoluted beds are products of plastic deformation. Although these sedimentary structures occur in other environments, associated symmetrical wave ripples, herringbone cross-beds, and bimodal directions of cross-laminae attest to shoreline deposition.

Flaser and wavy beds are abundant at most exposures of shoreline sandstone. These alternations of ripple cross-laminae and mud lenses indicate alternate periods of current activity and quiescence. Sandstone was deposited by ebb and flood currents, whereas mud accumulated from suspension during high water. Rip-up clasts of mud at the base of rippled sandstone beds corroborates high current velocities during ebb and flood tides. Bipolar directions of foreset laminae are a consequence of tidal rhythm and indicate deposition in a tidal environment.

Rippled beds are a common stratification type in shoreline sandstones of the Tonganoxie. A variety of ripple marks including wave ripples, current ripples, and climbing ripples locally occur within shoreline sandstone sections. All rippled beds are a product of the lower part of the lower flow regime. Asymmetrical, current ripples are the most common rippled bedform and are preserved as form sets and internal trough cross-lamination. Although rippled beds are formed in a variety of environments, bipolar directions of foreset laminae indicate deposition by ebb and flood tidal currents, and interbedding with symmetrical wave ripples also attests to shoreline deposition. These symmetrical wave ripples produced by oscillatory flow have straight to slightly sinuous, peaked crests of which a few are bifurcated. Wave ripples are commonly formed in the lower and upper shoreface and are exclusively a product of shoreline deposition.

Climbing ripples are rare, but are associated with wave ripples; they are produced when the angle of climb is greater than the angle of the stoss sides of the ripples. This large angle of climb is produced by net aggradation of sand and results in the full profile of the ripple. Climbing ripples are produced in several environments, but the association with wave ripples and current ripples and the bipolar directions of foreset laminae suggest deposition in a shoreline environment.

Planar laminations are a common stratification type in shoreline sandstones of the Tonganoxie. Planar laminations are produced by a variety of current velocities both by unidirectional and oscillatory flow, and are commonly a product of the lower part of the upper flow regime, but can be produced by depostion from suspension. Although planar laminations are produced in many environments, association with the aforementioned sedimentary structures suggests deposition on a beach or nearshore area under strong shoaling waves.

Structureless sandstones have no apparent sedimentary structures and are abundant in shoreline sandstone stratigraphic sections. These massive or homogeneous beds may be produced by rapid sedimentation, but the occurrence of vertical burrows in adjacent beds suggests that bioturbation may have destroyed the primary stratification. Structureless sandstones are formed in environments ranging from the upper shoreface to the transition zone with bioturbation commonly increasing with increased water depth.

Planar cross-beds are a rare stratification type in shoreline sandstones of the Tonganoxie; they are produced in the upper part of the lower flow regime, but reflect lower flow velocities than those of trough cross-bedding. These tabular cross-strata are deposited by migrating two-dimensional dunes. Associated herringbone cross-bedding, where sets show bimodal directions, results from tidal activity. These cross-beds are commonly produced in the intertidal zone, but also occur in the upper and lower shoreface.

Convolute bedding is rare within shoreline strata of the Tonganoxie Sandstone. These convolutions are produced by plastic deformation of partially liquefied sandstone. Convolute bedding is produced in several environments soon after deposition. Associated sedimentary structures indicate that convolute bedding was probably a result of tidal activity. Liquefaction may have resulted from breaking waves or the rise and fall of sea level produced by the ebb and flood tidal currents.

The aforementioned sedimentary structures, stratification sequences, and flow regimes indicate that these sandstones were produced by shoreline processes.

Shale

Shale is the predominant rock type in Anderson County, Kansas, and comprises most upper Tonganoxie strata in the northern part of the study area. Although no comprehensive study of these shales has been undertaken, facies relationships, sedimentary structures, lithologic character, and the presence of land-derived plants suggest a continental origin for most Tonganoxie shales.

Lins (1950, p. 134) in his study of the Tonganoxie Sandstone in Leavenworth and northern Douglas Counties, Kansas, concluded that these "valley shales" were deposited "in broad shallow lakes, swamps, and on the partly inundated flood plain of the Tonganoxie Valley." Although he suggested that the shale unit graded laterally into sandstone, my observations indicate that most shale beds are restricted to the upper part of the Tonganoxie, above the sandstone unit. This relative restriction of shale to the upper parts of the Tonganoxie is consistent with the depositional model of a valley-fill fluvial system, and that these shales are abandoned channel-fill muds and some estuarine muds. The laminated clay and fine silt of these deposits attests to slow accumulation from suspension by flood waters. The poor drainage and concomitant reducing conditions of these abandoned channels are evidenced by the blue color of the iron-bearing shales and preservation of carbonaceous plant debris. An abandoned channel filled with carbonaceous shale at locality P1 corroborates this conclusion.

A few stratigraphic sections between the Upper and Lower Sibley coals show alternating sand and planar-laminated shale that suggests tidal activity. These alternating laminations and association with a nearshore sandstone indicate some of these shales may be post-fluvial estuarine deposits.

Although plant fragments were the only indigenous fossils found in the shale unit during this study, Patterson (1933), Bowsher and Jewett (1943), and Ball (1964) found marine invertebrates in shale layers adjacent to coal beds. The apparent restriction of marine invertebrates to shale beds adjacent to coal horizons is consistent with the T-R unit hypothesis, and will be discussed later.

Shale comprises most Tonganoxie strata in Anderson County, Kansas, and differs in lithology from shale in the northern part of the study area. This shale is predominantly a gray green, planar, laminated shale containing very thin to thin, glauconitic sandstone beds and load casts. Although the only indigenous fossils found in this study were trace fossils, Bower (1959, p. 17) noted from this area southward, that casts and molds of brachiopods, pelecypods, and gastropods are common and locally abundant. Glauconitic sandstone beds and marine fossils indicate that this shale is a marine deposit; but until a comprehensive study including disaggregation for fossils is made, a conclusive statement about environments of deposition is not warranted.

Mudstone

Mudstones are relatively rare within the Tonganoxie, but are more common than believed by previous authors. Although several coal beds overlie well-bedded shales, mudstone is locally developed below all three coal horizons. Several features indicate Tonganoxie mudstones represent paleosols. Recent literature (Retallack, 1988) distinguishes paleosols from other rocks using three main features including root traces, soil horizons, and soil structures.

Root traces are common in Tonganoxie mudstones, and are usually preserved as limonitic mottles; however, at locality

F6 root traces are casts composed of calcite. Most root traces taper and branch downward, but a few larger root casts at locality F6 were observed in a horizontal position oriented perpendicular to larger roots with blunt apices. This pattern suggests a tabular or adventitious root system. A rather rich flora of plants has been identified from the Stranger Formation by Cridland, Morris, and Baxter (1963) including plants from the phyla Lycopsida (scale trees), Sphenopsida (arthrophytes characterized by vertical ribbing and jointed stems), Filicineae (true ferns), Gymnospermae (primitive seed-bearing plants). This rich flora undoubtedly had diverse root systems. Calamites is a commonly preserved plant fossil in Tonganoxie strata which has an adventitious root system. Adventitious roots originate from the stem, rather than from the base of the trunk, and in the case of Calamites, are commonly found in a horizontal position lying in and out of the ground. Tree ferns also had adventitious roots forming a false stem. Lycopsid illustrations show roots originating from around the trunks base which also suggests adventitious rooting. Cordaites (primitive members of the conifer lineage) apparently had a tabular or adventitious root system. Root traces found in Tonganoxie mudstones are consistent with the root systems of plant fossils identified in the Stranger Formation by Cridland, Morris, and Baxter (1963).

Generally, soil horizons are weakly developed in

Tonganoxie mudstones, and would not qualify as USDA argillic, spodic, or calcic horizons. The contact of the uppermost horizon is usually abrupt and smooth to irregular, whereas the lower contact of the lowermost horizon is usually gradual to diffuse and wavy to irregular. Lower contacts commonly grade upward from well-bedded shale to disturbed shale, and finally unbedded mudstone which implies post-depositional destruction of stratification, rather than reflecting an original lack of depositional bedding. Most boundaries between horizons within the mudstone are gradual to diffuse, smooth to wavy, and differentiated by a change in color and soil structure. The uppermost mudstone horizon is usually overlain by a coal which qualifies as a histic epipedon or O horizon. Several mudstones have a lighter colored upper elluvial horizon, but would not qualify as one of the USDA E horizons. This lighter color suggests partial translocation of clay and sesquioxides. The illuvial horizon below the upper horizon is darker with angular blocky to subangular blocky structure. Most of these horizons would classify as cambic horizons, but the middle horizon at locality F6 is an argillic horizon.

Although most horizons are structureless, a few illuvial horizons show angular blocky to subangular blocky soil structure. The weakly defined, fine to medium, angular blocky soil structure of the lower horizon in the northern facies is characteristic of a cambic horizon. The middle horizon at locality F6 shows a well-developed medium to coarse, subangular blocky soil structure. These strongly calcareous peds are bounded by darker cutans composed of clay and humus. An argillic horizon is suggested by this soil structure.

Root traces, soil horizons, and soil structure suggest most Tonganoxie mudstone are weakly developed (Retallack, 1988). A few mudstones (localities F3, A1, and A2) with no diagnostic horizons, and little evidence of soil development except root traces and a lack of bedding are probably Entisols (Buol, Hole, and McCracken, 1980). Entisols are slightly developed or recent soils. The mudstones of the northern facies with a histic epipedon, and a cambic horizon are probably Inceptisols (Buol, et al., 1980). Inceptisols are immature soils with weakly differentiated horizons. The mudstone at locality F6 below the Ottawa coal is moderately developed using the criteria of Retallack (1988). The histic epipedon, argillic horizon, and K horizon of caliche nodules suggests this mudstone is probably an Alfisol (Buol, et al., 1980). Plant roots replaced by calcite evidencing a high concentration of nutrient cations also supports this interpretation. Alfisols are soils with gray to brown surface horizons, medium to high base supply, and subsurface horizons of clay accumulation.

Ball (1964, p. 300) analyzed three mudstone samples by X-ray diffraction, and determined that they contained illite, kaolinite, vermiculite, and illite-mixed layer clay; however, no samples contained more kaolinite than generally found in Douglas Group shales. Ball (1964, p. 299) concluded that no clay beds within the Douglas Group have characteristics of paleosols, a conclusion which was apparently based soley on X-ray diffraction data. Goebel, Bettis, and Heckel (1989) described a paleosol in the Stranger Shale and underlying Iatan Limestone in southwestern Iowa. Goebel, et al. (1989, p. 224) concluded that the solution features on top of the Iatan Limestone indicate "...initial exposure to a humid climate with strong meteoric influx." The upper paleosols in southwestern Iowa displayed characteristics of Entisols, Inceptisols, and Vertisols which were formed in a somewhat dryer climate. These conclusions are consistent with my observations of paleosols of the Tonganoxie Sandstone Member developed farther down the paleoslope. Although X-ray diffraction analysis wasn't utilized in this study, sharp upper contacts, gradational lower contacts, root traces, weakly to moderately developed horizons, soil structure, bleached appearance of a few upper horizons, caliche nodules, and a lack of fissility indicate most Tonganoxie mudstones represent ancient soils or paleosols.

Coal

Depositional conditions represented by Tonganoxie coals have been a subject of considerable debate. These coals have been ascribed to both autochthonous and allochthonous theories of accumulation of plant remains. The allochthonous theory accredited by Moore (1934), Bowsher and Jewett (1943) and Ball (1964) postulates that coal did not accumulate in situ but was transported by water prior to deposition. Lins (1950, p. 135) concluded that the Tonganoxie coals were autochthonous, continental deposits in which the vegetal matter which formed these coals accumulated in situ. These previous authors have considered, for the most part, that Tonganoxie coals formed under similar depositional conditions at all locations. My observations indicate that these coals and the time-stratigraphic equivalent carbonaceous shales were initiated and deposited under a variety of conditions.

All three coal horizons within the Tonganoxie represent climate change surfaces (Busch, 1984) which are contacts between nonmarine facies presumed to have formed under subaerial conditions (eg., paleosols or calcretes) and overlying nonmarine facies presumed to have formed under more humid conditions (eg., coal or lacustrine limestones). Climate changes initiate geologically instantaneous facies changes to more humid and environmentally disjunct facies.

Certain climate change surfaces within the Tonganoxie are conspicuous such as coal overlying paleosols. More cryptic climate change surfaces include contacts between shale or channel sandstones and overlying carbonaceous shale or coal. These cryptic climate change surfaces are also represented by the abrupt occurrence of plant fragments tens of centimeters below coal beds or carbonaceous shales. Although climate changes are geologically instantaneous, a few depositional environments (eg., fluvial channels) are not immediately juxtaposed because they are farther up the paleoslope and indirectly controlled by sea level. The abrupt occurrence of plant fragments in channel sandstones is probably the result of a storm or flood marking the actual climate change and start of transgression, but deposition continues until sea level (ultimate base-level) rises enough to trap the coarse clastic sediments upstream. Coals with gradational lower contacts also occur above abandoned channel deposits because of similar indirect sea level controls. Coals which overlie paleosols show sharp contacts because of the lack of deposition in this subaerial environment preceding more humid conditions. Thick coals have pure medial parts and commonly grade upward into clay and silt shales. These gradational upper contacts signify less humid conditions and concomitant deterioration of coal forming environments.

Busch (1984) described two types of coals associated with T-R units. Type 1 coals are generally thick because they were deposited during an entire fifth-order T-R unit transgressive phase. Type 2 coals are generally thin because they were deposited for only part of a fifth-order T-R unit transgressive phase. Most Tonganoxie coals are Type 1 coals, but the Upper Sibley coal is a Type 2 coal locally. In southern Platte County, Missouri, northern Leavenworth and southern Douglas Counties, Kansas, the Upper Sibley coal grades upward into or interfingers with the marginal marine Westphalia Limestone represented by a coaly, argillaceous, ostracode, high-spired-gastropod micrite. Coal-forming environments were terminated at these localities resulting in thinner coals with a marine cap. It is noteworthy that Type 2 coals occur in paleotopographic lows at fifth-order T-R unit transgressive maxima and change laterally (in a seaward direction) into a transgressive surface south of Franklin County, Kansas.

Analysis of Tonganoxie coals using hierarchal genetic stratigraphy has yielded meaningful information about depositional environments. All depositional environments are affected by climate change; therefore, coals and time-stratigraphic equivalents were initiated in several environments. Although most coals are lenticular, corresponding climate change surfaces or transgressive surfaces can be traced laterally through several environments.

The delineation of depositional environments associated with coals is based on lateral and vertical relations of sedimentary structures, texture, and mineralogy of the sandstones. Analysis of these components indicate coals were deposited in a fluvial system in the northern part of the study area. These coals were deposited in swamps, while contemporaneous deposition of carbonaceous shale occurred within the channel. Coal beds in Franklin County, Kansas, are associated with different facies than coals in the northern part of the study area. Although the Ottawa coal is rooted in a paleosol locally, the associated coarsening upward sequence including herringbone cross-bedded, flaser-bedded, and planar-laminated very fine sandstone and undulating burrowed siltstone indicate that these coals are coastal marsh deposits.

The sedimentary environment preceding the climate change shaped the topography on which the coal swamps developed. Most coals overlying paleosols occur on paleotopographic highs where subaerial exposure caused soil development. Coals in paleotopographic lows commonly developed on shale where deposition was still taking place prior to a climate change.

Although the coals within the fluvial system are a product of sixth-order climate change, the overall sequence of strata from the sandstone unit, to the shale unit, and finally marine limestone and shale represent a more gradual advancement of marine conditions resulting in the reduction of the river gradient. Progress toward marine conditions represents a deepening event having greater magnitude and periodicity. Coals within the Tonganoxie indirectly show this marine advancement by forming in environments which progressively represent more marine conditions.

Moore (1934), Bowsher and Jewett (1943) and Ball (1964) concluded that all Tonganoxie coals, except the Ottawa coal, did not accumulate in situ but were transported by water prior to deposition. These authors accredited the allochthonous origin of coals because of the following observations: (1) poorly preserved plant remains arranged parallel to bedding, (2) presence of marine fossils above and below some coal beds locally and (3) lack of underclay. T-R unit genetic stratigraphy accounts for observations 1 and 2 because of rapid sea level rise and concomitant reworking of the preceding environment. Marine invertebrate fossils below coals are expected when a punctuated deepening event results in rapid transgression. Although most coals represent continental conditions, climate change and subsequent transgression transported extraneous fossils onto the surface of the preceding environments especially in paleotopographic lows. Ball (1964, p. 305) concluded that "polished articulate brachiopod, echinoid and plant fragments were transported extraneous additions to the environment." Transported fossils below coals substantiates rapid sea level rise, whereas indigenous fossils indicate establishment of marine or marginal marine conditions after climate change. Intercalations of coal and the littoral marine, coaly, ostracode, high-spired-gastropod micrite indicate these respective environments didn't differ appreciably. Reworking of sediment occurs by wave action in a littoral marine environment; however, transportation of all plant debris by currents prior to deposition is at best problematical. Well-preserved fragile plant fossils are common in Tonganoxie coals and adjacent beds and show no evidence of transportation as detritus. Regarding point 3, aforementioned observations indicate several mudstones underlying coals are paleosols which strengthens an autochthonous theory of origin for Tonganoxie coals. Although a few coals were reworked by wave action, I am of the opinion that Tonganoxie coals accumulated in situ and were rooted in rocks representing environments which preceded climate change; they are autochthonous.

HIERARCHAL GENETIC STRATIGRAPHY OF THE TONGANOXIE SANDSTONE MEMBER

Paleoenvironmental interpretations indicate that the Tonganoxie Sandstone Member of the Stranger Formation is composed of upward-shallowing units that are separated by transgressive surfaces or climate change surfaces. The upward-shallowing units or PACs (sixth-order T-R units) within the Tonganoxie Sandstone Member tend to be thicker than PACs formed in marine facies because of increased deposition of siliciclastics in specific continental environments (i.e., fluvial channels). Each genetic surface is labeled beginning with the letter S (i.e., Stranger Formation). The study interval is part of the second fifth-order T-R unit within the Stranger Formation. The Iatan Limestone contains the best developed marine facies within this fifth-order T-R unit; therefore, this interval will be named the Iatan fifth-order T-R unit and labeled T-R unit S2.1 (Figure 17). Each sixth-order T-R unit is named for the genetic surface forming its lower boundary. Subsequent sixth-order T-R units within the Iatan fifth-order T-R unit are named the Blue Mound sixth-order T-R unit and Lower Sibley sixth-order T-R unit and labeled T-R unit S2.2 and T-R unit S2.3, respectively.

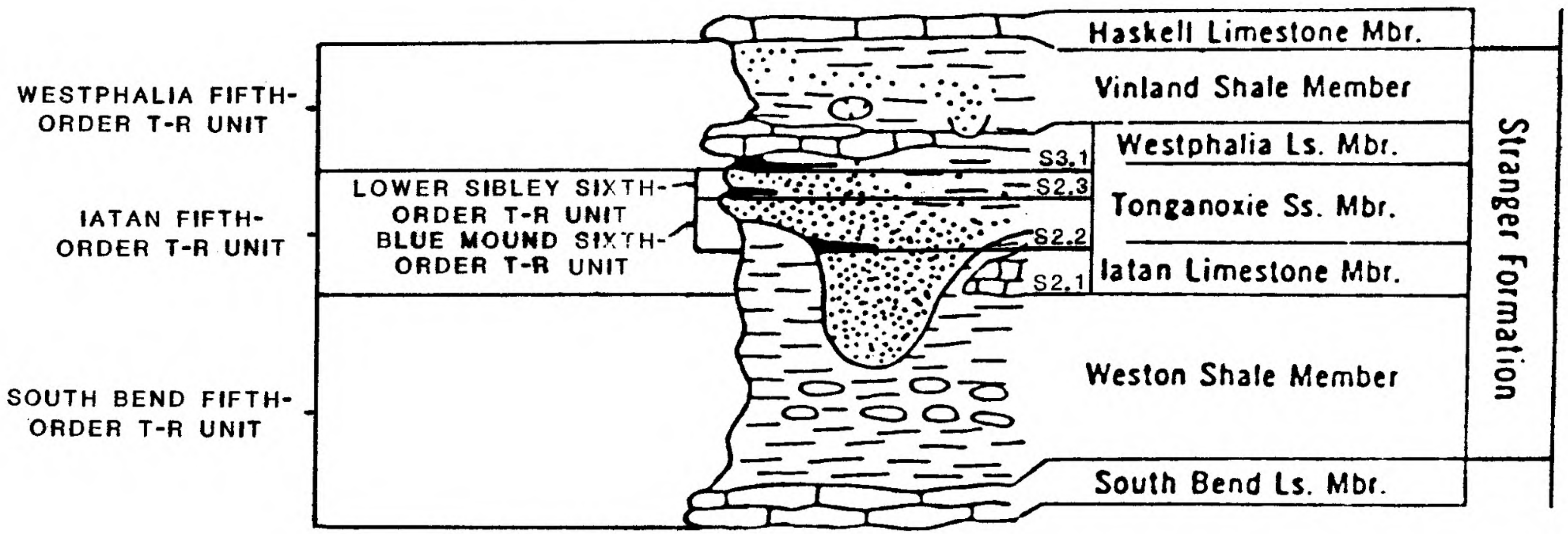


Figure 17. Sixth- and fifth-order T-R units of part of the Stranger Formation.

Standard Hierarchal Genetic Stratigraphy of the Tonganoxie Sandstone Member

The standard stratigraphic section of that part of the Stranger Formation studied here (i.e., from the base of the Iatan Limestone to the base of the Westphalia Limestone or Upper Sibley coal) contains three sixth-order genetic surfaces (S2.1 through S2.3) bounding three sixth-order T-R units (Figure 17). These sixth-order T-R units comprise one complete fifth-order T-R unit (the Iatan fifth-order T-R unit). The facies below sixth-order T-R unit S2.1 is a marine shale at the top of the uppermost sixth-order T-R unit in the South Bend fifth-order T-R unit. These marine deposits were formed during maximum marine regression associated with the top of the South Bend fifth-order T-R unit.

The initial transgression for the Iatan fifth-order T-R unit is indicated by several facies including an algal-rich limestone; an intraclast-bearing, fossiliferous conglomerate; and a carbonaceous structureless sandstone. The Iatan fifth-order T-R unit ranges from 4.8 m. (15.7 ft.) to 29.3 m. (96.1 ft.) thick and consists of three sixth-order T-R units (S2.1-S2.3). These sixth-order T-R units range from 1.0 m. (3.3 ft.) to 20.2 m. (66.3 ft.) thick. According to Busch and West (1987), three sixth-order T-R units would represent an interval of time ranging from 150,000 to 390,000 years.

The Iatan fifth-order T-R unit is comprised of sixth-order T-R units S2.1-S2.3 which represent a series of successively less extensive transgressions or climate changes. Sixth-order T-R unit S2.1 has the most open marine facies in the Iatan fifth-order T-R unit. Thus, the transgressive apex of the Iatan fifth-order T-R unit is within sixth-order T-R unit S2.1. Although the Iatan Limestone represents the best developed marine facies, this transgressive surface changes laterally into a climate change surface in a short distance. This genetic surface is commonly removed by fluvial entrenchment associated with the regressive sequence of the Iatan fifth-order T-R unit. This regressive sequence is represented by sixth-order T-R units S2.2-S2.3. Genetic surfaces S2.2 and S2.3 are climate change surfaces at all localities and successively become more cryptic indicating less extensive climate change.

The relative magnitude of the marine transgression in sixth-order T-R unit S3.1 (Figure 18) is greater than the relative magnitude of the marine transgression in sixth-order T-R unit S2.3 which is marked by a climate change surface at all localities in the study area. This increase in the relative magnitude of sea level rise in sixth-order T-R unit S3.1 evidenced by a change from a climate change to a transgressive surface marks the initial transgression of the Westphalia fifth-order T-R unit. Thus, sixth-order T-R unit S3.1 is both the upper boundary of the

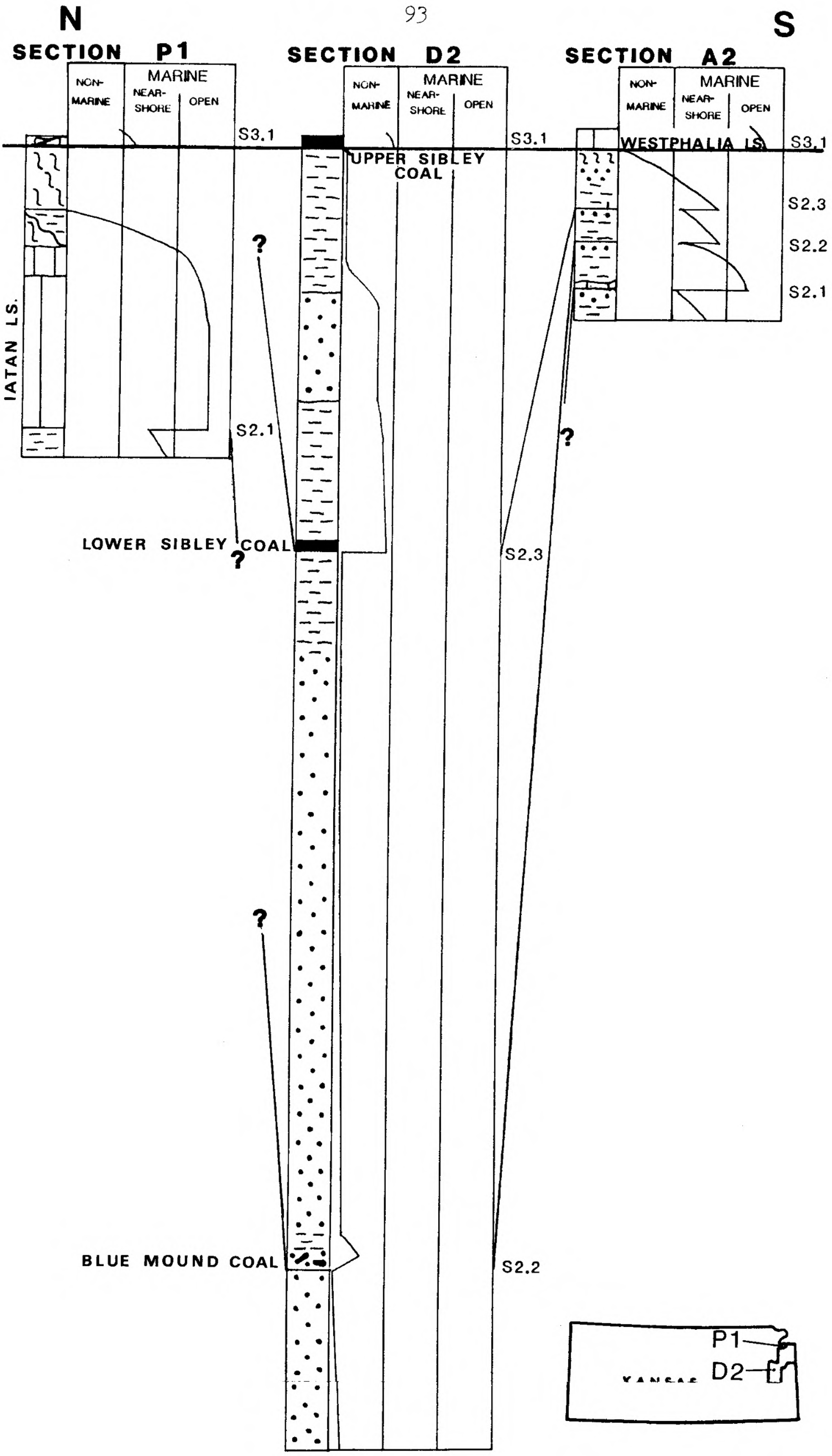


Figure 18. Sea-level curves and correlations of sixth-order T-R units in part of the Stranger Formation.

Iatan fifth-order T-R unit and the lower boundary of the Westphalia fifth-order T-R unit.

This study shows that the Tonganoxie Sandstone is composed of a series of transgressive-regressive units separated by genetic surfaces (i.e., transgressive or climate change) commonly found between environmentally disjunct facies. The marine T-R units shallow upward (i.e., are asymmetrical), while nonmarine T-R units show a deterioration of humid conditions (i.e., coal to shale). These T-R units or PACs are locally thicker than postulated by the Hypothesis of Punctuated Aggradational Cycles (Goodwin and Anderson, 1985) because of increased deposition in nonmarine fluvial channels. Although these sixth-order T-R units are locally thicker than PACs, correlation of the genetic surfaces throughout the study area through several environments indicates that these units are laterally extensive (allocyclic) and can be considered as PACs.

Tonganoxie Sixth-order Paleogeographic Changes

Paleogeographic maps were produced for times of maximum transgression attained in sixth-order T-R units bounding the Iatan fifth-order T-R unit (S2.1 & S3.1). A paleogeographic map was also drawn for maximum regression achieved at the top of the Tonganoxie interval (T-R unit S2.3). These maps were produced by listing the lithology and fossil associations at each locality for either maximum transgression or maximum regression within each aforementioned sixth-order T-R unit. General changes in lithology were then marked on the map as facies boundaries. These paleogeographic maps have minimal lateral extent and consist of generalized parallel facies boundaries because of the lack of complete stratigraphic sections and the physiographic nature of the outcrop belt paralleling the paleoslope. Two facies boundaries were modified from Ball's (1964) distribution maps of the Iatan and Westphalia Limestones.

Composite paleogeographic maps were produced for maximum transgression and maximum regression to determine areas of recurrent facies changes. These composite maps were produced by overlying facies boundaries from the paleogeographic maps. Additional facies boundaries of the unmapped sixth-order T-R units supplemented the composite maps where control points existed. Areas of recurrent facies change indicate the possible influence of structural controls. The paleogeographic maps and generalized isopach information from the cross-sections can be used to delineate topographic highs and lows within the area of study.

Unit S2.1.--Maximum transgression for sixth-order T-R unit S2.1 (Figure 19) within the study area is represented by a phylloid algal limestone containing a few brachiopods, bryozoans, and crinoids. This thick limestone has been

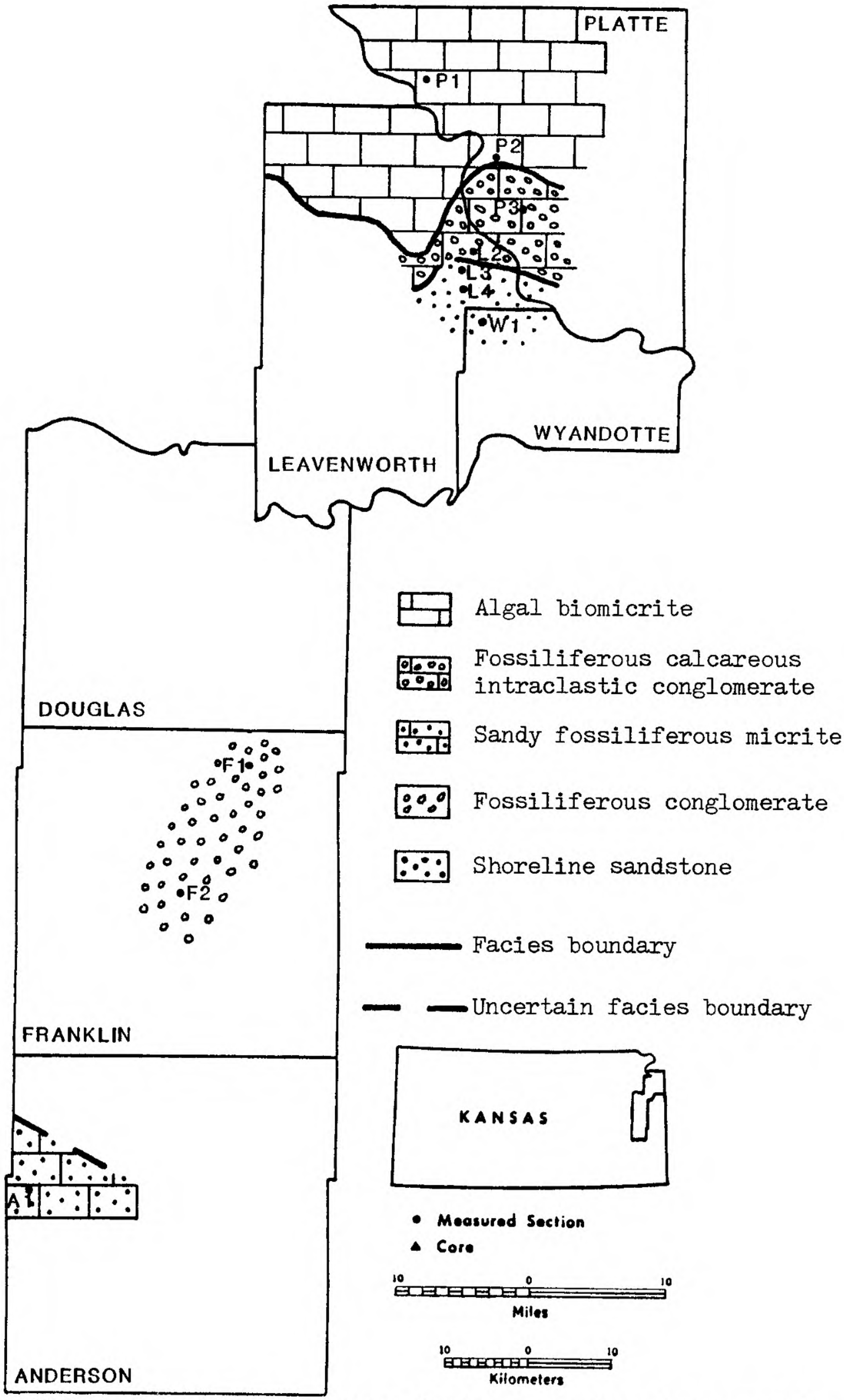


Figure 19. Paleogeographic map showing facies at maximum transgression for sixth-order T-R unit S2.1 of the Stranger Formation.

described as an algal mound facies (Heckel and Cocke, 1969) which grades northward into a thinner, more diversely fossiliferous, well-bedded, nonmound limestone facies. Mound development occurred at the southern edge of this limestone unit between a paralic clastic facies to the south and a more open, subtidal, marine facies to the north. At localities P3 and L2, the limestone changes into an intraclastic conglomerate (calcirudite) which rests on beds as old as the Stoner Limestone. The Iatan Limestone was the principal source of intraclasts and distance of transport was short. Information in previous sections indicates that this conglomerate represents a high energy beach gravel.

Directly south of these beach gravel deposits at localities L3 and L4, this unit consists of nearshore sandstone deposits. Azimuths of ripple marks showing abundant opposing dips at locality L3 indicate the shoreline was oriented approximately east-west with an open marine environment toward the north. The southward thinning of these paralic clastic sediments and underlying Weston Shale corroborates more open marine conditions in the northern parts of the study area during maximum transgression of T-R unit S2.1. South of locality L4 to northern Franklin County, Kansas, this unit is apparently absent because of subsequent erosion by downcutting of the Tonganoxie Sandstone Member. At localities F1 and F2 (Figure 19), maximum transgression of T-R unit S2.1 is represented by a granule conglomerate: calcareous, submature, fossiliferous seqrudite that includes few to several crinoids, brachiopods, bivalves, fusulinids, gastropods, bryozoans, and macerals. This conglomerate rests on shale that contains sparse to abundant clay-ironstone concretions and is interbedded with calcareous sandstone which is locally cross-bedded. This conglomerate represents a transgressive lag which was deposited on the continent as sea level rose episodically. Maximum transgression of T-R unit S2.1 at locality A1 (Figure 19) is represented by a coarse calcarenite: ferruginous, osagid, fossiliferous, silty micrite. This limestone contains sparse echinoids, brachiopods, fusulinids, bivalves, and ostracodes with common osagid coatings and quartz silt. The quartz silt and abraded fossils with osagid coatings indicate that this calcarenite represents deposition in a high energy, intertidal or shallow subtidal environment with some influx of terrigenous sediment because of proximity to the shoreline.

Maximum regression in T-R unit S2.1 is represented by several different nonmarine environments. In the northeast part of the study area (localities P1 through F1), maximum regression is represented by channel and divide facies of a fluvial system. In Franklin County, Kansas, (localities F2 through F6), maximum regression is represented by a mudstone with root mottles and traces which ranges considerably in thickness, and locally contains caliche nodules. This mudstone represents a paleosol which developed on shale and burrowed siltstone which is interpreted to have been in an alluvial (possibly low lying coastal plain) environment. The channel facies was not observed in T-R unit S2.1 south of locality F1. An isopach map (Figure 16) shows southwestward oriented linear sandstone bodies diverted to the northwest and returning to a southwest orientation. These facies changes and isopach changes indicate that a southwestward flowing river may have been influenced by a topographic high in northern Franklin County, Kansas. Maximum regression in Anderson County, Kansas, is represented by a sandy shale with sandstone intercalations increasing in abundance upward. This sandy shale is believed to have been deposited in an alluvial (possibly low lying coastal plain) environment.

Sixth-order T-R unit S2.1 is thickest in the channel facies and thinnest on the divides. The east-west oriented shoreline near Leavenworth, Kansas, with more open marine conditions toward the north indicates that the northern part of the study area was topographically lower than the area south of Leavenworth, Kansas, during maximum transgression of T-R unit S2.1. A relatively thick mudstone containing caliche nodules coincides with the diversion of a southwestward flowing river system suggesting the possibility of a topographic high in northern Franklin

County, Kansas. The ferruginous, osagid, fossiliferous, silty micrite at locality A1 indicates that this area may have been a topographic low during maximum transgression of T-R unit S2.1.

Unit S2.2.--Maximum transgression for sixth-order T-R unit S2.2 north of Anderson County, Kansas, is predominantly represented by a bituminous coal or carbonaceous shale. The coal represents deposition in a relatively humid, swampy, subaerial environment. This climate change surface was initiated in both channel and divide deposits north of locality F1. In the divide areas (localities P1 and P3) of this fluvial system, genetic surface S2.2 is more cryptic and may be represented by an alluvial shale and a very thin, unfossiliferous, nodular limestone. South of locality F1 to locality F6, maximum transgression is represented by the Ottawa coal lentil which was initiated on a mudstone representing a subaerial environment (paleosol). In Anderson County, Kansas, genetic surface S2.2 is more cryptic and maximum transgression is apparently represented by a well-bedded shale which overlies a shale with many intercalated beds of sandstone. Based on fossils reported from this shale by Bower (1959), I infer deposition in a shallow marine environment.

Maximum regression for sixth-order T-R unit S2.2 is represented by several nonmarine facies. North of locality F4, maximum regression is represented by channel and divide facies of a fluvial system. The channel facies was observed as far south as locality F4 and rests disconformably on shoreline sandstone deposits. Small to medium, high-angle, trough cross-beds show southwest oriented paleocurrent directions and some opposed cross-bedding directions. These cross-beds are oriented nearly perpendicular to a sandstone build-up with a northwest strike in western Franklin County, Kansas (Figure 16). The vertical sequence of sedimentary structures and sandstone trends in this area indicate that the depositional environment was probably a shoreline deposit during the regressive phase of sixth-order T-R unit. Maximum regression at locality F6 is represented by a mudstone with root mottles. This mudstone represents deposition in a subaerial (e.g., paleosol) environment. In Anderson County, Kansas, at locality A1, maximum regression is represented by a sandy shale with sandstone intercalations increasing upward. This sandy shale is interpreted to have been deposited in an alluvial environment.

Sixth-order T-R unit S2.2 is thickest in the northern part of the study area (locality D2) in the channel facies. Maximum regression is typically represented by an alluvial shale where the underlying channel facies developed. The occurrence of paleosols corresponds with thinner portions of T-R unit S2.2. These facies and isopach changes indicate that paleosols developed on topographically higher areas during deposition of sixth-order T-R unit S2.2.

Unit S2.3.--Maximum transgression for sixth-order T-R unit S2.3 is represented by a lenticular, bituminous coal bed in the northern part of the study area. This coal represents deposition in a relatively humid, swampy, subaerial environment. This climate change surface was initiated on both subaerial mudstones and alluvial shales. In the divide areas (localities P1 and P3) of this fluvial system, this climate change surface is represented by an alluvial shale overlying a mudstone with root traces. In central Franklin County, Kansas, climate change surface S2.3 is more cryptic and apparently is represented by a change from a channel facies to a nearshore facies. Farther south at locality F5, the channel facies was not observed and climate change surface S2.3 is contained within a thick sandstone deposit representing a nearshore facies. At localities F6 and A1, maximum transgression is represented by a lenticular bedded, silty shale containing common load casts and rippled intercalations with horizontal burrows. This shale also contains rhythmic interlaminations of siltstone that suggest deposition by regular processes. This silty shale is interpreted as a nearshore shale (possibly lower intertidal) influenced by tidal activity.

Maximum regression for sixth-order T-R unit S2.3 is predominantly represented by a non-fossiliferous shale and a non-fossiliferous mudstone that contains root traces and mottles (Figure 20). This shale represents deposition in an alluvial (possibly low lying coastal plain) environment, whereas the mudstone represents deposition in a subaerial (i.e., paleosol) environment. The channel facies was not observed in sixth-order T-R unit S2.3; however, maximum regression at locality D3 is represented by a very fine-grained sandstone deposit which thins northward and disappears north of the Kansas River. This siliceous, mature quartzarenite contains common ripple marks, flaser bedding, vertical burrows, and a few flame structures. These sedimentary structures indicate that this sandstone represents deposition in a nearshore (possibly intertidal zone) environment. Sixth-order T-R unit is thinnest in the northern parts of the study area. The subaerial environment at localities L5, L6, and L8 coincides with thinning of the interval. A diagrammatic cross-section (Figure 11) with a Haskell Limestone datum shows that this thinning corresponds to a paleotopographic high. This interval thickens towards the Kansas River where maximum regression is represented by an alluvial shale rather than a subaerial paleosol. A paleotopographic high, near the present day Kansas River (Figure 11), apparently influenced deposition of the aforementioned nearshore sandstone. This sandstone is absent north of locality L9, but thickens southward to locality D4 where the entire interval is comprised of sandstone. This locality also coincides with the restricted

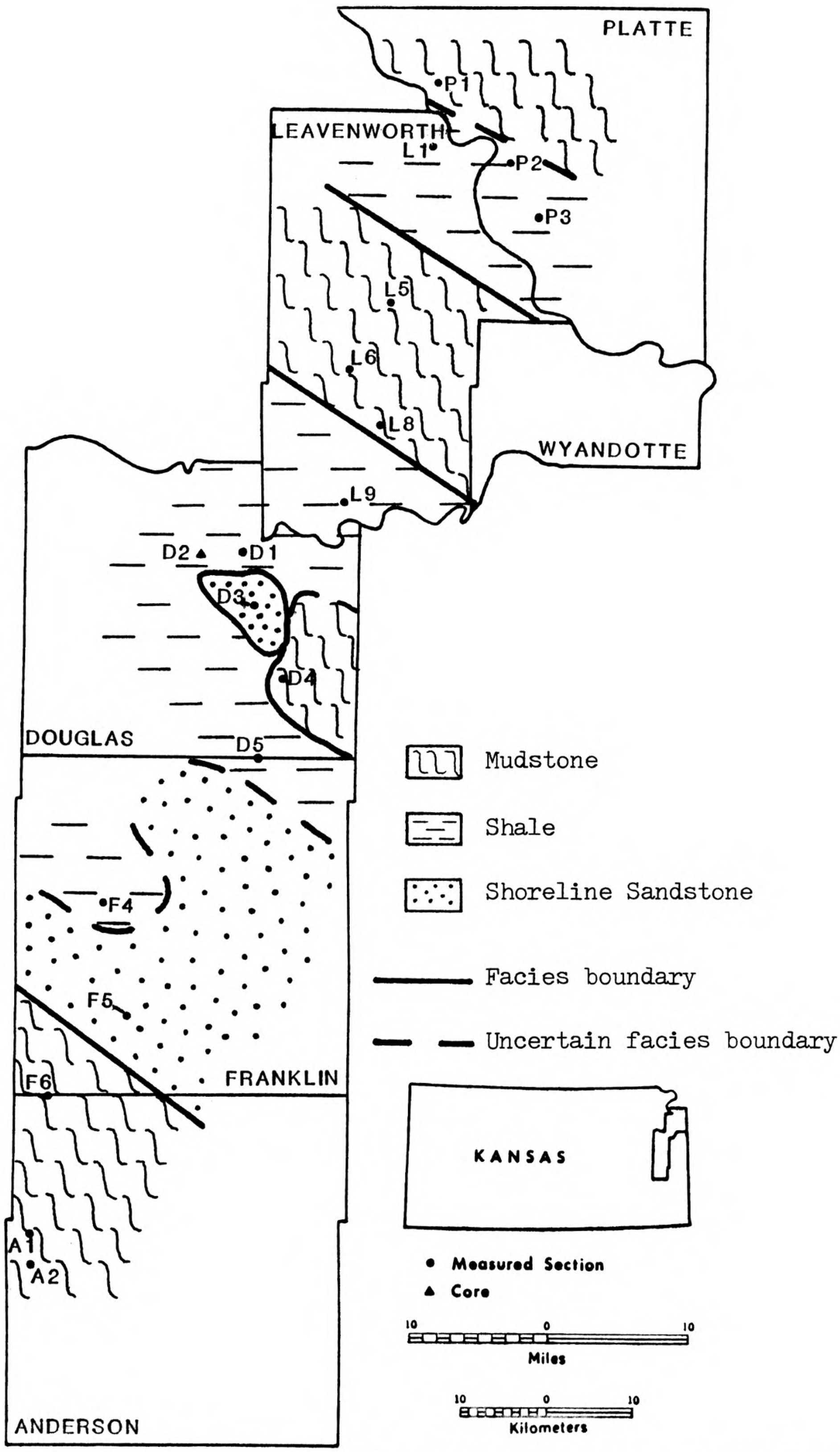


Figure 20. Paleogeographic map showing facies at maximum regression for sixth-order T-R unit S2.3 of the Stranger Formation.

deposition of the Westphalia Limestone during maximum transgression of sixth-order T-R unit S3.1. The thinning of the stratigraphically younger nearshore sandstone toward the north and the development of the restricted Westphalia Limestone facies in the Blue Mound area suggest that the northern Douglas County, Kansas, paleotopographic high may have been proximal to a shoreline during sixth-order T-R unit S2.3. Proximity to a shoreline would explain the deposition of shale rather than a paleosol commonly found on paleotopographic highs. South of locality D4, genetic surfaces bounding this interval are more cryptic; however, subaerial paleosols that developed during maximum regression indicate possible paleotopographic highs in northwestern Franklin and northern Anderson Counties, Kansas.

Unit S3.1.--Maximum transgression for sixth-order T-R unit S3.1 (Figure 21) within the northern part of the study area is represented by a coaly, argillaceous, ostracode, high-spired gastropod micrite. The discontinuous, thinly laminated limestone represents a restricted intertidal and shallow subtidal (possibly an intertidal marsh or lagoon) depositional environment. The abundance of well-preserved plant fossils and coal interlaminations attest to the restricted swamp-like conditions. The northern restricted marine facies was not observed south of Douglas County, Kansas. Maximum transgression in the northern part is also represented by a bituminous coal which

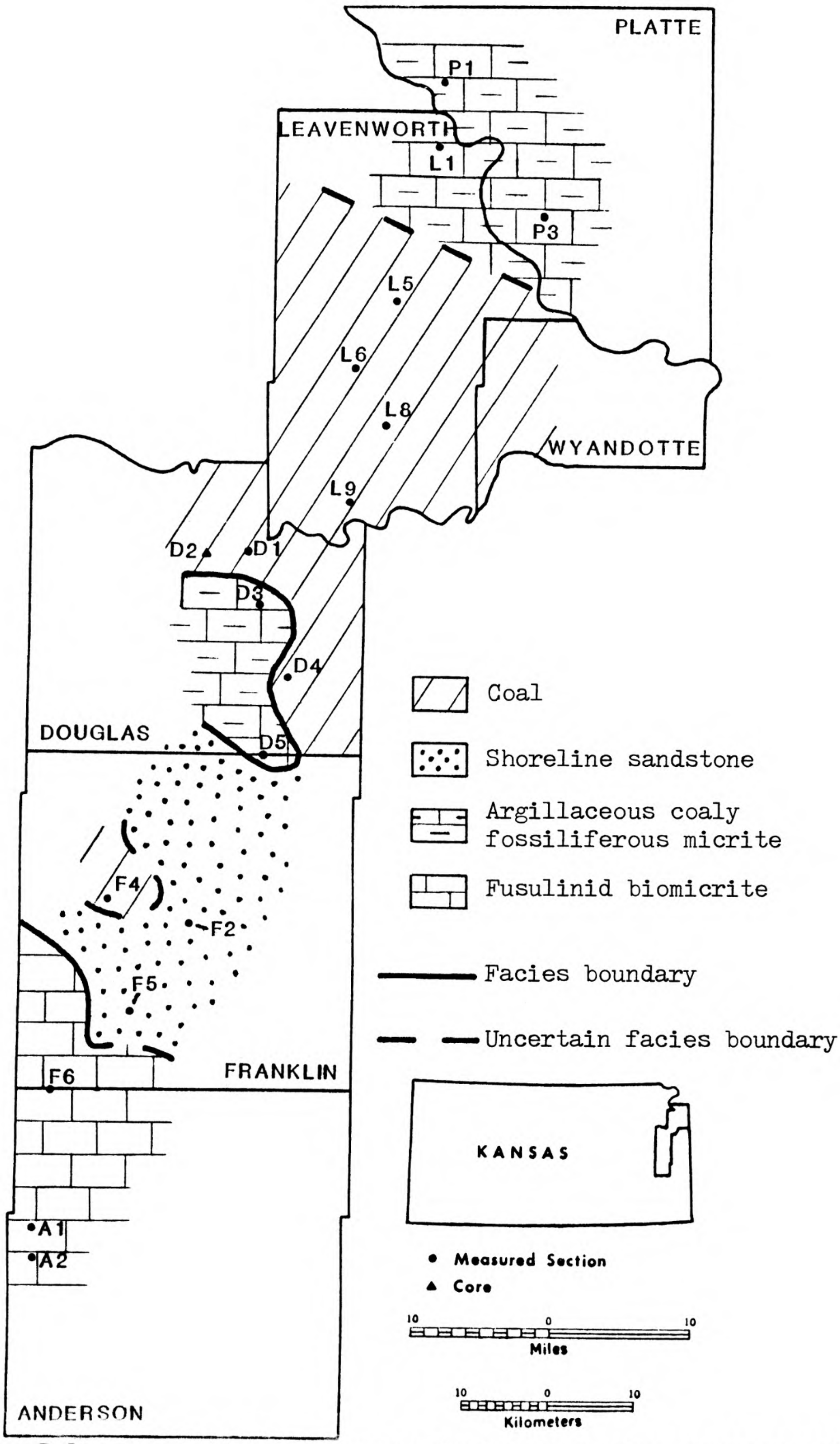


Figure 21. Paleogeographic map showing facies at maximum transgression for sixth-order T-R unit S3.1 of the Stranger Formation.

commonly overlies a paleosol. This coal represents deposition in a relatively humid, swamp-like, subaerial environment. Maximum transgression in the southern part of the study area (localities F6, A1 and A2) is represented by a silty, osagid, fusulinid biomicrite. The environment of deposition is inferred to be a very shallow subtidal or intertidal environment. Abundance of quartz silt and osagid coatings indicates proximity to the shoreline. The conglomeratic base of this limestone overlying a paleosol attests to episodic sedimentation at the start of transgression.

Maximum regression in sixth-order T-R unit S3.1 was not analyzed; however, several rhizoliths and vertical burrows were observed on the upper bedding surface of the Westphalia Limestone indicating subaerial exposure.

The best developed (thickest limestone) marine facies and concomitant Type 2 coals in the northern part of the study area coincides with the thickest intervals of the overlying Westphalia fifth-order T-R unit (Figure 11). Type 1 coals representing paleoenvironmentally more restricted environments (during maximum transgression) correspond to thin intervals of the overlying Westphalia fifth-order T-R unit. These isopach and facies changes indicate that the restricted marine facies developed in paleotopographic lows, whereas bituminous coals without a marine cap were developed on paleotopographic highs. The more open marine southern facies thins northward and finally disappears north of the Franklin County, Kansas line. This limestone invariably overlies a paleosol. Thinning of this paleosol southward coincides with thickening of the overlying Westphalia fifth-order T-R unit. These isopach and facies changes indicate that a paleotopographic high existed in Franklin County, Kansas, with more open marine conditions to the south in Anderson County, Kansas.

<u>Composite Facies Maps.</u>--The composite maps of facies changes at maximum transgression (Figure 22) for sixth-order T-R units S2.1 through S3.1 and maximum regression (Figure 23) for sixth-order T-R units S2.1 through S2.3 show that facies changes occur along a series of northwest-southeast trending paleotopographic highs and lows. Areas with recurrent facies changes occur in northeastern and central Leavenworth, northern Douglas, and central and southwestern Franklin Counties, Kansas. During maximum regression (Figure 23) recurrent facies also occur in central Leavenworth County, Kansas. Recurrent facies changes shown in Figure 22 and 23 indicate the possible influence of structural elements on the deposition of Tonganoxie sediments.

<u>Summary of Paleogeographic Trends.</u>--The paleogeographic maps and cross-sections illustrate the gradual shallowing upward and deterioration of humid conditions between genetic surfaces. These maps and cross-sections also show the

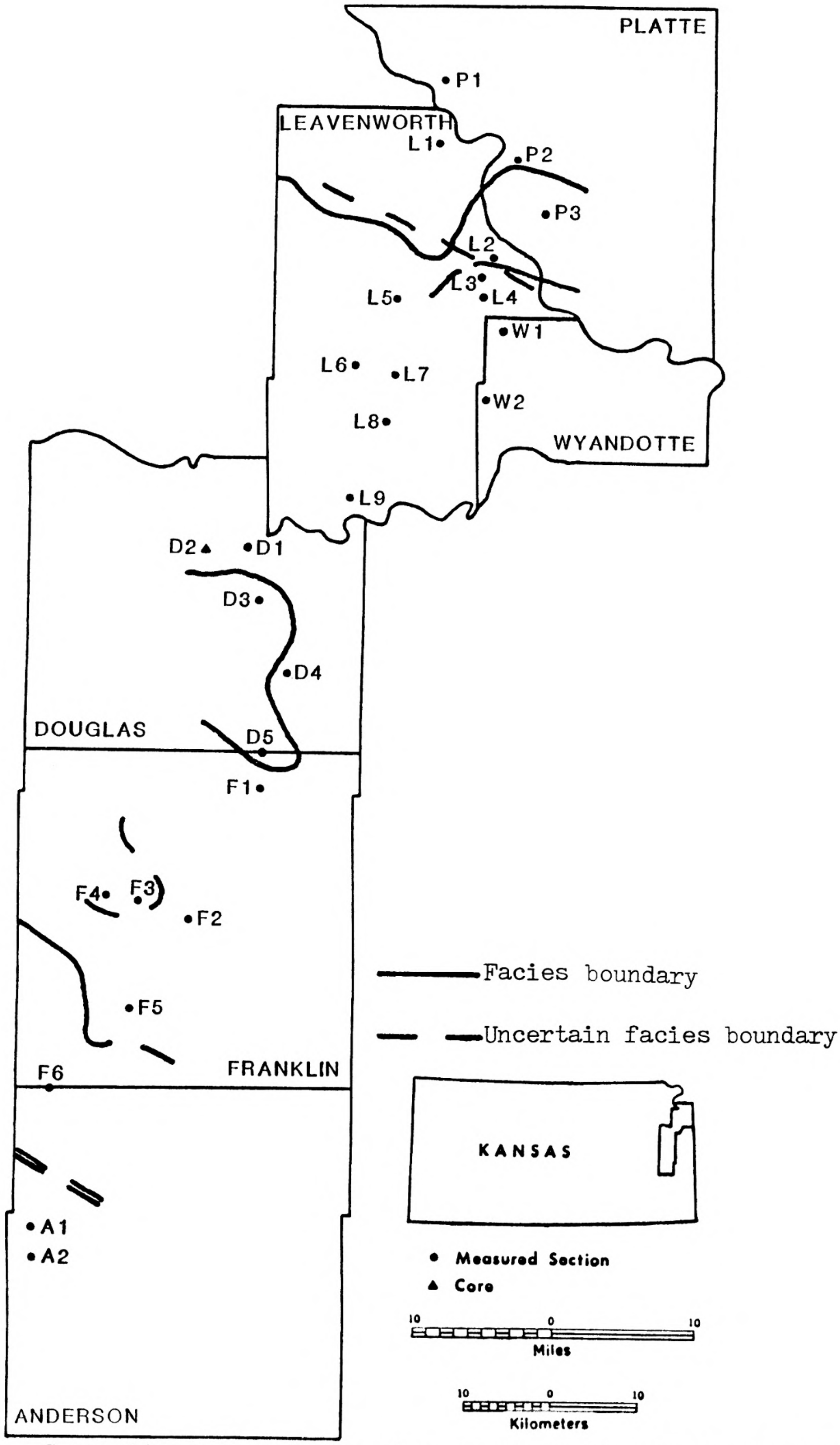


Figure 22. Composite map of facies changes at maximum transgression for sixth-order T-R units S2.1- S3.1 of the Stranger Formation.

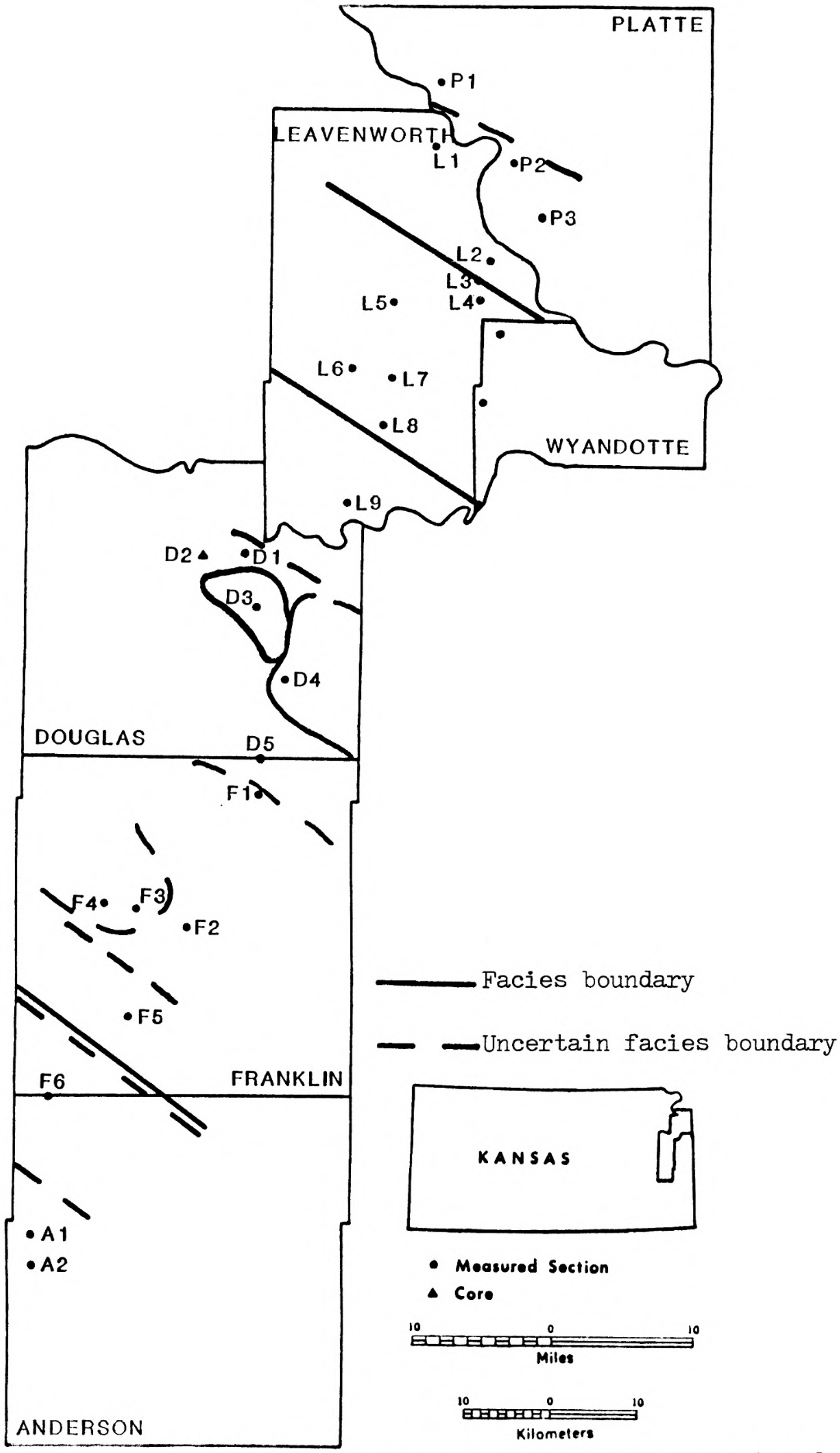


Figure 23. Composite map of facies changes at maximum regression for sixth-order T-R units S2.1-S3.1 of the Stranger Formation.

paleoenvironmental changes of the Iatan fifth-order T-R unit as a series of successively less extensive sixth-order transgressions and climate changes. Maximum transgression for sixth-order T-R unit S2.1 also corresponds to the most transgressive conditions for the entire Iatan fifth-order T-R unit. Sixth-order T-R unit S2.1 contains the only marine facies in the Iatan fifth-order T-R unit. These marine facies are in the extreme northern and southern parts of the study area; however, a non-fossiliferous limestone described by Ball (1964, p. 376) located directly south of locality F2 may also represent the transgressive maxima of sixth-order T-R unit S2.1. Maximum transgression in the rest of the study area is predominantly represented by a transgressive lag deposit.

The Iatan fifth-order regressive sequence comprises most of the Iatan fifth-order T-R unit and consists of a series of successively less extensive climate changes. Overall trends include the development of coal beds representing relatively humid, swamp-like, subaerial conditions north of Anderson County, Kansas. The geographic extent of these coal beds becomes progressively smaller upward through the Iatan fifth-order T-R unit. In Franklin County, Kansas, the climate change surface represents sixth-order T-R unit S2.2 that is more cryptic and is contained within a thick shoreline sandstone where environmental conditions were not condusive to coal development. South of Franklin County, Kansas, climate changes are represented by nearshore shales that were influenced by tidal activity. Maximum regression for sixth-order T-R units is predominantly represented by paleosols and alluvial shales; however, a fluvial sandstone in Leavenworth and Douglas Counties, Kansas, represents maximum regression in sixth-order T-R unit S2.1.

Facies changes in the fifth-order transgressive sequence (sixth-order T-R unit S2.1) suggest that the extreme northern and southern parts of the study area were topographically lower than the central portions. The overall facies changes in the fifth-order regressive sequence indicate a series of northwest-southeast trending paleotopographic highs and lows oriented approximately perpendicular to the paleoslope. Paleotopographic highs are located in central Leavenworth, northern Douglas, and central and southern Franklin Counties, Kansas. The size and lateral extent of these paleotopographic highs varies. Topographic highs in central Leavenworth and central Franklin Counties, Kansas, are broad features, whereas the topographic highs in northern Douglas and southern Franklin Counties are smaller. The composite paleogeographic maps (Figures 22 and 23) and cross-sections (Figures 9 and 11) show a greater effect of the topographic highs during the maximum regressive phases of the sixth-order T-R units. In summary, the topographic highs and lows affected the thickness and depositional environments of the sediments within the Iatan fifth-order T-R unit.

Structural Controls over Tonganoxie Deposition

The principal structural features within the area of study include the Forest City Basin, Schell City-Rich Hill Anticline, and Bourbon Arch (Figure 5). The major structural features are conspicuously oriented in a northwest-southeast direction (Figure 24). Two northwest plunging anticlines in Leavenworth, Wyandotte, and Douglas Counties, Kansas, may be a northwest extension of the Ladue-Freeman Anticline (Figure 24). The Schell City-Rich Hill Anticline trends northwest across central Franklin County, Kansas, and is an upthrown fault block directly southeast of the study area in Linn County, Kansas. South of the Schell City-Rich Hill Anticline is the Bourbon Arch which trends northwest across Anderson County, Kansas. The northern edge of the Bourbon Arch is shown in Figure 5 as a northwest extension of a fault block in Bourbon County, Kansas; however, the Precambrian structure contour map (Figure 24) shows a more northern orientation in Anderson County, Kansas beyond this fault trace. The Bourbon Arch remained a positive and active structural feature during the Late Pennsylvanian (Price, et al. 1985). These structures are considered to be foreland expressions of the Pennsyl-

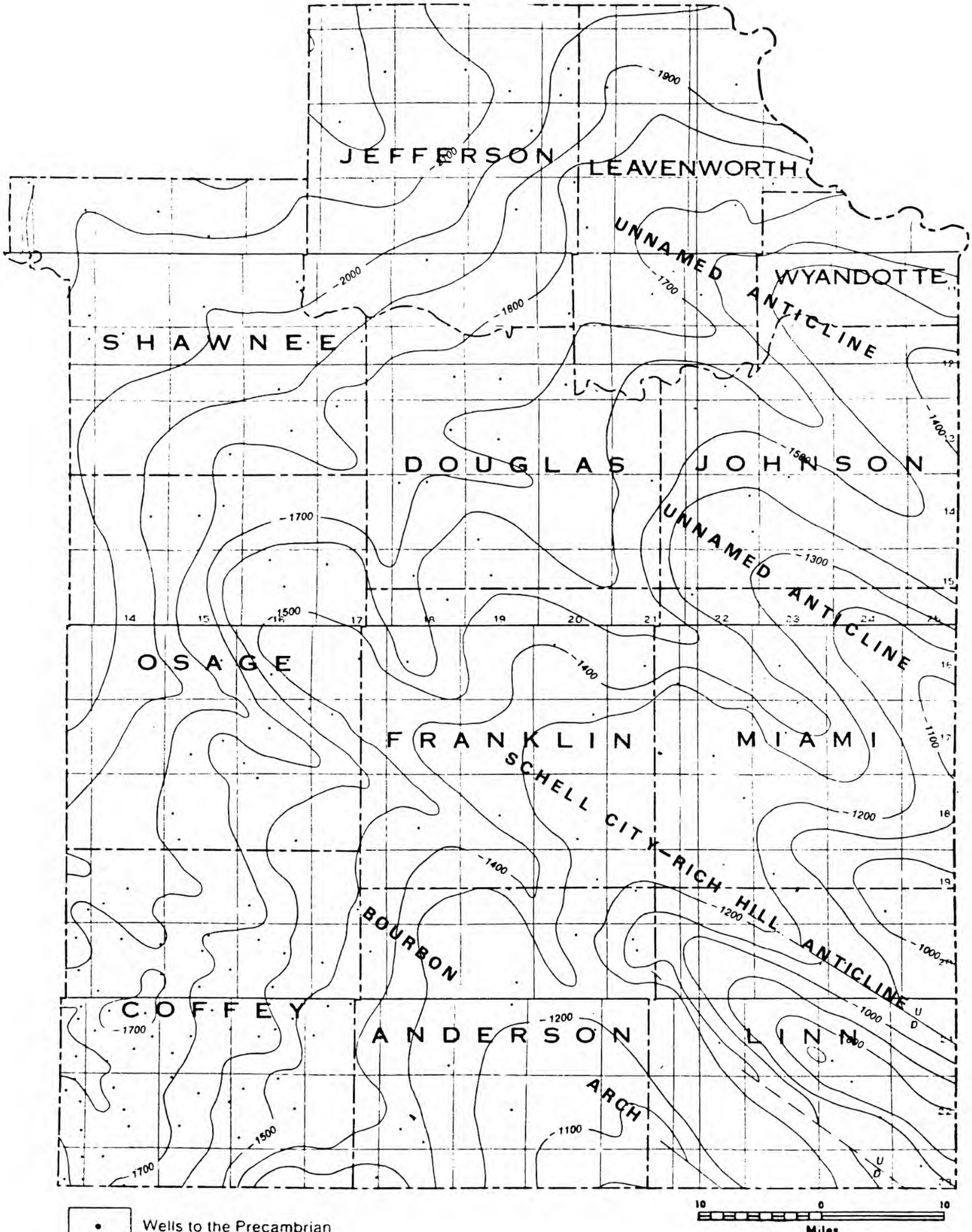


Figure 24. Structure contour map of the top of the Precambrian rocks within the area of study (from Cole, 1976).

vanian Ouachita orogeny produced by continent to continent collision to the south (Berendson and Blair, 1986).

Although lack of control data prevented production of isopach maps, the cross-section (Figure 11) shows thinning and thickening of the Iatan and Westphalia fifth-order T-R units. The isopach changes in the Westphalia fifth-order T-R unit reflect paleotopographic highs and lows at the conclusion of Tonganoxie time. Geologically instantaneous climate change results in the Upper Sibley coal and Westphalia Limestone tracing paleotopography during maximum regression of the Iatan fifth-order T-R unit. Comparison of isopach changes (Figure 11) with the Precambrian structure contour map (Figure 24) shows the influence of aforementioned minor and major structural elements. A general correlation exists between structural highs and thinning of T-R units and between structural lows and thickening of T-R units. Structural elements also influence facies changes observed during maximum transgression and regression of sixth-order T-R units. Both composite facies maps of maximum regression and maximum transgression show numerous facies changes above the structures. Genetic surfaces with both marine and nonmarine facies commonly show the marine facies coinciding with structural lows and the nonmarine facies overlying structural highs. For example, during maximum transgression of T-R unit S3.1 (Figure 11), the humid, subaerial coal facies overlies the Schell City-

Rich Hill Anticline and both unnamed northwest plunging anticlines to the north. The restricted marine facies of the Westphalia Limestone coincides with northwest trending structural lows between the structural highs.

The unnamed northwest plunging anticline in Leavenworth and Wyandotte Counties, Kansas, is an area of recurrent facies change. During maximum transgression of fifth-order T-R unit S2.1, the marine algal biomicrite grades southward into a beach gravel and finally into a tidal flat environment near the northern edge of the anticlinal feature. These paralic sediments and underlying Weston Shale also thin toward the anticline which apparently caused the shoaling environments. A topographic high associated with thinning of sixth-order T-R unit S2.3 and fifth-order T-R unit S3.1 directly overlies this anticline. Paleosols developed above this structural high, whereas shale was deposited on the flanking structural lows.

The unnamed northwest plunging anticline in extreme southern Leavenworth and northeastern Douglas Counties, Kansas, is also an area of numerous facies changes. A paleotopographic high associated with thinning of the Westphalia fifth-order T-R unit directly overlies this anticline. Although the study area is near the northern edge of this anticline, the subaerial coal facies is developed above this structural feature, whereas the restricted marine coaly micrite was deposited in the flanking structural lows. During sixth-order T-R unit S2.3, a nearshore sandstone was deposited in a structural low on the northwestern edge of this anticline. This anticlinal feature apparently caused thinning of the nearshore sandstone toward the north, where it disappeared north of the Kansas River. During maximum regression of sixth-order T-R unit S2.3, a paleosol developed on a paleotopographic high which overlies the northern edge of this anticline, whereas shale was deposited in a structural low on the southern flank.

The Schell City-Rich Hill Anticline is a rather broad structural high which caused numerous facies changes. A paleotopographic high associated with thinning of the Westphalia fifth-order T-R unit overlies this anticline. This large feature was a barrier to marine influx which clearly caused the lithofacies change of the Westphalia Limestone from a restricted marine, coaly micrite on the northern flank to a more open marine, fusulinid biomicrite on the southern flank. During maximum transgression of the Iatan fifth-order T-R unit, a transgressive lag deposit was deposited on this topographic high. The aforementioned area in northwestern Franklin County, Kansas, (Figure 16) where no sandstone was deposited, directly overlies the Schell City-Rich Hill Anticline. This large structural feature apparently caused the northwest diversion of the fluvial sandstone channels in sixth-order T-R unit S2.1 and subsequent deposition of shoreline sandstones in sixth-order T-R unit S2.2. This shoreline sandstone thickened toward the south in the structural low between the Schell City-Rich Hill Anticline and Bourbon Arch.

The Bourbon Arch also caused facies changes, but not to the degree of the Schell City-Rich Hill Anticline. The Bourbon Arch caused the development of thick paleosols at the Franklin-Anderson County, Kansas, line during maximum regression of sixth-order T-R units S2.1, S2.2, and S2.3. The upper paleosol thins toward the south on the southwestern flank of the Bourbon Arch, whereas the two lower paleosols undergo a facies change to a sandy shale. A sandy biosparite was deposited on the southwestern flank of the Bourbon Arch during maximum transgression of the Iatan fifth-order T-R unit.

In summary, both minor and major structural elements affected deposition of the Iatan Limestone, Tonganoxie Sandstone, and Westphalia Limestone. Paleotopographic highs and lows influenced by these structural features affected both thickness and depositional environments of the sediments within the Tonganoxie Sandstone.

MARKOV CHAIN ANALYSIS

The Markov process is a systematic, statistical method "in which the probability of the process being in a given state at a particular time may be deduced from knowledge of the immediately preceding state." (Harbaugh and Bonham-Carter, 1970, p. 98). Markov chain analysis was initially going to be used to define lithofacies relationships, and build a general facies model for the entire Tonganoxie Sandstone Member. The lack of complete stratigraphic sections within the study area precluded this approach. The Markov process was used to test the PAC hypothesis (Goodwin, et al., 1986) that deeper or more humid facies overlie shallower or subaerial (often arid) facies at genetic surfaces between T-R units. The upper bounding surface of the Tonganoxie (T-R unit S3.1) was utilized to check for Markovian properties because of the relative abundance of outcrops. The underlying and overlying rock types at genetic surface S3.1 were rated according to humidity or relations with sea level. The facies ratings in order of increasing humidity or water depth are: (1) mudstone, (2) shale, (3) shoreline sandstone, (4) coal, (5) restricted marine limestone, and (6) open marine limestone.

The frequency of the rock types was: mudstone, 8; shale, 7; sandstone, 1; coal, 5; restricted limestone, 5; and open limestone, 3. The indepedent trials matrix (Table

Table 3. Independant Trials Matrix

		MS	SH	SS	C	RLS	OLS
Mudstone	MS	.00	.24	.03	.45	.17	.10
Shale	SH	.27	.00	.03	.43	.17	.10
Sandstone	SS	.22	.19	.00	.36	.14	.08
Coal	C	.33	.29	.04	.00	.21	.13
Restricted Limestone	RLS	.25	.22	.03	.41	.00	.09
Open Limestone	OLS	.24	.21	.03	.38	.15	.00

Table 4. Transition Probability Matrix

		MS	SH	SS	C	RLS	OLS
Mudstone	MS	.00	.00	.00	.63	.00	.38
Shale	SH	.00	.00	.00	.10	.00	.00
Sandstone	SS	.00	.00	.00	1.0	.00	.00
Coal	C	.00	.00	.00	.00	1.0	.00
Restricted Limestone	RLS	.00	.00	.00	.00	.00	.00
Open Limestone	OLS	.00	.00	.00	.00	.00	.00

3) represents the probability that a transistion occurs randomly. The independent trials matrix of a coal overlying a mudstone is calculated by dividing the number of coal beds by the total number of non-mudstone beds. Here the probability of a coal overlying a mudstone is 0.45. The transition probability matrix (Table 4) gives the actual probability of the given transition. The transition probability of a coal following a mudstone is the number of transitions from mudstone to coal divided by the sum of transitions from mudstone to coal, shale, sandstone, restricted limestone, and open limestone. Here this probability is 0.63. The difference matrix (Table 5) with positive and negative values is obtained by subtracting the independent trials matrix from the transition probability matrix. The positive entries indicate which transitions have occurred with greater than random frequency. The chi-square test is used to check that the differences given in Table 5 are the result of a random process. In the bedding sequence at genetic surface S3.1, the total number of positive entries is 30, the rank is 6, and the degrees of freedom is 24. The results of the chi-square test (Table 6) is 75.84 with 24 degrees of freedom. The limiting value at the 95 percent confidence level of the null hypothesis is 36.42; therefore, Markovian properties are indicated in the upper strata of the Tonganoxie Sandstone Member.

A transition (e.g., sandstone overlain by coal) caused

Table 5. Difference Matrix

		MS	SH	SS	C	RLS	OLS
Mudstone	MS	.00	-.24	-.03	.18	-.17	.28
Shale	SH	-.27	.00	-.03	.57	-.17	-.10
Sandstone	SS	-.22	-.19	.00	.64	-.14	-.08
Coal	C	-.33	-.29	-.04	.00	.79	-.13
Restricted Limestone	RLS	-.25	-.22	-.03	-.41	.00	-.09
Open Limestone	OLS	-.24	-.21	-.03	-.38	-.15	.00

Table 6. Test of significance

χ^2	d.f.	Critical value for rejection at = 0.05.
75.84	24	36.42

a concern about sample validity. The statistical rule for sample size using the chi-square test is that no more than 20 percent of the cells can have a value less than 5. Here twenty-seven percent of the values are less than five; therefore, the sample size and repeatability of the results are questionable.

The positive entries in the difference matrix (Table 5) indicate transitions which have a greater than random frequency of occurring. The sequence of positive entries is diagrammed in Figure 25. This diagram shows the transitions that occurred at the base of the Westphalia fifth-order T-R unit with a higher than random probability. This diagram with facies ratings relative to sea level illustrates deeper or more-humid facies overlie shallower or subaerial facies at all transitions. Although sample valdity is a concern, examination of the facies ratings shows no transitions from a deeper or more humid environment at this genetic surface. The results of the Markov analysis support the PAC hypothesis. These Markovian properties are regarded as the result of climate change and associated glacio-eustatic sea level fluctuation.

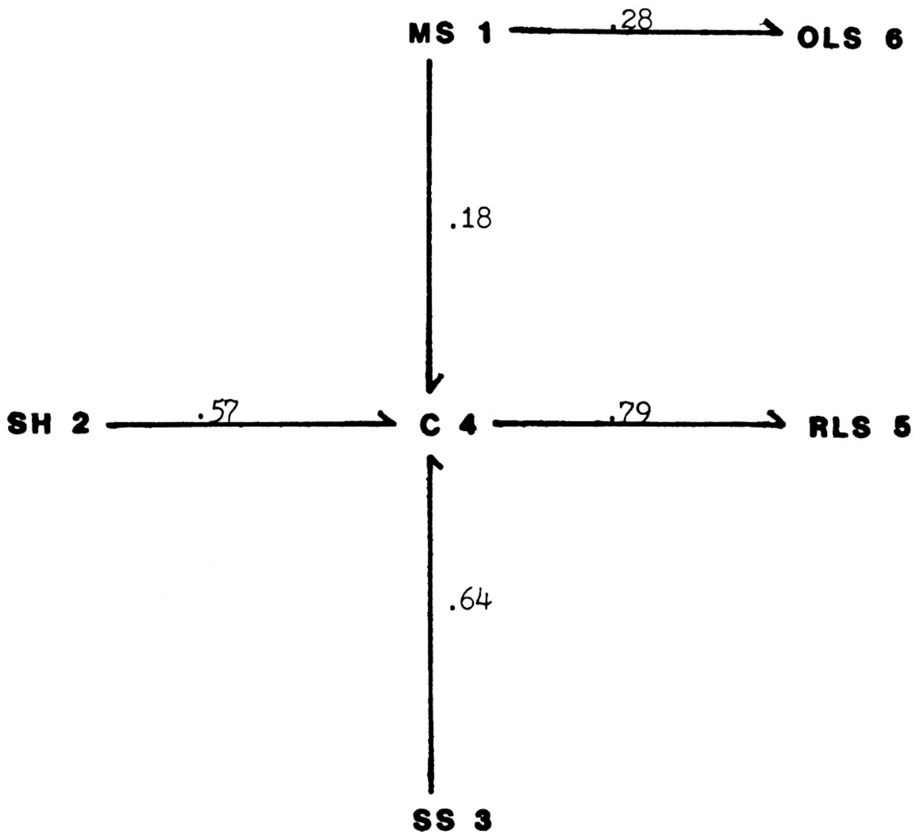


Figure 25. Sequence of positive entries in the difference matrix for genetic surface S3.1 in the Stranger Formation. MS = mudstone, SH = shale, SS = sandstone, C = coal, RLS = restricted limestone, OLS = open limestone.

CONCLUSIONS

The Tonganoxie Sandstone Member consists of several lithologies including two types of conglomerate, two types of sandstone, shale, mudstone, and coal. The sandstone part of the Tonganoxie Sandstone Member contains several stratification types and sedimentary structures.

The conglomerates rest disconformably on the Stanton Formation, Weston Shale Member, and Iatan Limestone Member, and attain a maximum thickness of 3.4 m. (11.2 ft.). The calcareous limestone conglomerate is a light gray, fine-sandy, pebble conglomerate classified as a calcareous, submature, fossiliferous, recrystallized sedrudite. The lack of siliceous cement, overcrowding of grains, and the abundance of carbonate sand are diagnostic features of this conglomerate. The quartzose conglomerate is a medium-sandy, pebble conglomerate classified as a siliceous, ferruginous, and locally calcareous, submature, micaceous, recrystallized sedrudite. Imbrication of discoidal limestone and clay pebbles is developed locally, and dip directions are in the approximate opposite direction of associated trough cross-bed azimuths. Recrystallized and dissolved grains, and the abundance of Fe-oxides as cement and stain are characteristic of this conglomerate.

Two types of sandstone occur in the study area. Sandstones in the northern part of the study area are predominantly fine- to medium-grained sandstones classified as siliceous, submature quartzarenites. These sandstones contain abundant trough cross-beds with set size decreasing upward. The most common dip directions are south-southwest and southwest. The northern sandstone facies also contains planar beds, asymmetrical ripples, flaser to wavy beds, structureless beds, and sole marks. The other sandstone facies crops out in east-central Leavenworth and central Franklin Counties, Kansas. This sandstone is predominantly a very fine to fine, siliceous, locally calcareous, mature quartzarenite, and consists of rippled beds, flaser and wavy beds, planar laminations, structureless beds, planar cross-beds, and convoluted beds.

Shale is the predominant rock type in Anderson County, Kansas, and comprises most upper Tonganoxie strata in the northern part of the study area. Shale of the upper Tonganoxie in the northern part of the study area is light gray to medium gray with blue overtones, and grades vertically from planar and rippled, very thin- to thin-bedded siltstone and sandstone to silty shale, and finally clay shale. Shale in Anderson County, Kansas, is pale olive to gray green and contains common calcareous and glauconitic sandstone intercalations and load casts.

Mudstone occurs below all coal beds locally, but develops extensively below the Upper Sibley coal and Westphalia Limestone. Tonganoxie mudstones share several characteristics including sharp upper contacts, gradational lower contacts, very weakly to moderately developed horizons, root traces and mottles, bleached appearance of upper horizons, and lack of fissility.

The Tonganoxie Sandstone Member contains three horizons of bituminous coal beds that are named Blue Mound, Lower Sibley, and Upper Sibley. These coal beds are lenticular, and range considerably in thickness from featheredge smuts to 76 cm. (2.5 ft.). All coal beds are restricted to the northern part of the study area, and their absence south of Franklin County, Kansas, is a striking characteristic of Tonganoxie coals.

Analysis of sedimentary structures and lithofacies relationships indicates that the Tonganoxie Sandstone Member of the Stranger Formation (Upper Pennsylvanian, Virgilian) represents a variety of depositional environments. This study suggests that the Tonganoxie is a confined valley-fill deposit in the northern part of the study area. Distinguishing features of the sandstones of this facies include: (1) dominance of large- to moderate-scale trough cross-beds, (2) upward decrease in scale of troughs, (3) slight upward fining in grain size, (4) thin channel lag deposit, (5) silt and shale on top of sandstone, (6) interruption of sandstone deposition by coal or carbonaceous shale, (7) base of channel in contact with a variety of underlying facies, (8) high width/thickness ratio and, (9) relatively straight channels. These characteristics typify a confined valley-fill depositional model (Brown, et al., 1973). The shale units above the sandstone section represent abandoned channel-fill and post-fluvial estuarine deposits, whereas mudstones with root traces and mottles represent paleosols. Coals were deposited in relatively humid, swamp-like, subaerial environments as a result of climate change.

Most sandstones in the southern part of the study area represent shoreline deposits. Shale associated with these shoreline sandstones was deposited in an alluvial (possibly low lying coastal plain) environment or shallow water marine environment. This study indicates a calcareous limestone conglomerate described by Ball (1964) is correlative with the Iatan Limestone and represents a beach or nearshore gravel deposit. A sandstone section south of these beach deposits with current and wave ripples showing bimodal azimuth directions indicates that an east-west oriented shoreline was established near Leavenworth, Kansas, at the beginning of Tonganoxie sedimentation.

Analysis of the Tonganoxie Sandstone Member using a hierarchal transgressive-regressive approach has provided insight into environmental conditions on a finer scale than cyclothems. The recognition of climate change surfaces within the Tonganoxie enabled the correlation of minor transgressions through this nonmarine interval. This interval, extending from the top of the Iatan Limestone to the base of the Westphalia Limestone, represents most of a fifth-order T-R unit and is divisible into sixth-order T-R units. Although these sixth-order T-R units are locally thicker than PACs, they are correlative over the entire study area, and conform to Goodwin and Anderson's (1985) Hypothesis of Punctuated Aggradational Cycles (PACs).

The Tonganoxie Sandstone Member represents the regressive phase of the Iatan fifth-order T-R unit and is comprised of two complete sixth-order T-R units and the regressive phase of one sixth-order T-R unit. The Iatan Limestone contains the transgressive apex of the Iatan fifth-order T-R unit and coincides with the basal sixth-order genetic surface (S2.1) of the Tonganoxie Sandstone Member. The two genetic surfaces (S2.2 and S2.3) contained in the Tonganoxie Sandstone bound the Blue Mound sixth-order T-R unit and Lower Sibley sixth-order T-R unit. The upper bounding genetic surface (S3.1) represented by the base of Upper Sibley Coal or Westphalia Limestone mark the initiation of the overlying Westphalia fifth-order T-R unit. The Iatan fifth-order T-R unit may represent a time interval of about 300,000-500,000 years (Busch and West, 1987); therefore, sixth-order T-R units may represent time intervals of about 100,000-167,000 years.

Paleogeographic maps and cross-sections illustrate the gradual shallowing upward and deterioration of humid conditions between genetic surfaces. Facies changes in the fifth-order transgressive sequence (sixth-order T-R unit S2.1) suggest that the extreme northern and southern parts of the study area were topographically lower than the central parts. Overall facies changes in the fifth-order regressive sequence indicate a series of northwest-southeast trending paleotopographic highs and lows oriented approximately perpendicular to the paleoslope. Topographic highs are located in central Leavenworth, northern Douglas, and central and southern Franklin Counties, Kansas.

Minor and major structural elements including two unnamed northwest plunging anticlines, Schell City-Rich Hill Anticline, and Bourbon Arch affected deposition of the Iatan Limestone, Tonganoxie Sandstone, and Westphalia Limestone. A general correlation exists between structural highs and thinning of T-R units and between structural lows and thickening of T-R units. Genetic surfaces with both marine and nonmarine facies commonly show the marine facies coinciding with structural lows and nonmarine facies overlying structural highs. Paleotopographic highs and lows influenced by these structural features affected both thickening and depositional environments of Tonganoxie sediments.

Markov analysis shows deeper or more-humid facies overlie shallower or arid subaerial facies at the upper bounding surface of the Tonganoxie (T-R unit S3.1) which supports the PAC hypothesis. These Markovian properties are regarded as the result of climate change and associated glacio-eustatic sea level fluctuation.

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APPENDIX I

This appendix contains locations of all outcrops, and descriptions of measured sections not described by previous authors. The measured sections include formal stratigraphic names, descriptions of all lithology changes, and thickness of beds. The bed numbers in this appendix correspond to the bed numbers of the cross-sections shown in Figure 9 and Figure 10.

P1. Active quarry, NW1/4, NW1/4, sec. 33, T. 54 N., R. 36 W., Platte Co., Missouri. Measured and described by Jacki Spriggs in Jan., 1986.

Unit Descriptions

Bed Number	Thickness m.	ft.
Haskell Ls. Mbr.		
21. Fossiliferous, calcitic, shale; medium dark gray; planar, subparallel thin laminations by macerals and mica; sparse brachiopods, crinoids, and forams..........................	.12	.39
20. Fine calcirudite: ferruginous, silty, brachiopod, crinoid, osagid biomicrite; sharp contacts; medium dark gray to dark yellow orange; single, resistant, planar, parallel medium bed.................................	.21	.69
19. Mudstone; sharp lower contact; medium gray; planar, subparallel to nonparallel, thin to thick laminations; sparse crinoids, forams, and brachiopods.....................	.29	.95
18. Shale; sharp upper contact; dark gray; planar, parallel, thin to medium laminations.	.40	1.31
17. Fossiliferous shale; gradational upper contact; gray black; planar, parallel, thin laminations; weathers to granular rubble; common crinoids,forams; sparse brachiopods..	.11	.36
16. Fine calcirudite: brachiopod biomicrite; sharp contacts; medium gray with common dark gray burrows; single, planar, parallel medium bed; abundant brachiopods; common crinoids; sparse gastropods, bivalves, and forams.....	.29	.95
Vinland Sh. Mbr.		
15. Fossiliferous, calcitic mudstone; sharp upper contact; medium gray; curved, non-parallel, discontinuous bedding; sparse brachiopods.................................	.30	.98
14. Calcilutite: partly recrystallized, argillaceous, brachiopod micrite; gradational contacts by weathering; medium gray; weathers light brown; curved, nonparallel, discontinuous bedding; sparse brachiopods.................	.30	.98
13. Fossiliferous, calcitic mudstone; gradational contacts; medium gray; curved, nonparallel, discontinuous bedding; sparse brachiopods.................................	.42	1.38
12. Same as bed 14.........................	.31	1.02

Section P1 continued.

11. Fossiliferous, calcitic mudstone; gradational contacts; medium gray; curved, nonparallel, discontinuous bedding; common myalinids, sparse crinoids and brachiopods.	1.12	3.67
10. Calcilutite: Partly recrystallized, argillaceous, bivalve, brachiopod micrite; gradational contacts; medium dark gray; weathers light brown; single, planar, parallel, thick bed; sparse bivalves and brachiopods..	.30	.98
9. Fossiliferous, calcitic mudstone; gradational contacts; medium gray; curved, nonparallel, discontinuous, thin to medium beds; common to abundant myalinids; sparse brachiopods..............................	1.20	3.94
Westphalia Ls. Mbr.		
8. Coal; gradational upper contact increasing in silt content upward; black to medium dark gray; planar, parallel, very thin beds grading upward into subparallel, discontinuous, medium laminations.................................	.10	.33
7. Medium calcilutite: coaly micrite; gradational upper contact; medium dark gray; undulating, subparallel, discontinuous, thin to medium laminations by carbonized plant fragments; very thin to thin, undulating, intercalated coal stringers.................	.21	.69
Tonganoxie Ss. Mbr.		
6. Mudstone; sharp upper contact; blue gray to medium dark gray with dark yellow orange mottles in upper 30 cm.; remnant bedding near base; common to abundant root casts.........	.95	3.12
5. Shale; gradational upper contact by lack of bedding; medium blue gray; planar, parallel, discontinuous to continuous thin laminations; sparse, calcitic, silty, horizontal burrows.	1.00	3.28
4. Silty mudstone; channel fill; sharp upper contact; light blue gray; no bedding........	1.20	3.94
3. Lenticular bedded very fine sandstone: siliceous, mature quartzarenite; sharp lower contact; exposed near channel margin below disconformity; medium gray shale with yellow gray sandstone; parallel, discontinuous to continuous ripple cross-laminations in thin-laminated shale; very thin planar-lamianted, light olive gray, calcitic sandstone bed below a nodular limestone bed near the upper contact.................................	2.20	7.22

Section P1 continued.

Iatan Ls. Mbr.

2. Fine calcirudite: slightly pyritized, recrystallized, osagid, fusulinid biosparite; sharp contacts; medium light gray, single, resistant, planar, parallel, thick bed; sparse pyrite replaced fusulinids; osagid-encrusted skeletal fragments of brachiopods, bryozoans, and phylloid algae.......................... .80 2.62

1. Medium calcirudite: recrystallized, algal biomicrite; sharp upper contact; light gray; irregular, undulating, parallel to subparallel very thin to thin beds; common sparry algal fronds; sparse bryozoans, brachiopods, and fusulinids............... 4.45 14.60

P2. Roadcut, SE1/4, NE1/4, sec. 31, T. 53 N., R. 35 W., Platte Co., Missouri. Measured and described by S.M. Ball in July, 1959. Section P2 modified after Ball (1964, p. 352).

P3. River bluff and abandoned quarry, SW1/4, NE1/4, sec. 17, T. 52 N., R. 35 W., Platte Co., Missouri. Measured and described by S.M. Ball. Section P3 from Ball (1964, p. 91).

L1. Streamcut, SW corner, NE1/4, sec. 4, T. 8 S., R. 22 E., Leavenworth Co., Kansas. Originally measured and described by A.L. Bowsher in July, 1942. Section description in Basic Geology Division, State Geological Survey of Kansas files. Section L1 slightly modified after Ball (1964, p. 377).

L2. Abandoned quarry, NE1/4, SE1/4, sec. 18, T. 9 S., R. 23 E., Leavenworth Co., Kansas. Measured and described by S.M. Ball and H.A. Mendoza in June, 1959. Section L2 from Ball (1964, p. 378).

L4. Streamcut, SE1/4, NE1/4, sec. 35, T. 9 S., R. 22 E., Leavenworth Co., Kansas. Measured and described by Jacki Spriggs in July, 1985.

Section L4 continued.

Unit Descriptions

Bed Number	Thickness m.	ft.
Tonganoxie Ss. Mbr.		
22. Structureless fine sandstone: siliceous, submature quartzarenite; disconformable lower contact; massive; light brown; no bedding...	3.30	10.82
21. Fine sandy clay granule conglomerate: clayey, immature sedrudite; disconformable lower contact; light brown with gray olive, flat-granule, clay clasts....................	.30	.98
20. Structureless conglomeritic fine sandstone: siliceous, submature quartzarenite; disconformable lower contact; light brown; abundant clay-ironstone flat pebbles in lower 20 cm.; sparse planar bedding by flat to spherical, clay-ironstone clasts.........	1.51	4.95
19. Trough X-bedded fine sandstone: siliceous, mature quartzarenite; erosional contacts; dark yellow brown with dark brown bedding planes; trough, tangential, thin beds by hematitic crusts...................	.65	2.13
18. Trough X-bedded fine sandstone: siliceous, mature quartzarenite; erosional contacts; dark yellow brown with gray black bedding planes; trough, very thin to thin X-beds by macerals and mica................	.35	1.15
17. Structureless very fine sandstone: siliceous, mature quartzarenite; sharp contacts; irregular thickness; lenticular external form; light brown; stained dark yellow orange; no bedding..................	.30	.98
16. Very fine sandy pebble conglomerate: immature sedrudite; disconformable lower contact; irregular thickness; light brown; no bedding...................................	.17	.56
15. Structureless fine sandstone: siliceous, submature, quartzarenite; pebble conglomerate at base; lenticular external form; irregular thickness; light brown; no bedding..........	.21	.69
14. Flaser to wavy bedded fine sandstone: siliceous, immature quartzarenite; sharp contacts; light brown with gray olive flasers; undulating, parallel, thin to medium beds by clay.......................................	.20	.66
13. Clayey fine sandy granule conglomerate: siliceous, immature sedrudite; disconformable lower contact; irregular thickness; gray olive; no bedding..........................	.15	.49

Section L4 continued.

12. Shale; gradational lower contact; irregular thickness; gray olive; planar, parallel, thin to medium laminations........	.05	.16
11. Same as bed 14.........................	.31	1.02
10. Slightly imbricated conglomeritic fine sandstone: siliceous, submature quartzarenite; sharp contacts; massive; moderate yellow brown to dark yellow orange; sparse faint laminations and imbricated flat pebbles.....	1.14	3.74
9. Trough X-bedded fine sandstone: siliceous, mature quartzarenite; sharp contacts; dark yellow orange; thin, tangential, trough X-beds by macerals and mica.......................................	.61	2.00
8. Fine sandy pebble conglomerate: siliceous, submature sedrudite; external channel form; disconformable lower contact; dark yellow orange; no bedding; common to abundant clay-ironstone pebbles.............	.10	.33
7. Shale; sharp contacts; irregular thickness; intercalated, medium gray, fine sandstone; dark gray; planar, parallel thin laminations................................	.22	.72
6. Planar laminated very fine sandstone: siliceous, submature, coaly quartzarenite; sharp contacts; lower 5 cm. is a black, sandy coal; upper 6 cm. is dark gray, planar, parallel, thin to medium laminations by macerals...............................	.11	.36
5. Structureless fine sandstone: siliceous, mature, quartzarenite; sharp contacts; light gray stained dark yellow orange; no bedding.	.71	2.33
4. Planar laminated very fine sandstone: siliceous, submature, carbonaceous sedarenite; sharp contacts; light gray to gray black mottled black; planar, parallel, thin to thick laminations by profuse macerals; bedding thickness increases upward..........	.09	.30
3. Structureless very fine sandstone: siliceous, mature quartzarenite; bulbuous, sharp lower contact; medium gray; weathers dark yellow orange; no bedding.............	.10	.33
Weston Sh. Mbr.		
2. Mudstone; sharp contacts; profuse clay ironstone concretions; pale orange to dark yellow orange; no bedding; 1 cm. of rooted mudstone at upper contact..................	.07	.23
1. Shale; lower half poorly exposed; medium dark gray; planar, parallel thin laminations.	13.05	42.80

L3. Streamcut and roadcut, SE1/4, SE1/4, sec. 23, T. 9 S., R. 22 E., Leavenworth Co., Kansas. Measured and described by Jacki Spriggs in June, 1985.

Unit Descriptions

Bed Number	Thickness m.	ft.
Tonganoxie Ss. Mbr.		
36. Planar laminated very fine sandstone: siliceous, mature quartzarenite; resistant very thick bed; yellow gray; planar, parallel; thin laminations with sparse ripple marked beds by mica	1.20	3.94
35. Flaser bedded very fine sandstone: siliceous, mature quartzarenite; sharp contacts; dusky yellow with moderate olive brown clay; upper 4 cm. is oxidized and contains more clay	.62	2.03
34. Structureless very fine sandstone: siliceous, mature quartzarenite; oxidized, less resistant, middle wavy bedded unit; yellow gray with a very dark red hematitic crust	.37	1.21
33. Wavy bedded very fine sandstone: siliceous, mature quartzarenite; upper 10 cm. is flaser bedded; yellow gray with moderate olive brown clay; thin wavy and planar beds by mica and macerals	.80	2.62
32. Convolute bedded very fine sandstone: siliceous, mature quartzarenite; sharp contacts by 3 mm. hematitic crusts; yellow gray with very dark red hematitic very thin convolutions	.08	.26
31. Wavy bedded very fine sandstone: siliceous, mature quartzarenite; sharp contacts; yellow gray with moderate olive brown clay; asymmetrical, sigmoidal, out of phase ripples by mica and macerals	1.60	5.25
30. Interbedded planar laminated and X-laminated very fine sandstone: siliceous, mature quartzarenite; sharp contacts; less resistant, middle shale with ripple marks showing opposing dips; planar topped ripple marks by mica and macerals in upper bed	.60	1.97
29. Wavy bedded very fine sandstone: siliceous, mature quartzarenite; sparse flaser bedding; yellow gray with light olive brown clay; asymmetrical, linguoid to sinuous ripples showing sparse opposing dips; less resistant, 2-6 mm., out of phase clay drapes.	.82	2.69

Section L3 continued.

28. Interbedded shaly, carbonaceous, planar laminated siltstone and X-laminated and planar laminated very fine sandstone; gradational lower contact; dark yellow orange sandstone; dark yellow brown siltstone; lower 15 cm. and upper 21 cm. contain brown gray shale; upper 3 cm. is a dark yellow orange, mottled shale with small clay-ironstone concretions.......	1.00	3.28
27. X-laminated very fine sandstone: siliceous, mature quartzarenite; upper 25 cm. is flaser to wavy bedded with 1 cm. thick medium blue gray flasers; dusky yellow, asymmetrical, thin X-laminations by mica and macerals..................................	.45	1.48
26. Shale with very thin X-laminated and planar laminated very fine sandstone beds; sharp upper contact by hematitic crust; sand content decreases upward; dark green gray; weathers medium blue gray; dusky yellow X-laminated and planar laminated very thin sandstone beds............................	.80	2.62
25. In-phase X-laminated very fine sandstone: siliceous, mature quartzarenite; interbedded carbonaceous, nonresistant and resistant beds with a climbing ripple bed; dusky yellow; lower 5 cm. is dark yellow orange; in-phase, thin X-laminations by mica and macerals.....	.29	.95
24. Coal; bituminous; black; very thin bed.	.02	.07
23. Planar laminated very fine sandstone: siliceous, mature quartzarenite; sharp contacts; dusky yellow; planar, parallel, very thin to thin laminations...............	.11	.36
22. Planar laminated very fine sandstone: siliceous, mature, carbonaceous quartzarenite; sharp, undulating contacts; olive yellow brown; planar to slightly undulating, parallel, thin laminations by profuse macerals........	.11	.36
21. Silty shale with very thin sandstone intercalations; more resistant sandstone beds are planar laminated and symmetrical, straight, sharp-crest, ripple marked; olive gray; sparse horizontal burrows...................	.85	2.79
20. Asymmetrical X-laminated very fine sandstone: siliceous, mature quartzarenite; dusky yellow; asymmetrical ripple marks by hematite.................................	.08	.26

Section L3 continued.

19. Planar laminated very fine sandstone: siliceous, mature quartzarenite; yellow gray; weathers light gray; planar, parallel very thin to thin laminations by hematite........	.20	.66
18. Same as bed 20.........................	.21	.69
17. Same as bed 19.........................	.62	2.03
16. Interbedded planar laminated very fine sandstone: siliceous, mature quartzarenite and planar laminated very fine sandstone: siliceous, mature, carbonaceous, micaceous quartzarenite; less resistant brown gray, planar, parallel thin to medium laminations by profuse macerals and mica; resistant, dark yellow orange, planar, parallel, thin to medium laminations by hematite...........	.51	1.67
15. Interbedded asymmetrical X-laminated very fine sandstone and symmetrical X-laminated very fine sandstone; resistant gray orange, ripples with concave foresets by dark red brown hematite; less resistant, carbonaceous, dusky yellow, wave ripples with foresets by macerals and mica..........	.90	2.95
14. Planar laminated very fine sandstone: siliceous, mature quartzarenite; sharp contacts by hematitic crusts; dusky yellow with dark red brown laminations; planar, parallel, thin to medium laminations by hematite.................................	.07	.23
13. Interbedded coal and X-laminated very fine sandstone: siliceous, mature, carbonaceous quartzarenite; light gray, sandy bone clay and coal; dusky yellow, X-laminated very thin beds by macerals and mica..................	.06	.20
12. Interbedded ripple marked very fine sandstone and planar laminated, carbonaceous very fine sandstone; less resistant, pale yellow brown, planar laminations grading upward into dusky yellow; resistant, dark yellow orange, asymmetrical, ripple marked, thin bed.................................	.37	1.21
11. Convolute bedded very fine sandstone: siliceous, mature, micaceous quartzarenite; sharp contacts by convolutions; dark yellow orange lower 25 cm.; light olive gray upper 25 cm.; persistant, resistant, convolutions up to 45 cm. in diameter...................	.50	1.64
10. Planar laminated very fine sandstone: siliceous, mature quartzarenite; pale yellow brown; planar, parallel, thin beds in lower 25 cm.; undulating, thin beds in upper 15 cm.	.40	1.31

Section L3 continued.

Weston Sh. Mbr.		
9. Silty shale; poorly exposed; gradational contacts; medium dark gray; common sandy convolutions increasing in abundance upward; several slump structures....................	13.05	42.80
8. Shale; gradational upper contact by increased sand content upward; medium dark gray; planar, parallel thin laminations near base grading upward into subparallel, uneven coarse laminations; sparse clay-ironstone concretions randomly distributed......	2.00	6.56
7. Fine calcirudite: submature, ferruginous, osagid, brachiopod, echinoid, crinoid biomicrite; laterally extensive, scarp-forming limestone; gradational upper contact; blue gray; weathers gray red; less resistant, shaly middle unit is light blue gray; planar, parallel, thin to medium beds; abundant osagid, brachiopods, echinoids, crinoids; sparse bivlaves, bryozoa, and gastropods....	.35	1.15
6. Fossiliferous shale; sharp upper contact; gray black; weathers medium blue gray; planar, parallel, very thin to thin laminations; sparse to common crinoids, gastropods, brachiopods, bivalves, bryozoans, and ammonites...............................	1.43	4.69
5. Clay-ironstone concretionary bed; laterally extensive; light olive gray with a very thin light brown concentric rind; continuous to nodular......................	.06	.20
4. Fossiliferous shale; micaceous; lower 5 cm. is very calcitic with abundant fossils; sharp contacts; dark gray; planar, parallel, very thin to coarse laminations; fossil content decreases upward; sparse to common crinoids, corals, brachiopods, bivalves, bryozoans, and juvenile ammonites...........	1.41	4.62
3. Shale; micaceous; sharp contacts by clay-ironstone concretions; medium dark gray; uneven to even, thin laminations; randomly distributed clay-ironstone concretions.......	1.12	3.67
2. Same as bed 3.		
South Bend Ls. Mbr.		
1. Fine calcirudite: submature, partly recrystallized, osagid, mixed-fossil biomicrite; sharp contacts; medium blue gray; weathers pale yellow brown; planar, parallel, thin to medium beds; sparse to abundant crinoids, brachiopods, fusulinids, bivalves, echinoids, gastropods, and osagid..........	.39	1.28

L5. Streamcut, SE1/4, NW1/4, SE1/4, sec. 36, T. 9 S., R. 21 E., Leavenworth Co., Kansas. Originally measured and described by A.L. Bowsher. Section description in Basic Geology Division, State Geological Survey of Kansas files. Section L2 slightly modified after Ball (1964, p. 91).

L6. Streamcut, NW1/4, SW1/4, NW1/4, sec. 27, T. 10 S., R. 21 E., Leavenworth Co., Kansas. Originally measured and described by A.L. Bowsher. Section description in Basic Geology Division, State Geological Survey of Kansas files. Section L6 from Ball (1964, p.91).

L7. Streamcut, SW1/4, NE1/4, sec. 36, T. 10 S., R. 21 E., Leavenworth Co., Kansas. Measured and described by Jacki Spriggs in Oct., 1985.

Unit Descriptions

Bed Number	Thickness m.	ft.
Tonganoxie Ss. Mbr.		
7. Poorly exposed medium sandstone: siliceous, mature quartzarenite.............	3.06	10.04
6. Festoon X-bedded medium sandstone: siliceous, submature quartzarenite; unobserved upper contact; dusky yellow; curved, subparallel to parallel, thin, festoon X-beds by mica; subparallel to flow direction.........	3.75	12.30
5. Structureless medium sandstone: siliceous, submature quartzarenite; sharp lower contact; dusky yellow; no bedding.....	2.60	8.53
4. Large trough X-bedded medium sandstone: siliceous, submature quartzarenite; sharp contacts by reactivation surfaces; dusky yellow; curved, parallel, thin foresets by mica with dip increasing upward.............	2.15	7.05
3. Same as bed 4..........................	2.10	6.89
2. Same as bed 4..........................	2.80	9.18
1. Poorly exposed medium sandstone: siliceous, submature quartzarenite..........	.75	2.46

L8. Streamcut, NW1/4, NW1/4, sec. 24, T. 11 S., R. 21 E., Leavenworth Co., Kansas. Originally measured and described by A.L. Bowsher. Section description in Basic Geology Division, State Geological Survey of Kansas files. Section L8 slightly modified after Ball (1964, p. 91).

L9. Streamcut, near center east line, sec. 16, T. 12 S., R. 21 E., Leavenworth Co., Kansas. Originally measured and described by A.L. Bowsher. Section description in Basic Geology Division, State Geological Survey of Kansas files. Section L9 from Ball (1964, p. 91).

W1. Roadcut, south line, SW1/4, sec. 8, T. 10 S., R. 23 E., Wyandotte Co., Kansas. Measured and described by Jacki Spriggs in June, 1984.

Unit Descriptions

Bed Number	Thickness m.	ft.
Pleistocene		
18. Covered.................................	.50	1.64
Tonganoxie Ss. Mbr.		
17. X-laminated very fine sandstone: siliceous, mature quartzarenite; sharp contacts; poor exposure; light olive gray; asymmetrical, X-laminations by macerals and mica; profuse carbonized plant fragments....	2.11	6.92
16. Planar very thin-bedded fine sandstone: siliceous, submature quartzarenite; sharp contacts; pale yellow brown; planar, parallel, very thin beds by macerals, mica, and Fe-oxides; Calamites logs at base.............	.15	.49
15. Medium sandy pebble conglomerate: ferruginous, immature sedrudite; sharp contacts; translocated clay because of extreme leaching; very poorly indurated; predominantly limonitic clay pebbles with some wood fragments........................	.50	1.64
14. Channel-fill fine sandstone: siliceous, submature, carbonaceous quartzarenite; sharp contacts; irregular thickness; relatively planar upper contact; pale yellow brown mottled black; symmetrical channel-fill; curved, parallel, thin to thick beds by profuse, large macerals.....................	1.10	3.61
13. Medium sandy pebble conglomerate: ferruginous, immature sedrudite; irregular thickness because of superjacent channeling; sharp contacts; dark yellow orange; no bedding; translocated clay because of extreme leaching; poorly indurated except for a resistant, calcitic 15 cm. bed; predominantly limonitic clay pebbles......................	.90	2.95

Section W1 continued.

12. Planar thin-bedded slightly granular fine sandstone: siliceous, ferruginous?, submature quartzarenite; sharp contacts; yellow gray mottled dark yellow orange; planar, parallel thin beds by Fe-oxides; 3% discoidal clay granules....................	.22	.72
11. Medium sandy pebble conglomerate: ferruginous, immature sedrudite; sharp contacts; moderate red brown; X-bedded medium grained sandstone intercalations; poor induration; 35% discoidal clay pebbles; 10% sandstone pebbles............................	.15	.49
10. Trough X-bedded fine sandstone: ferruginous, submature sedrudite; sharp contacts; pale yellow brown mottled red brown; tangential,concave, parallel thin foresets by mica............................	.25	.82
9. Same as bed 11 except for intercalations of X-bedded sandstone......................	.50	1.64
8. Trough X-bedded granular medium sandstone: calcitic, ferruginous, submature subsedarenite; sharp contacts; pale yellow brown stained moderate red brown; slightly concave, parallel thin foresets by granules, macerals and color; 6% limonitic clay grains...................	.10	.33
7. Trough X-bedded granular medium sandstone: ferruginous, submature subsedarenite; sharp contacts by reactivation surfaces; pale yellow brown stained moderate red brown; tangential, concave, thin foresets by macerals and granules; 15% clay and sandstone granules...	.34	1.12
6. Same as bed 8..........................	.11	.36
5. Medium sandy pebble conglomerate: ferruginous, submature sedrudite; sharp, irregular, basal contact; moderate red brown; well indurated; very thin to thin sandstone intercalations; inversely graded limestone and clay pebbles...........................	.45	1.48
4. Pebbly medium sandstone: ferruginous?, submature, carbonaceous subsedarenite; sharp upper contact; pale yellow orange; leached upper is moderate red brown; weak, parallel, slightly undulating, discontinuous, very thin to thin beds by macerals and Fe-oxides; friable; weak imbrication of discoidal clay and sandstone pebbles.................	.18	.59
3. Medium sandy pebble conglomerate: calcitic, ferruginous, submature sedrudite; gradational contacts; moderate red brown; weak, parallel thin beds by grain size; very		

Section W1 continued.

thin to thin, ferruginous, X-laminated sandstone intercalations; weak imbrication; spherical to discoidal limestone and shale pebbles; less wood fragments than subjacent unit; extremely ferruginous.................. .53 1.74

2. Medium sandy pebble conglomerate: partly calcitic, partly siliceous, submature, recrystallized sedrudite; sharp, basal disconformity; gradational upper contact; flat pebbles show weak imbrication; log fragments at base; common limestone and mudstone pebbles; sparse wood and fossil fragments.................................... .39 1.28

1. Fine calcirudite: submature, mixed-fossil biosparite; sharp contacts; light blue gray to medium blue gray; single, planar, parallel thick bed; sparse to common brachiopods, phylloid algae, fusulinids, crinoids, osagid, and gastropods.............................. .54 1.77

W2. Roadcut, near center west line, NW1/4, sec. 8, T. 11 S., R. 23 E., Wyandotte Co., Kansas. Measured and described by S.M. Ball in July, 1958. Section W2 slightly modified after Ball (1964, p. 389).

D1. Roadcut, NE1/4, NW1/4, NE1/4, sec. 5, T. 13 S., R. 20 E., Douglas Co., Kansas. Originally measured and described by A.L. Bowsher and P. Kaiser in Sept., 1942. Section description in Basic Geology Division, State Geological Survey of Kansas files. Section D1 from Ball (1964, p. 385).

D2. Core, NW1/4, NE1/4, SE1/4, sec. 2, T. 13 S., R. 19 E., Douglas Co., Kansas. Measured and described by Jacki Spriggs in Oct., 1985.

Unit Descriptions

Bed Number	Thickness m.	ft.

Upper Sibley Coal.

23. Coal; bituminous; gradational contacts; black; no bedding.......................... .30 .98

22. Shale; carbonaceous; gradational contactsl medium dark gray; planar, parallel, discontinuous, very thin to thin laminations; carbonaceous fragment abundance increases

Section D2 continued.

Upward from about 60 cm. below coal.........	1.52	4.99
21. Planar interlaminated very fine sandstone and silty shale; gradational upper contact; light gray and medium light gray; planar, parallel, very thin to medium laminations by grain size, macerals, and mica..............	2.74	8.99
20. Flaser to wavy-bedded very fine sandstone: siliceous, mature quartzarenite; gradational upper contact; light gray with medium gray clay flaser beds; very thin flaser beds and discontiuous to continuous wavy beds by macerals, clay and mica; flame structures and contorted bedding; common to abundant vertical burrows with bulbuous bases which taper upward..........................	2.74	8.99
19. Shale; medium light gray; planar, parallel, laminations; grain size gradually increases upward to very coarse siltstone-very fine sandstone; upper 60 cm. contains common X-laminations by sparse macerals;		
18. Coal; bituminous; gradational upper contact; black; calamites logs oriented parallel to bedding; no core recovered at basal contact................................	.26	.85
17. Shale to lenticualr-bedded shale; medium light gray; thin, continuous lenticular X-laminated beds; upper zone is void of sandstone and consists of clay; gradational contacts..................................	2.44	8.00
16. Flaser to wavy bedded fine sandstone: siliceous, immature, carbonaceous quartzarenite; sharp lower contact; gradational upper contact; light gray with medium gray clay beds; simple, very thin flaser beds by clay and macerals; clay content gradually increases upward...........................	1.04	3.41
15. Trough X-bedded fine sandstone: siliceous, submature quartzarenite; light gray with very light gray avalanche faces; very thin to thin concave X-beds by color and sparse macerals........................	2.01	6.59
14. X-laminated fine sandstone: siliceous, mature quartzarenite; light gray; weak X-laminations by macerals and mica in basal half; sparse X-laminations in upper half....	2.74	8.99
13. X-bedded fine sandstone: siliceous, submature quartzarenite; light gray; very thin, concave X-beds by macerals and mica; foreset thickness decreases upward....	2.74	8.99

Section D2 continued.

12. X-bedded fine sandstone: siliceous, submature quartzarenite; light gray; very thin X-beds by macerals and mica; lower dip angle and less macerals than subjacent unit; planar, parallel, thin laminations by macerals at the upper contact; no core recovered below bed 12......................	1.52	4.99
11. X-bedded fine sandstone: siliceous, submature, micaceous, carbonaceous quartz-arenite; light gray with black bounding contacts; thin X-beds by macerals with one case of opposing dip; two carbonaceous zones 30 cm. below upper contact..................	2.13	6.99
10. Structureless fine sandstone: siliceous, submature, micaceous quartzarenite; light gray; no bedding............................	2.74	8.99
9. Pebbly medium sandstone: siliceous, submature, micaceous, carbonaceous, quartz-arenite; light gray with medium blue gray carbonaceous flat-pebble clasts which are commonly cross-sections of seemingly oriented <u>Calamites</u> logs and fragments; 20% 1-3 cm. wide, 1-2 mm. thick carbonaceous clasts; no bedding; very thin, light olive gray, carbon-aceous, shale intercalation.................	.90	2.95
8. Carbonaceous shale; gradational lower contact; medium blue gray with black over-tones; profusely carbonaceous; <u>Calamites</u> logs and fragments..........................	.46	1.51
7. Structureless medium sandstone: siliceous, submature quartzarenite; sharp upper contact; light gray with medium gray flat pebble clasts in upper 60 cm. which are commonly X-sections of clayey <u>Calamites</u> logs; four, planar, parallel, thin beds by macerals at lower contact............................	1.83	6.00
6. No core recovered.		
5. Structureless medium sandstone: siliceous, submature quartzarenite; light gray; no bedding....................................	.30	.98
4. Trough X-bedded medium sandstone: siliceous, submature, micaceous, carbonaceous quartzarenite; light gray; very thin, concave X-beds by macerals and mica.................	1.52	4.99
3. Planar laminated fine sandstone: siliceous, submature, very carbonaceous quartzarenite; sharp contacts; very light gray with black interlaminations; planar, parallel, interlaminationed sandstone and coal.......	.05	.16

Section D2 continued.

2. Trough X-bedded medium sandstone: siliceous, submature, micaceous, carbonaceous quartzarenite; lower contact not observed; light gray; thin X-beds by macerals and mica.	.91	2.98
1. Low-angle X-bedded medium sandstone: siliceous, submature, micaceous quartzarenite; light gray; relatively low-angle (11) very thin beds by clay and mica..................	.91	2.98

D3. Roadcut and streamcut, SW1/4, SE1/4, sec. 22, T. 13 S., R. 20 E., Douglas Co., Kansas. Originally measured and described by J.M. Jewett. Section description in Basic Geology Division, State Geological Survey of Kansas files. Section D3 slightly modified after Ball (1964, p. 91).

D4. Streamcut, NW1/4, NE1/4, sec., 23, T. 14 S., R. 20 E., Douglas Co., Kansas. Originally measured and described by H.G. O'Connor. Section D4 from O'Connor (1960, p. 177).

D5. Streamcut, center north line, SW1/4, sec. 15, T. 14 S., R. 20 E., Douglas Co., Kansas. Measured and described by S.M. Ball, M.M. Ball, and Dwight J. Laughlin. Section D5 from Ball (1963, p. 23).

F1. Roadcut, SW1/4, SW1/4, NW1/4, sec. 34, T. 15 S., R. 20 E., Franklin Co., Kansas. Measured and described by Jacki Spriggs in Oct., 1985.

Unit Descriptions

Bed Number	Thickness m.	ft.
Tonganoxie Ss. Mbr.		
15. Structureless fine sandstone: siliceous, submature quartzarenite; yellow gray; faint, planar, parallel, very thin beds............	.25	.82
14. Trough X-bedded fine sandstone: siliceous, submature quartzarenite; yellow gray; concave, very thin foresets by Fe-oxides................................	.12	.39

Section F1 continued.

13. Planar bedded fine sandstone: siliceous, submature quartzarenite; sharp contacts; yellow gray; planar, parallel, very thin beds bt Fe-oxides..................	.10	.33
12. Trough X-bedded fine sandstone: siliceous, submature quartzarenite; yellow gray; concave, very thin to thin foresets by Fe-oxides; also exposed as rib and furrow; 4 m. wide sets..............................	.32	1.05
11. Granular fine sandstone: calcitic, submature subsedarenite; yellow gray with dark yellow orange limonite granules; limonite and discoidal clay pebbles......................	.30	.98
10. Slightly granular fine sandstone: calcitic, mature, micaceous quartzarenite; sharp upper contact; yellow gray; sparse clay clasts....................................	.19	.62
9. Granule conglomerate: calcitic, submature, sedrudite; sharp contacts; medium light gray basal pebble conglomerate; gray red upper granule conglomerate; graded bed; clay and limonite clasts; sparse to common crinoids, brachiopods, bivalves and fusulinids; sparse macerals.....................	.20	.66
8. Structureless fine sandstone: calcitic, mature quartzarenite; sharp contacts; light gray; single, planar, parallel, thin bed; dense; sparse limonite clasts and macerals on sole..................................	.05	.16
7. Silty Shale; siltstone intercalations; slope former; poor exposure; moderate yellow brown to medium dark gray; planar, parallel, thin to thick laminations; upper zone is a planar, parallel, thin laminated siltstone; very thin to thick laminated, ferruginous siltstone intercalations; horizontal burrows in medium dark gray shale; lower moderate yellow brown zone is blocky and contains more siltstone................................	2.85	9.35

Iatan Ls. Mbr.

6. Structureless fine sandstone: calcitic, mature quartzarenite; irregular thickness; sparsely fossiliferous, conglomeratic basal zone; sharp contacts; medium light gray; discontinuous, thin, lenticular-shaped bedding; weathers olive brown; sandy granule conglomerate contains discoidal clay clasts, limonite clasts, and crinoids.......................	.10	.33
5. Interbedded fine sandstone and silty		

Section F1 continued.

shale: calcitic, mature quartzarenite; gradational contacts with grain size fining upward; planar, parallel, very thin beds by macerals; dusky yellow; dark yellow orange, ferruginous siltstone and silty shale.................. .15 .49

4. Fine sandy granule conglomerate: calcitic, submature sedrudite; sharp, irregular basal contact; slightly imbricated, flat pebble gray green clay clasts (5%); light olive brown with moderate brown limonite clasts (25%)........ .25 .82

3. Conglomeritic very fine sandstone: calcitic, submature, flat-pebble subsedarenite irregular thickness; dense; medium light gray with dark yellow orange limonite clasts; thin, thin, planar, parallel bedding by grain size; basal calcitic very fine sandstone; convex downward sole; sparsely fossiliferous; crinoids, brachiopods, and fusulinids....... .50 1.64

2. Granule conglomerate: calcitic, submature sparsely fossiliferous sedrudite; sharp contacts; irregular thickness pale yellow brown; discontinuous, thin bed; discoidal to spherical, yellow orange limonite granules; flat gray green shale granules.............. .07 .23

Weston Sh. Mbr.

1. Clay shale; light olive gray; discontinous, planar, subparallel to nonparallel, very thin to medium laminations............. .39 1.28

F2. Roadcut, SW1/4, SW1/4, sec. 14, T. 17 S., R. 19 E., Franklin Co., Kansas. Originally measured and described by A.L. Bowsher in July 1942. Section F2 modified from section description in Basic Geology Division, State Geological Survey of Kansas files.

F3. Roadcut, SW1/4, SE1/4, sec. 7, T. 17 S., R. 19 E., Franklin Co., Kansas. Measured and described by Jacki Spriggs in July, 1984.

Unit Descriptions

Bed Number — Thickness m. ft.

Tonganoxie Ss. Mbr.

9. Fine sandy pebble conglomerate: siliceous,

Section F3 continued.

partly ferruginous, immature sedrudite; sharp, disconformable lower contact; light brown to yellow orange; no bedding; clast size and abundance decrease upward; highly weathered and stained; discoidal clay and ironstone clasts near base with sparse plant fragments.	1.40	4.59
8. Planar laminated very fine sandstone: siliceous, mature quartzarenite; sharp contacts; gray orange; planar to slightly undulating, parallel, thin laminations by Fe-oxides..................................	.39	1.28
7. Planar laminated shale; yellow gray; planar, parallel, very thin lamiantions by sparse macerals............................	.04	.13
6. Coal; bituminous; gradational upper contact increasing in silt upward; black....	.13	.43
5. Mudstone; sharp upper contact; very light gray; no bedding; soft; bleached; root casts and mottles...............................	.04	.13
4. Undulating wavy laminated siltstone: siliceous, mature quartzsiltite; gradational contacts; very light gray with dark yellow orange; weathers very dark red; wavy, parallel, thin to very thick laminations by abundant well-preserved plant fossils........	.70	2.30
3. Carbonaceous siltstone; gradational contacts; very light gray; wavy, subparallel, discontinous, very thin beds by profuse whole plant fossils parallel to bedding; siltified bark......................................	.04	.13
2. Carbonaceous silty shale; gradational upper contact; dark gray; sparse, discontinuous, subparallel, undulating thin laminations..	.04	.13
1. Mudstone; irregular sharp upper contact; greenish gray; no bedding; common to abundant limonite root casts in upper 15 cm..........	.15	.49

F4. Streamcut, NW1/4, SE1/4, sec. 11, T. 17 S., R. 18 E., Franklin Co., Kansas. Originally measured and described by N.K. Newell. Section F4 modified after section description in Basic Geology Division, State Geological Survey of Kansas files.

F5. Streamcut, SW corner, NW1/4, T. 18 S., R. 19 E., Franklin Co., Kansas. Originally measured and described by M.M. Ball. Section F5 modified after section description in Basic Geology Division, State Geological Survey of Kansas files.

F6. Roadcut, southline, sec. 18, T. 19 S., R. 18 E., Franklin Co., Kansas. Originally measured and described by M.M. Ball. Section F6 modified after section description in Basic Geology Division, State Geological Survey of Kansas files.

A1. Roadcut, NW corner, SE1/4, sec. 1, T. 21 S., R. 17 E., Anderson Co., Kansas. Originally measured and described by N.K. Newell. Section A1 modified after section description in Basic Geology Division, State Geological Survey of Kansas files.

A2. Streamcut, NW1/4, SE1/4, sec. 13, T. 21 S., R. 17 E., Anderson Co., Kansas. Originally measured and described by A.L. Bowsher. Section A2 modified after section description in Basic Geology Division, State Geological Survey of Kansas files.

APPENDIX II

This Appendix consists of descriptions of thin sections studied with a polarizing petrographic microscope. Five hundred points were counted on each of eleven thin sections using Chaye's (1949) method. Orthochemical, allochemical, and terrigenous components were identified for carbonate rocks. Terrigenous components and cements were identified for terriginous rocks. Abundance of each type of particle was determined in percent. A rock name was assigned to each sample designating grain size, maturity, and composition for carbonate rocks and grain size, cements, maturity, miscellaneous transported constituents, and clan designations for terrigenous rocks (Folk, 1951, 1959).

Sample W-2-1
South Bend Limestone

Type of Particle	Number of points	Percent of points	Percent of skeletal grains
Orthochems (matrix)			
Micrite	380	76.0	----
Microspar	10	2.0	----
Allochems (grains)			
Osagid	26	5.2	23.6
Bivalves	16	3.2	14.6
Brachiopods	14	2.8	12.7
Gastropods	13	2.6	11.8
Echinoids	8	1.6	7.2
Ostracodes	8	1.6	7.2
Crinoids	7	1.4	6.4
Oolites	6	1.2	5.5
Algae	4	0.8	3.6
Bryozoans	4	0.8	3.6
Pellets	3	0.6	2.7
Trilobites	1	0.6	0.2
Total	500	100.0	100.0

Rock Name:

Fine calcirudite: immature, partly recrystallized, gastropod, brachiopod, bivalve, osagid biomicrite

Sample L-3-11
Limestone in the Weston Shale

Type of Particle	Number of points	Percent of points	Percent of skeletal grains
Orthochems (matrix)			
Micrite	287	57.4	----
Allochems (grains)			
Osagid	72	14.4	33.8
Echinoids	51	10.2	23.9
Brachiopods	29	5.8	13.6
Crinoids	17	3.4	8.0
Bivalves	11	2.2	5.2
Trilobites	10	2.0	4.7
Gastropods	8	1.6	3.7
Fusulinids	4	0.8	1.9
Intraclasts	4	0.8	1.9
Bryozoans	1	0.2	0.5
Ostracodes	1	0.2	0.5
Unidentifiable skeletal grains	5	1.0	2.3
Total	500	100.0	100.0

Rock Name:

Fine calcirudite: immature, ferruginous, brachiopod, echinoid, osagid biomicrite

Sample P-2-1
Iatan Limestone

Type of Particle	Number of points	Percent of points	Percent of skeletal grains
Orthochems (matrix)			
Micrite	350	70.0	----
Microspar	25	5.0	----
Allochems (grains)			
Algae	104	20.8	83.2
Brachiopods	6	1.2	4.8
Ostracodes	5	1.0	4.0
Oolites	4	0.8	3.2
Bivalves	3	0.6	2.4
Gastropods	3	0.6	2.4
Total	500	100.0	100.0

Rock Name:

Fine calcirudite: immature, partly recrystallized, algal biomicrite

Sample P-2-3
Iatan Limestone

Type of Particle	Number of points	Percent of points	Percent of skeletal grains
Orthochems (matrix)			
Micrite	330	66.0	----
Spar	25	5.0	----
Allochems (grains)			
Intraclasts	95	19.0	66.4
Algae	8	1.6	5.6
Brachiopods	6	1.2	4.2
Crinoids	5	1.0	3.4
Bryozoans	5	1.0	3.4
Echinoids	5	1.0	3.4
Pellets	5	1.0	3.4
Bivalves	4	0.8	2.8
Osagid	4	0.8	2.8
Ostracodes	1	0.2	0.7
Trilobites	1	0.2	0.7
Unidentifiable skeletal grains	4	0.8	2.8
Terrigenous Components			
Quartz silt	1	0.2	0.7
Opaques	1	0.2	0.7
Total	500	100.0	100.0

Rock Name:

Medium calcirudite: immature, partly recrystallized, intramicrite

Sample A-1-4
Iatan Limestone

Type of Particle	Number of points	Percent of points	Percent of skeletal grains
Orthochems (matrix)			
Micrite	362	72.4	----
Allochems (grains)			
Osagid	27	5.4	57.4
Brachiopods	6	1.2	12.8
Bivalves	6	1.2	12.8
Echinoids	3	0.6	6.4
Fusulinids	3	0.6	6.4
Ostracodes	2	0.4	4.2
Terrigenous Components			
Quartz silt	91	18.2	----
Total	500	100.0	100.0

Rock Name:

Coarse calcarenite: immature, ferruginous, silty, osagid micrite

Sample A-1-10
Westphalia Limestone

Type of Particle	Number of points	Percent of points	Percent of skeletal grains
Orthochems (matrix)			
Micrite	259	51.8	----
Allochems (grains)			
Fusulinids	113	22.6	54.8
Osagid	47	9.4	22.8
Gastropods	9	1.8	4.4
Bivalves	8	1.6	3.9
Brachiopods	6	1.2	2.9
Echinoids	5	1.0	2.4
Bryozoans	4	0.8	1.9
Ostracodes	2	0.4	1.0
Crinoids	2	0.4	1.0
Unidentifiable skeletal grains	10	2.0	4.9
Terrigenous Components			
Quartz silt	28	5.6	----
Opaques	6	1.2	----
Plagioclase silt	1	0.2	----
Total	500	100.0	100.0

Rock Name:

Fine calcirudite: immature, ferruginous, silty, osagid, fusulinid biomicrite

Sample L-1-6
Westphalia Limestone

Type of Particle	Number of points	Percent of points	Percent of skeletal grains
Orthochems (matrix)			
Micrite	339	67.8	----
Spar	13	2.6	----
Allochems (grains)			
Ostracodes	35	7.0	46.1
Brachiopods	15	3.0	19.7
Echinoids	7	1.4	9.2
Bivalves	6	1.2	7.9
Gastropods	2	0.4	2.6
Crinoids	1	0.2	1.3
Unidentifiable skeletal grains	10	2.0	13.2
Terrigenous Components			
Plant fragments	40	8.0	----
Quartz silt	26	5.2	----
Opaques	6	1.2	----
Total	500	100.0	100.0

Rock Name:

Fine calcirudite: immature, coaly, silty, ostracode biomicrite

Sample W-1-2
Tonganoxie Sandstone

Type of Particle	Number of points	Percent of points	Percent of essential grains
Terrigenous Components			
Quartz	190	38.0	66.2
Rock fragments			
Limestone	87	17.4	30.3
Chert	10	2.0	3.5
Misc. Transported Constituents			
Plant fragments	16	3.2	----
Opaques	1	0.2	----
Cements			
Calcite	196	39.2	----
Total	500	100.0	100.0

Rock Name:

Medium sandy pebble conglomerate: calcitic, submature, quartzose, plant-bearing calclithite

Sample W-2-11
Tonganoxie Sandstone

Type of Particle	Number of points	Percent of points	Percent of essential grains
Terrigenous Components			
Quartz	330	66.0	98.8
Feldspar			
Plagioclase	3	0.6	0.9
K-spar	1	0.2	0.3
Misc. Transported Constituents			
Opaques	24	4.8	----
Muscovite	7	1.4	----
Matrix			
Clay	94	18.8	----
Cements			
Quartz overgrowths	41	8.2	----
Total	500	100.0	100.0

Rock Name:

Clayey fine sandstone: siliceous, immature, muscovitic quartzarenite

Sample D-2-4
Tonganoxie Sandstone

Type of Particle	Number of points	Percent of points	Percent of essential grains
Terrigenous Components			
Quartz	314	62.8	88.4
Feldspar			
Plagioclase	19	3.8	5.4
K-spar	18	3.6	5.1
Rock Fragments			
Shale	4	0.8	1.1
Misc. Transported Constituents			
Muscovite	21	4.2	----
Plant fragments	18	3.6	----
Opaques	2	0.4	----
Biotite	1	0.2	----
Zircon	1	0.2	----
Matrix			
Clay	72	14.4	----
Cements			
Quartz overgrowths	19	3.8	----
Calcite	11	2.2	----
Total	500	100.0	100.0

Rock Name:

Clayey fine sandstone: siliceous, partly calcitic, immature, muscovitic, plant-bearing subarkose

Sample F-4-15
Tonganoxie Sandstone

Type of Particle	Number of points	Percent of points	Percent of essential grains
Terrigenous Components			
Quartz	341	68.2	95.5
Feldspar			
K-spar	12	2.4	3.4
Plagioclase	4	0.8	1.1
Misc. Transported Constituents			
Opaques	8	1.6	----
Muscovite	7	1.4	----
Zircon	2	0.4	----
Matrix			
Clay	18	3.6	----
Cements			
Quartz overgrowths	108	21.6	----
Total	500	100.0	100.0

Rock Name:

Very fine sandstone: siliceous, mature, muscovitic quartzarenite

DEPOSITIONAL ENVIRONMENTS OF THE
TONGANOXIE SANDSTONE MEMBER OF THE STRANGER FORMATION
(UPPER PENNSYLVANIAN) IN NORTHEASTERN KANSAS

by

JACKI L. SPRIGGS

B.S., North Dakota State University, 1982

AN ABSTRACT OF A THESIS

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ABSTRACT

Analysis of the Tonganoxie Sandstone Member of the Stranger Formation of the Douglas Group (Virgillian Stage, Lower Pennsylvanian Series) in northeastern Kansas using a hierarchal genetic stratigraphy approach (i.e., after Busch and West, 1987) has provided insight into depositional conditions on a finer scale than cyclothems. Recognition of climate change surfaces (Busch, 1987) within the Tonganoxie Sandstone Member enabled the correlation of minor transgressions through this nonmarine interval.

Studies of 27 measured sections utilizing stratigraphic, sedimentologic, and paleontologic observations provide the basis for interpretation of the depositional environments of the Tonganoxie Sandstone Member. This study suggests the Tonganoxie is a confined valley-fill deposit in the northern portion of the study area. The shale units above the sandstone section represent abandoned channel-fill and post-fluvial estuarine deposits, whereas mudstones with root traces and mottles, and very weakly- to moderately-developed horizons represent paleosols. Coals were deposited in relatively humid, swamp-like, subaerial environments as a result of climate change. Most sandstones in the southern portion of the study area represent shoreline deposits. Shale associated with these shoreline sandstones was deposited in an alluvial (possibly low-lying coastal plain) or shallow water marine environment.

The Tonganoxie Sandstone Member represents the regressive phase of the Iatan fifth-order T-R unit, and is comprised of two complete sixth-order T-R units and the regressive phase of one

sixth-order T-R unit. The Iatan fifth-order T-R unit represents a time interval of about 300,000-500,000 years (Busch and West, 1987); therefore, sixth-order T-R units may represent time intervals of about 100,000-167,000 years.

Paleogeographic maps and cross-sections illustrate the gradual shallowing upward and deterioration of humid conditions between genetic surfaces. Facies changes in the fifth-order transgressive sequence (sixth-order T-R unit S2.1) suggest that the extreme northern and southern portions of the study area were topographically lower than the central portions. The overall facies changes in the fifth-order regressive sequence indicate a series of northwest-southeast trending paleotopographic highs and lows oriented approximately perpendicular to the paleoslope. Topographic highs are located in central Leavenworth, northern Douglas and central and southern Franklin Counties.

Minor and major structural elements including two unnamed northwest plunging anticlines, Schell City-Rich Hill Anticline, and Bourbon Arch affected deposition of the Iatan Limestone, Tonganoxie Sandstone, and Westphalia Limestone. A general correlation exists between structural highs and thinning of T-R units, and between structural lows and thickening of T-R units. Genetic surfaces with both marine and nonmarine facies commonly show the marine facies coinciding with structural lows and nonmarine facies overlying structural highs. Paleotopographic highs and lows influenced by these structural features affected both thickening and depositional environments of Tonganoxie sediments.

Figure 9. Basal cross-section showing disconformity.

Figure 10. Field locality W1: Roadcut showing basal fluvial facies of the Tonganoxie Sandstone Member.

Figure 11. Upper cross-section showing correlation of sixth-order T-R units.