# THE SEQUENCE STRATIGRAPHY OF THE ALTAMONT LIMESTONE, BANDERA SHALE, AND PAWNEE LIMESTONE OF THE MARMATON GROUP (DESMOINESIAN, PENNSYLVANIAN) IN SOUTHEASTERN KANSAS AND NORTHEASTERN OKLAHOMA

By

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# INTRODUCTION

## Purpose

The purpose of this study is to first test whether cyclothemic-scale depositional sequences of the Marmaton Group (Desmoinesian Stage, Pennsylvanian Series) in southeastern Kansas and northeastern Oklahoma can be identified in outcrop and correlated into the subsurface. Secondly, the author will compare the results of correlating using two different models to define sequences. The first model, developed by workers at Exxon (Mitchum et al., 1977; Vail et al., 1977; Van Wagoner et al., 1987; and Posamentier et al., 1992), defines depositional sequence boundaries to be at unconformities and their correlative conformities. The second model, used by Galloway, defines genetic stratigraphic unit (GSU) boundaries to be at maximum flooding surfaces. The author will determine which method of defining sequences yields the better correlations. Figure 1 shows the formal stratigraphic nomenclature of the units in this study.

## Location

The two components of this project are located in adjacent areas. The surface study comprises Marmaton Group outcrops located along a northeast-trending line from southeastern Kansas to northeastern Oklahoma. Enclosure 1 shows locations of exposures. The subsurface portion of this study covers a 36- by 50-mile (58- by 80.5-kilometer) grid in Osage, Washington, and Nowata Counties, Oklahoma, from Townships 23 to 28 North and from Ranges 7 to 15 East. This is 6 to 50 miles (9.7 to 80.5 kilometers) west of the surface study. Enclosure 1 shows locations of well logs and stratigraphic cross sections.

## Methodology

### Surface Study

Surface exposures of the Marmaton Group examined in this study include the Labette Shale, Pawnee Limestone, Bandera Shale, Altamont Limestone, Nowata Shale,

| Chronostratigraphy | | | Lithostratigraphy | | | | |
|---|---|---|---|---|---|---|---|
| | | | | western Missouri and eastern Kansas | southeastern Kansas | northeastern Oklahoma | |
| Series | Stage | Group | Formation | Member or bed | Member or bed | Member or bed | |
| | | | Lenapah Limestone | Idenbro Ls Mbr | Idenbro Ls Mbr | Idenbro Ls Mbr | |
| | | | | Perry Farm Sh Mbr | Perry Farm Sh Mbr | Perry Farm Sh Mbr | |
| | | | | Norfleet Ls Mbr | Norfleet Ls Mbr | Norfleet Ls Mbr | |
| | | | Nowata Shale | | | | |
| | | | Altamont Limestone | Worland Ls Mbr | Worland Ls Mbr | Worland Ls Mbr | "Oologah Limestone" or Big Lime of informal usage (subsurface) |
| | | | | Lake Neosho Sh Mbr | Lake Neosho Sh Mbr | Lake Neosho Sh Mbr | |
| Pennsylvanian | Desmoinesian | Marmaton | | Amoret Ls Mbr | Amoret Ls Mbr | Amoret Ls Mbr | |
| | | | Bandera Shale | | | | |
| | | | Pawnee Limestone | Laberdie Ls Mbr | Laberdie Ls Mbr | Laberdie Ls Mbr | |
| | | | | Mine Creek Sh Mbr | Joe shale bed | | |
| | | | | Myrick Station Ls Mbr | Frog Cemetery limestone bed | | |
| | | | | Anna Sh Mbr | Anna Sh Mbr | Anna Sh Mbr | |
| | | | | Childers School Ls Mbr | Childers School Ls Mbr | Childers School Ls Mbr | |
| | | | | | | Sageeyah Ls Mbr | |
| | | | Labette Shale | | | | |

Ls = Limestone
Sh = Shale
Mbr = Member

Figure 1. Stratigraphic nomenclature of the Marmaton Group in western Missouri, eastern and southeastern Kansas and northeastern Oklahoma. Joe shale bed and Frog Cemetery limestone bed are informal stratigraphic terms.

and Lenapah Limestone, in ascending order. See Figure 2. Emphasis is placed on the Pawnee Limestone, Bandera Shale, and Altamont Limestone. Thirteen localities were selected for the study so that all of the units listed are represented. The combination of these thirteen exposures results in two complete composite sections containing units from the upper part of the Labette Shale up to the bottom of the Lenapah Limestone. One composite section is in southeastern Kansas and one is in northeastern Oklahoma.

Each exposure was measured and described in the field, then the microfauna and petrography were studied in the lab. Field descriptions include weathered and unweathered color based on Munsell's color chart, bedding and contact characteristics, fossils and grain components, and Dunham rock names applied to carbonates. Most sections were photographed as a whole and then at closer range to show detail in bedding. The beds of each section were numbered in ascending order. Shales were broken down with kerosene for recovery of microfauna. The limestone samples were cut into rectangular billets for thin-section preparation. Thin-section samples taken after 1994 were labeled with arrows to indicate the "up" direction. Thin-section slides were stained with Alizurin Red S, to test for dolomite. Petrographic descriptions based on the thin-section analyses include Dunham rock name, cements, fossils, and other rock constituents. Each thin-section slide was photographed.

After the surface data were compiled, interpretations of depositional environments were made and important sequence-stratigraphic surfaces (subaerial exposure surfaces, flooding surfaces, and condensed sections) were interpreted. The units at each location were assigned to a sequence-stratigraphic framework (systems tract and sea-level curve).

Subsurface Study

The focus of the subsurface study was expanded from the surface study to include units above and below the rock-stratigraphic units studied at the surface. In ascending order, these units are the Excello Shale Member (Senora Formation), Fort

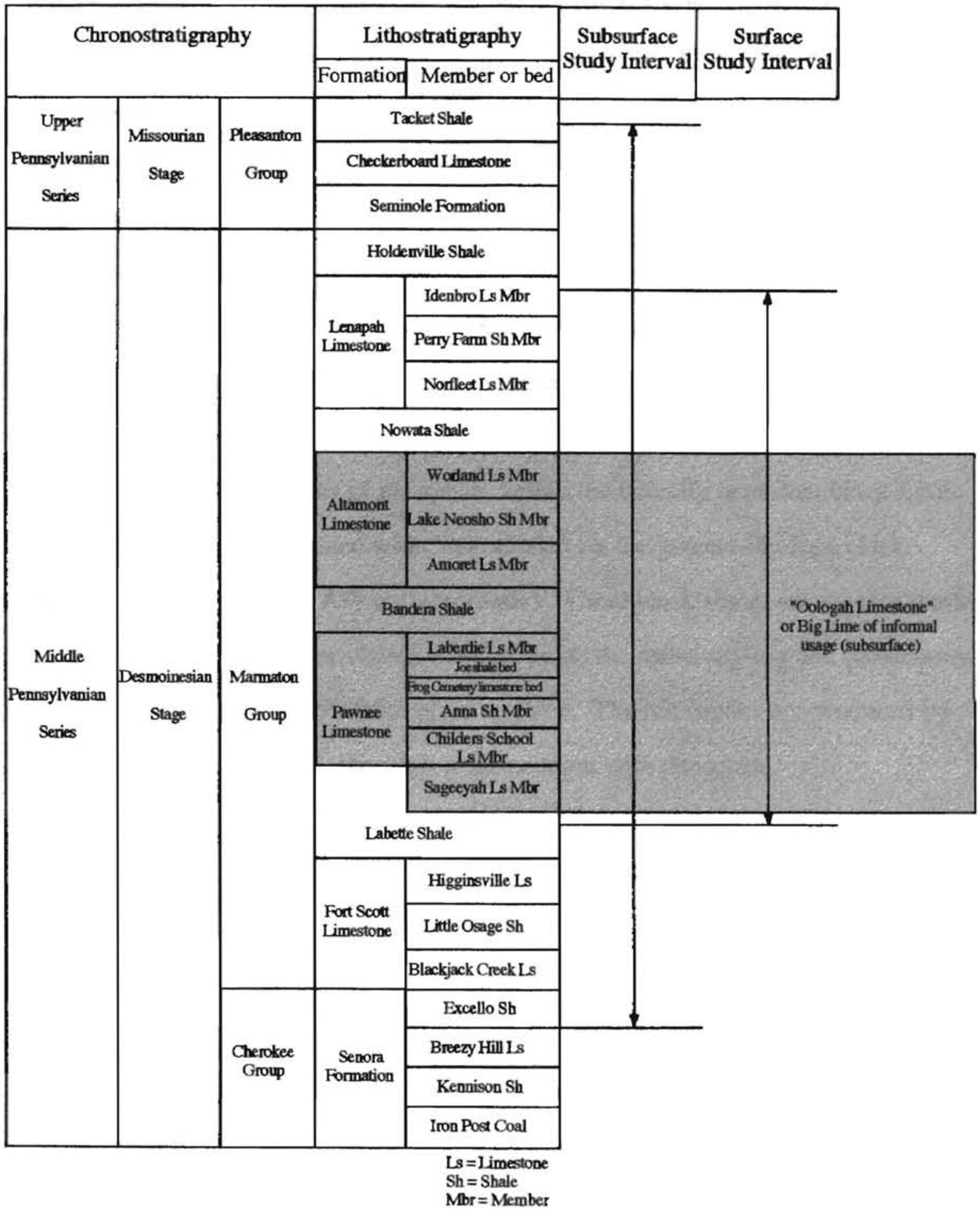


Figure 2. Unit intervals of both the surface and subsurface components of this study. Frog Cemetery limestone bed and Joe shale bed are informal terms.

Scott Limestone, Labette Shale, Pawnee Limestone, Bandera Shale, Altamont Limestone, Nowata Shale, Lenapah Limestone, Holdenville Shale, Seminole Formation, Checkerboard Limestone, and Tacket Shale. These units are of the Cherokee, Marmaton and Pleasanton Groups. See Figure 2. Note that the three formations (Pawnee Limestone, Bandera Shale, and Altamont Limestone) studied in the most detail are highlighted. One hundred nineteen well logs (gamma-ray and resistivity of strata each well) provided the initial data to construct six stratigraphic cross sections, six structural contour maps, and five isopach maps. Structural geologic maps of the top of the Oswego Lime in Osage County published by the U. S. Geological Survey supplemented the well logs the author collected.

The high concentrations of phosphate within the laterally persistent black fissile shales of this study are associated with "hot streaks" on the gamma-ray-logs. Hot streaks are readings over 150 API units (offscale). These black shales are reliable markers, acting as guides for the correlation of other units, the resistivity-log and gamma-ray-log patterns of which vary more from place to place. The hot streaks are produced by radioactive minerals (uranium, thorium) in association with phosphate.

## Geologic History

The major structural features that affected Middle Pennsylvanian sedimentation patterns in the study area were the Ouachita Mountains, Ozark Uplift, Nemaha Uplift, Cherokee Basin, Chautauqua Arch, and Northeast Oklahoma Platform. Figure 3 shows structural geology of basement rocks of the Midcontinent and nearby regions, and locations of these structural features. According to Rascoe and Adler (1983), collision of the North American and South American continental plates formed the Ouachita foldbelt. This uplift was a major source of siliciclastics deposited in the study area. Siliciclastic sediment was also shed into the study area from the Bourbon Arch and Nemaha Uplift to the north (Price, 1981). Within the Cherokee Basin, sediment from surrounding higher areas accumulated to form black shales, and carbonate rock thinned because the deep-

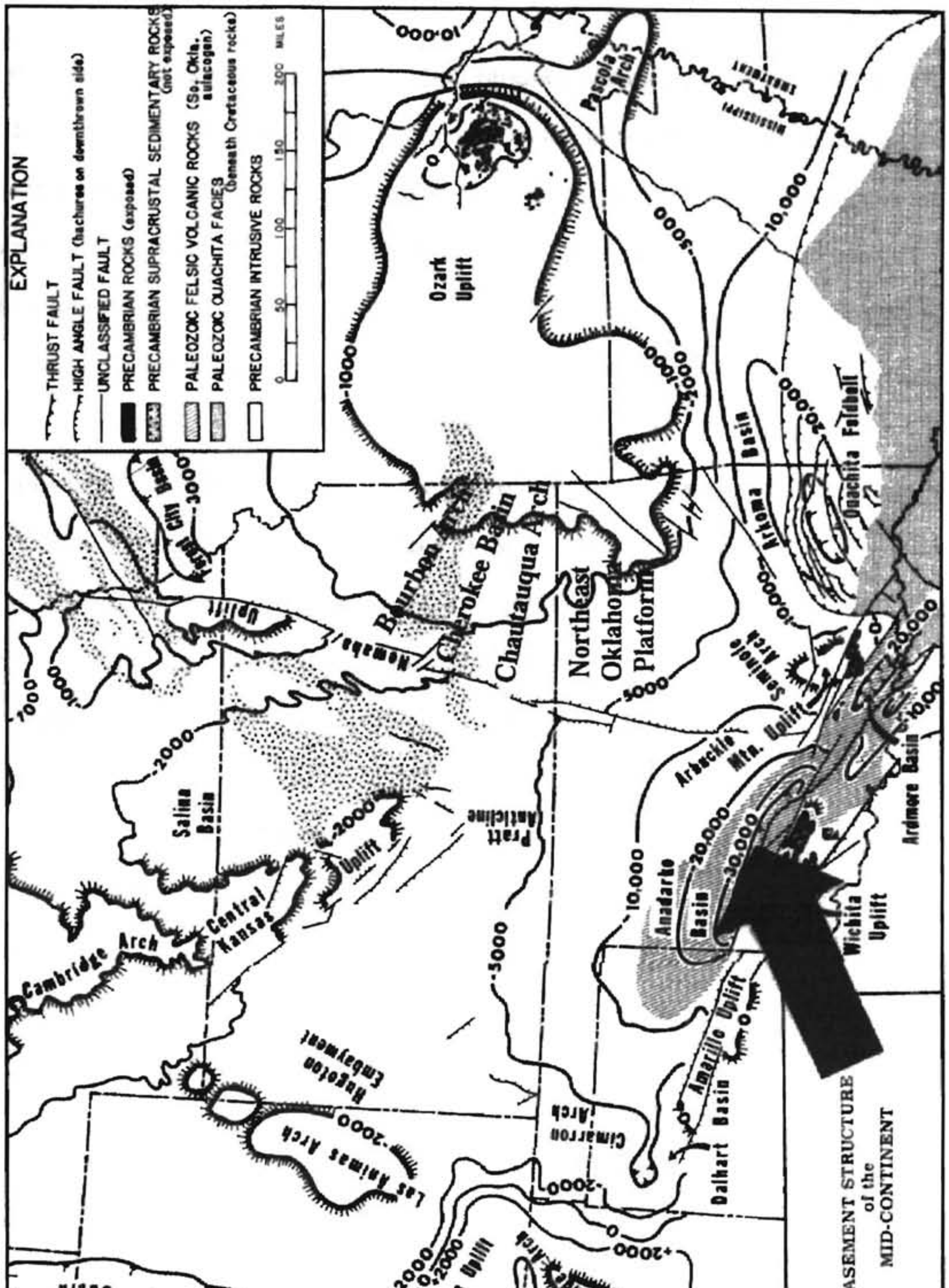


Figure 3 (modified from Rascoe and Adler, 1983; Logsdon and Brown, 1976; and Krumme, 1981). The arrow indicates the general, inferred direction of sea invasion.

er water levels did not support algae which produce carbonate (Heckel, 1969). On positive structures like the Chautauqua Arch, carbonates generally thickened due to the shallow water and shales generally thinned or pinched out because there was not enough accommodation space (Rascoe and Adler, 1983). Price (1981) described the Chautauqua Arch as an extension of the Ozarks before the Mississippian Period, which bounded the Desmoinesian Cherokee Basin on the south.

Figures 4 and 5 show the paleogeography of the area during the early Desmoinesian and late Desmoinesian, respectively. The sediment source during the early Desmoinesian was the Ozark Uplift to the northeast (Price, 1981). During late Desmoinesian, the primary source was the Ouachita Foldbelt (Krumme, 1981). The study area changed from a semi-continental fluvial-deltaic sandy environment during the early Desmoinesian, to a marine-limestone-and-shale environment during the late Desmoinesian (Rascoe and Adler, 1983).

Formations of the Marmaton Group were deposited in the Midcontinent during the Middle Pennsylvanian, on a gentle westward-sloping ramp (Price, 1981). When the sea invaded, the area was an epeiric sea environment; when the sea withdrew, the area was a terrestrial environment. Repeated transgression and regression produced stacks of depositional sequences that have some attributes in common.

## Previous Work

In later chapters, the author will discuss the stratigraphy of the Marmaton Group in the study area, and the concepts of cyclothems and sequence stratigraphy based on the works of others. Definitions and type sections of formations and their members will be given in Chapter II: STRATIGRAPHY. In order to understand the reason for the present study, knowledge of the development of cyclothemic and sequence-stratigraphic concepts is needed. These topics will be discussed in Chapter III: CYCLOTHEM CONCEPTS and Chapter IV: SEQUENCE STRATIGRAPHY.

II.

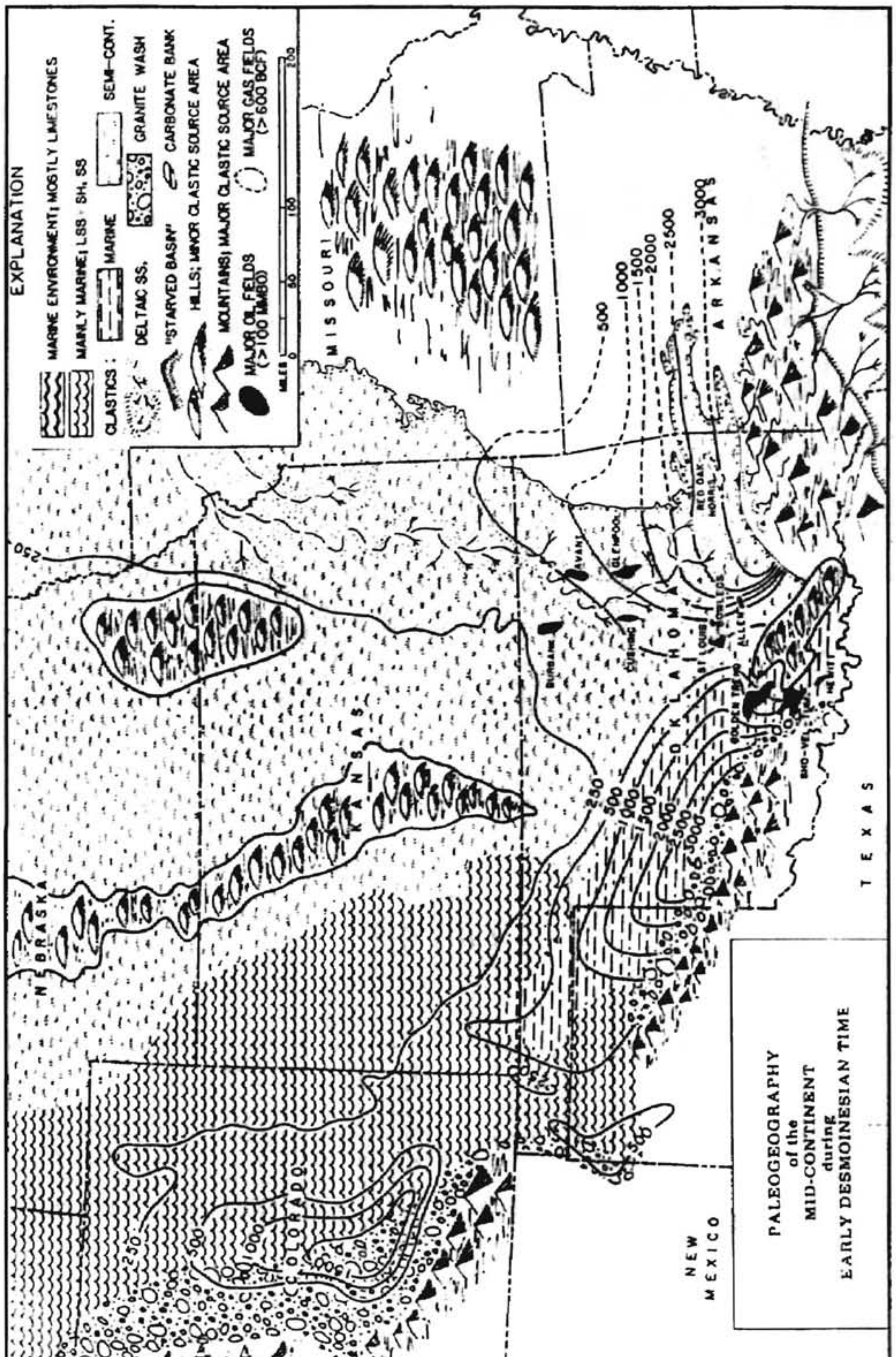


Figure 4 (from Rascoe and Adler, 1983).

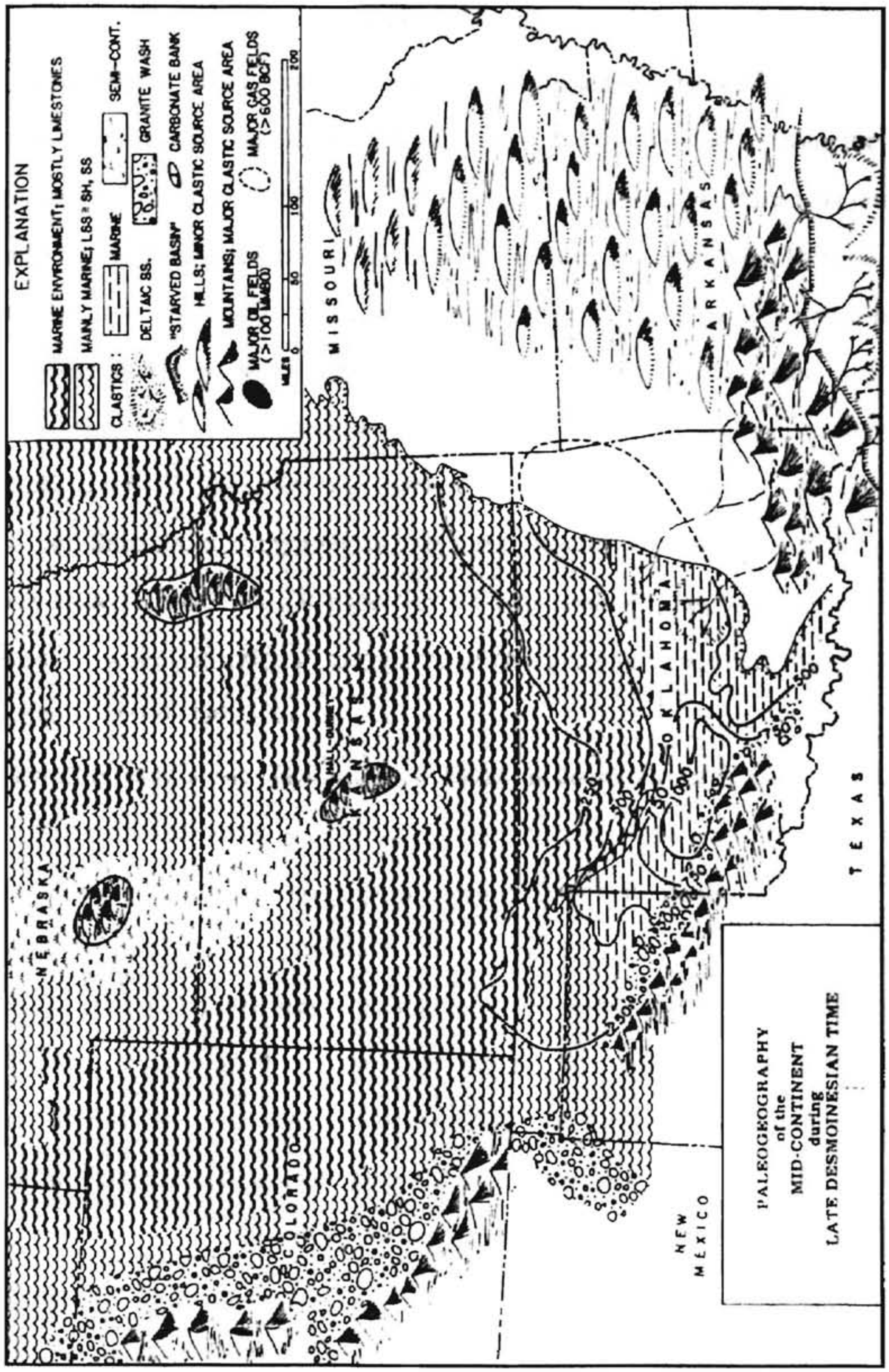


Figure 5 (from Rascoe and Adler, 1983).

# STRATIGRAPHY

The Marmaton Group in the study area is composed of interbedded siliciclastic and limestone formations. Based on the Marmaton Group type locality (along the Marmaton River, Bourbon County, Kansas), Jewett (1941) listed the Marmaton Group formations in ascending order as the Fort Scott Limestone, Labette Shale, Pawnee Limestone, Bandera Shale, Altamont Limestone, Nowata Shale, Lenapah Limestone, and Holdenville Shale. These siliciclastic and limestone formations alternate, and from them can be interpreted a vertical succession of cyclothems or depositional sequences. This cyclical pattern of deposition was characteristic of the Pennsylvanian System of the Midcontinent. Siliciclastic formations mostly are thick and quite varied of lithology (shale, silty shale, siltstone and sandstone lenses, with coals at many localities). Limestone formations generally are composed of two limestone members separated by a shale member (Heckel, 1977).

The Marmaton Group (Desmoinesian Stage) is distinguished from the overlying Pleasanton Group (Missourian Stage) by a regional disconformity and by absence of fauna (*Beedeina, Prismopora, Chaetetes*, and *Mesolobus*) that are abundant in Missourian strata (Moore, 1949; Schmidt, 1959).

The Marmaton Group formations and members in this study were named by several geologists over a period of more than 100 years. These geologists chose type localities for the formations (or their members) based on how well developed and how typical the unit was judged to be at that outcrop compared, as compared to other known outcrops of that unit. They chose names for the formations and members, generally after the town nearest the type locality.

The author has compiled information about the type locality and definition of each unit (surface study). Sources are Swallow (1866), Adams (1896, 1903), Drake (1897), Haworth (1898), Ohern (1910), Cline (1941), Jewett (1941), Alcock (1942), Moore (1949), Greene and Searight (1949), Oakes (1952), Schmidt (1959), Chenoweth

(1966), and Price (1981). In the following sections, descriptions of rock-stratigraphic units that are based on previous works are presented separately from interpretations in the following sections.

## Lithostratigraphic Descriptions

### Labette Shale

Haworth (1898) named the Labette Shale after the town of Labette, Labette County, Kansas at the suggestion of Adams. Since outcrops of the Labette Shale are poor, Haworth did not designate a type locality for the Labette Shale but did state that it varies between 30 feet (9.15 meters) thick near Fort Scott, Kansas and 60 feet (18.3 meters) thick near the town of Labette. Jewett (1941) later formally defined the Labette Shale to include all units above the Fort Scott Limestone and below the Pawnee Limestone. Until a better type locality could be found, Jewett designated a temporary type locality (Figure 6) near Labette from "near the middle of the north line and extending to a point near the northeast corner of Sec. 22, T. 33 S., R. 20 E." (Jewett, 1941, p. 312). He provided no descriptions of this measured section.

#### Sageeyah Limestone Member

Schmidt (1959) named the Sageeyah Limestone and included it as the lower member of the Pawnee Limestone in northeastern Oklahoma. Schmidt defined the Sageeyah Limestone to be the units above the Labette Shale and below the Anna Shale Member of the Pawnee Limestone. He designated the type section (Figure 7) to be at the "roadcut near the center of the west line of the SW, Sec. 22, T. 22 N., R. 15 E. approximately 3 miles (4.8 kilometers) west of the village of Sageeyah in Rogers County, Oklahoma" (Schmidt, 1959, p. 23). Schmidt includes the unit which is now referred to as the Childers School Limestone Member of the Pawnee Limestone in his description of the Sageeyah Limestone. The type section he designated and described (Schmidt, 1959, p. 108-110) follows:

Section measured in roadcut near the center of the west line of the SW.

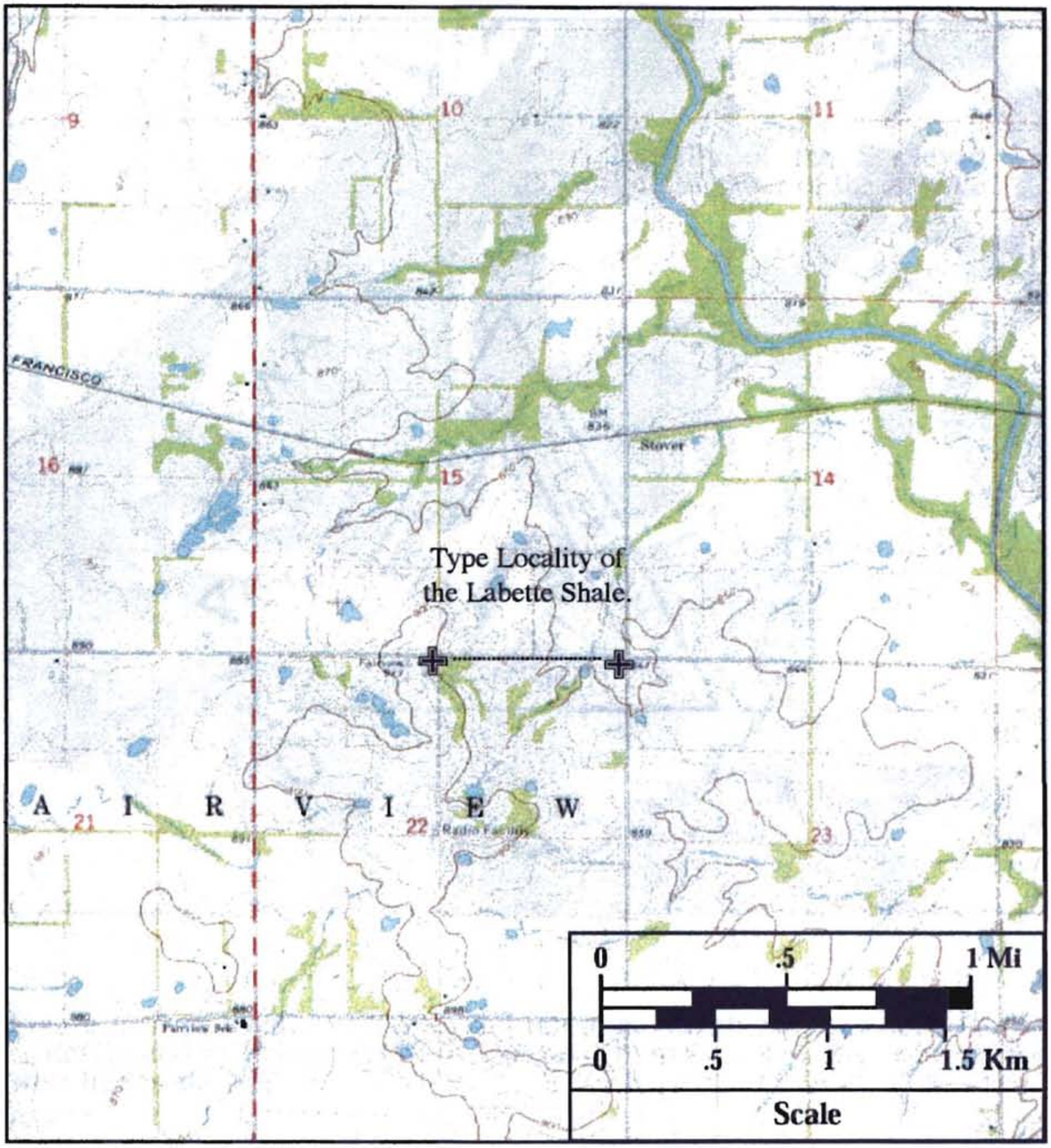


Figure 6. Labette Shale type location as designated by Jewett (1941). "Near the middle of the north line and extending to a point near the northeast corner of Sec. 22, T. 33 S., R. 20 E.", Labette County, Kansas.

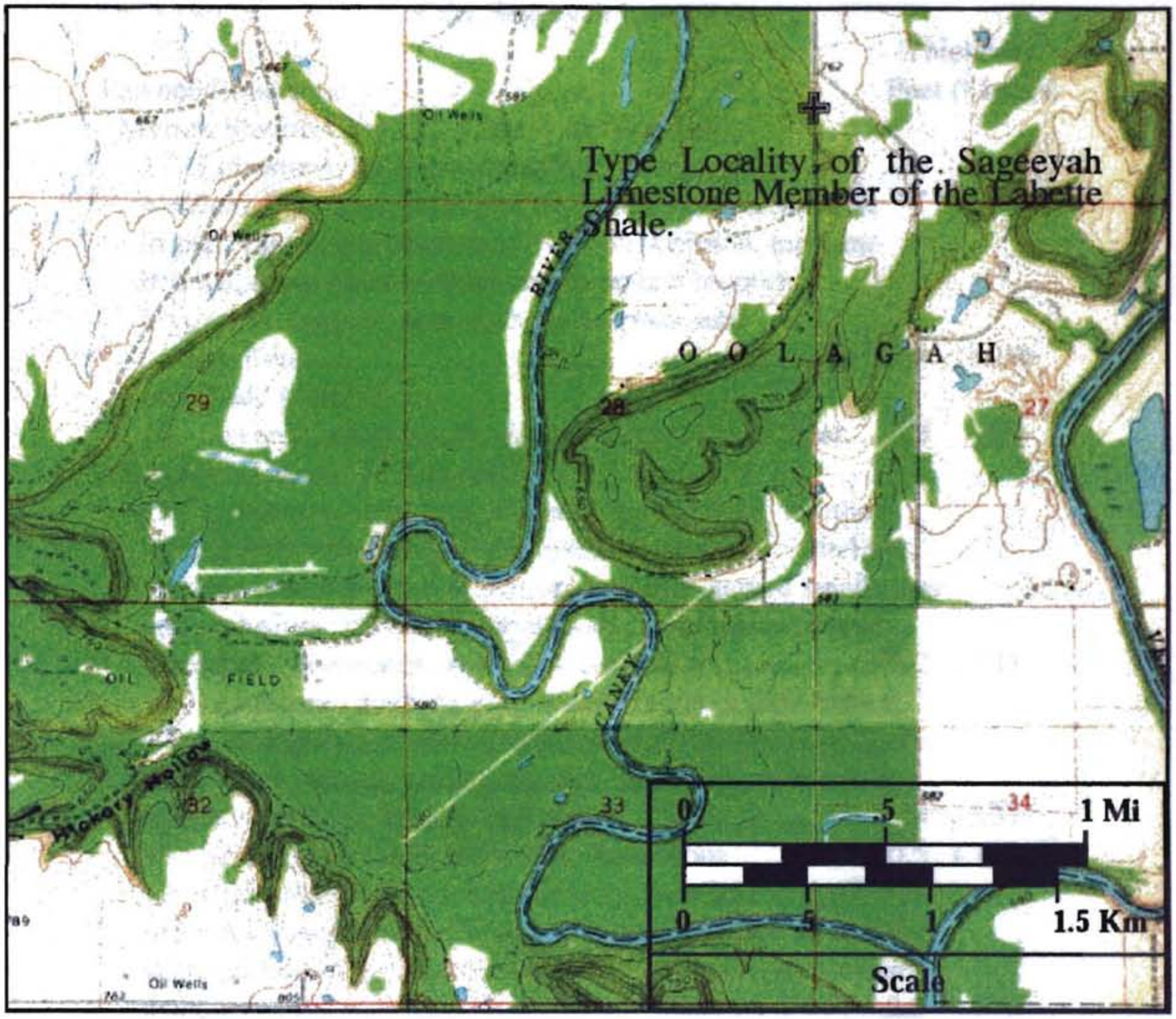


Figure 7. Type locality of Sageeyah Limestone Member of the Labette Shale as designated by Schmidt (1959). Located "in roadcut near the center of the west line of the SW, Sec. 22, T. 22 N., R. 15 E., Rogers County, Oklahoma.

1/4, Sec. 22, T. 22 N., R. 15 E., Rogers County, Oklahoma. Type section of the Sageeyah Limestone.

Thickness
Pawnee Limestone Feet (Meters)

Myrick Station-Coal City Limestone Member

17. Limestone, light gray, mottled, medium gray, weathers light gray, fine-grained, brecciated, calcarenitic in part, calcite inclusions and veinlets common, medium-bedded, some chert nodules; contains brachiopods, bryozoans, crinoid columnals, gastropods, and foraminiferas....................exposed .20.3 (6.19)

Anna Shale Member

16. Covered; contains phosphatic concretions in float......1.8 (.55)

Sageeyah Limestone Member

15. Limestone, light gray, medium gray at base, weathers light gray-brown, calcarenitic, medium-grained, crystalline, massive, wavy-bedded at the top, limonite stained small vugs and inclusions; contains brachiopods, gastropods, crinoid columnals, bryozoans, and a few fusulinids....................23.2 (7.1)

14. Limestone, medium gray, weathers into a light brown siliceous tripolite in places, argillaceous, fine-grained, dense, some chert present, alternating thin- and medium-bedded; contains abundant sponge spicules....................17.4 (5.3)

13. Shale, gray-black, hard, silty, micaceous....................0.5 (.15)

12. Limestone, light to medium gray, weathers to light brown tripolite, fine-grained, dense, argillaceous, siliceous, massive shale parting in the middle; contains very abundant sponge spicules....................2.0 (.61)

11. Shale, gray-brown, silty, micaceous....................0.45 (.14)

10. Limestone, dark to medium gray, weathers light brown, fine-grained, argillaceous....................0.8 (.24)

9. Shale, gray, silty, micaceous; contains crinoid columnals, brachiopod fragments, and a thin limestone lense in the middle part....................1.0 (.31)

8. Limestone, medium gray, weathers light brown, fine-grained, dense, argillaceous; contains crinoid columnals, brachiopods, and sparse fusulinids....................1.0 (.31)

7. Shale, gray-green....................0.4 (.12)

6. Limestone, medium gray, weathers light brown, fine-grained, argillaceous....................0.3 (.09)

5. Shale, gray-brown, silty, micaceous....................1.2 (.37)

4. Limestone, medium gray, weathers light brown, fine-grained, dense, argillaceous; contains some gastropods and crinoid columnals....................0.3 (.09)

Labette Shale?

3. Shale and thin-bedded siltstone, brown-gray, micaceous.......................................................................3.5 (1.07)

2. Shale, gray-brown, silty, blocky, micaceous, mostly covered.............................................................................9.6 (2.9)

Wimer School Limestone Member?

1. Limestone, dark gray, weathers light brown, dense to sub-lithographic, massive; contains foraminifers, brachiopods, crinoid columnals, gastropods.....................1.3 (.40)

Pawnee Limestone

Swallow (1866) named the Pawnee Limestone after Pawnee Creek in Bourbon County, eastern Kansas. Although he did adequately define nor designate a type locality for the Pawnee Limestone, he did provide the first description of the Pawnee based on a composite of creek exposures. The units were presented (Swallow, 1866, p. 24-25) in descending order as follows.

Pawnee Limestone Series

No. 203. Pawnee Limestone;* is heavy bedded, porous and compact, coarse and fine, drab, brown and blueish-gray, cherty, concretionary and mottled, 20 to 25 feet (6.1 to 7.6 meters). *Chaetetes, Crinoids*, etc. Locality, Indian and Pawnee Creeks, and south to Bone Creek.

No. 204. Dull brownish-blue hydraulic concretionary limestone, with pyritiferous shale partings, 6 feet (1.8 meters). Locality, same as No. 203.

No. 205. Black slate, 2 to 4 feet (.61 to 2.75 meters). *Discinas*. Locality, same as No. 204.

No. 206. Blue and brown argillo-sandy shales, 5 feet (1.53 meters). Locality, on the Marmaton, above Fort Scott, and Indian Creek.

No. 207. Impure black shaly limestone, full of fossils, and bed of *cone-in-cone*, 6 feet (1.8 meters). Locality same as No. 206.

No. 208. Blue and brown argillo-sandy shales, with thin bands of brown limestone and septaria of iron ore, 34 feet (10.4 meters). Locality, Indian and Wolverine Creek.

No. 209. Black, impure shaly limestone, full of fossils, 1 foot (.31 meters). *Spirifer, Productus and Chonetes*. Locality, same as No. 206.

No. 210. Coal and coal smut, 6 inches (15.2 centimeters). Locality, same as No. 206.

No. 211. Brown and blue argillo-sandy shales, with a few bands of iron ore, 25 feet (7.6 meters).

Total Pawnee Limestone Series, 112 feet and 6 inches (34.3 meters).

*The lower part of this limestone is almost exactly like the Fort Scott Limestone; both in lithological characters and fossils; hence it is very difficult to distinguish them when the upper gray beds of this limestone and the shales below are not exposed. Between Indian Creek and the Marmaton, both of these rocks crop out in the numerous ravines and slopes, and they are very much broken and disturbed, making it almost impossible to make a correct section between those streams, without this knowledge of the similarity of these limestones.

Expanding on Swallow's work, Jewett (1941) defined the Pawnee Limestone as the units above the Labette Shale and below the Bandera Shale. He lists the Pawnee Limestone members, in ascending order, as the Anna Shale, Myrick Station Limestone, Mine Creek Shale, and Laberdie Limestone. Since no previous workers had designated a specific locality as the type section, Jewett designated it to be the outcrop at "State Highway 7, slightly north of the center of Sec. 7, T. 27 S., R. 24 E., Bourbon County" (see Figure 8). "The upper 20 to 25 feet (6.1 to 7.6 meters) is not well exposed there, but can be seen fairly well at the middle of the east line of Sec. 2, T. 27 S., R. 24 E." (Jewett, 1941, p. 315). This section is also the type section of the Anna Shale Member. He presents the type section (Jewett, 1941, p. 316) as follows.

Section at the type exposure of the Pawnee Limestone, including type exposure of the Anna Shale Member near the center of the N/2, S/2, Sec. 7, T. 27 S., R. 24 E., Bourbon County, Kansas

| Pawnee Limestone | Feet (Meters) |
|---|---|
| Laberdie Limestone Member (25 feet ±, 7.6 meters±) | |
| (9) Limestone, mostly covered | 20-25 (6.1-7.6) |
| (8) Limestone, light gray, slightly crystalline, wavy and thin beds, slightly more massive near base. Giant cup corals in part, and *Chaetetes* near base, exposed in vertical section | 5.4 (1.6) |
| Mine Creek Shale Member | |
| (7) Shale, slightly carbonaceous | 0.25 (.08) |
| Myrick Station Limestone Member | |
| (6) Limestone, brown and gray, very slightly crystalline, generally earthy, massive, but thinner bedded near to "worm borings", large fusulinids | 1.5± (.5±) |
| Anna Shale Member (1.8 feet, .54 meters) | |

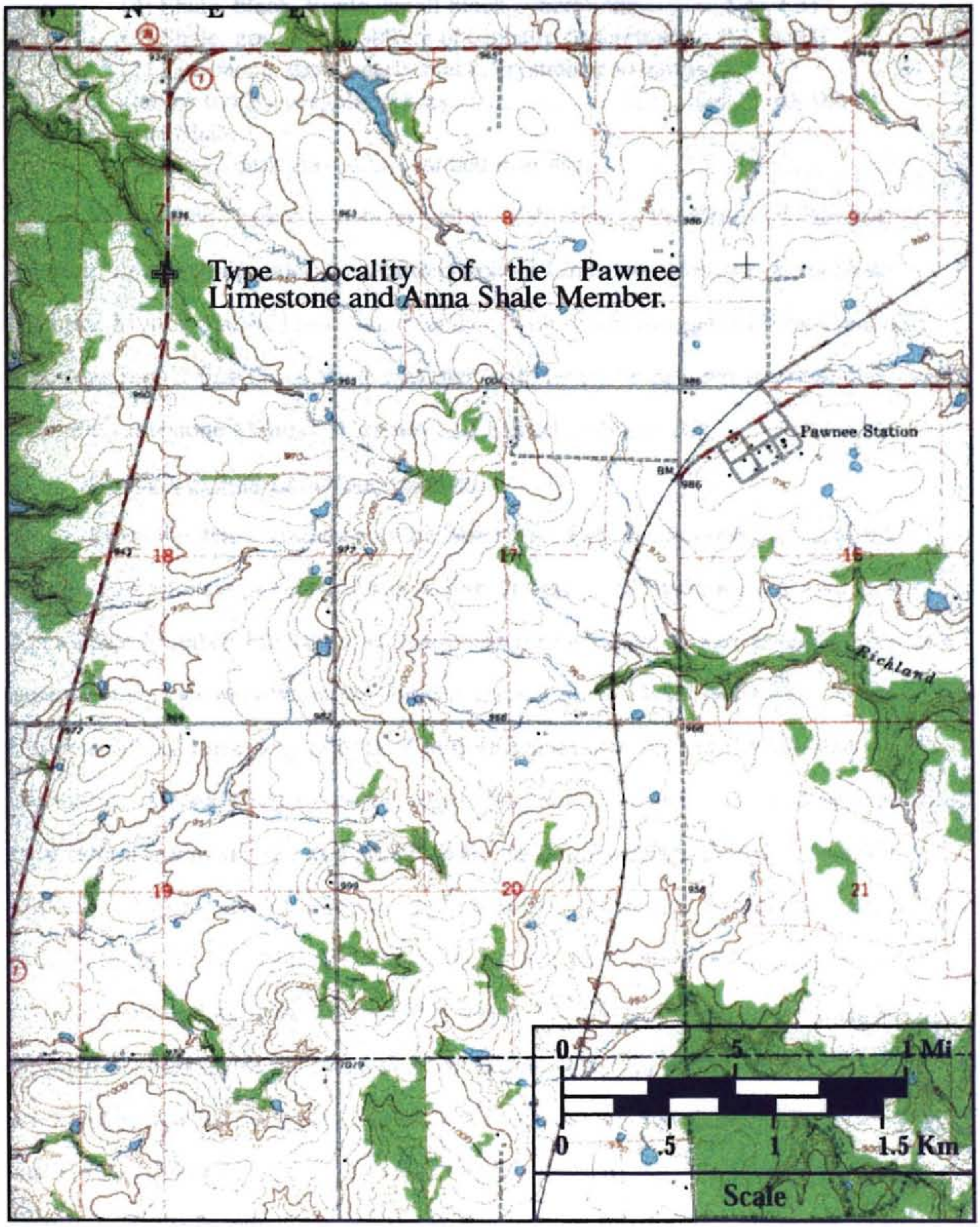


Figure 8. Map showing the type locality for the Pawnee Limestone and the Anna Shale Member "near the center of the N/2, S/2, Sec. 7, T. 27 S., R. 24 E., Bourbon County, Kansas" (Jewett, 1941, p. 316).

(5) Shale, gray.........................................................0.3 (.09)
(4) Shale, black, fissile, small black concretions............1.1 (.3)
(3) Shale, gray, small oblong phosphatic concretions.....0.1 (.03)
(2) Limestone, dark, nearly black, crystalline to earthy,
slabby, mostly irregular lenses....................................0-0.3 (0-.09)

Labette Shale

(1) Shale, dark gray, thin coal bed near top...................................

Watney and Heckel (1994) revised the definition of the Pawnee Limestone to include, "in ascending order, the Childers School Limestone Member, Anna Shale Member, Myrick Station Limestone Member (with newly recognized Frog Cemetery limestone bed), Mine Creek Shale Member (with newly recognized Joe shale bed), and Laberdie Limestone Member" (Watney and Heckel, 1994, p. 26).

Childers School Limestone Member

Since the dense limestone at the base of the Pawnee (number 2 on Jewett's Pawnee Limestone type section) was so thin, Jewett (1941) included it as part of the Anna Shale Member, but suggested that eventually it should be named and defined as a separate limestone member of the Pawnee Limestone. Alcock (1942) later named it the Childers School Limestone after the Childers School at at the town of Childers, Oklahoma. Alcock noted the importance of separating this bed from the Anna Shale due to its lateral extent and use as a marker bed. He designated the Childers School Limestone Member type locality to be at an "artificial road cut, southwest corner of Sec. 6, T. 26 N., R. 17 E." (Alcock, 1942, p. 26). Here, the Childers School Limestone is "typical" and well defined. Price (1981) stated that Alcock was mistaken when he reported the location of the Childers School Limestone type section. He corrected the error and designated the location to be in Nowata County, Oklahoma, "near the south-east corner of Sec. 1, T. 26 N., R. 16 E." (Price, 1981, p. 58). See Figure 9. Alcock (1942, p. 26-27) presented the section as follows:

Pawnee Formation

Childers School Limestone Member New Name

The Childers School Limestone Member is here defined as consisting of the limestone lying below the Anna Shale Member of the Pawnee

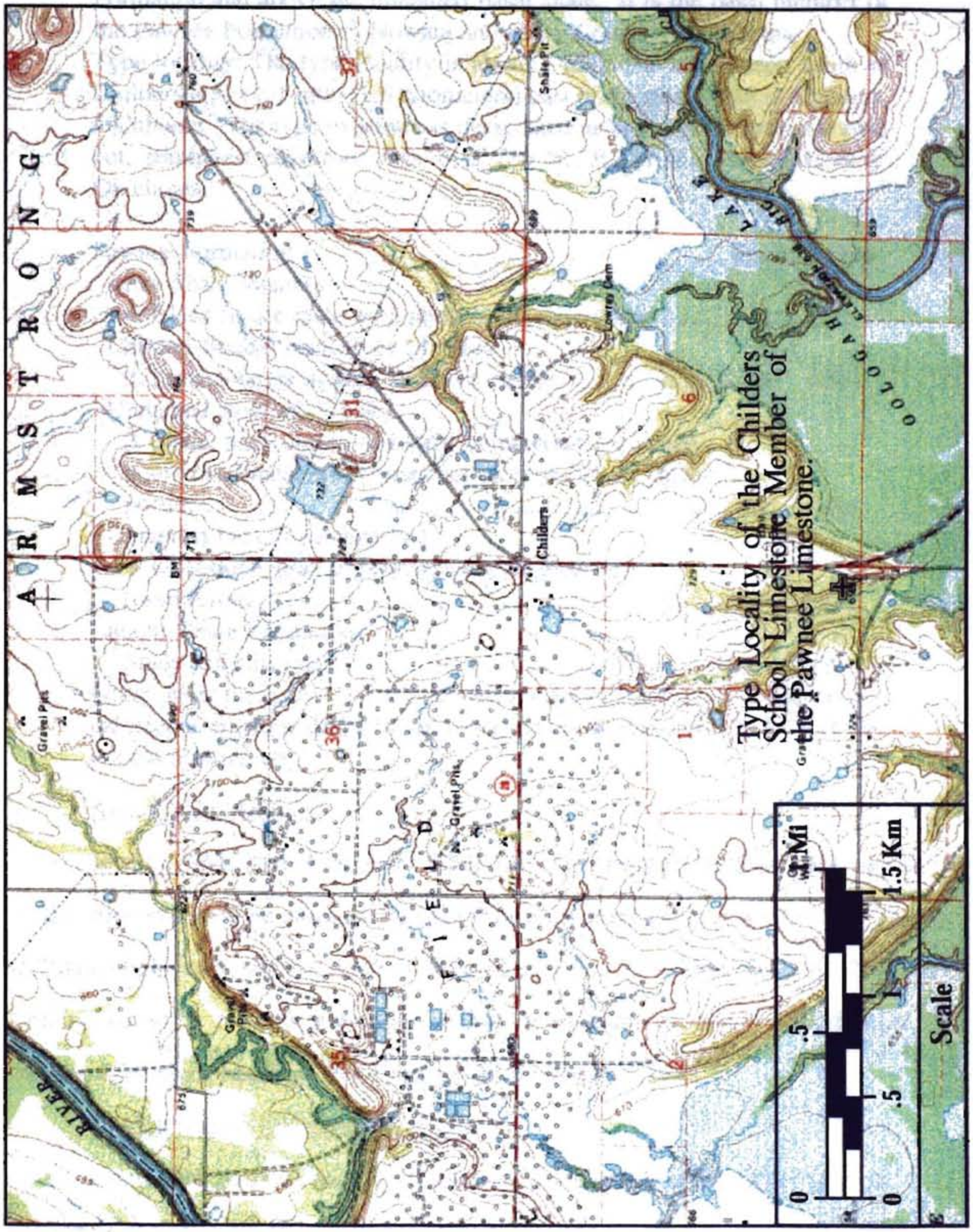


Figure 9. Childers School Limestone type locality near SE, Sec. 1, T. 26 N., R. 16 E.

Formation and above the unnamed basal shale. It is the basal member of the Pawnee Formation in Nowata and Craig Counties, Oklahoma.
Type locality: The type locality is about 1 mile (1.6 kilometers) south of Childers School, 1 mile (1.6 kilometers) east of the post office of Childers, Oklahoma. The type exposure is designated as being in the artificial road cut, southwest corner of Sec. 6, T. 26 N., R. 17 E., Nowata County, Oklahoma.

| Pawnee Formation | Feet | (Meters) |
|---|---|---|
| Anna Shale Member | | |
| 4. Black fissile shale with phosphatic concretions............................ | | |
| Childers School Limestone Member | | |
| 3. Limestone, blue-gray, massive, dense............................ | 1.6 | (.5) |
| Unnamed basal shale bed | | |
| 2. Shale, gray, clayey to fissile, calcareous and marly, numerous limestone nodules concentrated in the upper portion............................ | 8.0 | (2.4) |
| Unnamed basal limestone bed | | |
| 1. Limestone, gray to brown, medium grained, fossiliferous............................ | 1.0 | (.3) |
| Labette Shale Formation | | |
| Shale and siltstone............................ | 18.0 | (5.5) |

Note: Near the bottom of bed (2) there is a thin band of gray, micaceous, calcareous siltstone that was not observed elsewhere and is believed to be a local occurrence.

Anna Shale Member

Jewett (1941) named the Anna Shale Member and designated the type locality to be the same exposure he designated as the Pawnee Limestone type locality, the outcrop at "State Highway 7, slightly north of the center of Sec. 7, T. 27 S., R. 24 E., Bourbon County" (p. 317). Jewett's description of this type section was presented under the Pawnee Limestone heading. See Figure 8 for the location map.

Myrick Station Limestone Member

Cline (1941) named the Myrick Station Limestone Member after "Myrick Station on the Missouri Pacific Railroad, just west of Lexington, Lafayette County, Missouri" (Cline, 1941, p. 37). He considered the Myrick Station to be the "lower limestone member of the Pawnee (the "Lexington cap rock" of Missouri Survey terminology)" (Cline, 1941, p. 37). The Myrick Station Limestone is not present in the current study but is present north of the area, in Kansas and Missouri. Since it is defined as part of the Pawnee, the author includes it here. Cline designated the type section for the Myrick Station Limestone to be at "outcrops in ravines in the south bluff on the Missouri River near Myrick Station on the Missouri Pacific Railroad, just west of Lexington, Lafayette County, Missouri" (Cline, 1941, p. 37). He measured a composite section which includes the Myrick Station Limestone (unit number 35). Cline composited the following section from four outcrops in Lafayette County, Missouri, near the town of Lexington. These outcrops are at "ravines which are crossed by U.S. Highway 24 at points 0.12 (.2), 0.25 (.4), 0.85 (1.4), and 1.15 (1.8) miles (kilometers) west of Myrick Station" (Cline, 1941, p. 35).

SECTION II

Lafayette and Johnson Counties, Missouri

| Top | Feet | Inches | (Meters) |
|---|---|---|---|
| Missouri Series | | | |
| Pleasanton Group | | | |
| 57. Sandstone; yellowish gray; brown, limonitic areas on fresh surface; friable, medium-grained; massive to cross-bedded; 6-8 feet; full thickness probably not exposed ("Wayside") | 7 | | (2.1) |
| Des Moines Series | | | |
| Henrietta Group | | | |
| 56. Shale; green-gray, weathering drab; silty | 4 | 6 | (1.4) |
| 55. Shale; soft, dark blue-gray to black with some green mottling | | 6 | (.15) |
| 54. Clay; red and green mottled, weathers to red soil | 3 | 9 | (1.1) |
| 53. Shale and siltstone; thin discontinuous beds interrupted by lenses of fine-grained sandstone, the whole weathering drab | 10 | | (3) |
| 52. Limestone (Lenapah?); persistent bed of coarsely crystalline crinoidal gray limestone with rusty iron-stained areas | | 7 | (.18) |
| 51. Shale and siltstone (Nowata); thin-bedded but with blocky fracture; thin lenticular bodies of fine-grained green-gray sandstone in upper half; lower half largely composed of blue-gray to green-gray well bedded shale; lower few feet platy; locally the upper few feet contain | | | |

red and green mottled shale and siltstone.................32 6 (9.9)
50. Green clay.............................................................3 (.9)
49. Limestone (top of Worland); two or three beds of massive, light gray, fine-grained, sub-lithographic fossiliferous limestone, weathering deep buff to brown; a few rather large fusulinids........................................2 (.6)
48. Shale and nodular limestone; lithology variable; highly fossiliferous with *Mesolobus*, other chonetids, and fusulinids..............................................................1 3 (.4)
47. Limestone; two beds of massive, jointed limestone, lithologically much like zone 49; island-like masses of *Chaetetes* rise above main ledge of limestone to give irregular upper surface; fossiliferous; *Chaetetes*, large fusulinids, *Composita, Neospirifer, Chonetes*, and bryozoa abundanta; 2 1/2 - 3 feet (zones 47-49 are Worland Limestone).....................................................................2 9 (.8)
46. Shale; green-gray, thin-bedded, soft, calcareous, fossiliferous; especially abundant and persistent are large crinoid stems, a small species of *Mesolobus*, and a large species of *Ambocoelia*......................................2 8 (.8)
45. Dark shale; gray to black with zone of ash-gray, almond-shaped phosphatic concretions....................... 3 (.08)
44. Shale; green, fossiliferous; fauna like zone 46......2 6 (.8)
43. Carbonaceous shale; varies from 3 inches to mere film ..................................................................... 1.5 (.04)
42. Shale; green, silty, micaceous, thin-bedded, non-fossiliferous; laterally replaced by sandstone which may extend downward to cut out lower beds..............3 (.9)
41. Coal; varies from 2 to 10 inches where present but locally cut out by sandstone of zone 42 (Mulberry)..... 5 (.1)
40. Interval composed largely of green clay but at one locality undetermined thickness of shale rest on underlying Pawnee Limestone; locally sandstone of zone 42 extends downward to cut out part of green clay......................................................................10 (3)
39. Limestone (top of Pawnee); gray, weathers yellow, fine-grained, sub-lithographic, hard, massive, fossiliferous; *Squamularia*, large *Chaetetes* heads, and Bryozoa common.................................................4 6 (1.4)
38. Shale; green to blue-gray, thin-bedded.................. 3.5 (1)
37. Limestone; thin-bedded, fine-grained, fossiliferous, nodular at base; abundant *Linoproductus, Composita, Dictyoclostus*, and a large species of *Chonetes*; *Chonetes* is particularly characteristic, being abundant enough locally to form coquina (zones 37, 38, and 39

are upper Pawnee Limestone).....................................2 (.6)

36. Shale; dark gray to black, earthy, with nodular limestone; two coquina-like zones of *Derbya*; a few *Dictyoclostus* throughout.............................................1 10 (.6)

35. Shale; thin-bedded, blue-gray mottled with light gray clayey areas.................................................................2 4 (.7)

34. Shale; black, earthy, calcareous nodules in upper part........................................................................1 5 (.4)

33. Limestone (Myrick Station Member of Pawnee); light gray, fine-grained, hard, conchoidal fracture; wavy bedding but weathers massive.............................5 5 (1.6)

32. Shale; black, carbonaceous, slaty............................1 4 (.4)

31. Coal (Lexington)....................................................1 6 (.4)

30. Shale; black carbonaceous, earthy, fossiliferous with large *Compositas*.......................................................... 8 (.2)

29. Underclay; blue-gray to light gray (zones 29 to 36 comprise Labette Shale)................................................2 (.6)

28. Limestone; dove-gray to blue-gray, weathers buff, fine- to medium-grained, hard, massive, uneven upper and lower surfaces, fossiliferous (top of Fort Scott Limestone = the "*Chaetetes* limestone" = the "Lexington bottom-rock" = Higginsville Limestone of this report)............4 3 (1.3)

27. Shale; thin-bedded, light gray to almost white; upper part clayey, highly plastic when west, stained by iron sulphates, acrid to taste ("white shale" of drillers).......6 3 (1.9)

26. Shale; red and green, thin-bedded, but with blocky fracture, soapy feel when wet......................................9 6 (2.9)

25. Shale; blue-gray to black, darkest below................6 6 (2)

24. Limestone; brownish gray, fine- to medium-grained, hard; closely spaced joints cause it to weather into small rhomboidal blocks ("Rhomboidal limestone" of Missouri Survey = Houx limestone of this report)........................................................... 9 (.2)

23. Shale; black, slaty, with here and there gray phosphatic concretions ("slate vein" of miners)..........................1 10 (.6)

22. Shale; thin-bedded, earthy; black above, dark blue-gray below; fossiliferous with many *Marginifera* and *Composita*, and a few *Dictyoclostus* and *Mesolobus*..................................................................1 10 (.6)

21. Coal (Summit).................................................... 6 (.2)

20. Underclay; ash-gray, plastic when wet...............1 (.3)

19. Limestone; gray, weathers yellow; nodular, highly irregular bounding surfaces........................................1 (.3)

18. Shale; gray, poorly exposed.................................7 6 (2.3)

17. Limestone; argillaceous; gray, weathers buff; one

| | | | |
|---|---|---|---|
| massive, well jointed bed; fossiliferous with *Syringopora, Chaetetes*, and crinoid stems (lower Fort Scott = "Mulky cap rock" = Blackjack Creek Limestone of this report; zones 17-28 constitute Fort Scott Limestone) | 2 | 6 | (.8) |
| Cherokee Group | | | |
| 16. Shale; poorly exposed; dark gray to olive-green; lenses of platy gray phosphatic concretions | 2 | | (.6) |
| 15. Shale and siltstone; weathers drab to yellow; lenses of sandstone | 13 | 6 | (4.1) |
| 14. Sandstone; fine-grained, hard, limonitic bond, weathers brown | 2 | 6 | (.8) |
| 13. Shale, drab | 2 | 9 | (.8) |
| 12. Limestone; thin, earthy, coquinoid; 0-6 inches | | 3 | (.08) |
| 11. Coal (Bedford?) | | 6 | (.2) |
| 10. Shale; blue-gray above, dark blue and carbonaceous below | 14 | 3 | (4.3) |
| 9. Sandstone | 7 | | (2.1) |
| 8. Siltstone and shale; drab sandy siltstone at top grading into dark blue-gray carbonaceous silty shale below; thin-bedded throughout | 23 | | (7) |
| 7. Limonitic zone; probably is badly weathered sideritic limestone as it contains internal molds of *Marginifera* and some gastropods | | 4 | (.1) |
| 6. Shale; dark blue-gray, almost black, with zones of pancake-like clay ironstone concretions | 3 | | (.9) |
| 5. Shale | 13 | 8 | (4.2) |
| 4. Black shale | 2 | | (.6) |
| 3. Coal (Bevier) | 1 | | (.3) |
| 2. Underclay | 1 | | (.3) |
| 1. Limestone (Ardmore) | 5 | | (1.5) |

Mine Creek Shale Member

The Mine Creek Shale Member was named by Jewett (1941). The Mine Creek is not present in the current study, but is north of the study area. Since it is part of the formal definition of the Pawnee Limestone, the author includes it here. Jewett designated the type locality of the Mine Creek Shale to be "near the middle of the south side of Sec. 23, T. 21 S., R. 25 E. on a tributary of Mine Creek in Linn County, Kansas" (Jewett, 1941, p. 318). Figure 10 shows the Mine Creek Shale type locality. The type section Jewett (Jewett, 1941, p. 319-20) presented follows:

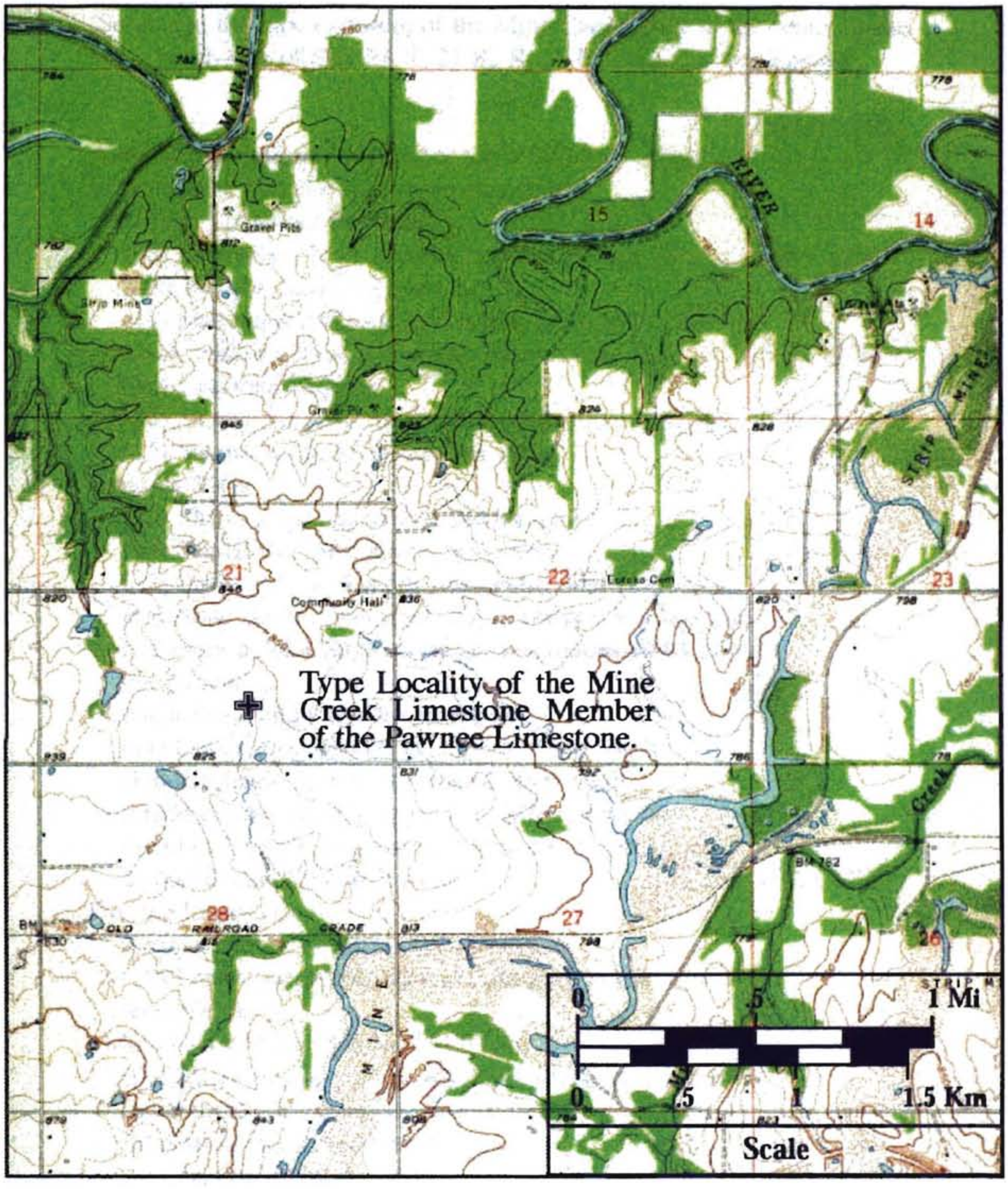


Figure 10. Mine Creek Shale type locality at Center of S., Sec. 23, T. 21 S., R. 25 E., Linn County, Kansas.

Section at the type exposure of the Mine Creek Shale at the center of the south side of Sec. 23, T. 21 S., R. 25 E., Linn County, Kansas

| | Feet | (Meters) |
|---|---|---|
| Altamont Limestone (exposed at top of hill near school house east of Pawnee Limestone exposure) | | |
| Worland Limestone Member | | |
| (18) Limestone, light in color, nodular in basal part | 2.0± | (.6±) |
| Lake Neosho Shale Member | | |
| (17) Shale, not well exposed, mostly gray, but a zone of black shale contains phosphatic concretions | 3.0± | (.9±) |
| Tina Limestone Member | | |
| (16) Sandstone, gray, micaceous, calcareous, massive | 0.5 | (.2) |
| (15) Sandstone, gray, micaceous, shaly | 0.5 | (.2) |
| Bandera Shale | | |
| (14) Shale, gray, calcareous, and limonitic | 3.0 | (.9) |
| (13) Sandstone, gray, micaceous, shaly | 2.0 | (.6) |
| (12) Shale, gray and yellow, limonitic, one thin bed of sandstone about 3 feet from top, lower part less limonitic, and more blocky, large septarian concretions about 17 feet above base | 32.5 | (9.9) |
| Bandera Shale and Pawnee Limestone | | |
| (11) Covered portion including lower few feet of Bandera Shale, in which is the Mulberry coal, mined nearby, and the upper part of the Laberdie member, Pawnee Formation, exposed in a quarry a short distance south of road | 10.8 | (3.3) |
| Pawnee Limestone | | |
| Laberdie Limestone Member (lower part) | | |
| (10) Limestone, bluish gray to light gray, dense, sparingly fossiliferous | 1.5 | (.4) |
| Mine Creek Shale Member (16.5 feet) | | |
| (9) Limestone and calcareous shale, abundantly fossiliferous, fauna mostly brachiopods | 0.5 | (.1) |
| (8) Shale, gray, fossiliferous | 3.0± | (.9±) |
| (7) Coquina of brachiopods | 1.0-0.5 | (.3-.1) |
| (6) Shale, green near top, mostly gray, somewhat carbonaceous, blocky, limonitic | 12.0-13.0 | (3.7-4) |
| Myrick Station Limestone Member | | |
| (5) Limestone, dark bluish gray, weathers brown, upper part thin bedded, lower part massive, large fusulinids in upper part | 3.7 | (1.1) |
| Anna Shale Member | | |
| (4) Shale, gray | 0.5 | (.1) |

(3) Shale, black, platy........................................................1.5 (.4)
(2) Limestone, black, slabby............................................0.2± (.06±)
Labette Shale
(1) Shale, contains thin coal bed near top.

The units (15 and 16) listed above as the Tina Limestone Member were later renamed the Amoret Limestone Member (of the Altamont Limestone) by Greene and Searight (1949).

Frog Cemetery limestone bed

Price (1981) named the Frog limestone bed. It separates the Anna Shale from the overlying Joe shale bed. He designated the type section to be at the SW, SE, Sec. 14, T. 30 S., R. 21 E. (Figure 11) which is about "0.8 kilometers south of Frog Cemetery in southwestern Crawford County, Kansas...along the north bank of Hickory Creek" (Watney and Heckel, 1994, p. 97). This corresponds with number 41 in Price's appendix. He does not provide a measured section or description of the type section. Watney and Heckel (1994) modified this name to the Frog Cemetery Limestone bed, as used in the present study.

Joe shale bed

Price (1981) also named the Joe shale bed. It is a black fissile shale which separates the Frog Cemetery limestone bed from the Laberdie Limestone. Price designated the Joe shale bed type section to be "along the south side of the section line road in the NW, NE, Sec. 7, T. 31 S., R. 21 E." (Figure 12) but did not provide measurements or descriptions for this exposure (Price, 1981, p. 98).

Laberdie Limestone Member

The Laberdie Limestone Member was named by Jewett (1941) after Laberdie Creek, located "about 100 feet (30.5 meters) west of the quarry" (Jewett, 1941, p. 320). The Laberdie Limestone is defined as the upper member of the Pawnee Limestone, and as the part lying above the Mine Creek Shale where that member is present. Jewett designated the type locality for the Laberdie Limestone Member to be "in a quarry in the

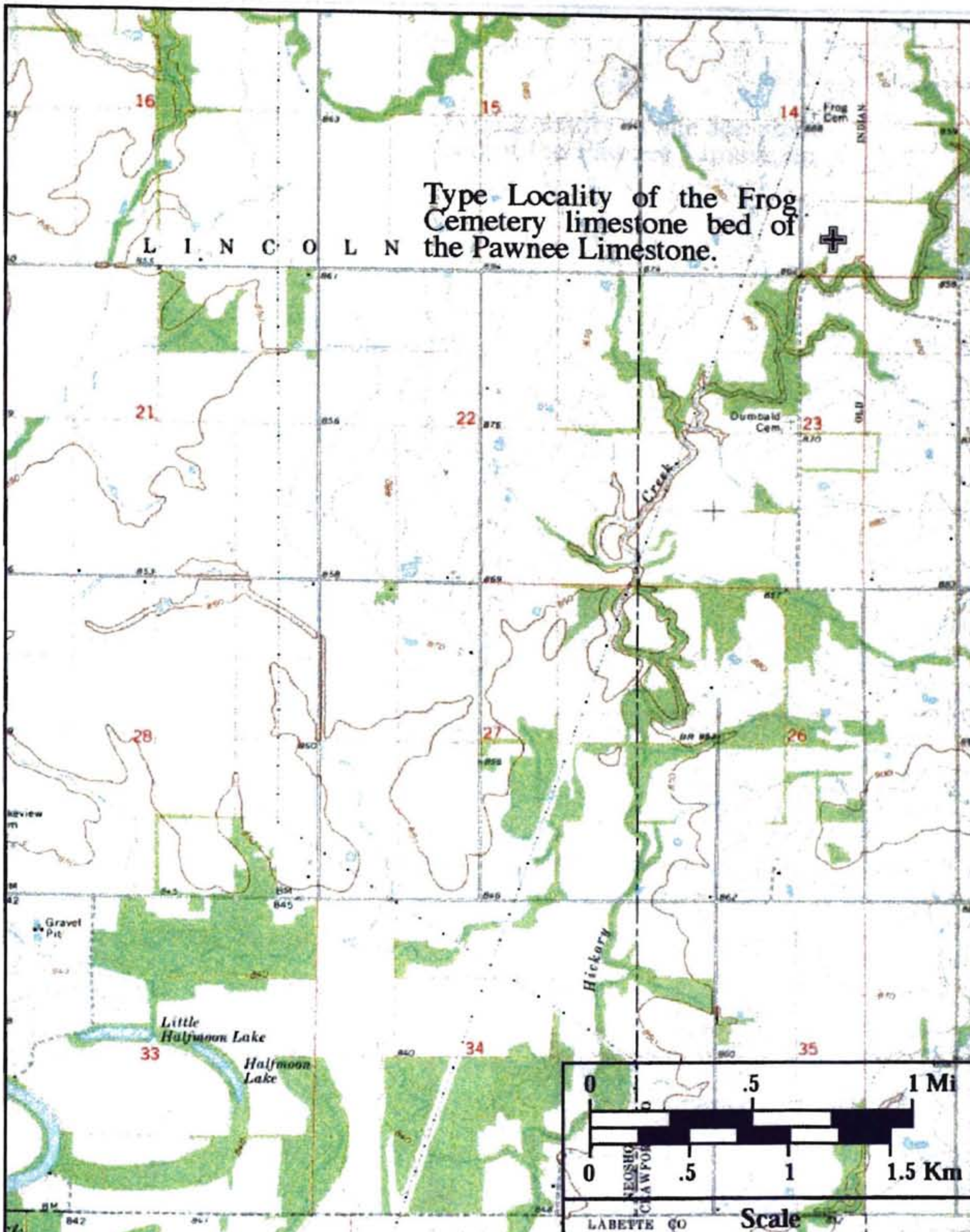


Figure 11. Frog Cemetery limestone bed type locality at SW, SE, Sec. 14, T. 30 S., R. 21 E., Crawford County Kansas.

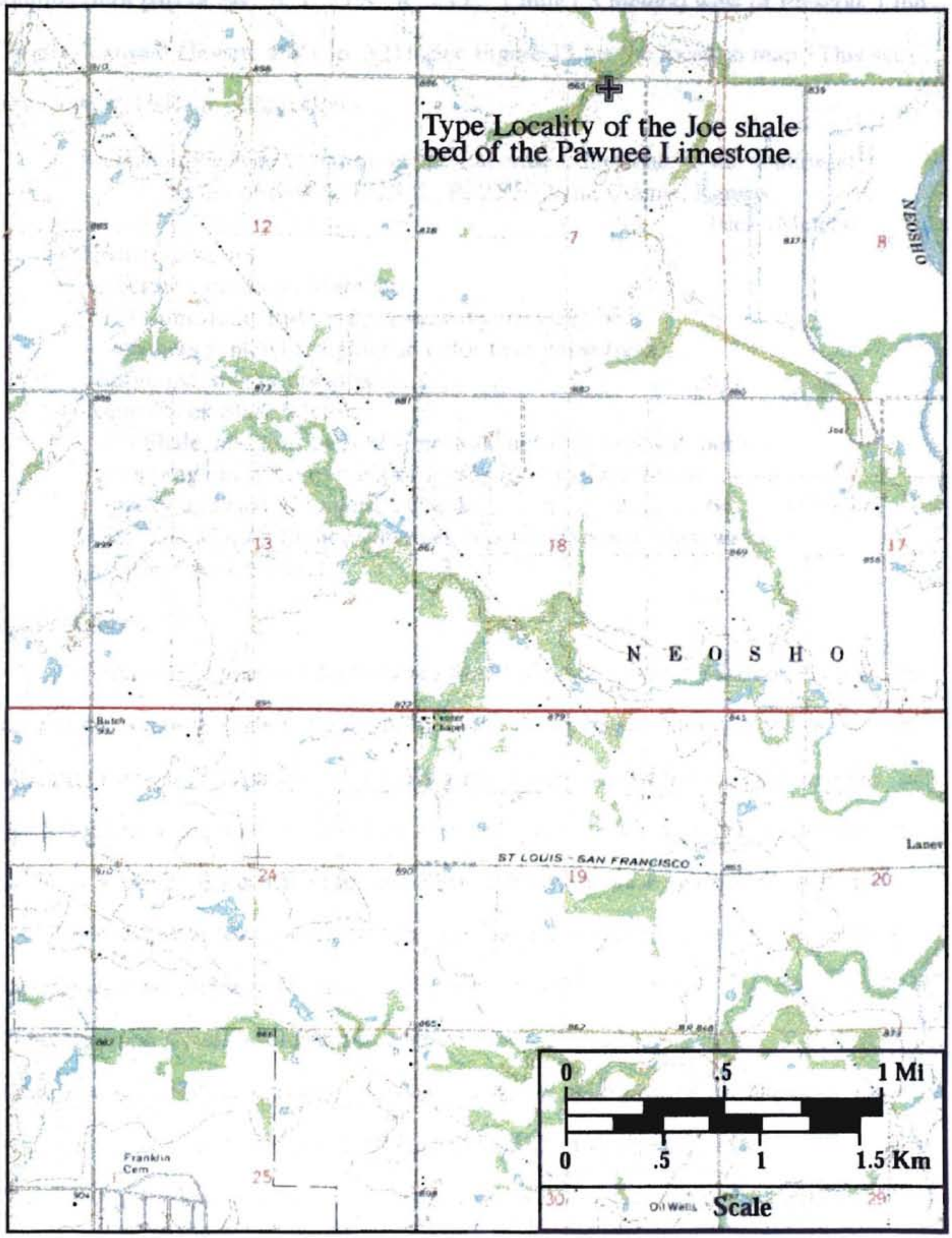


Figure 12. Joe shale bed type locality "along the south side of the section line road in the NW, NE, Sec. 7, T. 31 S., R. 21 E." (Price, 1981, p. 98).

southwestern part of Sec. 6, T. 23 S., R. 25 E., 1 mile (.3 meters) west of Prescott, Linn County, Kansas" (Jewett, 1941, p. 321) See Figure 13 for the location map. This section (Jewett, 1941, p. 322) follows.

Section at the type exposure of the Laberdie Limestone, in the southwest corner of Sec. 6, T. 23 S., R. 25 E., Linn County, Kansas

| | Feet | (Meters) |
|---|---|---|
| Pawnee Limestone | | |
| Laberdie Limestone Member | | |
| (2) Limestone, light gray, thin wavy irregular beds, weathers somewhat lighter in color than when fresh; more massive in lower part | 6.0 | (1.8) |
| Mine Creek Shale Member | | |
| (1) Shale, and thin beds of limestone not well exposed, but cropping out with myriads of fossils in road ditch below quarry and east of Laberdie Creek | 6± | (1.8±) |

Note: The Myrick Station Member is partly exposed when water in Laberdie Creek is low.

Bandera Shale

Adams (1903) named the Bandera Shale after the town of Bandera, Kansas. He defined the Bandera Shale to be the units above the Pawnee Limestone and below the Altamont Limestone. Adams did not designate a type locality but did state that the Bandera Shale was found on the Marmaton River near Bandera. It is near Bandera (Sec. 29, T. 25 S., R. 23 E.) that the Bandera Shale sandstones were quarried (Jewett, 1941).

Jewett (1941) designated two locations as the composite type section because one complete section was not found. The two exposures are at SW, Sec. 29, T. 25 S., R. 23 E., Bourbon County, Kansas and NW, SW, Sec. 29, T. 25 S., R. 23 E., Bourbon County, west of Bandera quarry. This area is shown on Figure 14. These two sections were described by Jewett (Jewett, 1941, p. 323, 325) as follows.

Section measured in the Bandera quarries, near the center of the north line of the SW, Sec. 29, T. 25 S., R. 23 E., Bourbon County, Kansas.

Feet (Meters)

Bandera Shale

(3) Sandstone, buff, slightly irregular beds, ripple marked,

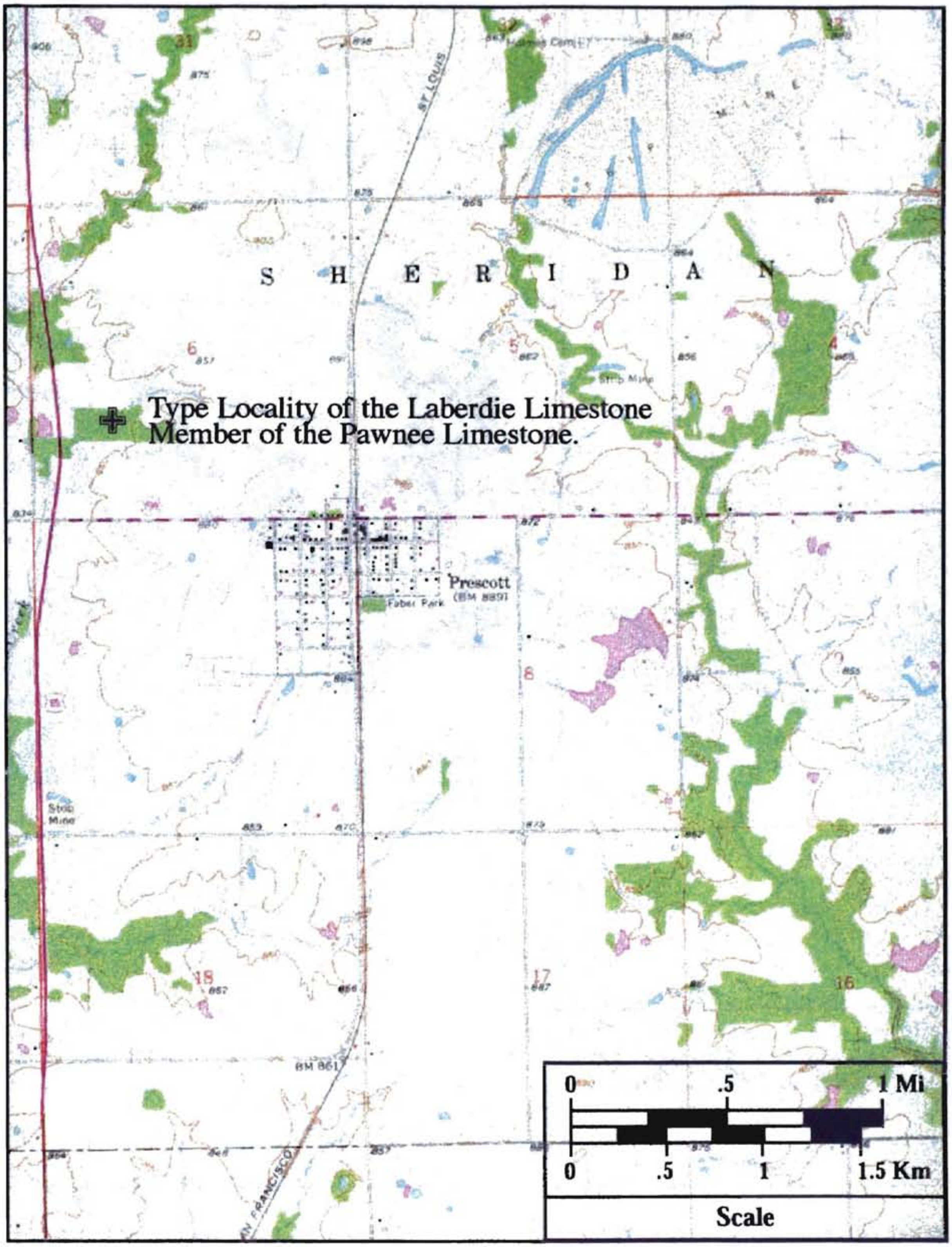


Figure 13. Type locality of Laberdie Limestone at SW, Sec. 6, T. 23 S., R. 25 E., Linn County, Kansas.

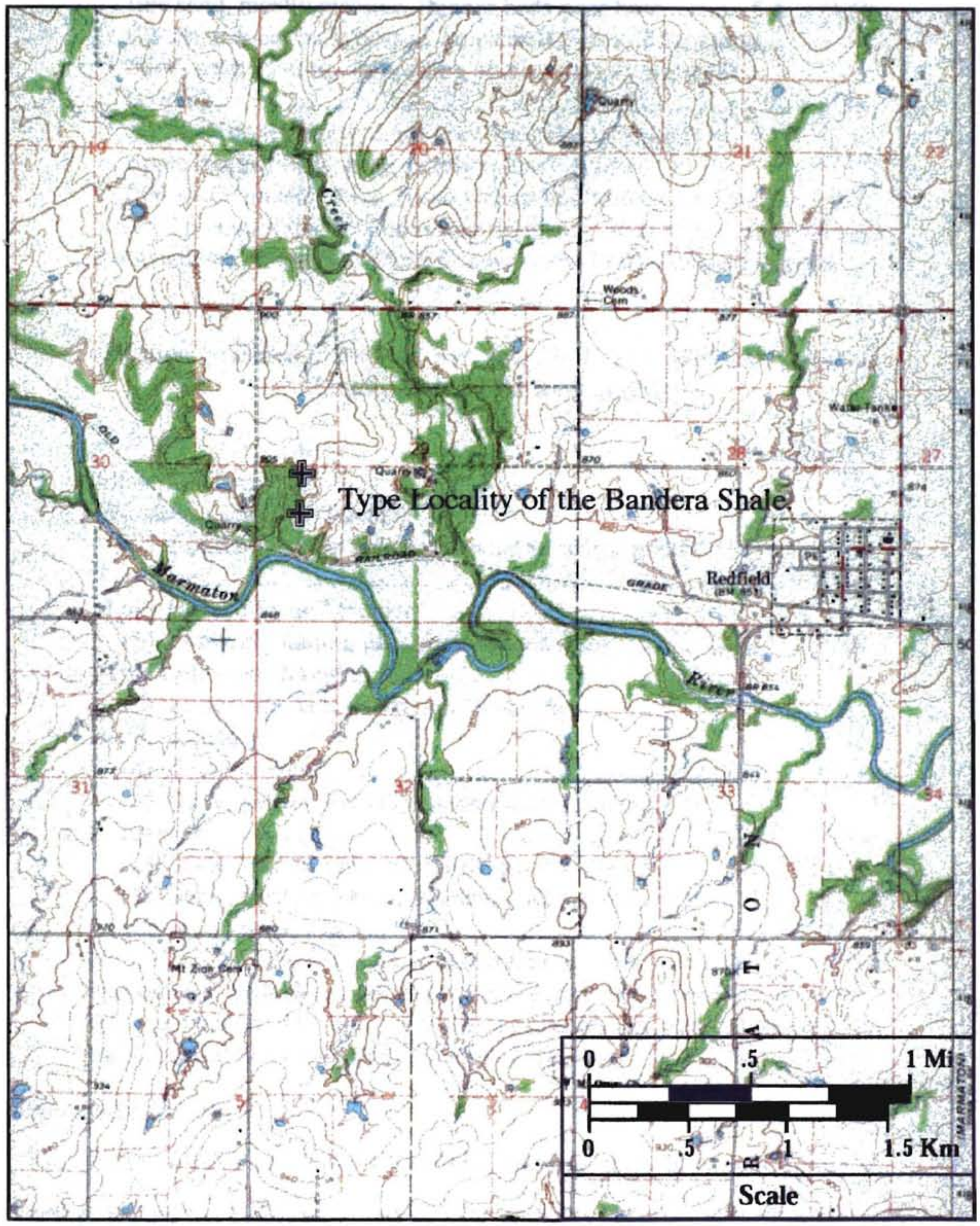


Figure 14. Locations of two Bandera Shale exposures composited to form the type section by Jewett (1941). One is located at NW, SW, Sec. 39, T. 25 S., R. 23 E. The other is "near the center of the north line of the SW, Sec. 29, T. 25 S., R. 23 E., Bourbon County, Kansas" (Jewett, 1941, p. 325).

fine sand, mostly massive, thinner beds near base............ 5.4 (1.6)

(2) Sandstone, buff, beds as much as 0.5 feet (.15 meters) thick, coaly coating on bedding planes, slightly irregular bedding.................................................................. 6.2 (1.9)

(1) Sandstone, mostly light gray, irregular or slightly ripple marked beds, beds mostly 0.2 to 0.3 feet (.06 to .09 meters) thick, fossil worms and trails........... 10.5 (3.2)

Note: The top of this section is approximately 20 feet (6.1 meters) below the Altamont Limestone. Plate 5 shows view in the Bandera quarry.

Section measured in the NW, SW, Sec. 29, T. 25 S., R. 23 E., Bourbon County (west of Bandera quarry)

| | Feet | (Meters) |
|---|---|---|
| Altamont Limestone | | |
| Worland Limestone Member | | |
| (7) Limestone, light gray, somewhat massive, poorly exposed...................................................................... | 2± | (.6±) |
| Lake Neosho Shale Member | | |
| (6) Shale, containing phosphatic concretions.................. | 2± | (.6±) |
| Tina Limestone Member | | |
| (5) Limestone, very sandy, and sandstone....................... | 0.4 | (.1) |
| Bandera Shale | | |
| (4) Shale, covered ........................................................ | 4.5 | (1.4) |
| (3) Shale, yellow and gray, some maroon, poorly exposed..................................................................... | 4.5 | (1.4) |
| (2) Shale, yellow and gray, partly maroon, blocky.......... | 4.5 | (1.4) |
| (1) Shale, partly covered, but nearly all visible, gray and yellow, no sandstone ................................................... | 4.5 | (1.4) |

Note: This exposure is entirely above that in the Bandera quarry, and the two together provide a nearly complete section of the Bandera Shale at the type locality. In some exposures, not far distant, the Tina Member of the Altamont Limestone is much thicker than here. See section 25, pl. 1.

Altamont Limestone

Adams (1896) named the Altamont Limestone after the town of Altamont, Kansas. He did not designate a type section, probably because there were no known continuous exposures of the Altamont in that area. Jewett (1941) also had difficulty locating a continuous exposure of the Altamont Limestone, but designated an exposure at the center of the west line of Sec. 5, T. 33 S., R. 19 E,. Labette County, Kansas,

# I.

# INTRODUCTION

## Purpose

The purpose of this study is to first test whether cyclothemic-scale depositional sequences of the Marmaton Group (Desmoinesian Stage, Pennsylvanian Series) in southeastern Kansas and northeastern Oklahoma can be identified in outcrop and correlated into the subsurface. Secondly, the author will compare the results of correlating using two different models to define sequences. The first model, developed by workers at Exxon (Mitchum et al., 1977; Vail et al., 1977; Van Wagoner et al., 1987; and Posamentier et al., 1992), defines depositional sequence boundaries to be at unconformities and their correlative conformities. The second model, used by Galloway, defines genetic stratigraphic unit (GSU) boundaries to be at maximum flooding surfaces. The author will determine which method of defining sequences yields the better correlations. Figure 1 shows the formal stratigraphic nomenclature of the units in this study.

## Location

The two components of this project are located in adjacent areas. The surface study comprises Marmaton Group outcrops located along a northeast-trending line from southeastern Kansas to northeastern Oklahoma. Enclosure 1 shows locations of exposures. The subsurface portion of this study covers a 36- by 50-mile (58- by 80.5-kilometer) grid in Osage, Washington, and Nowata Counties, Oklahoma, from Townships 23 to 28 North and from Ranges 7 to 15 East. This is 6 to 50 miles (9.7 to 80.5 kilometers) west of the surface study. Enclosure 1 shows locations of well logs and stratigraphic cross sections.

## Methodology

### Surface Study

Surface exposures of the Marmaton Group examined in this study include the Labette Shale, Pawnee Limestone, Bandera Shale, Altamont Limestone, Nowata Shale,

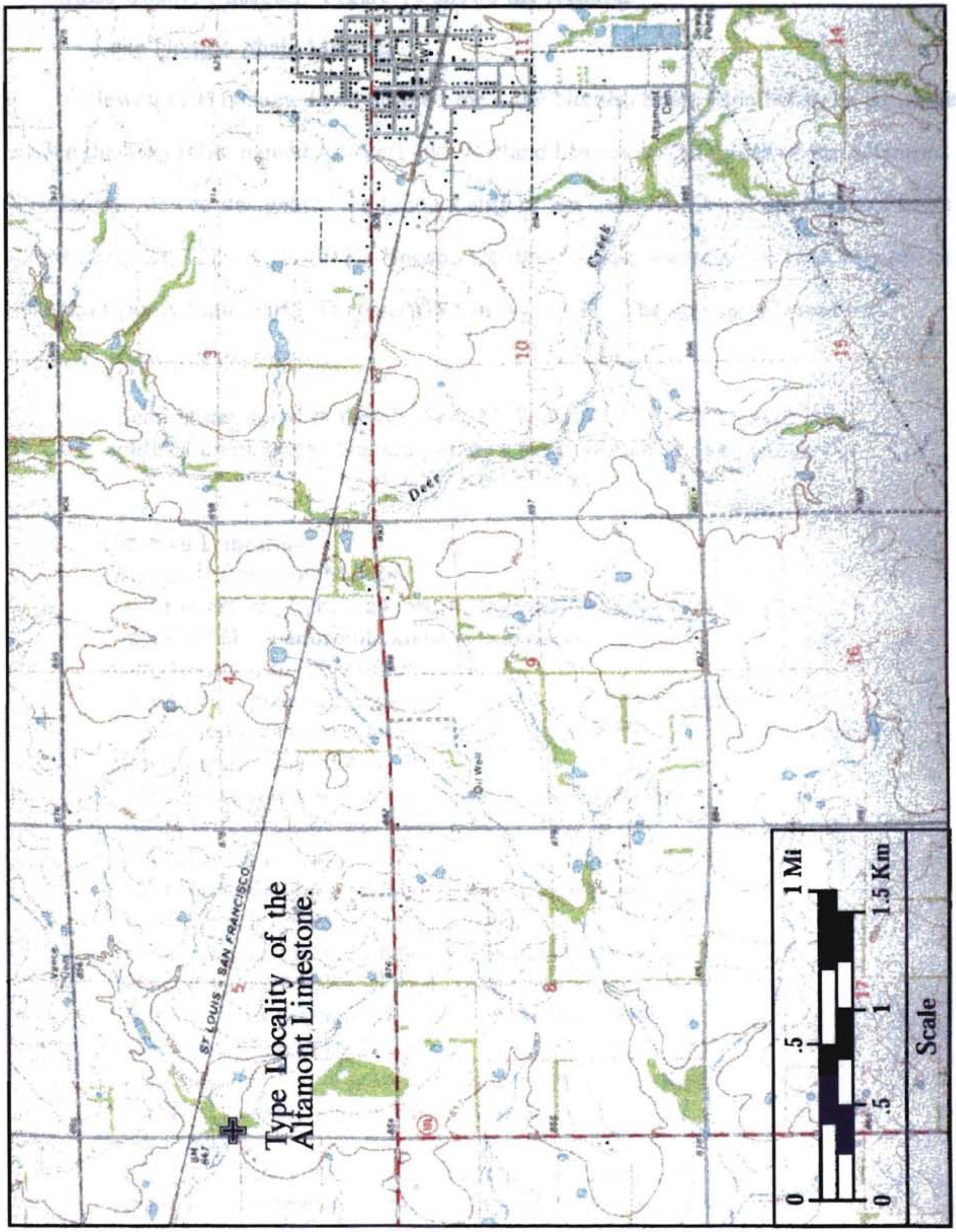


Figure 15. Altamont Limestone type exposure as designated by Jewett (1941) to be at the center of the west line of Sec. 5, T. 33 S., R. 19 E., Labette County, Kansas.

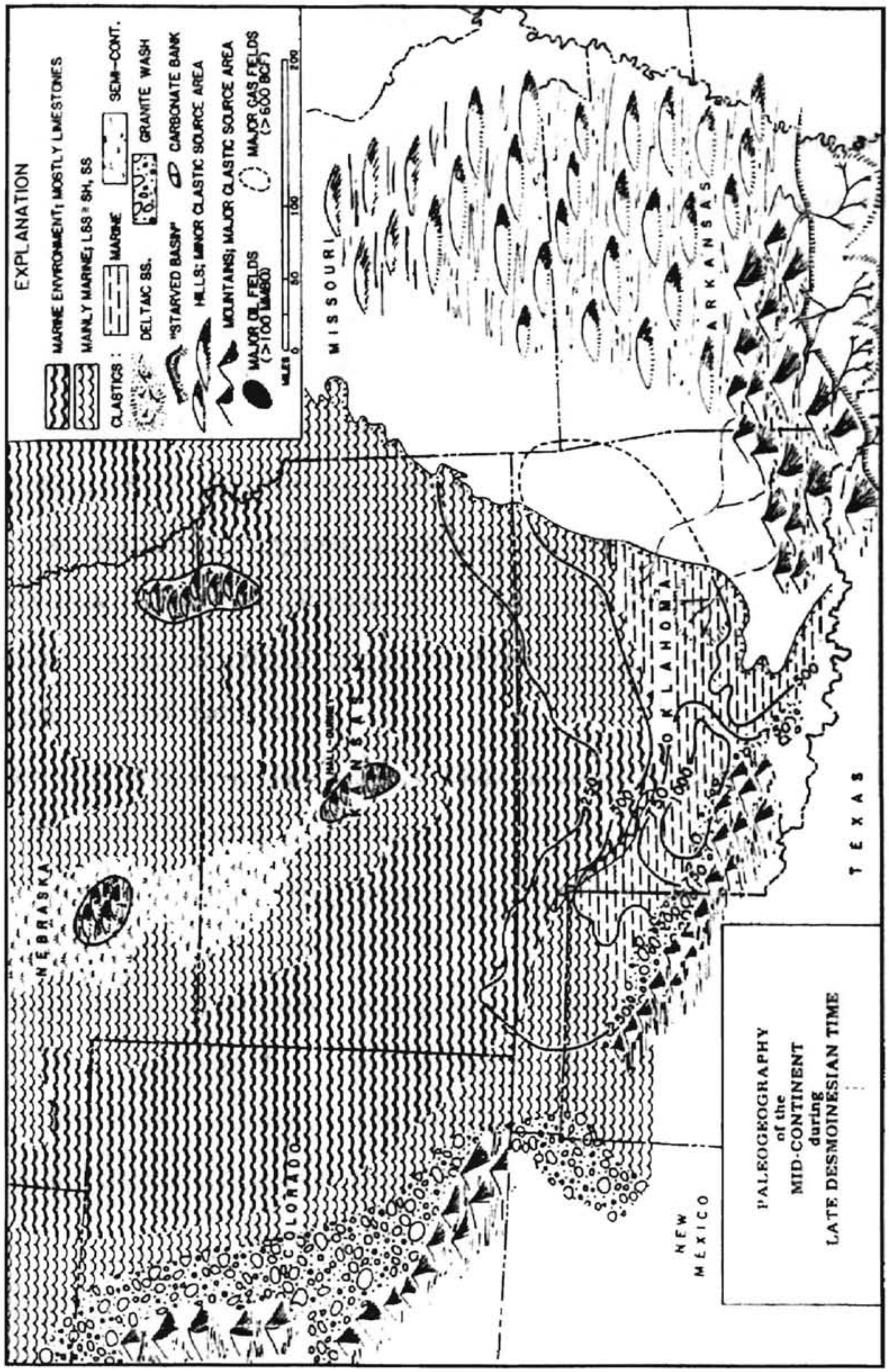


Figure 5 (from Rascoe and Adler, 1983).

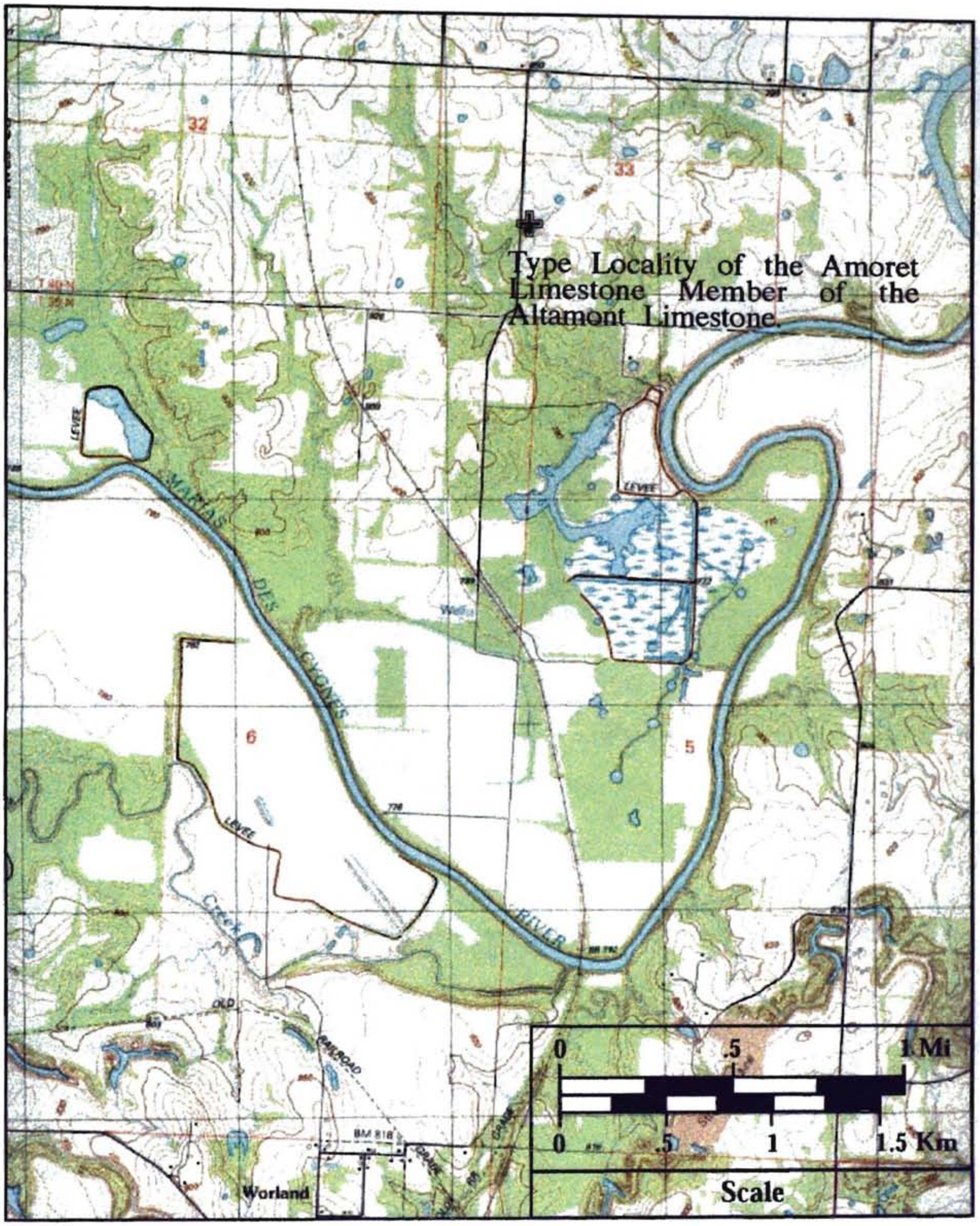


Figure 16. Map of Amoret Limestone type locality as designated by Cline (1941) to be at SW, Sec. 33, T. 40 N., R. 33 W., near Amoret, Missouri.

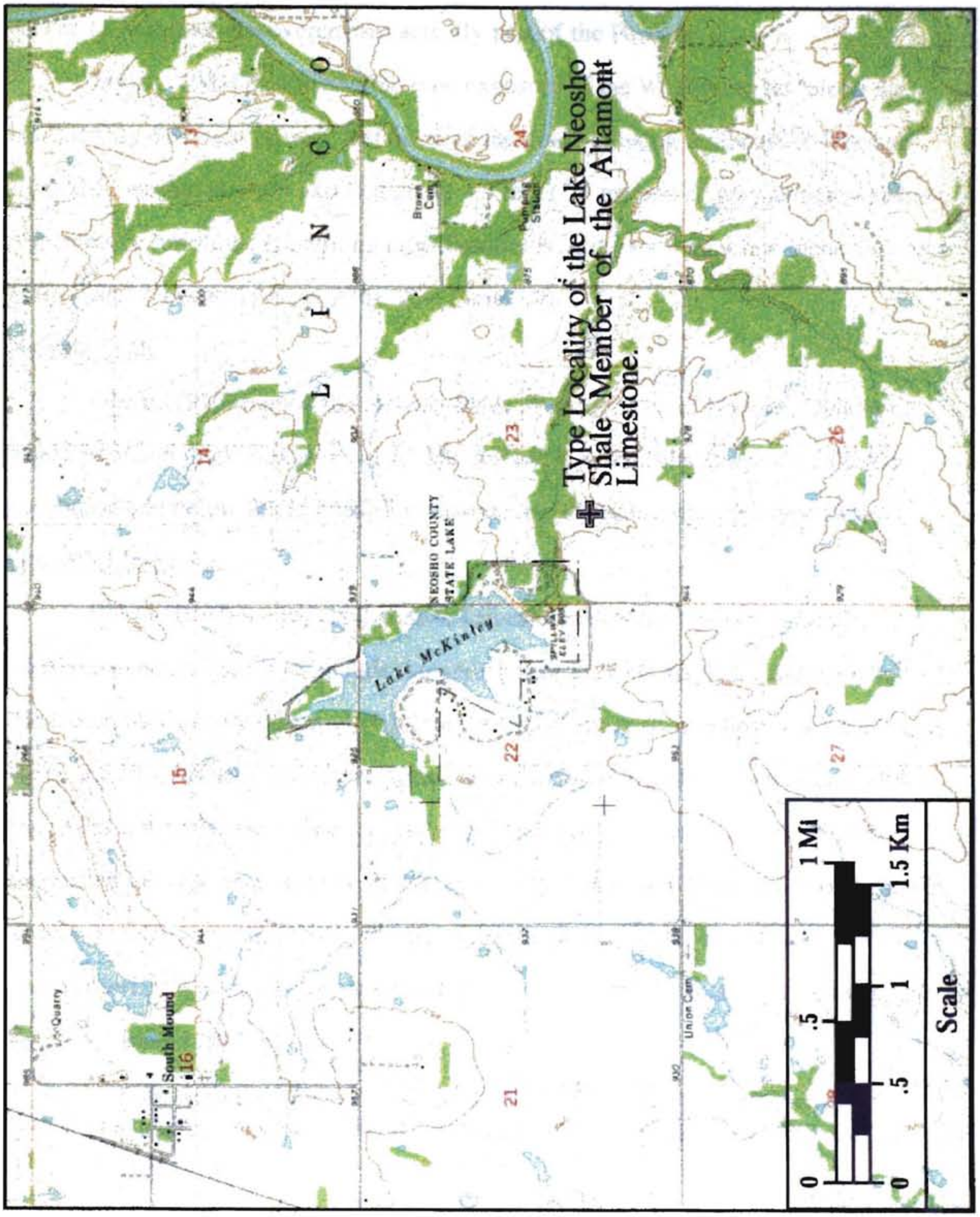


Figure 17. Type locality of the Lake Neosho Shale Member of the Altamont Limestone, at SW, Sec. 23, T. 30 S., R. 20 E., Neosho County, Kansas, southeast of Lake Neosho in Neosho County State Park as designated by Jewett (1941).

Greene (1933) applied the name Worland to what Cline (1941), Jewett (1941), and Moore (1944) later discovered was actually part of the Pawnee.

Jewett (1941) designated the type exposure of the Worland to be "along the Kansas City Southern railway just north of the grade crossing northeast of Worland, Missouri. At that place is exposed about 4.5 feet (1.4 meters) of gray-brown-weathering, massive limestone containing large fusulinids, and overlying a few inches of dark, platy shale" (Jewett, 1941, p. 334). See Figure 18.

Nowata Shale

Ohern (1910) named the Nowata Shale after the town of Nowata, Oklahoma where he found thick exposures of it. He defined it as the beds above the Oologah Formation and below the Lenapah Limestone. He did not designate a type locality.

Lenapah Limestone

Ohern (1910) named the Lenapah Limestone after the town of Lenapah, Oklahoma and defined it to include the units above the Nowata Shale and the Curl Formation (defined by Ohern (1910) to be the units above the Lenapah Limestone and below the Hogshooter Limestone, named after Curl Creek in the Nowata quadrangle). Ohern did not designate a type locality or present any measured sections. Moore (1937) designated the type section to be in a quarry located near Bells Spur, north of Lenapah in the NW, NE, Sec. 30, T.28N., R.16E., Nowata County, Oklahoma (Cade, 1953; Jewett, 1941). See Figure 16. Jewett (1941, p. 336), provides this section description as given by Moore (1937, p. 55).

Section in the NW, NE, sec. 30, T. 28 N., R. 16 E., Nowata County, Oklahoma, west side of U.S. Highway 169 (measured by R. C. Moore)

| | Feet | (Meters) |
|---|---|---|
| Lenapah Limestone | | |
| (3) Limestone, light gray, weathers gray and light yellowish brown, slabby in part somewhat nodular, some beds seem to be brecciated and contain fragments of very fine, dense, light-bluish algal (?) limestone, poorly fossiliferous, *Composita*.......................................... | about 6.0 | (1.8) |

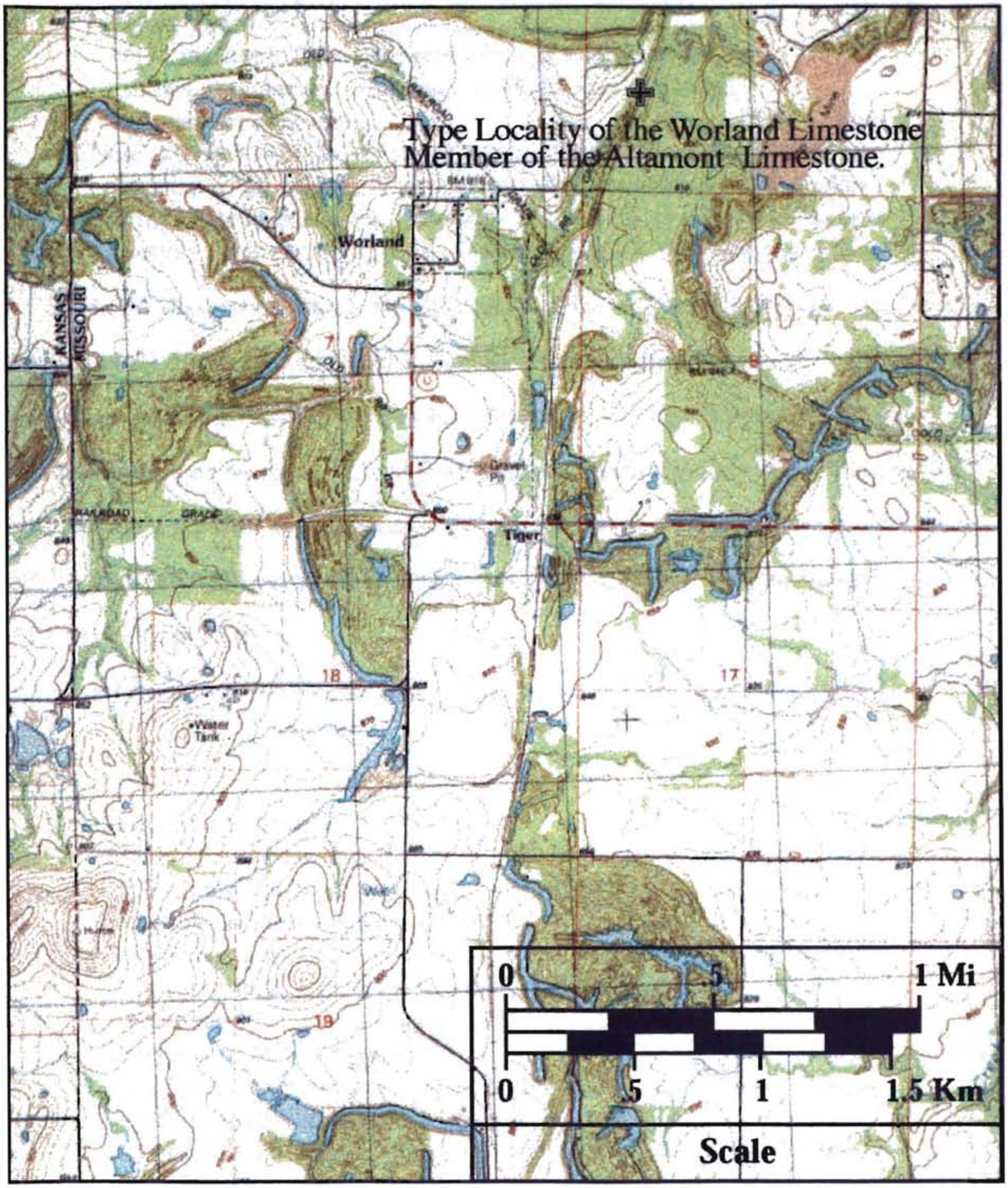


Figure 18. Type locality of Worland Limestone Member of the Altamont Limestone "along the Kansas City Southern railway just north of the grade crossing northeast of Worland, Missouri" as designated by Jewett (1941, p. 334).

| | Feet | (Meters) |
|---|---|---|
| (2) Shale, blue gray, calcareous, contains abundant *Marginifera* | 1.0 | (.3) |
| (1) Limestone, light gray, massive, but weathered surface shows irregular wavy laminae, medium gray somewhat crystalline; exposed | 15.0 | (4.6) |

Note: Moore (1937, p. 55) states that the lower 15 feet (4.6 meters) is equivalent to the nodular limestone and shale beneath the *Marginifera*-bearing shale farther north. It would follow, then, that bed 3 is Idenbro Limestone, and that beds 2 and 1 are equivalent to the Perry Farm Shale.

In the description above, the Lenapah Limestone is not divided into members. Jewett (1941) divided the Lenapah Limestone into three members which he named, in ascending order, the Norfleet Limestone Member, Perry Farm Shale Member, and Idenbro Limestone Member. Jewett provided a description of the Lenapah Limestone (not including the Norfleet Limestone Member) in a newer quarry, since the one Ohern (1910) used (above) became filled with water. See Figure 18. This section follows (Jewett, 1941, p. 337).

Section in the NE, SE, Sec. 30, T. 28 N., R. 16 E., Nowata County, Oklahoma

| | Feet | (Meters) |
|---|---|---|
| Lenapah Limestone | | |
| Idenbro Limestone Member | | |
| (5) Limestone, light gray, weathers tan and pitted, finely crystalline and somewhat slabby | 3 | 0.9 |
| (4) Shale, gray | 0.2 | 0.06 |
| (3) Limestone, light gray, massive, dense to slightly granular, "*Osagia*" and brachiopods | 1.6 | 0.48 |
| Perry Farm (Shale) Member | | |
| (2) Shale and limestone, greenish gray shale with medium dark gray nodular limestone in upper part *Marginifera* | 0.66 | 0.2 |
| (1) Limestone, mottled light gray and medium dark gray, massive but nodular structure is seen; no fossils observed, exposed | 12 | 3.7 |

<u>Norfleet Limestone Member</u>

Jewett (1941) named the lowest member of the Lenapah Limestone the Norfleet Limestone Member after the "Ivy Norfleet farm northeast of Mound Valley, in Sec. 35, T. 32 S., R. 18E., Labette County, Kansas" (Jewett, 1941, p. 338). He defined it to

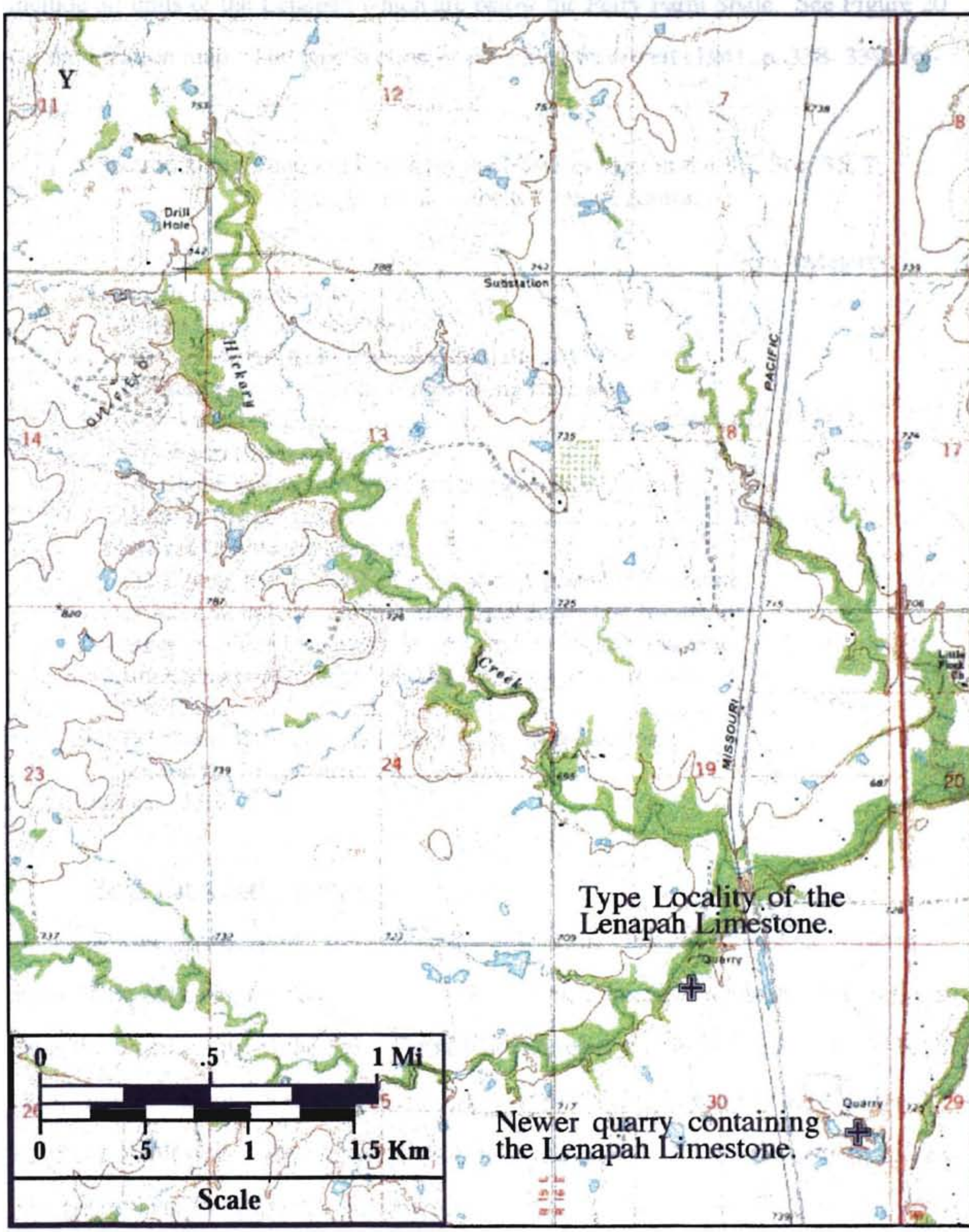


Figure 19. Type locality of the Lenapah Limestone in a quarry near Bells Spur, north of Lenapah in the NW, NE, Sec. 30, T.28N., R.16E., Nowata County, Oklahoma. Location of newer quarry at NE, SE, Sec. 30, T. 28 N., R. 16 E. containing the Lenapah is also shown. Jewett described the section in the newer quarry when the old quarry filled with water.

include all units of the Lenapah which are below the Perry Farm Shale. See Figure 20 for the location map. The type section as presented by Jewett (1941, p. 338- 339) follows.

Section along Pumpkin Creek on the Norfleet farm in the SE, Sec. 35, T. 32 S., R. 18 E., Labette County, Kansas

| | Feet | (Meters) |
|---|---|---|
| Lenapah Limestone | | |
| Idenbro Limestone Member | | |
| (5) Limestone, light gray, nodular, slightly crystalling, brachiopods (crops along road west of low-water bridge)....... | about 4.0 | (1.2) |
| Perry Farm Shale Member | | |
| (4) Shale, mostly covered, some gray, clayey, nodular shale in upper part....... | 10.0 | (3) |
| Norfleet Limestone Member | | |
| (3) Limestone, a "reef" of hummocky, granular limestone, or mass of calcareous material containing plant fossils, in creek north of low-water bridge, and dove-gray, massive limestone containing abundant Dictyoclostus 1/4 mile upstream....... | 3.0 | (.9) |
| (2) Shale, dark gray and black, platy in middle part, somewhat lighter near top....... | 5.0 | (1.5) |
| Nowata Shale | | |
| (1) Shale....... | | |

Perry Farm Shale Member

Jewett (1941) named the middle member of the Lenapah Limestone the Perry Farm Shale Member after the Perry farm, located near the type exposure. Jewett designates the type locality of the Perry Farm Shale Member as NW, NE, Sec. 7, T. 34 S., R. 18 E. This is "about 1.5 miles (.46 meters) west of Angola, Labette County Kansas", along the south side of the east-west road and along a private road to the southwest, east of a bridge over Pumpkin Creek (Jewett, 1941, p. 339). See Figure 21. Jewett's (1941, p. 339-340) type section follows.

Section at the type exposure of the Perry Farm Shale, NW, NE, Sec. 7., T. 34 S., R. 18 E., Labette County, Kansas

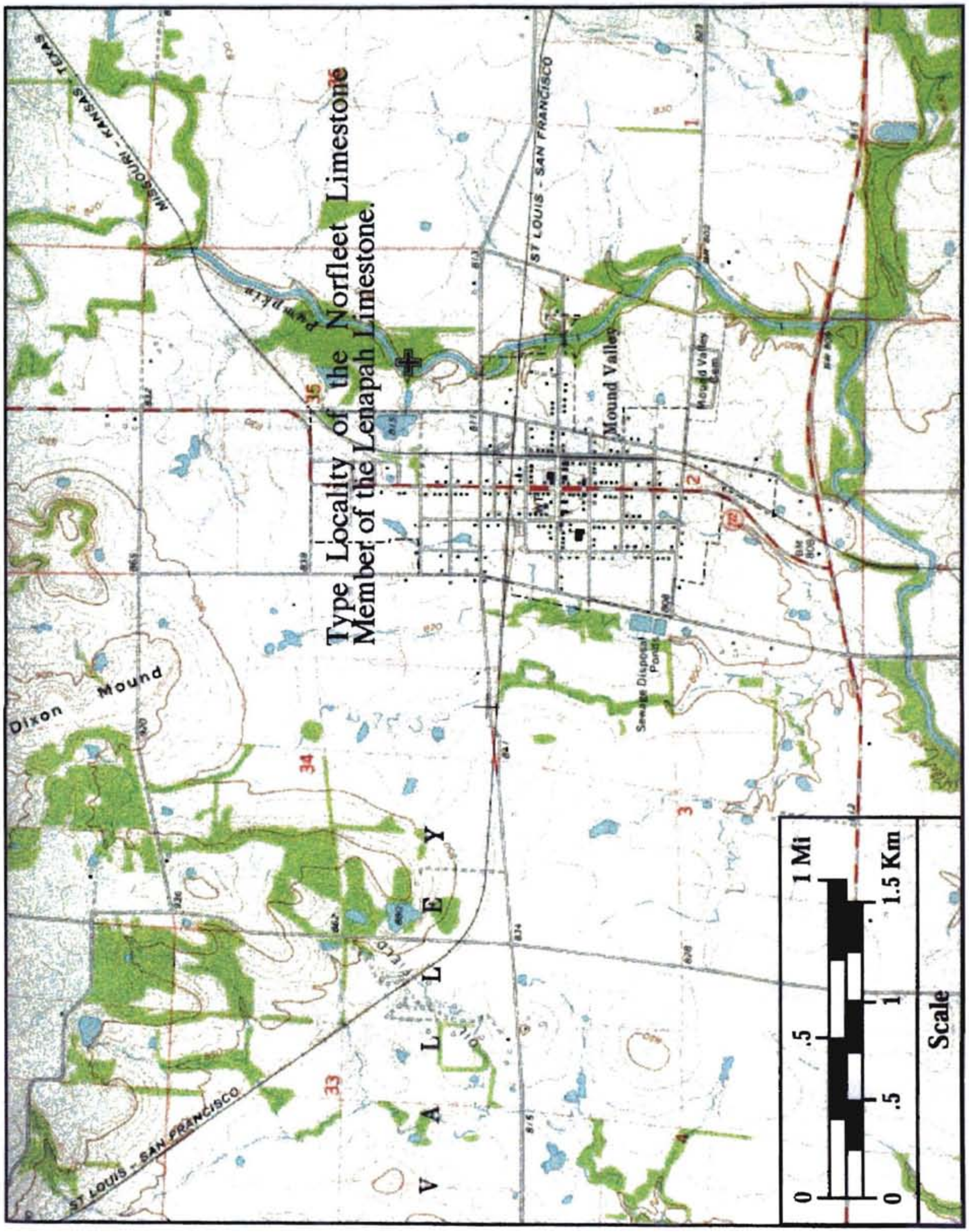


Figure 20. Type locality of the Norfleet Limestone Member of the Lenapah Limestone as Jewett (1941) designated along Pumpkin Creek on the Norfleet farm in the SE, Sec. 35, T. 32 S., R. 18 E., Labette County, Kansas

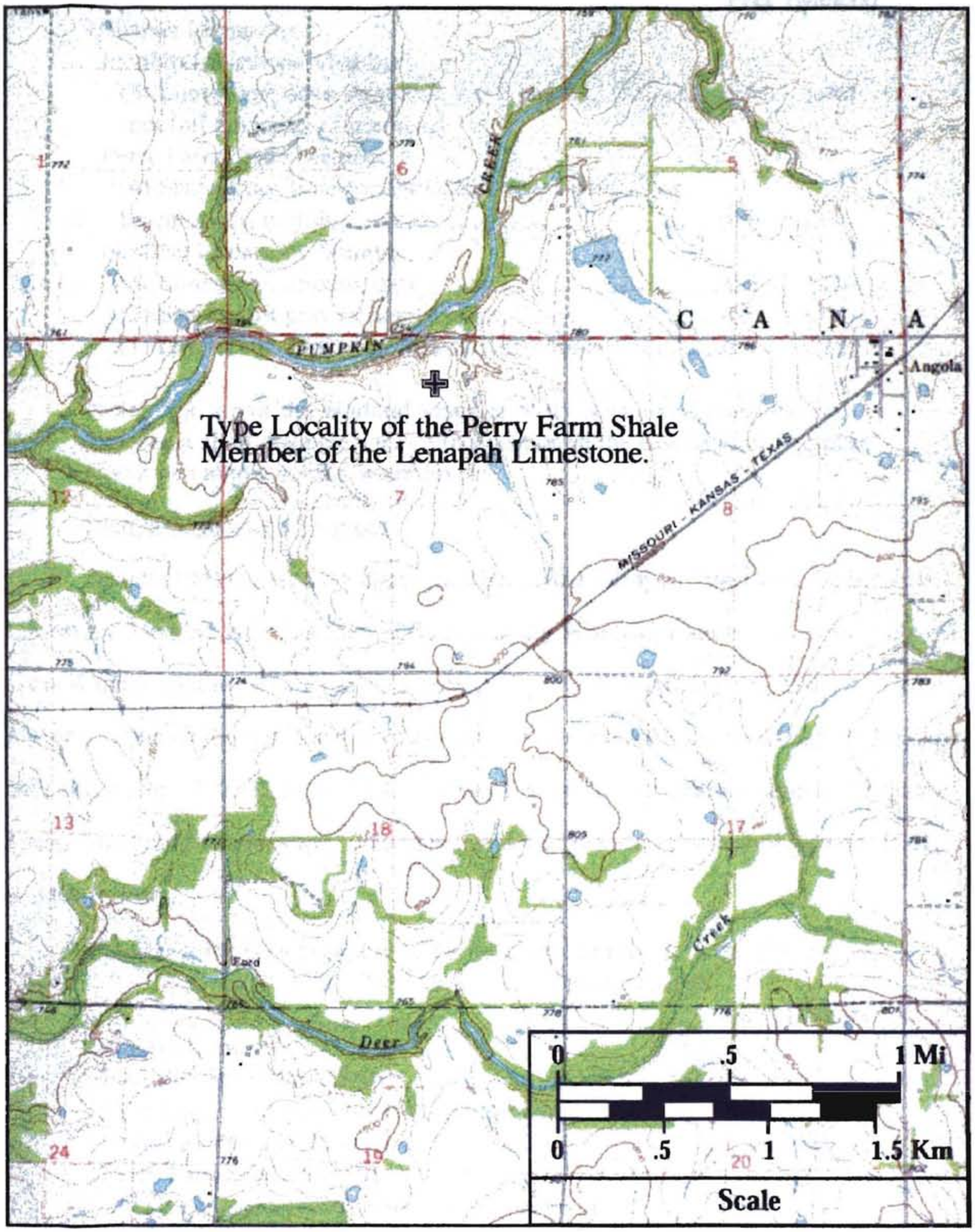


Figure 21. Type locality of the Perry Farm Shale Member of the Lenapah Limestone at NW, NE, Sec. 7, T. 34 S., R. 18 E.

| | Feet | (Meters) |
|---|---|---|
| Lenapah Limestone | | |
| Idenbro Limestone Member | | |
| (5) Limestone, dove gray, thin wavy beds........................ | 1.5 | (.46) |
| (not full thickness of member) | | |
| Perry Farm Shale Member | | |
| (4) Shale, gray, limestone nodules, very fossiliferous, brachiopods, molluscs, corals.......................................... | 10.0 | (3) |
| Norfleet Limestone Member | | |
| (3) Limestone, impure, dark............................................. | 0.5 | (.15) |
| (2) Shale, dark gray or nearly black, flaky....................... | 4.6 | (1.4) |
| (1) Limestone, dark gray, dense, concretionary................ | 0.5 | (.15) |

Note: The top of the Worland Member of the Altamont Limestone is exposed a short distance west of this section in the east bank of Pumpkin Creek just above normal water level.

Idenbro Limestone Member

Jewett (1941) named the upper member of the Lenapah Limestone the Idenbro Limestone Member after "Idenbro, a station on the Missouri, Kansas, and Texas railroad about 4 miles southwest of Parson, in Labette County, Kansas" (Jewett, 1941, p. 340). Jewett designated the type locality of the Idenbro Limestone Member to be in a drainage path at SW, Sec. 2, T. 32 S., R. 18 E. northeast of the Idenbro station. Figure 20 shows a map containing this location. The type locality as presented by Jewett (Jewett, 1941, p. 340) follows.

Section at the type exposure of the Idenbro Limestone, in the SW, Sec. 2, T. 32 S., R. 18 E., Labette County, Kansas

| | Feet | (Meters) |
|---|---|---|
| Lenapah Limestone | | |
| Idenbro Limestone Member | | |
| (3) Limestone, gray, nodular, predominantly algal, brachiopods, corals.......................................................... | 3.0± | (.92±) |
| Perry Farm Shale Member | | |
| (2) Shale, calcareous, limestone nodules......................... | 10.0± | (3.0±) |
| Norfleet Limestone Member | | |
| (1) Limestone, poorly exposed, weathers more or less nodular.................................................................... | about 2.0 | (.61) |

Note: This exposure probably does not include the entire thickness of the Idenbro Limestone, because some limestone has probably been eroded, but the full thickness is present below the soil above and not far from the outcrop.

## Lithostratigraphic Interpretations

### Labette Shale

#### Sageeyah Limestone Member

Schmidt described the Sageeyah as thin (up to five feet (1.52 meters) thick, absent locally in northern Craig County) from the Kansas-Oklahoma boundary to just north of Oologah, Oklahoma but thicker (up to 62 feet (18.9 meters) thick) southward from Oologah to Tulsa, Oklahoma. He states that the Labette Shale-Sageeyah Limestone boundary is gradational while the Sageeyah Limestone-Anna Shale boundary is sharp. North of Oologah the Sageeyah Limestone contains one or two beds with local silty shale and sandstone lenses. The Sageeyah limestone facies is a medium gray, fossiliferous calcareite "...which includes gastropods, brachiopods, crinoid columnals, bryozoans, and locally fusulinids and Osagia." The Sageeyah sandstone lenses are "...light-gray to brown in color, calcareous, and usually thin-bedded". The shale facies is "...brown to gray-green in color, silty, micaceous, and locally calcareous." (Schmidt, 1959, p. 23-24).

Near Oologah and southward to Tulsa, the Sageeyah undergoes changes in lithology. It can be divided into a lower and upper unit based on lithology and even color. The "lower part is composed of relatively unfossiliferous, alternating medium- and thin-bedded, very argillaceous, dense, medium-gray limestone which locally contains abundant silicious sponge spicules....fossiliferous, calcarenitic, slightly vuggy, massive, light-gray limestone occurs locally as a part of a biohermal development in the lower part of the Sageeyah and above the Labette Shale." "The upper part of the Sageeyah in the southern area ranges from a light-gray, breccia-like, cherty, mottled limestone to a light-gray, massive, crystalline, medium-grained limestone which is largely a calcarenite of fossil detritus. Characteristic fossils in the upper part of the Sageeyah includes bra-

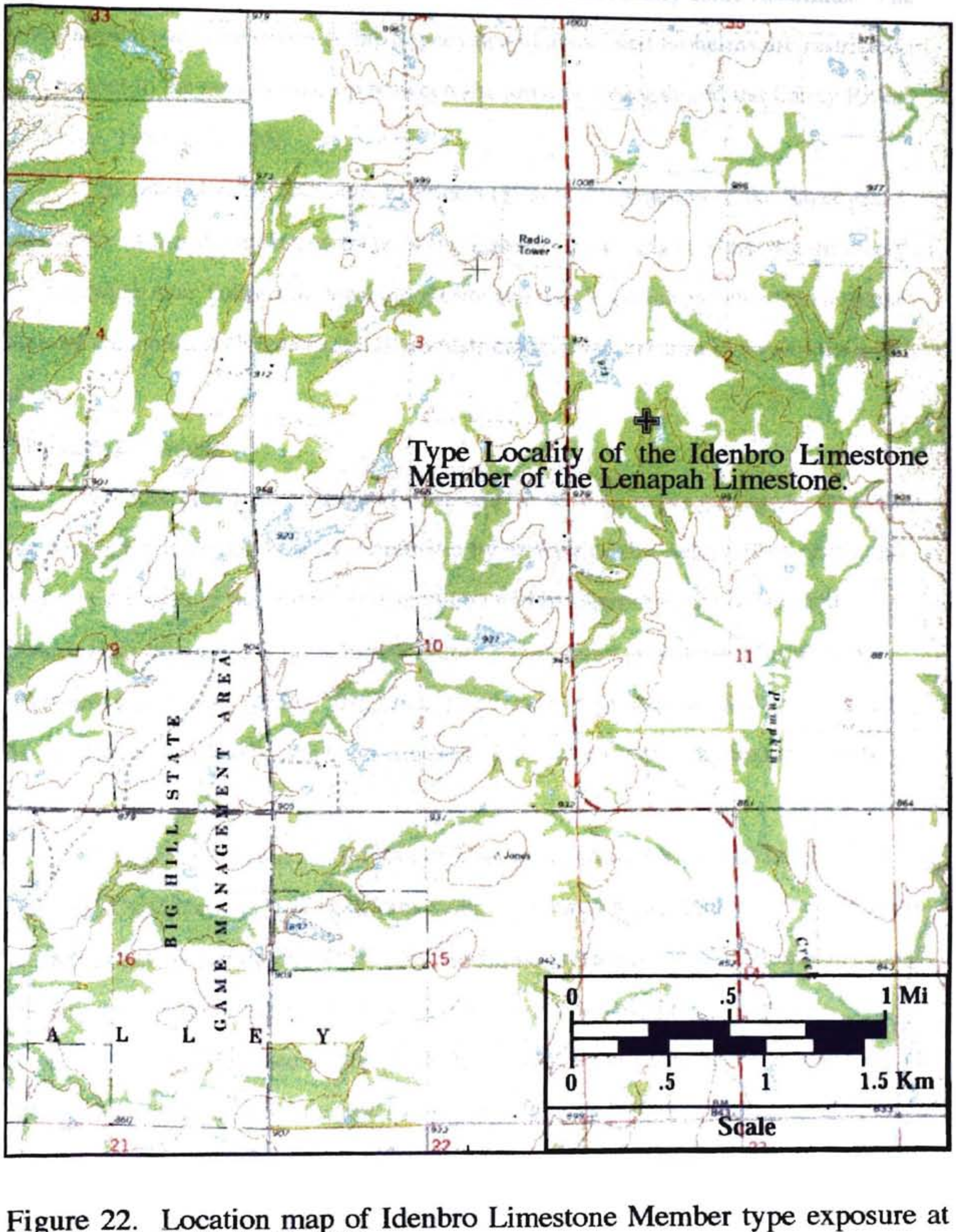


Figure 22. Location map of Idenbro Limestone Member type exposure at SW, Sec. 2, T. 32 S., R. 18 E.

chiopods, gastropods, crinoid columnals, bryozoans, and locally some fusulinids. The lower argillaceous limestones of the Sageeyah and associated bioherms are restricted in areal extent to the area of outcrop between the town of Oologah and the Caney River" (Schmidt, 1959, p. 24, 26).

The present study conforms to Price's (1981) interpretation of the Sageeyah Limestone as the uppermost member of the Labette Shale. Price (1981) determined that the Sageeyah near Tulsa is an algal calcilutite and that it grades northward to a sparse skeletal calcilutite with fewer (and more restricted) fauna and then to a calcareous siltstone.

"Oologah Limestone"

Because the name "Oologah Limestone" is used by many geologists, the author has decided to clear any possible confusion by explaining the history of its usage and why it is not used in this study. It is included within Interpretations rather than Descriptions because it is not a formal name. What many geologists refer to as the "Oologah Limestone" (or the "Big Lime") and use as a subsurface marker, is actually the convergence of the Pawnee and Altamont Limestones where the Bandera Shale thins.

Drake (1897) named a 50 foot (15.2 meter) thick limestone unit he observed near Oologah, Oklahoma the "Oologah Limestone". He presented a type section with measurements but no unit descriptions. The "Oologah Limestone" was later measured and described by workers including Alcock (1942) in the area of the type locality. Chenoweth (1966) obtained a core (Sinclair Core Hole No. 1 Douglass) of the complete "Oologah Formation" near the type locality, at "1,100 feet (335.5 meters) west of the east line and 300 feet (91.5 meters) north of the south line, sec. 16, T. 23 N., R. 15 E., 300 feet (91.5 meters) west of U.S. Highway 169" (Chenoweth, 1966, p. 196). See Figure 23. Chenoweth provided detailed descriptions of the core. Although Chenoweth did not use the name Sageeyah Limestone, he included it (described) as the lower unit

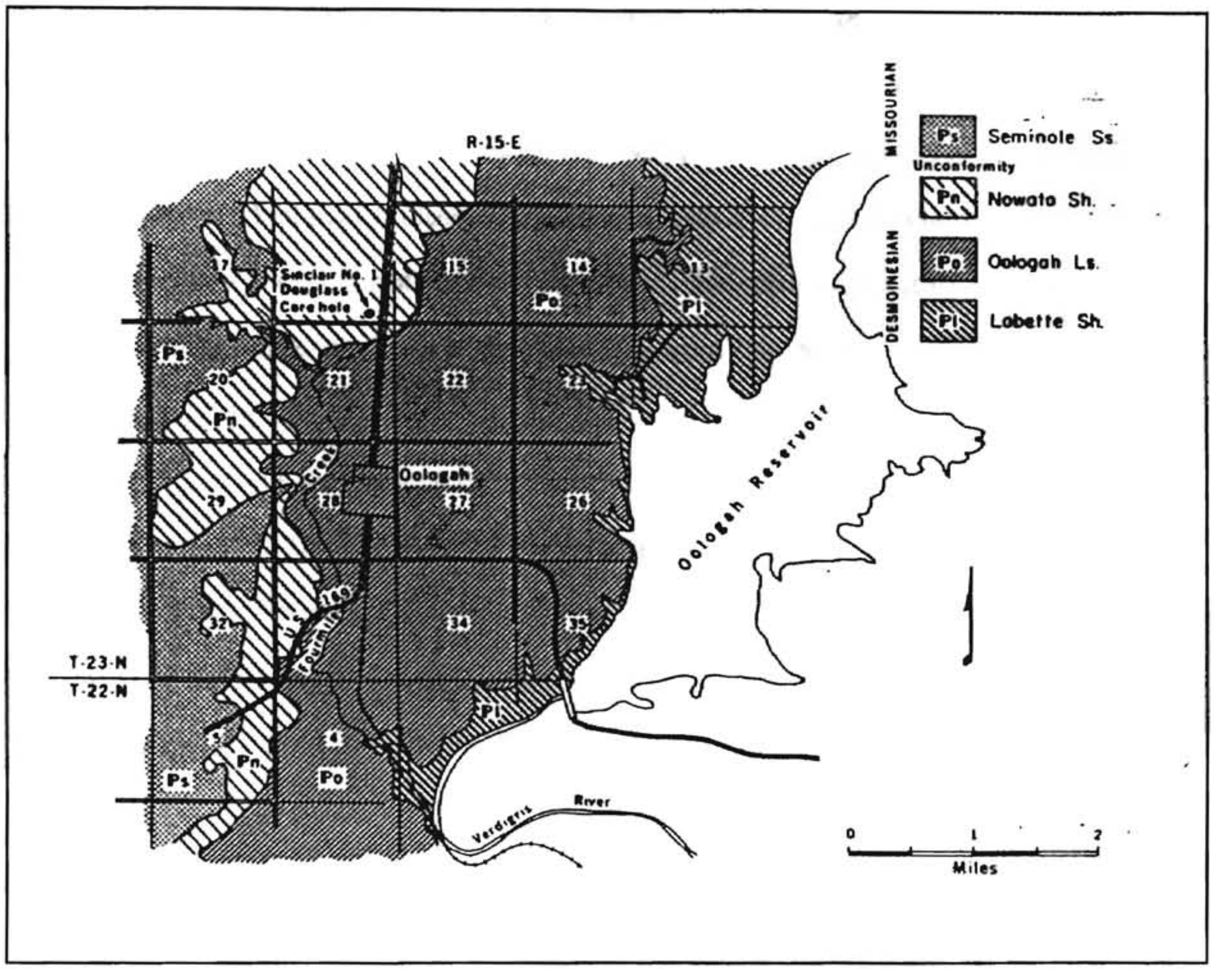


Figure 23. Location of Chenoweth's type section of the "Oologah Limestone" based on Sinclair Core Hole No. 1 Douglass. "Oologah Limestone" is not a formal stratigraphic name.

of the "Oologah Limestone".

Swallow (1866), Adams (1896, 1903), Ohern (1910) and other workers used the names Pawnee Limestone, Bandera Shale, and Altamont Limestone for the "Oologah" in northeastern Oklahoma and southeastern Kansas. Oakes (1952) revised the nomenclature and extended the name "Oologah Limestone" to the Kansas-Oklahoma line to include, in ascending order, the Pawnee Limestone, Bandera Shale, and Altamont Limestone as members. Chenoweth retained the term "Oologah Limestone" as Oakes used it (because the two limestones were nearly in contact with each other due to the thinness of the Bandera Shale) and attempted to establish an "Oologah Limestone" type section. Chenoweth's "Oologah Limestone" definition and type section were based on a subsurface core taken near Oologah, Oklahoma. Since this nomenclature is not based on a surface exposure it is not formally accepted. Therefore the author puts it within quotation marks and excludes it from this study from this point.

Pawnee Limestone

In the area of the present study, the members of the Pawnee Limestone are, in ascending order, the Childers School Limestone, Anna Shale, and Laberdie Limestone. Since the Myrick Station Limestone and Mine Creek Shale are included in the formal definition of the Pawnee Limestone, the author includes them in Interpretations.

Childers School Limestone Member

According to Price (1981), the Childers School Limestone Member of the Pawnee Limestone is a laterally extensive bed from southeastern Kansas to northeastern Oklahoma. It is absent northward of southeastern Kansas. It is a thin (0.1-0.2 feet (3-6 centimeters) thick) and lenticular "black, slabby calcarenite" in southeastern Kansas (Price, 1981, p. 61). It thickens to a dense, massive, one to two feet (.3-.6 meter) thick bed of skeletal calcarenite from Oologah to Tulsa, Oklahoma.

Price noted the presence of a thin coal bed below the Childers School around the Kansas-Oklahoma state line, within the Labette. Where the coal was found, the

Childers School contained plant debris in its lower part. Fossils were found above the plant debris zone, including "echinoderms, brachiopods, trilobites, bryozoans, and corals" (Price, 1981, p. 61). He interpreted these fossils to represent an open marine environment. He stated that the upper and lower Childers School contacts are sharp.

Anna Shale Member

When Jewett (1941) named the Anna Shale, he described it to contain a "local thin, dark, slabby limestone" in the lower part and in the upper part a "black, platty and locally fissile shale" (Jewett, 1941, p. 316). This was before the thin, dense limestone he mentioned was named the Childers School Limestone Member of the Pawnee Limestone. Locally, the black, fissile facies contained phosphate nodules and was surrounded above and below by a gray shale facies. He reported the Anna to range from three to 11 feet (.92-3.3 meters) in thickness. Moore (1944) noted its lateral extent from Illinois to northeastern Oklahoma. Jewett (1941) was mistaken when he described a coal bed within the Anna which is actually within the upper part of the Labette Shale (Price, 1981).

Price listed the lithologies of the Anna as (in ascending order): "1) gray fossiliferous shale, 2) dark gray to black flakey shale, 3) black indurated chippy shale, 4) black, phosphatic, and fissile shale, 5) black indurated chippy shale, 6) dark gray to black flakey shale, and 7) gray fossiliferous shale. The lithologies both above and below the black, phosphatic, and fissile shale facies are mirror images of one another and reflect progressive gradations into the overlying Myrick Station Limestone and the underlying Childers School Limestone (when present)" (Price, 1981, p. 66). He reported the Anna to vary between 7.5 cm and 2.85 m (.24 to 9.3 feet) due to local variations in facies and the southward convergence of the Anna with the Joe shale bed. He attributed the local variations to structural features. Thinning of the shale occurs over structural highs and thickening occurs in lower areas. Price corrected previous authors who placed a coal within the Anna. He found that the coal actually underlies the Anna Shale, and is within the Labette. He interpreted a marine shale between the Anna Shale and the coal, either within the Labette Shale, above the coal, or the Childers School Limestone. No benthic fossils were observed in the black fissile Anna Shale facies, but Price did find fish fragments and about 1000 conodonts per kilogram sampled. Vertical joints and weathered rectangular blocks were found. The most aerially extensive and most uniform in thickness part of the Anna is the black phosphatic shale facies. Price (1981) reported the phosphate nodules in detail. They are spherically-shaped and between 0.6 and 7.5 centimeters (.24 and 3.0 inches) in diameter. Phosphate nodule cores vary. North of Crawford County, Kansas, cores were found to be crystalline. South of this area, nuclei included orbiculoid brachiopods, phosphatic *Petrodus* denticals, and both phosphatic craniums and a shoulder girdles of paleoniscoid fish.

Price (1981) concluded that the Anna Shale converged with the Joe shale bed above it in southeastern Kansas. "Southward from the Wimer School section (Oklahoma), the Anna Shale Member is laterally equivalent to the Anna Shale, Myrick Station Limestone, and the Mine Creek Shale of Missouri" (Price, 1981, p. 70).

Myrick Station Limestone Member

In Cline's (1941) summary, "The term Myrick Station limestone is substituted for 'Lexington cap rock.' As the massive limestone is traced north of the Missouri River it dissipates into calcareous shale with discontinuous stringers of limestone. The 'Lexington cap rock' (of miners) of north-central Missouri (the 'Mystic cap rock' of Iowa) is the first prominent limestone bed above the coal." (Cline, 1941, p. 71)

Price (1981) explained that the Myrick Station Limestone interfingers with the Mine Creek Shale north of Missouri, and eventually disappears. It is thickest in southwestern Missouri. In southeastern Kansas the Myrick Station Limestone converges with the base of the Laberdie Limestone to form what he named massive Frog limestone bed (name amended to Frog Cemetery limestone bed by Watney and Heckel (1994). The Myrick Station was not observed in Oklahoma. In Missouri the Mine Creek Shale overlies the Myrick Station Limestone. North of Missouri, the Mine Creek Shale interfingers with the Myrick Station Limestone (Price, 1981).

Jewett (1941) mentions that in southeastern Kansas, at and near the type locality, the Pawnee appears as one ledge due to the extreme thinness (or absence) of the Mine Creek Shale. This has caused confusion in that area. Further north, where the Mine Creek Shale thickens, the Myrick Station Limestone and Laberdie Limestone are better defined (Jewett, 1941).

Mine Creek Shale Member

According to Watney and Heckel, "the Mine Creek Shale Member interfingers southward with the newly defined Frog Cemetery limestone bed" (Watney and Heckel, 1994, p. 26). The Mine Creek Shale was found by Jewett (1941) in Missouri, in Kansas, and in northeastern Oklahoma 20 miles (32 kilometers) south of the Kansas-Oklahoma border.

Jewett (1941) reported the Mine Creek to reach a maximum thickness of 16 feet (48.8 meters) in Kansas, where it was found to be mostly gray shale, slightly carbonaceous, and containing a thin limestone bed and a black shale in the upper part. Southward, the black shale of the Mine Creek becomes its most persistent facies. Jewett correlated the thin limestone bed at the top of the Mine Creek with the Houx limestone bed of the Little Osage Shale. Price observed the Mine Creek Shale to interfinger with the "lower Laberdie Limestone." Southward into southeastern Kansas and northeastern Oklahoma, the Mine Creek pinches out.

Frog Cemetery limestone bed

When Price (1981) named the Frog limestone bed, he interpreted it to have formed as the lower part of the Laberdie Limestone converged with the Myrick Station Limestone in southeastern Kansas. In southeastern Kansas, the Frog Cemetery limestone bed lies between the Anna Shale and the Joe shale bed. Towards Oklahoma, it pinches out between the Anna Shale and the Joe shale bed. Watney and Heckel (1994) interpreted the Frog Cemetery limestone bed to interfinger with the Mine Creek Shale.

Joe shale bed

Price (1981) interpreted the Joe shale bed to be stratigraphically equivalent to the upper part of the Mine Creek. Southward near the Kansas-Oklahoma border, Price interpreted the Joe shale bed to converge with the Anna Shale as the Frog Cemetery limestone bed disappeared. Northward, Price correlated the Joe shale bed with the upper part of the Mine Creek Shale and the base of the Laberdie Limestone.

Laberdie Limestone Member

According to Price (1981), the Laberdie Limestone is equivalent to the Coal City Limestone of Iowa. The Laberdie Limestone includes Pawnee Limestone strata overlying the Joe shale bed in southeastern Kansas. The Laberdie Limestone includes strata overlying the Anna Shale in northeastern Oklahoma. What is referred to as the "lower Laberdie" is not part of the Laberdie Limestone but is interpreted by Price to be "a carbonate facies of the Missouri Mine Creek Shale...which overlies type Laberdie" (Price, 1981, p. 52). Where the Mine Creek thins in southeastern Kansas and disappears in northeastern Oklahoma, the Laberdie Limestone is distinguished from the underlying Myrick Station Limestone by its lighter color and thinner bedding.

Bandera Shale

When Adams (1903) named the Bandera Shale, he reported that the Bandera Shale was equivalent to Haworth's (1896) lower Pleasanton shales. He listed its maximum thickness to be 100 feet (30.5 meters). According to Jewett (1941) the Bandera ranges from 40 to 50 feet (12.2 to 15.2 meters) thick in Kansas and consists of the Mulberry coal bed near its base.

Jewett noted the wide range of variations throughout the Bandera laterally. It generally contains gray shale. There are sandstones, interpreted by Jewett to be channel deposits. These sandstones are typically fine grained, ripple marked, and contain many fossil annelids and at least some silica cement. Where present, the sandstones separate a gray shale below from a reddish-purple shale above. The gray shale contains limonite concretions and "grades laterally into sandstone and sandy shale" (Jewett, 1941, p. 323). The sandy shale facies contain abundant fossilized plant parts, "especially near the underlying Mulberry coal". Although no single bed within the Bandera could be traced very far, there is a coal, up to two feet (.61 meter) thick, three feet above the Bandera base, which was mined in Linn and Bourbon Counties, Kansas, and Missouri. The coal bed was named the Mulberry coal, after Mulberry Creek in Bates County, Missouri, by Hinds (1912). Jewett (1941) interpreted the channel sandstones within the Bandera to represent the beginning of the cycle containing the Altamont Limestone.

Altamont Limestone

Adams (1903) noted that an exact thickness of the Altamont Limestone was not obtainable based on the poor quality of Altamont exposures. This is probably why he failed to designate an Altamont type locality when he named the limestone in 1896. Jewett (1941) observed a thickening of the Altamont and a coralline facies in the lower part of the Altamont in Labette County where he designated the Altamont type exposure. In Neosho County, north of the Altamont type, Jewett (1941) described the Altamont to reach 17 feet (5.2 meters) in thickness and consist of four limestones. Further north, in Bourbon and Linn Counties, the Altamont thins, but eight feet (2.4 meters) of the Worland Limestone Member is recognizable. However, all of the Altamont members are identifiable north and eastward of Kansas. He interpreted the Altamont to represent the "limestone phase of the Marmaton type of megacyclothem" (Jewett, 1941, p. 325-326).

Amoret Limestone Member

Jewett (1941) provided descriptions of what he referred to as the Tina Limestone. The author of the present study uses the name Amoret Limestone after Cline and Greene (published in Greene and Searight, 1949), Jewett notes that the Amoret Limestone Member is generally less than 2 feet (.61 meter) thick. It is generally an unweathered gray color, weathered buff color, nodular, limestone containing molluscs. The upper portion of the Amoret is algal "and locally is nearly a coquina of spired gastropods; *Squamularia* are common" (Jewett, 1941, p. 330). Locally the Tina limestone grades laterally into calcareous sandstone. In many exposures it is cross-bedded." In southeastern Kansas it is generally of constant thickness and lithology, "except that it pinches out locally and grades laterally into sandstone" (Jewett, 1941, p. 329). Locally in Labette County and in the southeastern portion of Neosho County, the Amoret thickens to 16 feet (4.9 meters) and contains mostly *Chaetetes* coral colonies (Jewett, 1941).

Lake Neosho Shale Member

When Jewett (1941) named and defined the Lake Neosho Shale Member of the Altamont Limestone, he noted the distinguishing presence of "oblong, irregularly-shaped" phosphate nodules at nearly every outcrop from Kansas to Iowa (Jewett, 1941, p. 331). The nodules contained vertebrate fossils at some exposures. He listed the Lake Neosho to be two and a half to six feet (.76 to 1.8 meters) thick, and very black in Kansas. Cline (1941) noted the presence of a coal in the middle part of the Lake Neosho northward of Kansas.

Worland Limestone Member

Cline (1941) noted the Worland Limestone to be laterally persistent from Oklahoma to Iowa, almost as extensive as the Lake Neosho Shale. Jewett (1941) described the Worland in Kansas as a three to 13 foot (.92 to 4 meter) thick, light gray, and massive limestone. Thinner limestone beds separated by thin shales were noted locally above the massive facies in southeastern Kansas. Jewett (1941) assigned a representative thickness of eight feet (2.4 meters) to the Worland Limestone in Kansas.

Nowata Shale

The thickness of the Nowata Shale, based on surface exposures has been misleading to previous authors. The Nowata is highly variable in thickness laterally.

Moore (1937) reported over 100 feet (30.5 meters) of Nowata Shale near Nowata, Oklahoma. Ohern (1910) reported the thickness of the Nowata Shale to be generally under 50 feet (15.2 meters) in northeastern Oklahoma. Ohern wrote that the Nowata increased in thickness southward. He noted that an increase in the Nowata's thickness to 130 feet (39.6 meters) was indicated by a drill record near Nowata. He observed about 600 feet (183 meters) of Nowata Shale near Tulsa, Oklahoma. Northward into Labette County, Kansas, he reported a rapid thinning where the Lenapah and Altamont Limestones were nearly touching. Further north of Labette County, the Nowata thickened.

Ohern (1910) described the Nowata of Oklahoma in general as a blue to green clay shale weathering to a green or buff color, depending on the amount of iron oxidation. In Kansas it is yellow to gray clay shale. "The lower part is almost wholly a mass of shale" (Ohern, 1910, p. 24). Sandstones are present throughout the Nowata's lateral extent. Ohern (1910) stated these were possibly local occurrences, but needed more data to verify. He traced a three feet (.92 meter) thick massive sandstone near Oologah, Oklahoma. Coal is found locally. Ohern referred to a coal bed in Oklahoma (mined near Collinsville) from the Talala-Watova area southward past Oologah as the Dawson coal. He noted that where present, the coal consistently lied about midway between the top of the Altamont Limestone and the base of the Lenapah Limestone.

Lenapah Limestone

Ohern (1910) stated that the Lenapah Limestone was composed of only one bed. However, Jewett (1941) defined three members within the Lenapah. Ohern described the Lenapah Limestone north of Nowata to form a dip slope where exposed, even though it is not very thick (8 to 10 feet, 2.4 to 3.0 meters in southeastern Kansas and at least 20 feet, 6.1 meters in northeastern Oklahoma). Southward towards Tulsa it is difficult to trace because it thins to 30 inches (.76 meter) and does not form dip slopes. From southeastern Kansas to Tulsa, the Lenapah varies little in lithology. Ohern (1910) described it as "a dense, blue, partly crystalline limestone, usually containing an abundance of fossils, especially of brachiopods. On weathering it gives little or not chert, thus differing markedly from similar beds below it" (Ohern, 1910, p. 26).

Norfleet Limestone Member

The thin Norfleet Limestone is difficult to detect at outcrop in southeastern Kansas. Jewett (1941, p. 338) interpreted any "dark shale or limestone" found beneath the Perry Farm Shale to be the Norfleet. Jewett described the Norfleet Limestone to be composed of "a few inches of dark, bluish-gray, dense limestone overlain by shale, which is mostly black and has a maximum thickness of about 5 feet (1.5 meters). Locally the upper part of the rock is very calcareous, but nevertheless is black and platy. At the top of the member is a limestone, which is a few inches to about 3 feet (.92 meter) thick. Its lithology ranges from dense dove-gray to dark slabby limestone and limestone breccia. On weathering, the latter facies produces very hummocky outcrops. Where more massive, this limestone contains an abundance of the brachiopod *Dictyoclostus*; crinoid stems are abundant in the more slabby facies" (Jewett, 1941, p. 338).

Perry Farm Shale Member

Jewett (1941) described the Perry Farm Shale as a fossiliferous shale containing mostly molluscs in the lower part and the brachiopods *Ambocoelia* and *Marginifera* in the upper part. It contains limestone nodules, especially in the upper part, where it grades into the overlying Idenbro Limestone. The Perry Farm Shale is about 10 feet (3.0 meters) thick near the Perry Farm type locality and thickens to 15 feet (4.6 meters) of "gray mottled limestone" near the Lenapah Limestone type locality (Jewett, p. 339).

Idenbro Limestone Member

Jewett (1941) described the Idenbro Limestone as a light colored, irregularly and wavy bedded, fossiliferous limestone. It weathers almost white. The fossils are mainly corals. The upper part is algal. Jewett traced it from Montgomery County to Linn

County, Kansas. He noted its thickness to average six feet (1.8 meters), but to increase southward to the Kansas-Oklahoma line.

# III.

# CYCLOTHEM CONCEPTS

## Cyclothem Definitions

A cyclothem is "...a term proposed by Weller (in Wanless & Weller, 1932, p. 1003) for a series of beds deposited during a single sedimentary cycle of the type that prevailed during the Pennsylvanian Period. It is an informal lithostratigraphic unit equivalent to 'formation'. Because of extremely variable development, a cyclothem cannot be defined rigidly in terms of the members actually present at any locality (Weller, 1956, p. 27-28). Cyclothems are typically associated with unstable shelf or interior basin conditions in which alternate marine transgressions and regressions occur; nonmarine sediments usually occur in the lower half of a cyclothem, marine sediments in the upper half. The term has also been applied to rocks of different ages and of different lithologies from the Pennsylvanian cyclothems.

Before Weller (1932) proposed the term cyclothem, Udden (1912) observed and reported on the cyclic nature of Pennsylvanian strata in the Peoria Quadrangle in Illinois. Udden observed four laterally extensive cycles in the Pennsylvanian in Illinois. Based on lithology, he divided each cycle into four stages. Each stage in a cycle is similar to its respective stage in the other cycles. Udden listed the four stages of each cycle in ascending order as "(1) accumulation of vegetation; (2) deposition of calcareous material; (3) sand importation; and (4) aggradation to sea-level and soil making" (Udden, 1912, p. 76).

He described stage 1 (vegetable accumulation) of the cycle to include a coal bed and above this a transition zone made of bone coal, miner's slate, and dark laminated shale. Carbonates were deposited during stage 2. Sand and silt were brought into the area via bottom currents during stage 3. The accumulation of finer sediments began stage 4. During this stage, clay and silt accumulated to form shales, underclays, and soils. On top of this soil horizon of stage 4, the vegetation of stage 1 accumulated, beginning another cycle (Udden, 1912).

Weller (1930) also observed that Pennsylvanian strata may be divided into cycles. He defined the typical Pennsylvanian cycle to contain the following, in general:

Marine:
9. Shale, containing "ironstone" bands in upper part and thin limestone layers in lower part
8. Limestone
7. Calcareous shale
6. Black "fissile" shale

Continental:
5. Coal
4. Underclay, not uncommonly containing concretionary or bedded fresh water limestone
3. Fresh-water limestone.
2. Sandy and micaceous shale
1. Sandstone

Unconformity

Moore (1931) discussed Pennsylvanian Midcontinent cyclicity based on his study of a line of outcrops through Iowa, western Missouri, Nebraska, Kansas, and northern Oklahoma. Moore observed the same type of laterally extensive cycles Udden (1912) saw in Illinois. The Pennsylvanian strata consisted of alternating marine and nonmarine units in an ordered, repeated pattern. Moore thought these cycles were correlatable with cycles observed in the mid-continent. "Evidence of cyclic sedimentation is seen in frequent and rather regular alternations from marine to nonmarine conditions but especially in a peculiar sequence of distinctive types of limestones and shale that is repeated several times. Some parts of the Pennsylvanian section lack evidence of such cycles" (Moore, 1931, p. 257). In 1936, Moore introduced the term megacyclothem "...to designate a combination of related cyclothems, or a cycle of cyclothems, such as in the Pennsylvanian of Kansas" (Bates and Jackson, 1987, p. 409).

## Cyclothem Interpretations

Udden (1912) interpreted stage 1 of the Illinois cycle to be the result of shallow water entering a swamp environment, bringing mud with it. Based on carbonate thicknesses, Udden interpreted stage 2 to have varied in length from one cycle to the next. Near the end of stage 2, silt was brought in by currents which would bring the sand in during stage 3. The thickness of the sands in each cycle was nearly constant laterally, thus Udden suggested that the sand was deposited up to the surface of the sea. Udden interpreted an inversely proportionate relationship between the amount of carbonate deposited during stage 2 and the amount of sand deposited during stage 3. Where the carbonates thickened, accommodation space decreased, allowing less sand to accumulated than in areas where carbonates were thin. Sand was deposited as close as possible to the surface of the sea during stage 3, after which currents no longer brought sand in and the finer sediments of stage 4 were deposited. These silt and mud deposits and the top of the underlying sand deposit weathered and decayed to form coal and a soil zone. On top of this soil, the vegetation of stage 1 accumulated, thus beginning another cycle.

Udden interpreted the cycles to be caused by the alternation of subsidence and sediment accumulation. He placed the cycle boundaries above stage 4 (the layer of shale and fire clay) and below stage 1 (the layer of vegetation or coal).

Weller (1930) argued that it made more sense to place the cycle boundaries at the base of the massive sandstones (unconformities) instead of at the base of the coals as Udden did. Although nondeposition most likely occurred between the underclay and coal deposits, the environment was stable during their deposition. Not only nondeposition, but erosion occurred before the sands were deposited. Weller interpreted the unconformity at the base of the sandstone to represent the occurrence of diastrophic events. From his diastrophic viewpoint, cycle boundaries should be placed at surfaces of diastrophic events.

Weller presented a hypothesis based on a diastrophic cycle to explain the presence of these laterally extensive cycles. He stated the probable cause of the cycles to be a combination of diastrophism and climatic changes. The diastrophic cycle he presented begins with the uplift of the North American continent. This exposed the Midcontinent to erosion as the sea retreated. Uplift continued for the Appalachians, but slowed down for the Midcontinent. This allowed siliciclastic sediments from the Appalachians to accumulate in the Midcontinent. As the Appalachians subsided, so did siliciclastic sedimentation of the Midcontinent, until it nearly stopped. Weller does not explain how, but states that local, shallow basins formed, in which fresh-water limestones were deposited. Then the surface was exposed to weathering during a long time of stability. As subsidence continued, drainage slowed in the Midcontinent and vegetation proliferated, which caused drainage to deteriorate even more. Swamps formed in this wet environment, which eventually produced coals. The Midcontinent became a shallow, epicontinental sea. During the transgression, black fissile shales were deposited in "stagnant conditions generally inhospitable to normal marine life". Subsidence continued, which allowed "calcareous sediments containing the remains of typical marine organisms" to accumulate. As uplift occurred again in the Appalachians, finer sediments were shed into the shallow sea to form marine shales. As uplift continued, the shallow sea eventually withdrew. Then another cycle began. Although there are variations between cycles in magnitude and length, Weller stated that the diastrophic events which produced one cycle, repeated in a "definite order" to produce the other cycles (Weller, 1930, p. 167-168).

Wanless and Shepard (1936) disagreed with earlier explanations for the presence of cycles in Late Paleozoic sedimentary strata. They did not think that the cycles were caused by the alternating cycle of a) subsidence accompanied by and followed with sedimentation and b) subsidence or by the alternating cycle of a) subsidence and b) uplift (diastrophism). The first hypothesis omits the process of uplift. There appears to be too much erosion at the base of channel sands in these cycles to be due to subsidence and sedimentation only. The second hypothesis would require episodes of subsidence greater than the episodes of uplift.

Wanless and Shepard (1936) introduced the idea of glaciation as the main cause of Pennsylvanian cycles. They listed their own evidence as well as that of other authors. Tillites were found at the equatorial region. Evidence of continental drift (Wegner) supported the glaciation theory . Most of their evidence comes from Pleistocene and modern examples. Little tectonic activity occurred during the Pennsylvanian. Global glaciation provides a mechanism for eustatic sea-level changes. They asserted that Paleozoic cycles are due to Paleozoic glaciation which caused global changes in both sea-level and climate. Evidence from the Pleistocene that the sea-level has risen since then includes the presence of peat deposits and forests on the "present shallow sea bottom". Evidence from the Pleistocene that the sea-level was once higher than it is today are the "fossiliferous marine sediments exposed on coastal plain terraces."

The explanation that the sea-level changes were caused by changes in the sea floor or other basins was ruled out by Wanless and Shepard because it would unlikely produce large, rhythmic changes in sea-level. The second explanation of sea-level changes being caused by variations in atmospheric moisture content is ruled out because these sea-level changes would most likely be too small to produce cycles in sedimentary strata. The third explanation that sea-level changes were caused by glaciation seems plausible.

Evidence of climatic changes are seen in the wide range of characteristics of the piedmont facies. Pleistocene data points to climatic changes as a plausible cause for cycles in the non-glaciated areas. Glaciation could have produced large changes in the climate which could have produced a repeated alternation between erosion and sedimentation particularly in the vicinity of fluvial basins. The effects would be seen even in areas very distant from glaciation areas.

Elias (1937) studied benthonic fossils of the Big Blue Limestone (Lower

Permian, Kansas) to determine the depths of its deposition. The Late Paleozoic Big Blue series in Kansas is comprised of laterally persistent cycles of marine (limestone and shale) and nonmarine (red shales, sands, and coals) units. Elias explained the cause of these cycles to be fluctuations in sea-level. He based his hypothesis somewhat on lithologic evidence but more on faunal evidence.

The lithologic evidence presented by Elias was the cyclic repetition of alternating marine and nonmarine units, the indication of subaerial exposure as the sea withdrew by the disconformities found at the bases of the nonmarine units, and the indication of a "gradual shallowing of the last marine invasions" by the evaporites found in the upper parts of the Big Blue (Elias, 1937, p. 405).

The faunal evidence Elias (1937) noted was the order of occurrence of the fauna indicating the cyclic nature of the Big Blue. He also noticed that fauna became less diverse in the Big Blue than it had been before. A decrease in faunal diversity is generally an indication of a shallowing.

Elias (1937) made depth estimations of the Big Blue based on modern fauna found in certain depths. He assumed benthonic life of the Late Paleozoic lived in similar environments as modern benthonic life. Elias concluded that the cyclic repetition of strata was caused by the advance and retreat of the sea and the "red shales that separate marine phases of two neighboring cycles are continental deposits and indicate emergence" (Elias, 1937, p. 428). Elias noted fault with the earlier hypothesis that cycles are caused by alternating subsidence and sedimentation. Although subsidence and sedimentation did occur, they were not enough to produce the symmetrical cycles of the Big Blue. Three other factors Elias listed as possible factors in faunal distribution are temperature, salinity, and food supply. He explained that these three factors were not as effective as depth was at determining the faunal zones since the area of deposition was very flat.

Israelsky (1947) constructed an oscillation chart based on samples retrieved from a well in the Lirett field in Louisiana. The chart illustrates "relative changes in depth of water at time of deposition within a well or surface column" based on foraminifera "arranged in order of their depositional depth significance" (Israelsky, 1947, p. 93). Israelsky used the number of each species he counted from each well sample to calculate the percentage of 1) benthonic and 2) pelagic assemblages. Then he determined the relative depth significance by plotting the percentage of each species group versus 1) *Rotalia beccarii* (brackish) and 2) *Uvigerina spp.* (deeper open-water). Then Israelsky numbered the species in "order of their apparent peak percentage appearance from shallower to deeper water. When these species' numbers were placed on a chart next to their sample well depth, oscillations in water depth could be seen, thus Miocene marine cycles were observed on the chart.

Weller (1956) continued to suggest that Pennsylvanian cyclothems were caused by diastrophism (alternating long periods of gradual subsidence and short periods of uplift). He stated that Wanless and Shepard's (1936) glacial control theory is based on inaccurate assumptions. However Weller acknowledges the importance of climatic changes as an influential factor on cyclothems.

Schenk's (1967) interpretation of the Altamont megacyclothem can be applied to other cyclic deposits of the Middle Pennsylvanian. He defined the Altamont megacyclothem to contain, in ascending order, "the upper part of the Bandera Shale (variegated terrigenous detritus usually with coal), the entire Altamont Limestone (carbonate, overlain by marine shale and then carbonate) and the lower part of the Nowata Shale (variegated terrigenous detritus, often with a coal)" (Schenk, 1967, p. 1370). According to Schenk, the Altamont megacyclothem was produced by a single transgressive-regressive event. He interpreted the depositional environments of the Altamont megacyclothem as follows.

The upper part of the Bandera Shale up to the middle of the Lake Neosho Shale was deposited during the transgressive phase of the Altamont megacyclothem. When the maximum flooding event occurred, the middle part of the Lake Neosho was deposited. During the regression which followed the maximum flooding event, the upper Lake Neosho Shale up to the lower part of the Nowata Shale were deposited.

The Altamont megacyclothem began with the rise of sea-level and the eastward retreat of the delta complex which had been depositing the sediments of the upper Bandera Shale. Basins became shallow marine environments in which the Amoret Limestone was deposited. Phylloid algae formed reefs (of the Amoret Limestone) over topographic highs. As sea-level continued to rapidly rise, the carbonate environment moved eastward. The transgressive phase occurred rapidly compared to the regressive phase, therefore the Amoret Limestone is thin compared to the Worland Limestone, except where the Amoret contains phylloid algal reefs. The Lake Neosho Shale was deposited as sea-level reached its maximum depth. After maximum flooding occurred, the regressive phase of the Altamont megacyclothem began and the sea retreated westward as the delta complex moved in from the east. The regression lasted longer than the earlier transgression, allowing a thick Worland Limestone to be deposited. As regression continued, the sea moved westward and the delta complex deposited sediments to form the Nowata Shale.

Schenk provides a diagram to illustrate the lateral movement of the Altamont megacyclothem facies. Figure 24 shows an aerial view of the Altamont megacyclothem units. These facies migrated first eastward during the transgression and then westward during the regression of the Altamont megacyclothem (Schenk, 1967).

"The regressive maximum, and so the beginning and end of the cycle, is recorded by deltaic sediments of the Bandera and Nowata Shales, respectively...Maximum water depth of the megacyclothem may have been between 50 and 200 m, with greater depths to the west and southwest" (Schenk, 1967, p. 1381).

Heckel and Baesemann (1975) wrote a paper combining Baesemann's conodont data and Heckel's interpretations of depositional environments of cyclic Pennsylvanian

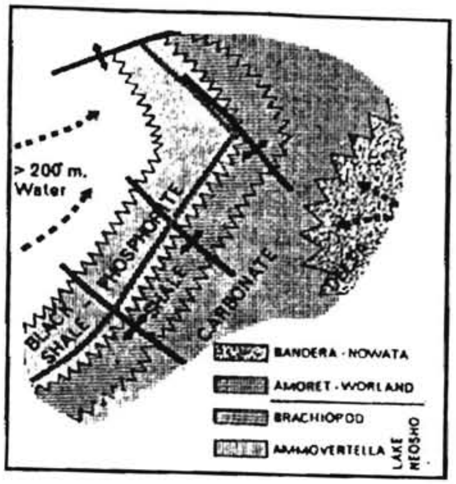


Figure 24 (from Schenk, 1967). Depositional environment at maximum transgression. Present outcrop belt of formation is cross lined; water movement direction is dashed lined; positive tectonic features are solid lined. At this time, phosphorite is precipitated along present outcrop belt. Bandera, Amoret, and lower half of Lake Neosho units have been deposited during rapid marine transgression. Upper half of the Lake Neosho, Worland, Nowata units will be deposited during slow marine regression. Litho- and biotopes move east-west.

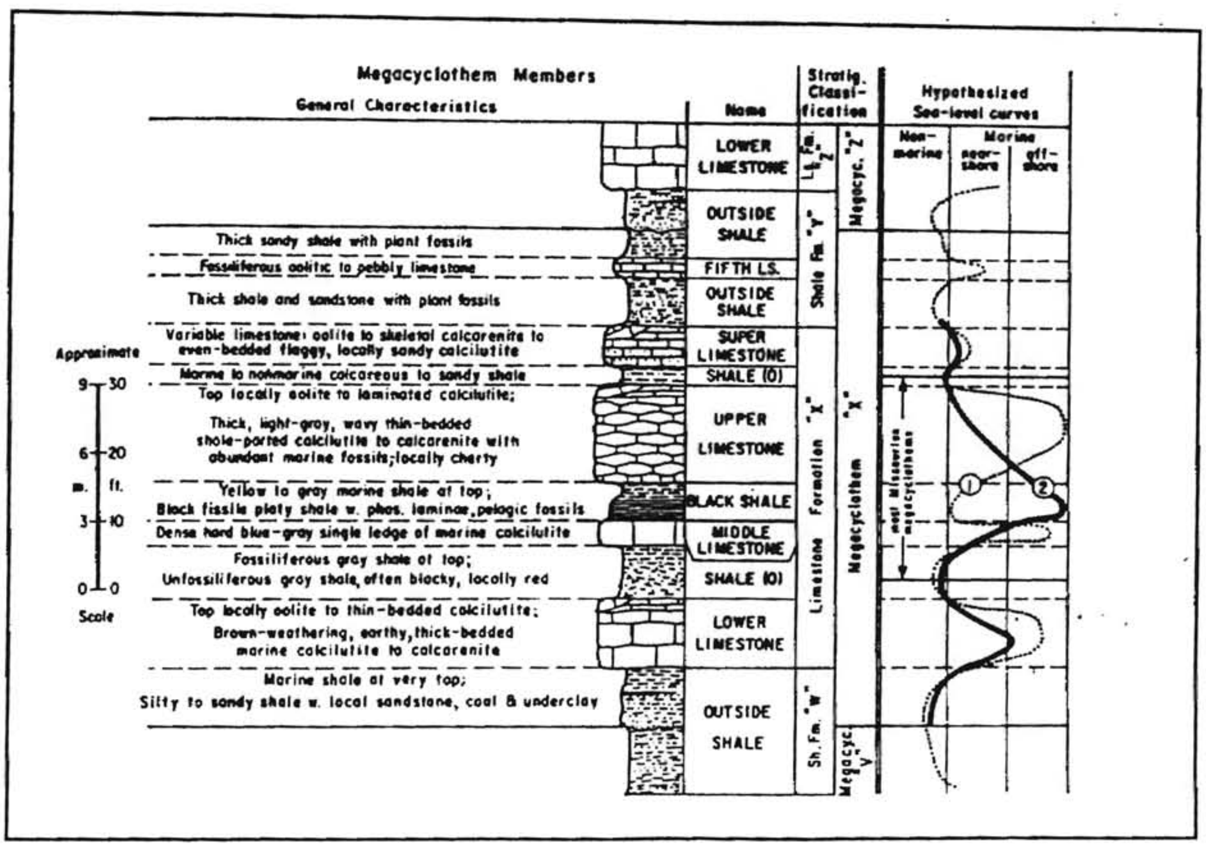


Figure 25 (from Heckel and Baesemann, 1975). Ideal Upper Pennsylvanian megacyclothem showing complete development of all members.

deposits, based on Seddon and Sweet's ecologic model of conodonts (1971). Heckel observed distinct patterns of lithology while Baesemann noted distinct patterns in the paleontology. They described the ideal Upper Pennsylvanian megacyclothem to contain the following in ascending order: outside shale, lower limestone, shale, middle limestone, black shale, upper limestone, shale, super limestone, outside shale, fifth limestone, and outside shale. They provided Figure 25 to illustrate the vertical sequence of units. The megacyclothems found in the Middle Pennsylvanian are simpler than those of the Upper Pennsylvanian and typically contain, in ascending order, only the outside shale, middle limestone, black shale, upper limestone, and outside shale again. Note that Megacyclothem "X" is named after Limestone Formation "X".

Baesemann (1973) studied the genera and species occurrence of multielement conodont in Missourian megacyclothems in Kansas, and observed distinct patterns in the numbers and diversities of conodonts in the megacyclothems. Both maximum abundance (more than 100 conodonts per kilogram) and diversity of conodonts occur within the middle part of the limestone formation, usually in the black shale member. Heckel applied the term megacyclothem "core" to the part of the cycle containing maximum conodont abundance and diversity, which could be the "black shale member alone, or it may include the top of the middle limestone member and/or the lower part of the upper limestone member" (Heckel and Baesemann, 1975, p. 490). The lowest diversity and the least abundance (or absence) of conodonts occurs within the outside shale formation. Fewer than 10 conodonts per kilogram and only "one or two multielement genera" are found here. The units between the outside shales and the core shales are transitional in conodont abundance and diversity. Baesemann reported typical conodont abundance from 5 to 50 per kg and diversity between 2 and 4 genera.

Heckel (1977) developed his interpretation of the "Kansas type" cyclothem further as more lithologic and paleontologic data was gathered by himself and other workers. The cyclothems of the present study are like those Heckel termed Kansas type.

The author applies Heckel's (1977) nomenclature to cyclothem units which he listed in ascending order as the upper part of the "outside (nearshore) shale, middle (transgressive) limestone, core (offshore) shale, upper (regressive) limestone, and outside (nearshore) shale" (lower part of it) (Heckel, 1977, p. 1045). He placed the cyclothem boundary within the outside (nearshore) shale. Thus, the lower part of an outside shale represents the end of a cyclothem, and the upper part of the same outside shale represents the beginning of the next cyclothem. Since the vertical sequence of units, as listed, is produced by a single transgressive-regressive event, Heckel refers to it as a cyclothem, using the term megacyclothem only for vertical sequences caused by more than one transgressive-regressive event.

Heckel (1977) interpreted each of these cyclothem units to represent a particular depositional phase. Figure 26 is a diagram Heckel constructed to help illustrate his interpretations. The outside (nearshore) shale was deposited in a nearshore environment, as the shoreline gradually regressed westward and detrital influx increased. Evidence for this includes the many lateral facies changes within the unit, characteristic of shoreline/deltaic areas,which undergo rapid changes. Channels and deltas, as well as tidal flats, bars, lagoons, and beaches are deposited in the shallow nearshore environment.

Heckel (1977) interpreted the middle limestone is interpreted to be deposited during the transgressive phase of the cycle, when eustatic sea-level was rising, and thus referred to it as a transgressive limestone. Because the water during the transgression is deep enough, the transgressive limestone exhibits fewer lateral facies changes than the shallower outside (nearshore) shale but more than the core (offshore) shale. Heckel explained that this limestone member of the cyclothem is very thin due to the rapid nature of the transgression and the presence of detrital sediment to the east.

The core shale members are deposited in the sediment starved offshore environment during the maximum transgressive (and early regressive) phase of the cycle when

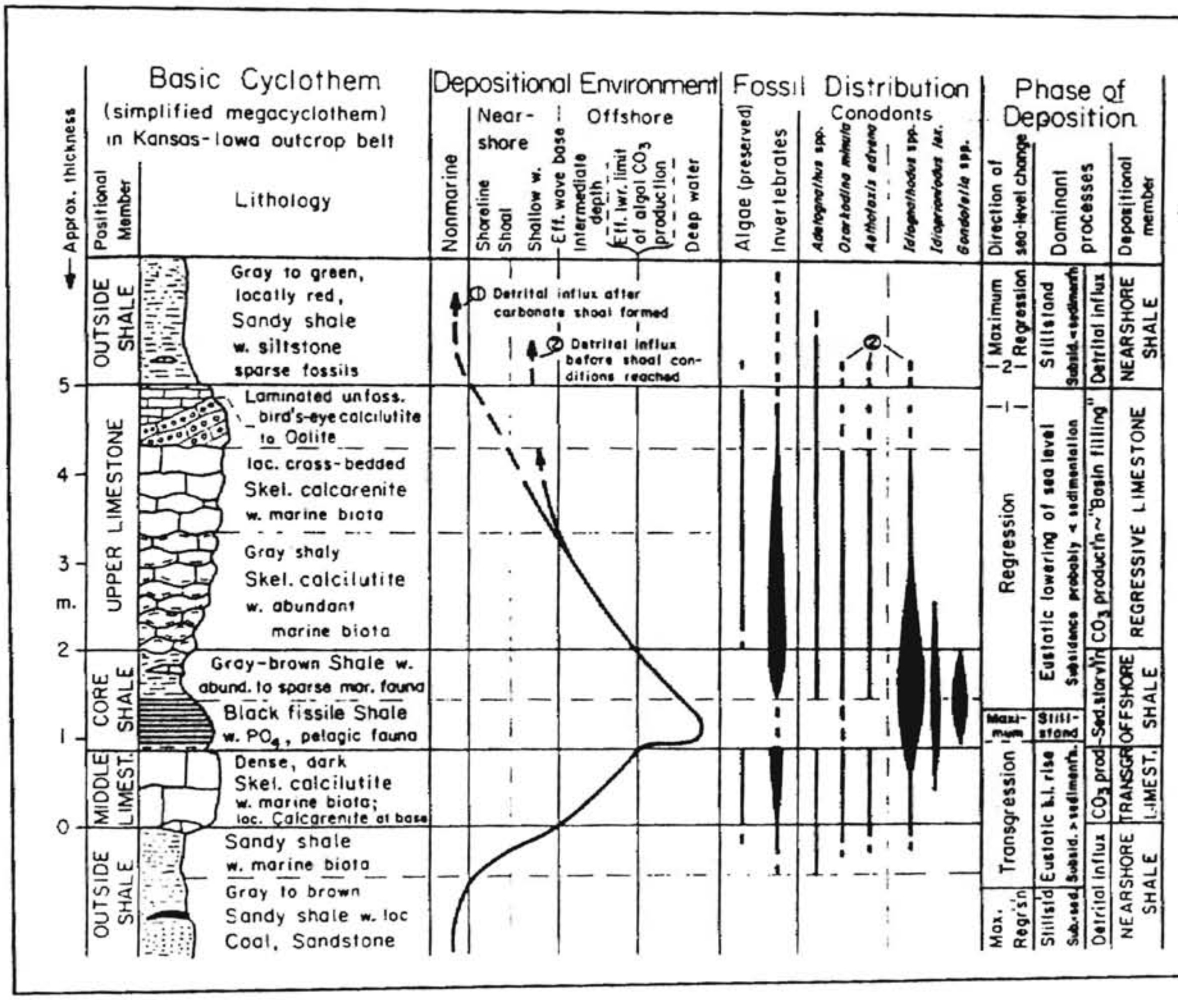


Figure 26 (Heckel, 1977). Diagram representing Heckel's interpretation of the Kansas type cyclothem of the Upper Pennsylvanian.

the shoreline was at a stillstand (and just beginning to retreat westward). Heckel (1977) refered to the core shale member of the cycle as the offshore shale. The core (offshore) shale exhibits very few lateral facies changes because the water is deep enough to not affect the deposition of the sediment (Schenk, 1967, p. 1380), even if the basin floor is not totally flat (Heckel, 1977, p. 1053). Heckel explained core shales containing the greenish-gray facies to be deposited during intermediate depths while the core shales containing a black facies to be deposited in deeper water. The deeper water allowed quasi-estuarine cirulation to develop, creating an upwelling environment in which organic matter flourished.

The upper limestone members are interpreted by Heckel and Baesemann (1975) to be deposited during the regressive phase of the cycle. Heckel (1977) refered to these as regressive limestones. They were interpreted by Heckel and Baesemann (1975) to be deposited during the eustatic lowering of sea-level and exhibit lateral facies changes in their upper parts but not their lower parts. They explained why units deposited during regression (marine and nonmmarine environments) are thicker than transgressive deposits due to the influx of siliciclastic sediment. If the amount of siliciclastic sediment influx was greater than the rate of sea-level fall, delta-plain deposits are observed. If the amount of siliciclastic sediment was less than the rate of sea-level fall, prodeltaic deposits are observed.

"The upper and lower limits of each megacyclothem typically lie within the adjacent sandy shale formations, which are termed "outside" shales from their position outside the limestone formations. Of the five limestone members (designated by relative position as "lower, middle, upper, super, and fifth") recognized in the most complete megacyclothem, only the middle and upper limestone members are present in most cyclic sequences. The other limestone members are present in less than half, and Heckel and Baesemann (1975, p. 506-507) regarded them as merely fortuitous, or, as with some "super" limestones, parts of the upper limestone member separated by a fortuitous shale. The middle and upper limestone members are separated by the most distinctive of the shale members, the one that commonly contains a black fissile facies, which typically carries nonskeletal phosphorite and lacks benthic fossils. Although sometimes absent in this shale member, the phosphatic black facies is present nowhere else in the Upper Pennsylvanian in eastern Kansas. Thus this member has been referred to as the "black shale member," although Heckel (1975, p. 9) suggested that "core" shale member is more appropriate where the black facies is absent....He "reserved the term megacyclothem for the concept of more complex sequences" (Heckel, 1977, p. 1046).

Conodont distributions in the Upper Pennsylvanian cyclic sequence have been studied in much more detail than benthic invertebrates. Heckel (1977) noted that his interpretation of the Kansas type cyclothem (Figure 26) agreed with Seddon and Sweet (1971) who stated that conodont diversity increases with depth. Heckel and Baesemann (1973) noted an increase in conodonts in core shales (offshore shales). Conodont distribution above and below the core shale are almost mirror images of each other. "Even if many conodont animals were nektobenthic, as some workers (Klapper and Barrick, 1978) believe, maximum diversity such as in nonblack facies of core shales should still be present in offshore deeper water deposits, where a consistent, fully marine environment more continually is established away from environmental stress caused by fluctuations of salinity and temperature that reduce diversity in shallow water (Sanders, 1971). Nevertheless, as Seddon and Sweet (1971, p. 869) already have indicated, any conodont present in substantial numbers in the anoxic black shale facies, where no other benthic organisms are known, very probably was pelatic. Pelatic habit thus is strongly indicated for the Late Pennsylvanian genera *Gondolella, Idioprioniodus, Idiognathodus,* and for an unnamed species of *Anchignathodus?* (formerly *Ozarkodina*) according to the thesis data collected by R. H. Wood, Jr., from the organically bound black facies of the Eudora shale (Stanton cyclothem) in eastern Kansas" (Heckel, 1977, p. 1050). Figure 27 illus-

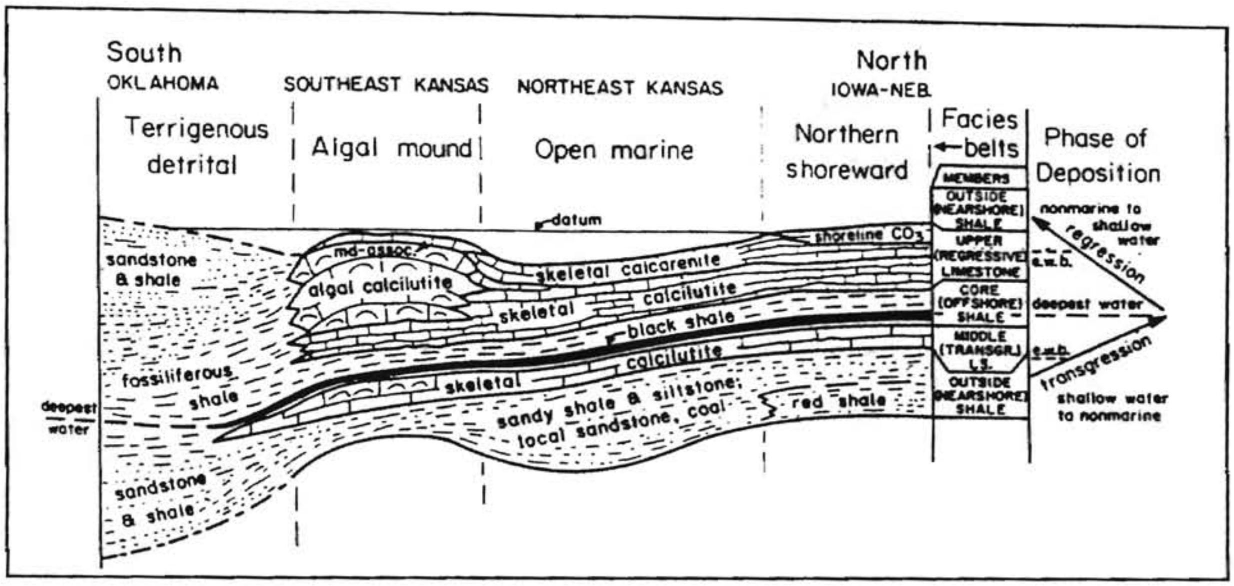


Figure 27. Basic pattern of lateral change in Upper Pennsylvanian cyclothem members across facies belts exposed along Mid-Continent outcrop. Datum is interpreted approximate sea level at time that increased detrital influx terminated deposition of upper (regressive) limestone member. Long dashed line shows position of deposits formed in deepest water during maximum transgression; short dashed lines show approximate limits of deposits formed below effective wave base (e.w.b.) in north. Southward thickening of sequence reflects greater overall subsidence in that direction. Axial direction of transgression (eastward) and regression (westward) lies roughly normal to line of outcrop (Heckel, 1977).

trates lateral variations within the units of the Kansas type cyclothem.

# IV.

# SEQUENCE STRATIGRAPHY

## Definitions

Sequence stratigraphy is the study of rock relationships within a chronostratigraphic framework of repetitive genetically related strata bounded by surfaces of erosion, nondeposition, or their relative conformities (Van Wagoner et al., 1988). These packages of genetically related strata are called sequences, hence the term sequence stratigraphy.

Sloss (1963) defined a sequence to be "major rock-stratigraphic units (of higher than group, megagroup, or supergroup rank) which can be identified, where preserved, in all cratonic areas" of North America (Sloss, 1963, p. 93). Mitchum et al. (1977) introduced the term depositional sequence which they defined to be "a stratigraphic unit composed of a relatively conformable succession of genetically related strata and bounded at its top and base by unconformities or their correlative conformities" (Mitchum et al., 1977, p. 53). All of the strata in this unit are genetically related and were deposited within "a single episodic event". The depositional sequence is therefore chronostratigraphically significant (Mitchum et al., 1977, p. 55).

The use of seismic data allowed workers to develop, apply, and improve sequence-stratigraphic models. With that, a set of sequence-stratigraphic terminology was conceived. Van Wagoner et al. (1987, 1988) defined two types of sequences based on the type of lower boundary present. "A type 1 sequence is bounded below by a type 1 sequence boundary and above by a type 1 or a type 2 sequence boundary. A type 2 sequence is bounded below by a type 2 sequence boundary and above by a type 1 or a type 2 sequence boundary" (Van Wagoner et al., 1988, p. 41). There are two types of sequence boundaries. Both the type 1 and type 2 sequence boundaries are "characterized by subaerial exposure...and a downward shift in coastal onlap landward of the depositional shoreline break" (Van Wagoner et al., 1988, p. 42). Additionally, a type 1 sequence boundary is characterized by subaerial erosion associated with stream rejuvenation and a basinward shift of facies. "A type 1 sequence boundary is interpreted to form when the rate of eustatic fall exceeds the rate of basin subsidence at the depositional-shoreline break, producing a relative fall in sea-level at that position" (Van Wagoner et al., 1988, p. 41). "Onlap of overlying strata landward of the depositonal-shoreline break also marks a type 2 sequence boundary. A type 2 sequence boundary is interpreted to form when the rate of eustatic fall is less than the rate of basin subsidence at the depositional-shoreline break, so that no relative fall in sea-level occurs at this shoreline position" (Van Wagoner et al., 1988, p. 42).

Within the depositional sequence is what Brown and Fisher (1977) called a systems tract. They defined a systems tract to be a linkage of contemporaneous depositional systems. Van Wagoner et al. (1988) divided type 1 and type 2 sequences into specific systems tracts. In ascending order, a type 1 sequence contains a lowstand, transgressive, and highstand systems tract. A type 2 sequence contains a shelf-margin, transgressive, and highstand systems tract. Each systems tract is associated with a particular facies, geometry, type of bounding surfaces, "position within a sequence, and parasequence and parasequence set stacking patterns" (Van Wagoner et al., 1988, p. 42). Each systems tract is interpreted to have been deposited within a particular interval of the eustatic sea-level curve. The lowstand systems tract may contain a lowstand fan, slope fan, or lowstand wedge. These are interpreted to have been deposited during rapid eustatic fall, late eustatic fall or early eustatic rise, and late eustatic fall or early eustatic rise, respectively. The transgressive system tract is interpreted to have been deposited during during rapid eustatic rise. The highstand systems tract is interpreted to have been deposited during late eustatic rise, eustatic stillstand, and early eustatic fall (Van Wagoner et al., 1988, p. 44). Van The systems tract nomenclature are not defined in terms of time "or position on a cycle of eustatic or relative change of sea-level. The actual time of initiation of a systems tract is interpreted to be a function of the interaction between eustasy, sediment supply, and tectonics" (Van Wagoner et al., 1988, p. 42).

"The lowstand systems tract, if deposited in a basin with a ramp margin, consists of a relatively thin lowstand wedge that may contain two parts. The first part is characterized by stream incision and sediment bypass of the coastal plain interpreted to occur during a relative fall in sea level during which the shoreline steps rapidly basinward until the relative fall stabilizes. The second part of the wedge is characterized by a slow relative rise in sea level, the infilling of incised valleys, and continued shoreline progradation, resulting in a lowstand wedge composed of incised-valley-fill deposits updip and one or more progradational parasequence sets downdip. The top of the lowstand wedge is the transgressive surface; the base of the lowstand wedge is the lower sequence boundary" (Van Wagoner et al., 1988, p. 44).

"The shelf-margin systems tract is the lowermost systems tract associated with a type 2 sequence boundary. This systems tract is characterized by one or more weakly progradational to aggradational parasequence sets; the sets onlap onto the sequence boundary in a landward direction and downlap onto the sequence boundary in a basinward direction. The top of the shelf-margin systems tract is the transgressive surface, which also forms the base of the transgressive-systems tract. The base of the shelf-margin systems tract is a type 2 sequence boundary" (Van Wagoner et al, 1988, p. 44).

"The transgressive-systems tract is the middle systems tract of both type 1 and type 2 sequences. It is characterized by one or more retrogradational parasequence sets. The base of the transgressive-systems tract is the transgressive surface at the top of the lowstand or shelf-margin tracts. Parasequences within the trasgressive-systems tract onlap onto the sequence boundary in a landward direction and downlap onto the transgressive surface in a basinward direction. The top of the transgressive-systems tract is the downlap surface. The downlap surface is a marine-flooding surface onto which the toes of prograding clinoforms in the overlying highstand systems tract downlap. This surface marks the change from a retrogradational to an aggradational parasequence set and is the surface of maximum flooding. The condensed section occurs largely within the transgressive and distal highstand systems tracts. The condensed section is a facies consisting of thin marine beds of hemipelagic or pelagic sediments deposited at very slow rates (Loutit and others, this volume). Condensed sections are most extensive during the time of regional transgression of the shoreline" (Van Wagoner, 1988, p. 44).

"The highstand systems tract is the upper systems tract in either a type 1 or a type 2 sequence. This systems tract is commonly widespread on the shelf and may be characterized by one or more aggradational parasequence sets that are succeeded by one or more progradational parasequence sets with prograding clinoform geometries. Parasequences within the highstand systems tract onlap onto the sequence boundary in a landward direction and downlap onto the top of the transgressive or lowstand systems tracts in a basinward direction. The highstand systems tract is bounded at the top by a type 1 or type 2 sequence boundary and at the bottom by the downlap surface" (Van Wagoner, 1988, p. 44).

"The subdivision of sedimentary strata into sequences, parasequences, and systems tracts provides a powerful methodology for the analysis of time and rock relationships in sedimentary strata. Sequences and sequence boundaries subdivide sedimentary rocks into genetically related units bounded by surfaces with chronostratigraphic significance. These surfaces provide a framework for correlating and mapping. Interpretation of systems tracts provides a framework to predict facies relationships within the sequence. Parasequence sets, parasequences, and their bounding surfaces further subdivide the sequence and component systems tracts into smaller genetic units for detailed mapping, correlating, and interpreting depositional environments" (Van Wagoner, 1988, p. 44).

## Sequence Stratigraphy Applied to Cyclothems

Sequence stratigraphy is useful to geologists because it allows the placement of vertical successions of cyclic strata into a chronostratigraphic framework rather than or in addition to a lithostratigraphic framework. By identifying important surfaces which represent time lines within the cyclothems, geologists are better able to interpret the geologic history and paleotopography of a study area. With the development of regional seismic data, sequence stratigraphy has become a more practical approach to interpreting the depositional histories of large areas.

Sloss (1963) used subsurface data from exploratory drilling to document six interregional unconformities present in the sedimentary strata of the North American continent. Although these interregional unconformities are similar to local unconformities in the outcrop (or even undetectable), they are visible and correlatable in the subsurface data. Sloss integrated the subsurface data with his own and others' surface outcrop data.

The six interregional unconformities separate six stratigraphic sequences. Sloss named these North American sequences, in ascending order, the Sauk, Tippecanoe, Kaskaskia, Absaroka, Zuni, and Tejas Sequences. He did not name the sequences according to time-stratigraphic terms because these sequences transgress time. They are rock units, not time units. Each sequence represents a phase of interregional transgression followed by regression, although the regressive phase of the sequence is not preserved as well. Figure 29 is a figure taken from Sloss (1963) showing time-stratigraphic relationships of the six North American sequences.

Sloss (1963) interpreted cratonic sequences across North America based on lithostratigraphy; Mitchum, et al. (1977) and Vail, et al. (1977) interpreted depositional sequences globally based on seismic data showing major interregional unconformities. These depositional sequences are chronostratigraphically significant because they each were deposited within a single episodic event (Mitchum et al., 1977, p. 55).

Seismic lines are one tool used to interpret chronostratigraphy. The limit to the use of seismic lines is the scale of view. Although resolution is improved, the seismic

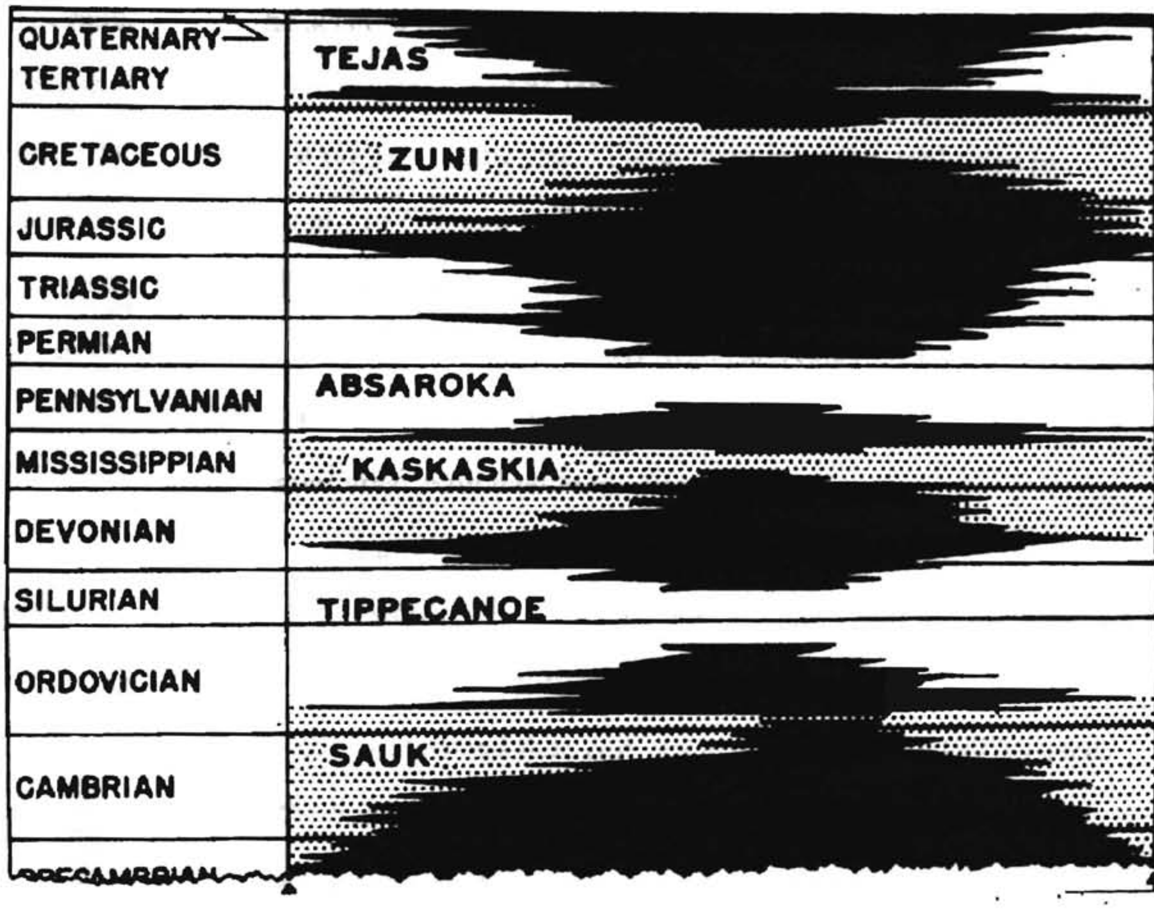


Figure 29 (from Sloss, 1963, p. 110). "Time-stratigraphic relationships of the sequences in the North American craton. Black areas represent nondepositional hiatuses; white and stippled areas represent deposition. (Stippling introduced only to differentiate successive depositional episodes.)"

stratigrapher can only see thicknesses of several tens of meters or more. Units which become too thin to see on the seismic line will appear to terminate. Although lithology cannot be determined from a seismic line, Vail, et al. (1977a) noted that based on seismic stratigraphy, geologists can correlate time units, define depositional sequences, depositional and post-depositional histories. They defined important surfaces.

Their three step procedure for determining the above is to 1) define the depositional sequences on the seismic line, 2) determine the facies of each depositional sequence (seen in the seismic line), and 3) interpret the relative sea-level changes based on the relationships seen on the seismic line. These three steps are explained in Mitchum, et al.; Vail, et al., 1977b; and Vail, et al., 1977c, respectively.

The first step is to define and analyze the boundaries of the depositional sequences. Depositional sequences are separated from each other by unconformities and their correlative conformities. These surfaces can be traced over wide regions with seismic lines and over smaller areas with well logs. For practical purposes, these surfaces are synchronous. When defining the boundaries of a depositional sequence, the sequence stratigrapher first identifies regional unconformities (which are the result of either erosion or nondeposition) and then traces these unconformities laterally where they may become paraconformities and then conformities. Vail, et al. (1977a) used Figure 30 to illustrate the basic concepts of the depositional sequence.

Sequence boundaries may be represented by an unconformity (discordant surface) or the unconformity's relative conformity (concordant surface). The concordant surfaces cannot be recognized on seismic data. Therefore one must look for the discordant surfaces in order to infer the relative concordant surface. Discordant surfaces are recognized on seismic lines by the presence of lapout and/or truncation. The two major types of lapout are: baselap (occurs at the lower boundary) and toplap (occurs at the upper boundary). Within the category of baselap are onlap and downlap. Truncation due to erosion or structural disruption may occur at the upper boundary. Where the

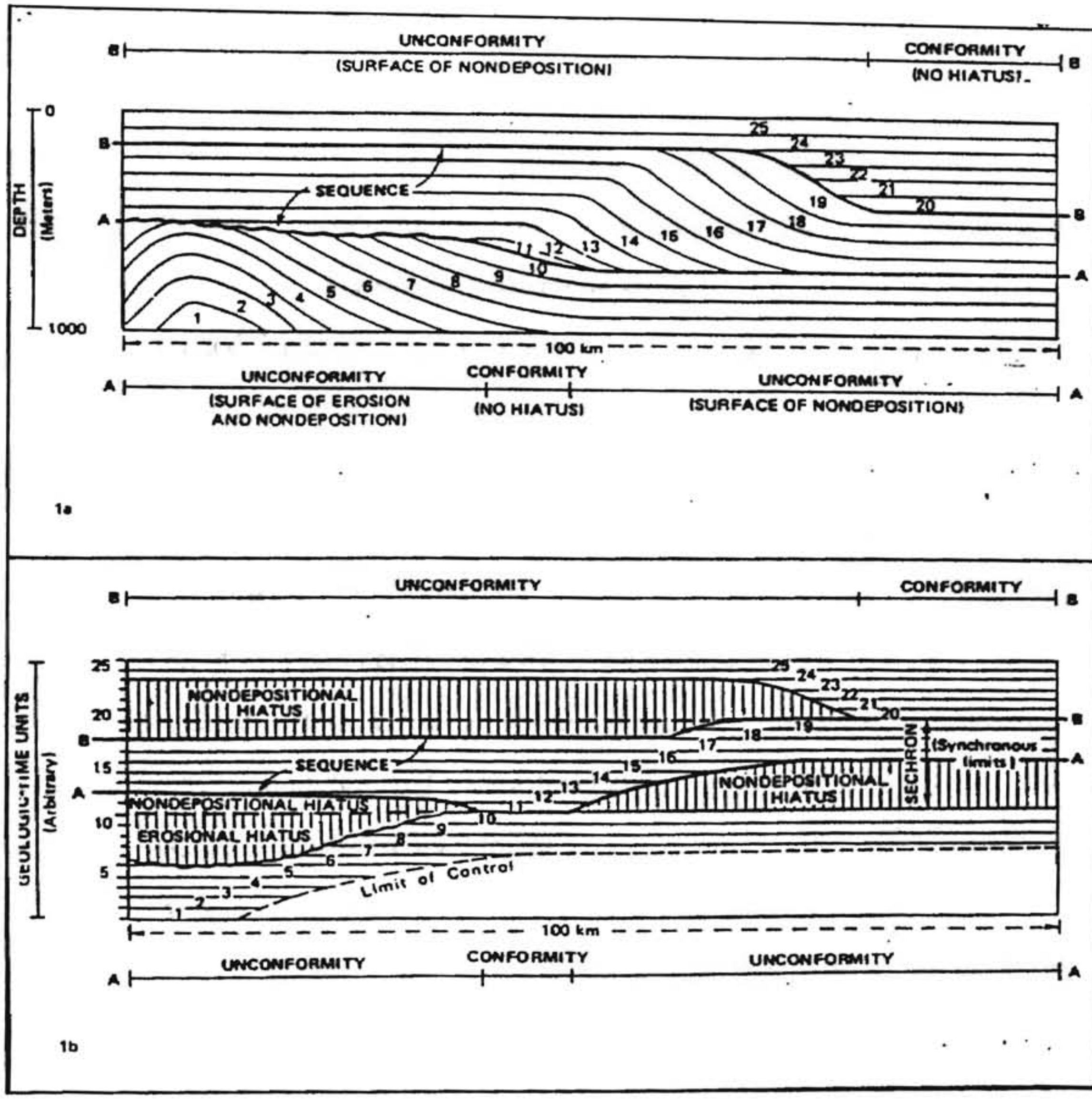


Figure 30. Basic concepts of depositional sequence. A depositional sequence is a stratigraphic unit composed of relative conformable successions of genetically related strata and bounded at its top and base by unconformities or their correlative conformities (Vail, et al., 1977, p. 54).

unconformity grades into paraconformities and/or conformities, correlation with the unconformity may be achieved by biostratigraphic analyses. Within the depositional sequence there are physical bedding or laminae surfaces. These are practically synchronous.(Vail et al., 1977a).

Vail, et. al. point out that during one "cycle of relative change of sea-level" more than one relative sea-level rise may occur, each followed by a stillstand, before a relative sea-level fall finally occurs, marking the end of the cycle (Vail et al., 1977b, p. 63). If this is the case, then we may see more than one sequence deposited during the cycle. Vail et al. constructed Figure 31 to show relative change of sea-level versus geologic time. The upper boundaries of the sequences are usually easier to see when a greater relative fall in sea-level occurs.

The second step in the procedure of determining the depositional history of sequences is to analyze the facies within the sequence(s) and construct a sea-level curve for a region. Vail, et al. explained the process of determining relative sea-level changes based on coastal onlap patterns found on seismic lines. The coastal facies of marine sequences are controlled by the relative sea-level changes more than the deep sea facies of the marine sequences and more than the facies of the nonmarine sequences are. The "depositional limits of onlap and toplap" within these coastal facies are the best evidence of the relative sea-level changes (Vail et al., 1977b, p. 65). A relative sea-level rise may be indicated by the presence of onlap within the coastal facies. Figure 32 (from Vail et al., 1977b) illustrates this. A relative sea-level stillstand may be indicated by the presence of toplap within the coastal facies (Figure 33). A relative sea-level fall may be indicated by either a "downward shift in coastal onlap" or a "downward shift in clinoform pattern" (Vail et al., 1977b, p. 71). Figure 34 illustrates this relationship. The former indicates rapid fall, the latter gradual fall. Note that relative rise and fall in sea-level are not equivalent to transgression and regression (Vail et al., 1977b). If terrigenous influx is high enough during a relative rise of sea-level, a regression may

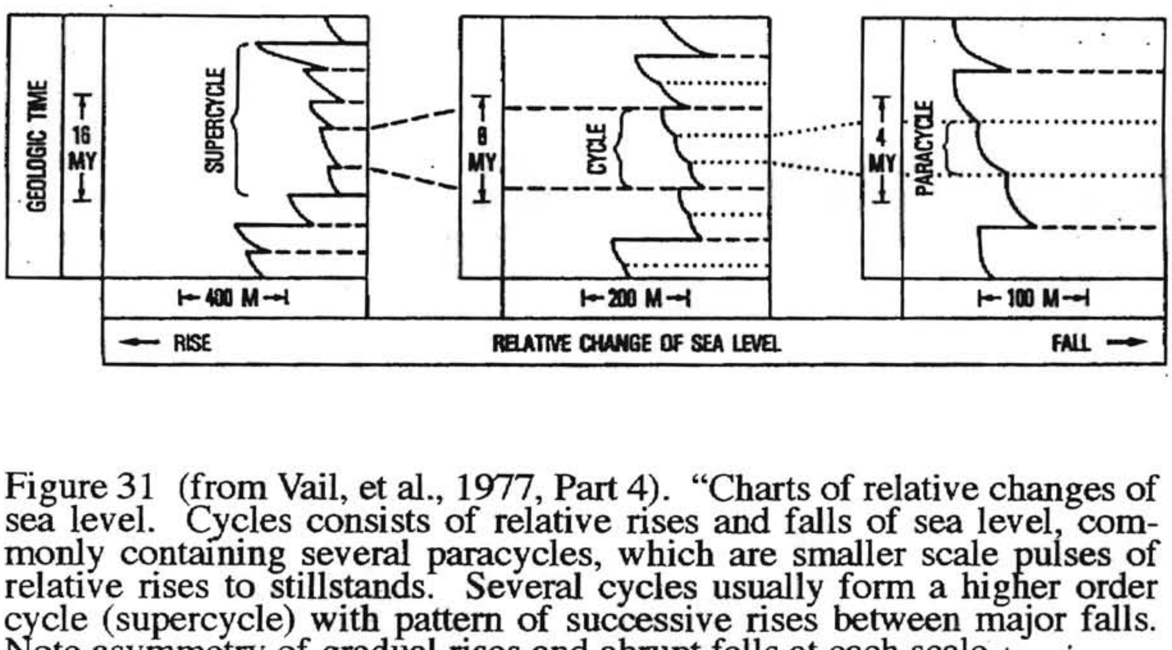


Figure 31 (from Vail, et al., 1977, Part 4). "Charts of relative changes of sea level. Cycles consists of relative rises and falls of sea level, commonly containing several paracycles, which are smaller scale pulses of relative rises to stillstands. Several cycles usually form a higher order cycle (supercycle) with pattern of successive rises between major falls. Note asymmetry of gradual rises and abrupt falls at each scale.

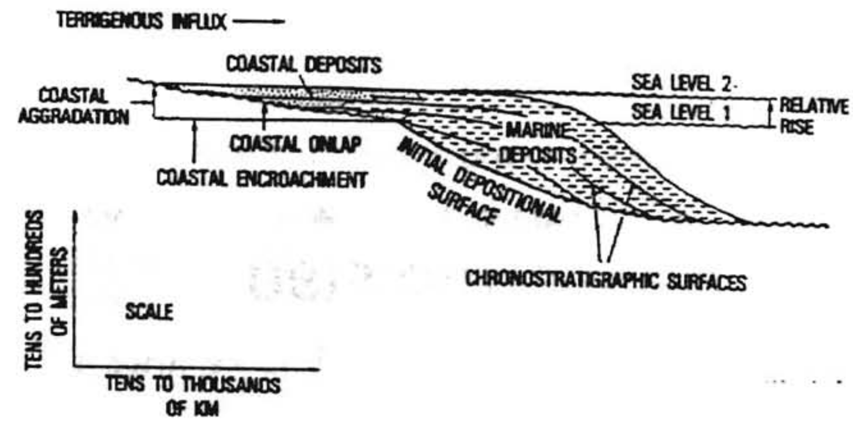


Figure 32. "Coastal onlap indicates a relative rise of sea level. Relative rise of base level allows coastal deposits of a maritime sequence to aggrade and onlap initial depositional surface" (Vail, et al., 1977b, p. 66).

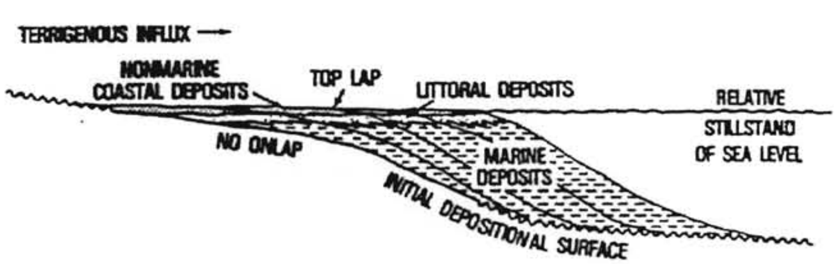


Figure 33. "Coastal toplap indicates relative stillstand of sea level. With no relative rise of base level, nonmarine coastal and/or littoral deposits cannot aggrade, so no onlap is produced; instead, by-passing produces toplap" (Vail, et al., 1977b, p. 70).

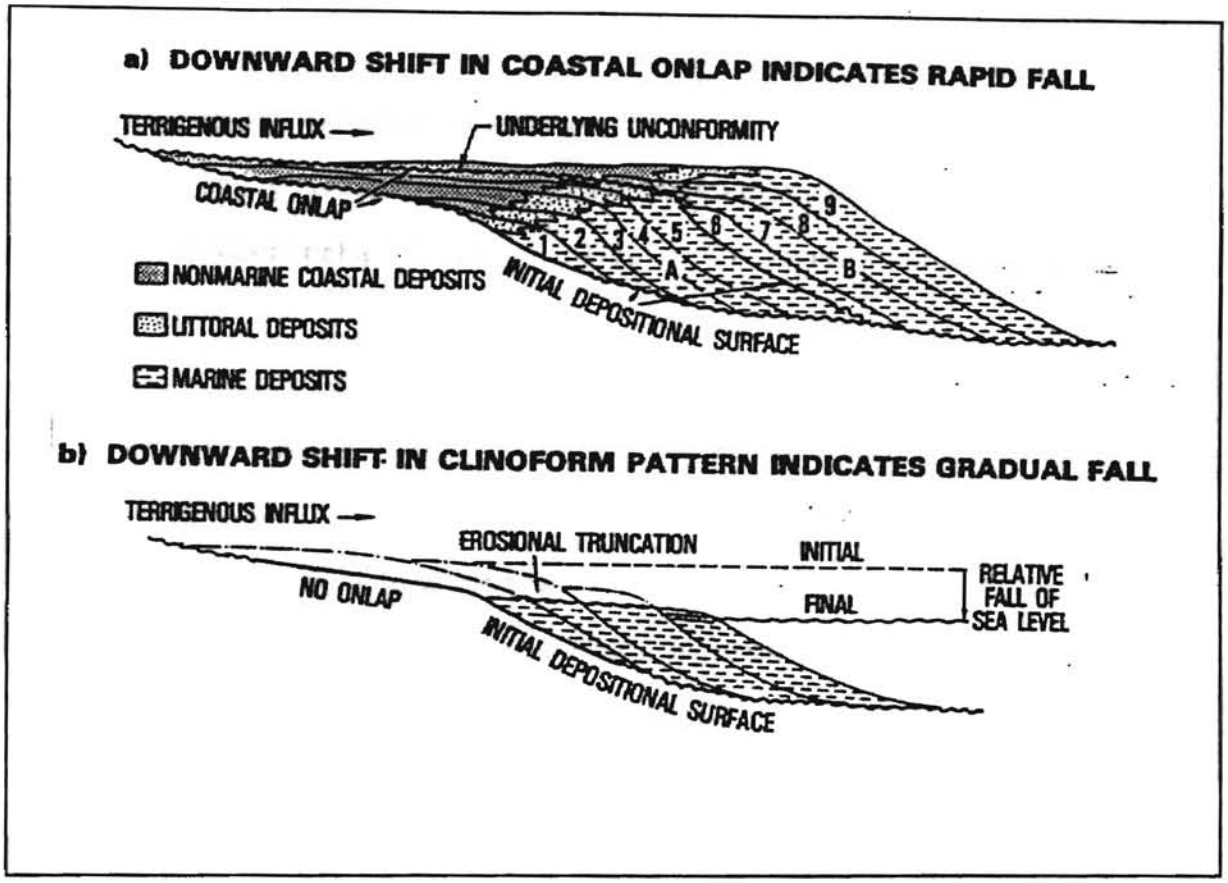


Figure 34. "Downward shift of coastal onlap indicates relative fall of sea level. With relative fall of base level, erosion is likely; deposition is resumed with coastal onlap during subsequent rise. (a) Downward shift in coastal onlap indicates rapid fall observed in all cases studied so far. (b) Downward shift in clinoform pattern (after Weller, 1960), indicate gradual fall; but has not been observed on seismic data" (Vail, et al., 1977b, p. 72).

occur. Figure 35 shows this.

Vail, et al. (1977b) explain how to construct a regional curve of relative sea-level changes. A stratigraphic cross section of the depositional sequences must first be constructed, indicating the ages of the boundaries, based on biostratigraphy. Note the types of lapout present. Secondly, a chronostratigraphic chart is needed, with the sequence plotted against time. Thirdly, a chart of regional relative sea-level changes is plotted with the magnitudes of change and stillstand versus time. The magnitude of relative rises and falls can be "determined with measurements of coastal aggradation, the vertical component of coastal onlap" (Vail et al., 1977b, p. 77). Figure 36 illustrates these three steps.

Vail, et al. (1977c) explain the use of interregional unconformities to construct global cycle charts during Phanerozoic time. Three major orders of cycles are defined and used in the construction of the chart. Many of these cycles can be correlated globally. "A global cycle may be determined from a modal average of three or more correlative regional cycles derived from seismic stratigraphic studies" (Vail et al., 1977c, p. 83). By averaging the highs and lows of regional curves of relative sea-level changes (Vail et al., 1977c) constructed for different continents during the same time, sequence stratigraphers can construct global curves of relative sea-level changes. Seismic data is the main tool used in the procedure. In particular, the best comparison between the regional cycles of the same age comes from the major interregional unconformities produced by the major relative sea-level falls (global lowstands). Global highstands are indicated by the presence of "widespread shallow marine to nonmarine deposits on the shelves and 'starved' basins. A global lowstand is an interval during which sea-level is below the shelf edge in most regions. A comparative lowstand occur when sea-level is at its lowest position on the shelf between periods of highstand" (Vail et al., 1977c, p. 92).

These global cycle charts are useful in estimating the geologic age of an area

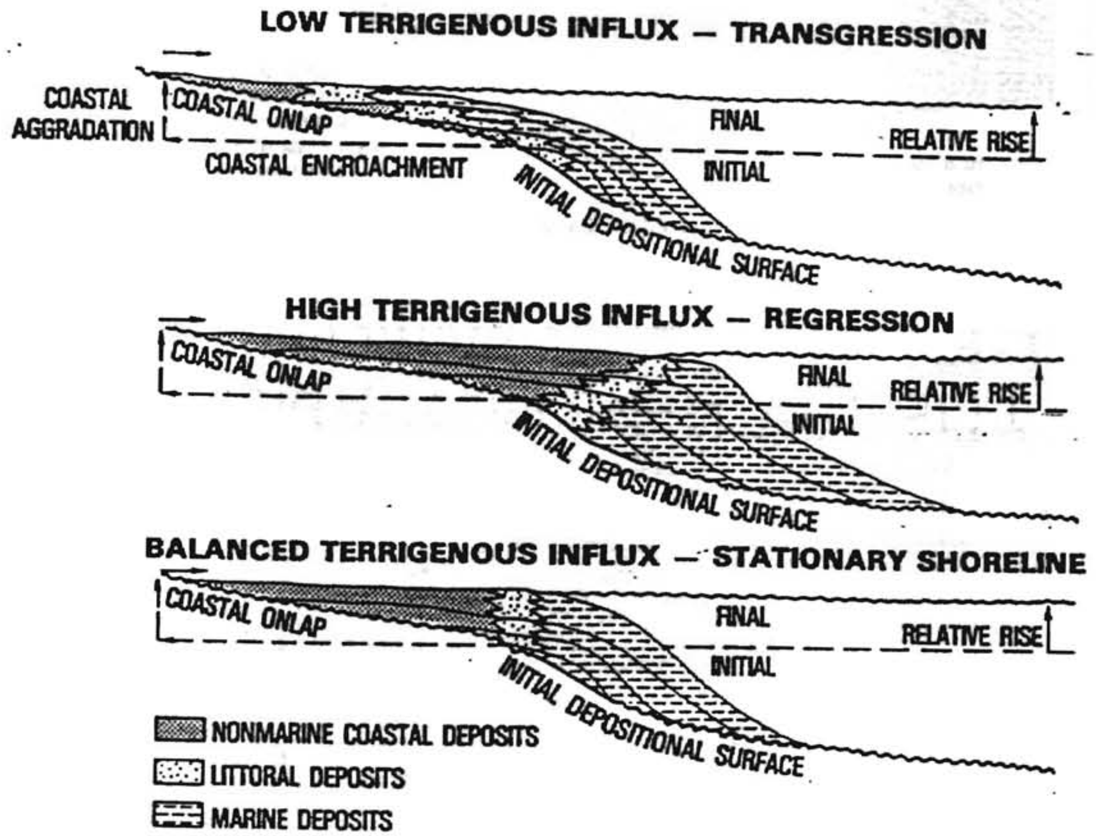


Figure 35. "Transgression, regression, and coastal onlap during relative rise of sea level. Rate of terrigenous influx determines whether transgression, regression, or stationary shoreline is produced during relative rise of sea level" (Vail, et al., 1977b, p. 66).

before drilling and in filling in missing parts of regional sea-level curves. Another possible major benefit of these global cycle charts is an international system of geochronology.

Vail, et. al. cite other authors for explanations of the causes of global changes in sea-level. Vail, et. al. write that the probable causes of the first-order and most second-order cycles are geotectonic mechanisms. The rest of the second-order and most of the third-order cycles are probably caused by the alternative advance/withdrawal of the glaciers.

Sarg (1988) expanded the Exxon workers' sequence-stratigraphic concepts to the specific area of carbonates. He constructed a model which predicts depositional history of carbonates based on facies distribution within sequences. Figure 37 illustrates the carbonate facies Sarg defined to occur on carbonate platforms and bank margins. "Depositional stratal patterns, facies distribution, and productivity of carbonate platforms are controlled most importantly by the rates of relative changes in sea-level (i.e., sum of rate of change of eustasy and subsidence). Depositional setting and climate also exert strong controls on basin water chemistry and carbonate productivity. Carbonate highstand systems tracts are characterized by aggradational-to-progradational geometry. A keep-up systems tract is interpreted to represent a relatively rapid rate of accumulation and displays a mounded/oblique stratal configuration at the platform/bank margin. A catch-up systems tract is interpreted to represent a relatively slow rate of accumulation and displays a sigmoid depositional profile at the platform/bank margin. Catch-up systems tracts appear to have significantly greater amounts of early submarine cement. During formation of a type 1 sequence boundary, two major processes may occur: (1) local-to-regional slope front erosion and (2) subaerial exposure of the platform. For a large-scale type 1 sequence boundary and given the appropriate climatic conditions, the meteoric lens may remain established for a long time over the platform. During formation of a small-scale type 1 or a type 2 sequence boundary, the meteoric lens is less well

# SEQUENCE STRATIGRAPHY DEPOSITIONAL MODEL

## Showing Surfaces, Systems Tracts and Lithofacies

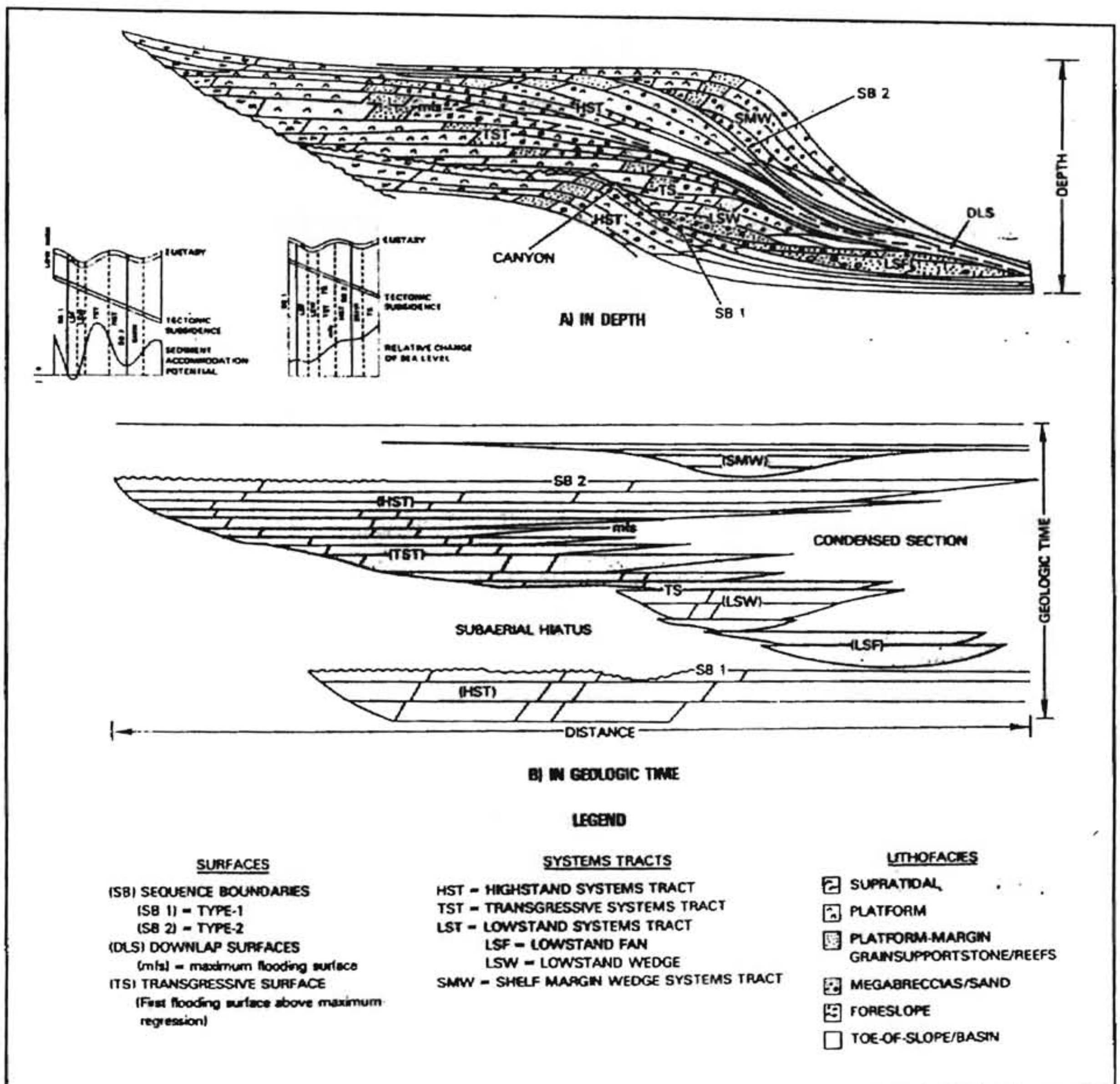


Figure 37. "Summary schematic diagram of carbonate lithofacies distribution in a sequence framework" (Sarg, 1988, p. 157).

established, and the dominant effects will be in the inner-platform areas. Two types of carbonate lowstand systems tracts are recognized: (1) allochthonous deposits derived from erosion of the bank margin and slope and characterized by channeled megabreccia deposition, and (2) autochthonous wedges deposited on the upper slope during either type 1 or type 2 sea-level lowstands. Gentle depositional slopes and well-circulated basins favor lowstand bank growth. With the appropriate climatic, hydrographic, and provenance conditions, evaporite or siliciclastic-lowstand deposition will occur" (Sarg, 1988, p. 179).

A forced regression occurs with a eustatic drop in sea-level. A normal regression "occurs during a relative sea-level stillstand or rise" (Posamentier et al., 1992, p. 1688). Posamentier et al. (1992) discussed the significance of forced regressions within a sequence-stratigraphic framework. Their paper focused on "the concepts presented by Posamentier and Vail (1988) with regard to lowstand regressive deposits" (Posamentier, 1992, p. 1687). "Forced regression is the mechanism by which lowstand prograding wedges are deposited during intervals of relative sea-level fall" (Posamentier, 1992, p. 1707).

Since the Exxon workers developed sequence-stratigraphic models based on seismic data others have applied the models using seismic and/or other types of data..Rather than using unconformities as sequence boundaries, Galloway (1989) built upon Frazier's (1974) model and used black fissile shales to bound what he termed genetic stratigraphic sequences. Galloway defined a genetic stratigraphic unit to be "a package of sediments recording a significant episode of basin margin outbuilding and basin filling bounded by periods of widespread basin-margin flooding" (Galloway, 1989, p. 132). In Figure 38, Galloway compares the genetic stratigraphic sequence to Exxon's type 1 and type 2 depositional sequences.

Galloway places the genetic stratigraphic sequence boundaries at the black shales (marine condensed sections). The strata from one marine condensed section to

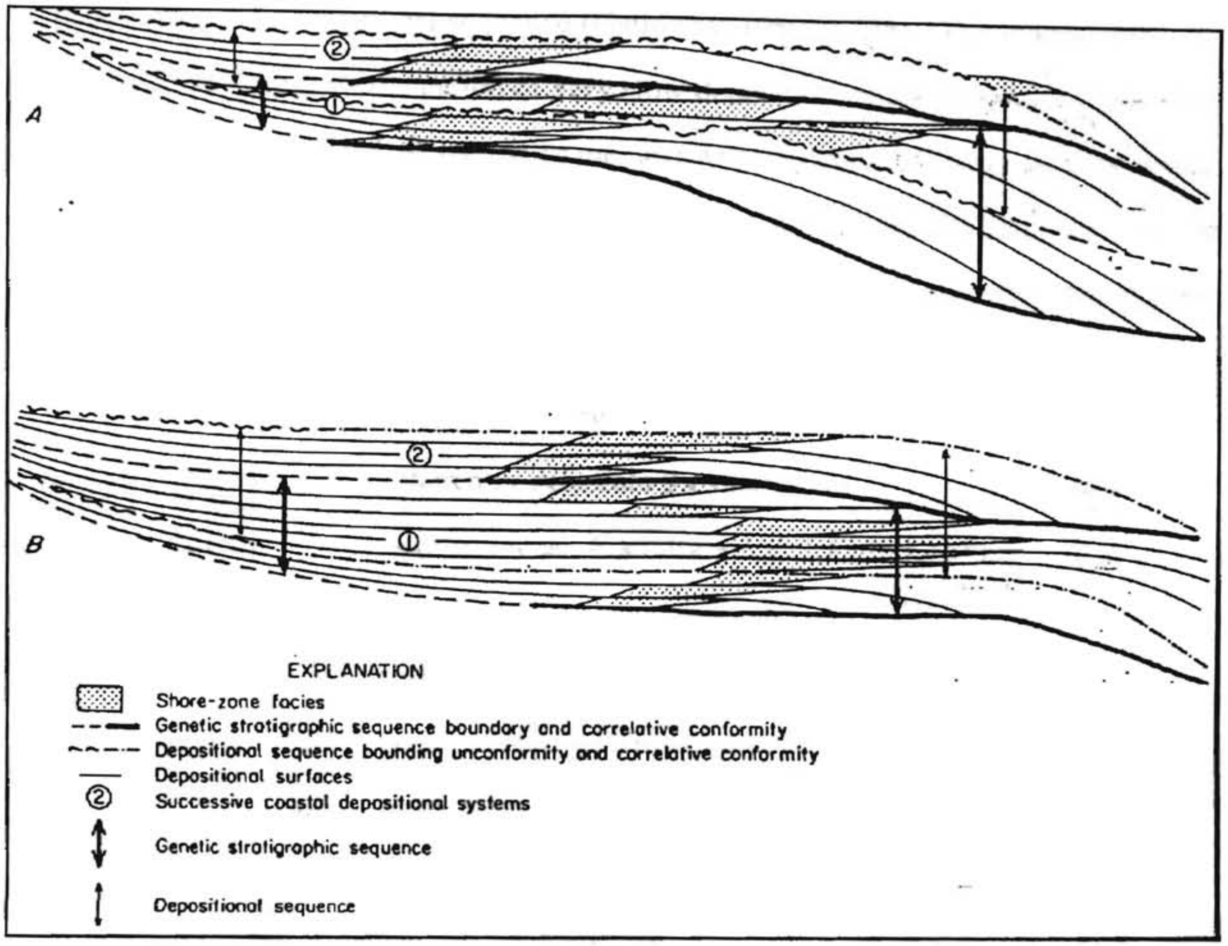


Figure 38. Comparison of boundaries for (A)Exxon type 1 and (B)Exxon type 2 depositional sequences with those of genetic stratigraphic sequence. (A)Exxon paradigm emphasizes subaerial unconformity and its equivalent stratal surface, which may be quite prominent where relative base level drops below progradational shelf edge. (B)In contrast, bounding unconformity is obscure and of limited extent in type 2 sequences where base level does not drop below platform margin. In both examples, downlapped hiatal surface created by transgression and flooding of coastal plain creates an easily correlated horizon that encapsulates prograded wedge of sandy coastal-plain, shore-zone, and marine-slope sediments" (Galloway, 1989, p. 133).

of phase" with the depositional sequence (Galloway, 1989, p.138). The marine condensed section represents the period of very slow deposition or nondeposition. The strata from one marine condensed section to the next were deposited during one depositional episode and are separated by a hiatal surface. These marine-flooding surfaces may be represented by "both unconformities and condensed sections" which may be recognized on well logs (Galloway, 1989, p. 131).

"The Exxon group focused on using seismic data and developing seismic stratigraphy. Seismic reflections inherently delineate the distribution and geometry of interfaces--depositional or erosional surfaces. A stratigraphy of surfaces emerges. Depositional systems and system tracts are interpreted by their stratigraphic and geographic relationship to sequence-bounding unconformities. In contrast, the application of three-dimensional facies analysis using subsurface data and emergence of the depositional systems concept subordinates stratal surfaces to the depositional facies of basin fills. The genetic stratigraphic sequence, as proposed here, synthesizes surface stratigraphy within the three-dimensional facies framework of depositional systems. The sequence retains the sedimentologist's emphasis on interpreting environments by internal features and facies geometries" (Galloway, 1989, p. 137).

Louitit et al. (1988) used condensed sections to date and correlate continental-margin sections. According to the authors, condensed sections provide the best tool for identification of depositional sequences. They are thin marine units full of diverse fossils and represent times of very slow to no deposition. They occur in the middle of sequences, approximately where the line of maximum transgression lies. They are easily recognized by their composition of abundant and diverse microfossils. They are also easily recognized on seismic sections of continental margins along downlap surfaces underneath clinoforms. Bioturbation is often present along these downlap surfaces in the outcrop. They used biostratigraphy and depositional sequence analysis to date and correlate the continental-margin sequences.

Goldhammer, et al. (1991) described the presence of three superimposed orders of cycles and their resultant stacking patterns. Youle et al. (1994) attempted "(1) to describe lithologies and geometries of Middle Pennsylvanian cyclothems in sequence-stratigraphic terms and (2) to interpret the relative sea-level history of the study area as revealed by the distribution of facies, stacking patterns, and geometries of these depositional sequences through time" (Goldhammer et al., 1991, p. 268).

Goldhammer, et al. (1994) discussed the presence of shallowing upward depositional cycles in Mid-Pennsylvanian strata. They attribute the cause of these cycles to high-frequency composite eustacy. Depositional cycles are the basis of depositional sequences. There are five orders of high-frequency cycles which superimpose one another. The cycles present in Mid-Pennsylvanian strata can be grouped into fifth, fourth, and third orders. They have "systematic, vertical succession of facies, cycle and sequence stacking patterns." The fifth order cycles "are composed of shallowing-upward packages of dominantly subtidal shelf carbonates with sharp cycle boundaries (either exposure or flooding surfaces). Fifth-order cycles are packaged into fourth-order sequences (type 1) bounded by regionally correlative subaerial exposure surfaces." Fifth and fourth order cycles may be packaged together into third-order sequences.

"High-frequency cycles and sequences are interpreted as dominantly aggradational allocycles generated in response to composite fourth- and fifth-order glacio-eustatic sea-level fluctuations." These fluctuations in sea-level are explained by the authors as occurring due to "two different orbital forcing (Milankovitch) scenarios." (Goldhammer et al., 1994).

Watney et al. (1995) compared both depositional sequences and GSUs to cyclothems of the Middle and Upper Pennsylvanian. The authors then used their data, which included "cores, surface exposures, well logs, regional mapping, and cross sections" to determine the cycle hierarchy within these strata. "to characterize second- and third-order cycles (genetic sets and sequence sets) containing higher frequency fourth-order (primary) GSUs and depositional sequences and minor fifth-order cycles. Regional cross sections and maps of individual primary GSUs reveal details of the stacking geometries and relative sea-level history" (Watney et al., 1995, p. 191-2).

Depositional sequences are similar to cyclothems in that they are "unconformity-bounded packages with components generally interpreted to represent a response to a rise and fall of relative sea-level". The difference lies in that the cyclothem "is a lithostratigraphic unit and the sequence is dependent on the bounding surface and is independent of the lithostratigraphy" (Watney et al., 1995, p. 158). "A lithologically defined cyclothem may contain multiple sequences or sequences may comprise multiple cyclothems" (Watney et al., 1995, p. 158).

## Recognition of Surfaces

Subaerial exposure surfaces, flooding surfaces, and condensed sections can be interpreted at outcrop and in the subsurface based on certain criteria. When a subaerial exposure surface is interpreted, it may be used as a depositional sequence boundary. Condensed sections or maximum flooding surfaces are used as GSU boundaries. Subaerial exposure surfaces, flooding surfaces, and maximum flooding surfaces are used as systems tracts boundaries.

### Subaerial exposure surfaces

Depositional sequences are bounded by subaerial exposure surfaces (unconformities or their correlative conformities) (Mithum et al., 1977). Subaerial exposure surfaces are difficult to correlate, especially when present within the outside shales "where paleosols are often not as well developed or preserved" (Watney et al., 1995, p. 154). Not all subaerial exposure surfaces are interpreted to be depositional sequence boundaries. Indicators of subaerial exposure include paleosols, paleokarst, and incised valley fill.

#### Paleosols

Retallack (1988) discussed root traces, soil horizons, and soil structures as diagnostic features of paleosols. A paleosol can be inferred by the presence of one or more of these types of evidence. Retallack presented a compilation of data for field identification of these features.

Root traces are evidence that a soil formed and supported plant life during subaerial exposure. Root structure types are indicative of plant types, which may be indicative of soil type. Roots which formed in moist environments are better preserved than dry environment roots. Figure 39, from Retallack (1988) shows different kinds of roots.

Soil horizons are another characteristic of paleosols. These are usually represented by a sharp erosional surface overlying gradational zones of former soil horizons (Retallack, 1988). Retallack provided a table (Figure 40) describing horizons within paleosols and a chart (Figure 41) of different types of paleosols based on soil horizons. For example, according to Figure 41, a coal is an O horizon and can be labelled a paleosol, more specifically a histosol.

Soil structure is the third general feature of paleosols. When examined closely, type of soil structure should be apparent. Soil type can be inferred from type of soil structure. Retallack provided a chart classifying soil structures according to size and shape (Figure 42). Slickensides can form in any soil type from compression during burial. They can form in clayey soils when the clay particles alternately shrink and swell due to alternate periods of wetness and dryness.

Paleokarst

Paleokarst is a feature of subaerial exposure. Paleokarst and solution piping may be present if the environment was wet enough. Clay or fragments from surrounding rock from the paleosol zone may infill voids formed during karst processes (Watney, et al., 1989 and 1995).

Incised valley fill

Incised valley fills are evidence of subaerial exposure. These form when sea-

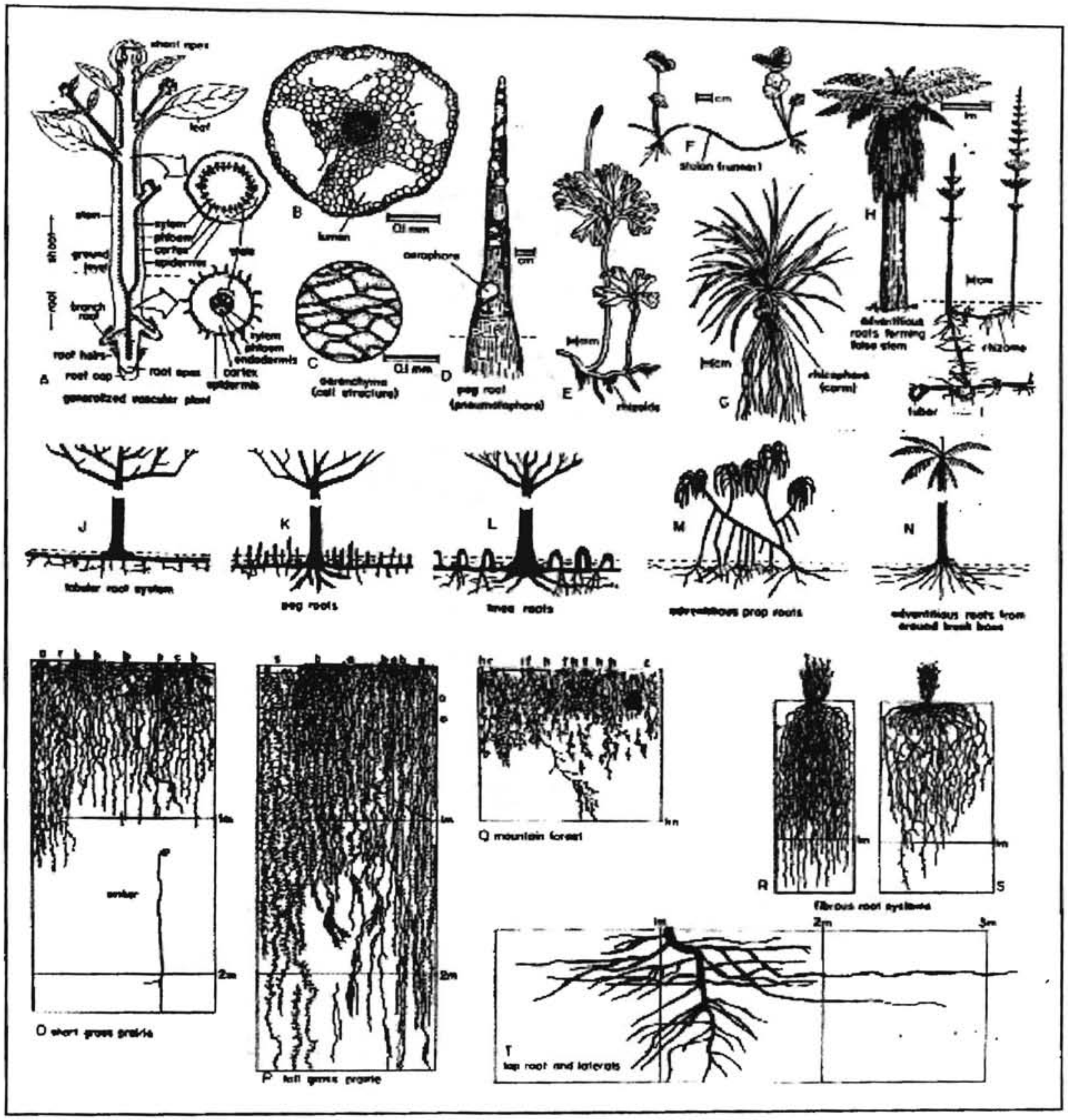

Figure 39. Types of root structures (from Retallack, 1988).

## DESCRIPTIVE SHORTHAND FOR LABELING PALEOSOL HORIZONS

| Category | New Term | Description | Old Term |
|---|---|---|---|
| *Master Horizons* | O | Surface accumulation of organic materials (peat, lignite, coal), overlying clayey or sandy part of soil | O |
| | A | Usually has roots and a mixture of organic and mineral matter; forms the surface of those paleosols lacking an O horizon | A |
| | E | Underlies an O or A horizon and appears bleached because it is lighter colored, less organic, less sesquioxidic, or less clayey than underlying material | A2 |
| | B | Underlies an A or E horizon and appears enriched in some material compared to both underlying and overlying horizons (because it is darker colored, more organic, more sesquioxidic or more clayey) or more weathered than other horizons | B |
| | K | Subsurface horizon so impregnated with carbonate that it forms a massive layer (developed to stage III or more of Table 4) | K |
| | C | Subsurface horizon, slightly more weathered than fresh bedrock; lacks properties of other horizons, but shows mild mineral oxidation, limited accumulation of silica carbonates, soluble salts or moderate gleying | C |
| | R | Consolidated and unweathered bedrock | R |
| *Gradations Between Master Horizons* | AB | Horizon with some characteristics of A and B, but with A characteristics dominant | A3 |
| | BA | As above, but with B characteristics dominant | B1 |
| | E/B | Horizon predominantly (more than 50%) of material like B horizon, but with tongues or other inclusions of material like an E horizon | A&B |
| *Subordinate Descriptors* | a | Highly decomposed organic matter | — |
| | b | Buried soil horizon (used only for pedorelict horizons with paleosols; otherwise redundant) | b |
| | c | Concretions or nodules | cn |
| | e | Intermediately decomposed organic matter | — |
| | f | Frozen soil, with evidence of ice wedges, dikes, or layers | f |
| | g | Evidence of strong gleying, such as pyrite or siderite nodules | g |
| | h | Illuvial accumulation of organic matter | h |
| | i | Slightly decomposed organic matter | — |
| | k | Accumulation of carbonates less than for K horizon | ca |
| | m | Evidence of strong original induration or cementation, such as avoidance by root traces in adjacent horizons | m |
| | n | Evidence of accumulated sodium, such as domed columnar peds or halite casts | sa |
| | o | Residual accumulation of sesquioxides | — |
| | p | Plowing or other comparable human disturbance | p |
| | q | Accumulation of silica | si |
| | r | Weathered or soft bedrock | ox |
| | s | Illuvial accumulation of sesquioxides | ir |
| | t | Accumulation of clay | t |
| | v | Plinthite (in place, pedogenic laterite) | — |
| | w | Colored or structural B horizon | — |
| | x | Fragipan (a layer originally cemented by silica or clay, and avoided by roots) | x |
| | y | Accumulation of gypsum crystals or crystal casts | cs |
| | z | Accumulation of other salts or salt crystal casts | sa |

**Note:** This table has been adapted for use with paleosols from one by Guthrie and Witty (1982), showing proposed terminology from the new edition of the USDA *Soil Survey Manual*, compared to that of the 1951 edition. Some of the subordinate descriptors are considered more important than others; these letters (a, e, i, h, r, s, t, v, w) should all be written first after the master horizon if in combination with other letters, and they should not be used in combination with each other. Master horizons can be subdivided by numbers (e.g., B1, B2, B3). If the parent material of a paleosol consists of interbedded shale and sandstone, these will show different kinds of alteration in the same profile. Such different layers separated by discontinuities are numbered from the top down, without using the number 1; for example, A, E, E/B, Bt, 2Bt, 2BC, 2C, 3C. If you can form a clear mental picture of this profile, you are well on the way to mastering this pedological shorthand.

Figure 40. Soil horizons within paleosols (from Retallack, 1988).

## A SHORT AND SUPERFICIAL KEY TO SOIL ORDERS OF THE U.S. DEPARTMENT OF AGRICULTURE FOR FIELD IDENTIFICATION OF PALEOSOLS

| Features | Order |
|---|---|
| ***If paleosol has:*** | ***It may be a(n):*** |
| • Abundant swelling clay (mainly smectite) to a presumed uncompacted depth of 1 m or to a bedrock contact, together with hummock and swale structure (mukkara), especially prominent slickensides or clastic dikes | Vertisol |
| • No horizons diagnostic of other orders, and very weak development (Table 5) | Entisol |
| • No horizons diagnostic of other orders, but weak development (Table 5) | Inceptisol |
| • Light coloration (high Munsell value), thin calcareous layer (calcic horizon) close to surface of profile and developed to stage II or more (Table 4), or evidence of pedogenic gypsum or other evaporite minerals | Aridisol |
| • Organic (but not carbonaceous or coaly), well-structured (usually granular) surface (A) horizon (*mollic epipedon*), usually with evidence of copious biological activity (such as abundant fine root traces and burrows) and with subsurface horizons often enriched in carbonate, sometimes enriched in clay | Mollisol |
| • Surface organic (O) horizon of carbonaceous shale, peat, lignite, or coal (*histic epipedon*) originally (before compaction) at least 40 cm thick | Histosol |
| • Thick, well-differentiated (A, Bt, and C horizons) profile, with subsurface (Bt) horizon appreciably enriched in clay (*argillic horizon*) and often red with sesquioxides or dark with humus, and also with evidence (such as effervescence in acid or calcareous nodules or abundance of easily weathered minerals such as feldspar) for high concentrations of nutrient cations (such as $Ca^{++}$, $Mg^{++}$, $Na^{+}$, and $K^{+}$) | Alfisol |
| • Thick, well-differentiated (A, Bt, and C horizons) profile, with subsurface (Bt) horizon appreciably enriched in clay (*argillic horizon*) and often red with sesquioxides or dark with humus, but also with evidence (such as lack of reaction with acid or abundant quartz or kaolinite) for low concentrations of nutrient cations | Ultisol |
| • Thick, well-differentiated (A, Bs, and C horizons), with sandy subsurface (Bs or Bh) horizon cemented with opaque iron or aluminum oxyhydrates or organic matter (*spodic horizon*), and always with little or no clay or carbonate | Spodosol |
| • Thick, well-differentiated to uniform profile, clayey texture, with subsurface horizons highly oxidized and red, and almost entirely depleted of weatherable minerals (*oxic horizon*) | Oxisol |

*Note:* This key has been simplified for field observation. Precise identification of soils and their diagnostic horizons requires laboratory work and careful reference to Soil Survey Staff (1975).

Figure 41. Types of paleosols (from Retallack, 1988).

| TYPE | PLATY | PRISMATIC | COLUMNAR | ANGULAR BLOCKY | SUBANGULAR BLOCKY | GRANULAR | CRUMB |
|---|---|---|---|---|---|---|---|
| SKETCH |  | | | | | | |
| DESCRIPTION | tabular and horizontal to land surface | elongate with flat top and vertical to land surface | elongate with domed top and vertical to surface | equant with sharp interlocking edges | equant with dull interlocking edges | spheroidal with slightly interlocking edges | rounded and spheroidal but not interlocking |
| USUAL HORIZON | E,Bs,K,C | Bt | Bn | Bt | Bt | A | ...A |
| MAIN LIKELY CAUSES | initial disruption of relict bedding; accretion of cementing material | swelling and shrinking on wetting and drying | as for prismatic, but with greater erosion by percolating water, and greater swelling of clay | cracking around roots and burrows; swelling and shrinking on wetting and drying | as for angular blocky, but with more erosion and deposition of material in cracks | active bioturbation and coating of soil with films of clay, sesquioxides and organic matter | as for granular; including fecal pellets and relict soil clasts |
| SIZE CLASS | very thin < 1 mm | very fine < 1 cm | very fine < 1 cm | very fine < 0.5 cm | very fine < 0.5 cm | very fine < 1 mm | very fine < 1 mm |
| | thin 1 to 2 mm | fine 1 to 2 cm | fine 1 to 2 cm | fine 0.5 to 1 cm | fine 0.5 to 1 cm | fine 1 to 2 mm | fine 1 to 2 mm |
| | medium 2 to 5 mm | medium 2 to 5 cm | medium 2 to 5 cm | medium 1 to 2 cm | medium 1 to 2 cm | medium 2 to 5 mm | medium 2 to 5 mm |
| | thick 5 to 10 mm | coarse 5 to 10 cm | coarse 5 to 10 cm | coarse 2 to 5 cm | coarse 2 to 5 cm | coarse 5 to 10 mm | not found |
| | very thick > 10 mm | very coarse > 10 cm | very coarse > 10 cm | very coarse > 5 cm | very coarse > 5 cm | very coarse > 10 mm | not found |

Figure 42. Classification of soil peds (from Retallack, 1988).

level drops enough for streams to carve out new valleys. When sea-level begins to rise again, the incised valleys are infilled with sediment.

Marine-Flooding surfaces

"A marine-flooding surface is a surface that separates younger from older strata, across which there is evidence of an abrupt increase in water depth" (Van Wagoner et al., 1988, p. 39). The flooding event may cause submarine erosion, in which case the surface would represent a minor hiatus in deposition. The surface may be correlatable with a conformable surface in an adjacent area where deposition was not interrupted. A marine-flooding surface may be a sequence or a parasequence boundary. If the overlying strata onlap the surface, it is a sequence boundary. Otherwise, it bounds a parasequence within a sequence (Van Wagoner, 1988, p. 39). The flooding unit bounded below by the marine-flooding surface is referred to as the transgressive limestone by Heckel (1983).

Condensed sections

Condensed sections were defined by Loutit et al. (1988) as "thin marine stratigraphic units consisting of pelagic to hemipelagic sediments characterized by very low-sedimentation rates. They are areally most extensive at the time of maximum regional transgression of the shoreline" (Loutit et al., 1988, p. 186). The condensed section represents the maximum flooding surface which is used to bound GSUs. In the Kansas type cyclothem described by Heckel (1973), condensed sections lie within the core shale. The maximum flooding surface separates the transgressive from the highstand or forced regressive systems tract (Van Wagoner et al., 1988).

Evidence of a marine condensed section (listed by Watney et al., 1989) includes (1) high concentration and diversity of conodonts (the maximum flooding surface is represented by maximum number and diversity of conodonts (Seddon and Sweet, 1971; Heckel and Baesemann, 1973), (2) high concentration of phosphate, glauconite, and radioactive elements, and (3) high fissility due to horizontal orientation of clay minerals composing the shale.

Seddon and Sweet (1971) presented an ecologic model for conodonts of the Ordovician eastern North America and Devonian in Western Australia. They viewed conodonts as "small planktonic organisms" and that each conodont species preferred a water depth to live in (Seddon and Sweet, 1971, p. 879). Figures 43 and 44 illustrate Seddon and Sweet's model in both areas. Heckel and Baesemann (1973) adapted the Seddon and Sweet (1971) model to Upper Pennsylvanian (Missourian) megacyclothems. Heckel and Baesemann (1973) interpreted depositional environments of megacyclothem units based on conodont distribution patterns. The surface of maximum conodont abundance (over 100 conodonts per kilogram sampled) and diversity (over four genera per kilogram sampled) lied within the core shale of the megacyclothem (Heckel and Baesemann, 1973). This is called the maximum flooding surface in sequence-stratigraphic terminology.

Most of the core shales of the Kansas type cyclothems are black, fissile shales. There has been a long debate on whether the black shales of the Pennsylvanian were deposited in a shallow or a deep water environment. Weller (1956) thought the black shales of the Pennsylvanian were deposited in shallow waters with restricted circulation. Schenk (1967) and Heckel (1977) interpreted black shales of Upper Pennsylvanian Kansas type cyclothems to be deeper, offshore deposits. Coveney, et al. (1991) explained that not all Pennsylvanian black shales were deposited offshore and that the authors were able to determine the depositional environments of black shales based on molybdenum abundances.

Schenk (1967) explained that an upwelling process in the Midcontinental epeiric sea produced the concentrations of phosphate and phosphate nodules in the Lake Neosho Shale Member of the Amoret Limestone. He lists the depths at which phosphate precipitates to be between 50 and 200 meters. The phosphate was transported upward to the surface water from the eastward traveling bottom currents. At the surface,

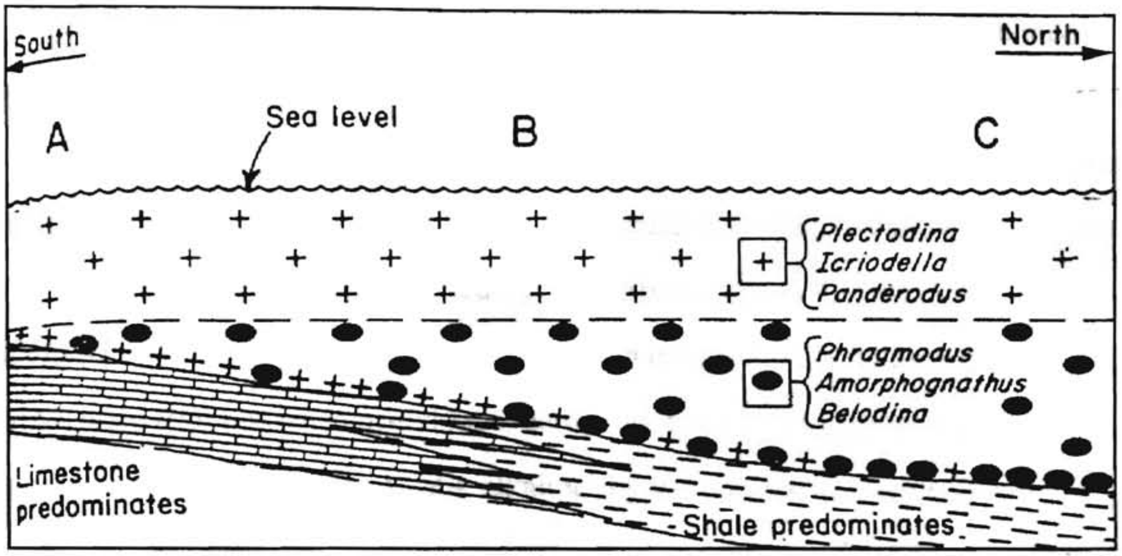


Figure 43. Vertical stratification of Ordovician conodonts in eastern North America (from Seddon and Sweet, 1971).

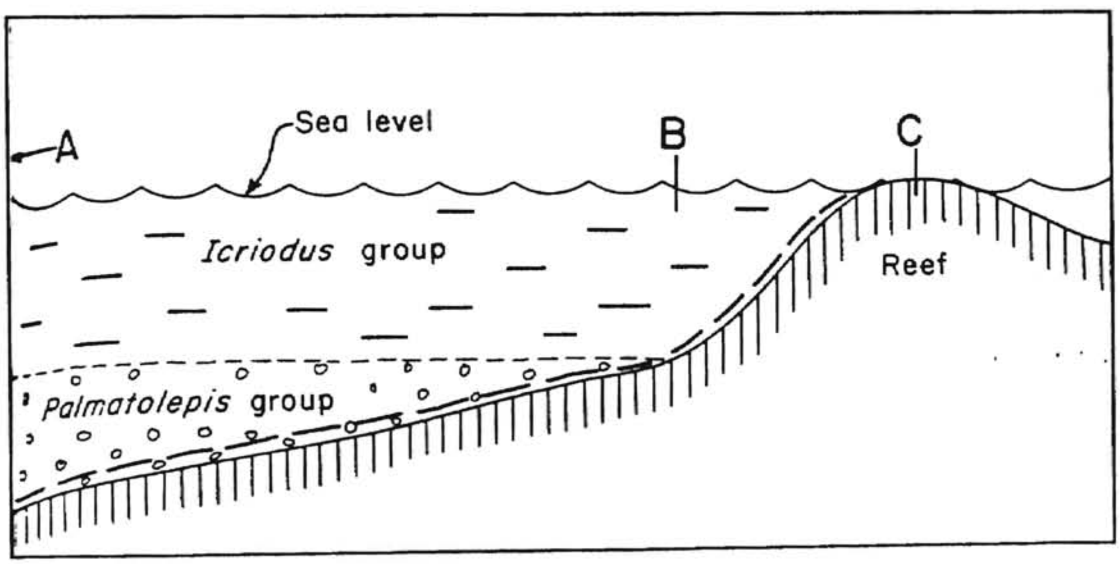


Figure 44. Vertical stratification of Late Devonian conodonts in Western Australia (from Seddon and Sweet, 1971).

it allowed organic activity to flourish. Dead organic material floated to the bottom where it became phosphatized. Deposition was extremely slow (Schenk, 1967).

Phosphate nodules formed around nuclei, including fish teeth, and phosphatized wood and molluscs. "That the pebbles are a product of the black-shale environment is indicated by faunal content, associated pyrite, carbon content, bituminous odor, and strict lithologic control. Slickensides, polish, and compaction bedding suggest that the pebbles were firm before compaction. The environment of formation was marine but reducing, probably neutral to slightly alkaline (by the presence of pyrite and absence of calcite), and "deeper than wavebase" (fissility of black shale). The pebble horizon is continuous along 740 km of outcrop and is little affected by tectonic features" (Schenk, 1967, p. 1379).

"The black-shale, phosphorite interval of the Lake Neosho Shale marks maximum transgression of the Altamont megacyclothem over the traverse line. This interval is unaffected by the small-scaled tectonic features which strongly modify shallow-water carbonates. The unit is bordered above and below by successively shallower water lithofacies and biofacies, terminating with continental deltaic deposits....Algae are concentrated at the bottom and top of the Amoret and Worland Limestones, respectively, perhaps reflecting shallow, brackish, or hypersaline water. The fauna of the black shale is marine with restricted and very tolerant forms; in addition, there are nektonic (fish teach and cephalopods) and planktonic (wood) remains" (Schenk, 1967, p. 1380).

Swade (1982) studied two Upper Desmoinesian (Cherokee Group through Marmaton Group) cores from south central Iowa and documented the vertical sequence of conodonts and lithotopes. Swade's thesis provided valuable conodont information needed in the interpretation of times of maximum transgression. He applied Heckel's (1980) eustatic model to the Upper Desmoinesian cyclothems to recognize the phases of deposition within each (Swade, 1982).

Based on lithologic and paleontologic evidence, Heckel (1977) developed a depositional model (similar to Schenk's model for the Altamont Limestone) for the Kansas type Pennsylvanian cyclothem to explain the presence of black fissile core shales. The area which is now the North American Midcontinent was located within the trade-wind path and north of the paleoequator (which was along the Appalachians). This position helped establish "large-scale quasi-estuarine circulation" (Heckel, 1977, p. 1055) in the epeiric sea over the Midcontinent, eventually starting an upwelling process. This upwelling cycle caused the deoxygenation of the sea bottom during times of maximum transgression. The trade-winds pulled the "cold, deep, oxygen-poor, phosphate-rich water from the western ocean...along the bottom through the basins of West Texas" upwards to "the eastern Mid-Continent" so that it caused the surface water to be displaced westward with the westward moving winds. This circulation pattern increased organic matter production at the water surface. As the high amount of organic matter was carried westward with the surface water, it settled to the bottom of the sea. When it reached the bottom, it was carried eastward with the bottom current. Along the sea bottom surface, it decayed, prevented oxygenation, and increased phosphate amounts. Figure 45 illustrates Heckel's version of the upwelling theory.

"This model for offshore phosphatic black shale deposition obviates the difficulty of explaining in shallow tropical water the combination of nonskeletal phosphorite production, and widespread lateral uniformity of a quiet anoxic environment between two marine limestones. It supports large-scale Pennsylvanian transgressions and regressions in the Mid-Continent sea, but remains compatible with the local cyclic sedimentary process of delta outbuilding and abandonment along the shoreline. In face, large-scale marine transgressions and regressions account for the widespread distribution of delta-shoreline deposits from the Appalachians to Kansas. The offshore black shale model can be expanded to a more general depositional model than not only explains the lateral variation in black-shale-bearing Pennsylvanian cyclothems by suggesting that water depths at maximum transgression during that time were generally too shallow to

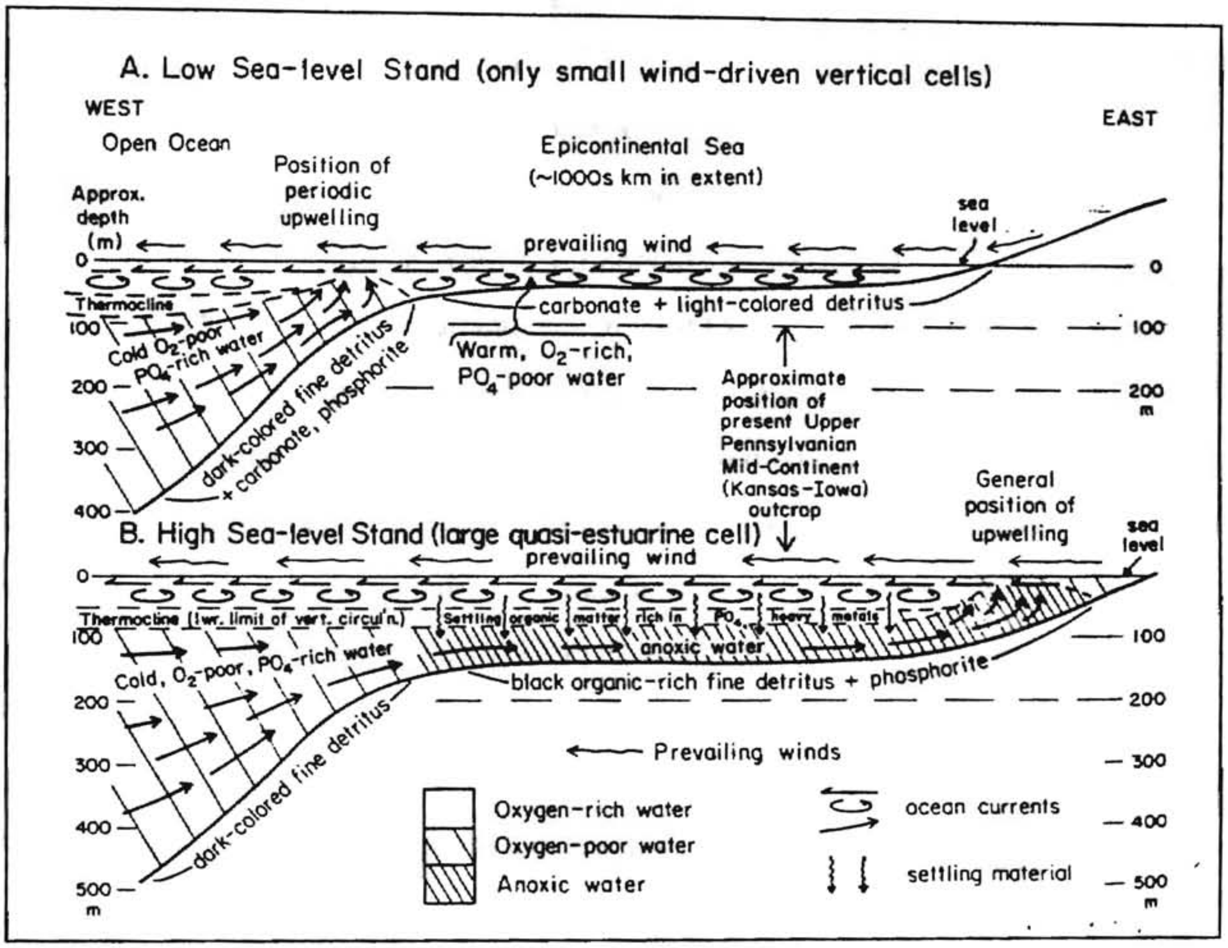


Figure 45. Vertical circulation patterns of upwelling process (from Heckel, 1977).

establish an effective thermocline" (Heckel, 1977, p. 1045).

When Evans (1966) studied the Heebner Shale of the Oread Formation (Shawnee Group, Virgilian Stage, Pennsylvanian System), he concluded that it was deposited in "quiet and unoxygenated conditions required for the formation of the organic-rich middle unit of the Heebner Shale were attained below wave base, in considerably deeper water, and that the black shale represents accumulation in the central part of the depositional basin rather than at its periphery" (Evans, 1966, p. 120-121). Evans' evidence included the "well established southward decline in organic content, oil yield ratio and uranium content, as well as the physical thinning of the black shale itself, appear to be associated with increasing nearness to a land area. Of particular importance is the reduction in oil yield ratio, which most likely reflects variation in the chemical composition of the preserved organic material. Such a compositional difference may be related to an increasing influx of terrestrially derived plant material or to partial and preferential oxidation of the parent organic substances as a result of increasing shallowness of the sea. Although the latter explanation seems more probable, both theories support a basinal origin for the black shale. Even more conclusive in this regard is the occurrence, between the southern terminus of the black shale unit and continental equivalents to the south, of light colored calcareous shales that contain a rather diverse marine fauna. Evidence of more normal marine conditions between the area of pronounced restriction and a known terrestrial environment certainly does not favour a paludal origin" (Evans, 1966, p. 121).

Evans ruled out the possibility of a swampy, shallow water depositional environment for the Heebner. His evidence included the fact that the organic matter necessary for the formation of the Heebner would have come from vegetation. Since there was no evidence of disruptive root systems in the Heebner, he ruled out the swamp environment. He also noted that for the black shale to have been deposited in a shallow marine environment, sea-level would have had to drop relative to the level during Leavenworth deposition. Since he found no evidence of Leavenworth erosion, even in the "updip extremities" of the outcrops, he ruled out a regression and shallow environment. "The Leavenworth Limestone, Heebner Shale and Plattsmouth Limestone were deposited during a single major advance and retreat of the sea, with no significant regression following the deposition of the Leavenworth Member" (Evans, 1966, p. 126). Evans constructed a diagram (Figure 46) to illustrate his interpretation of facies relationships in southern Kansas and northern Oklahoma.

Coveney, et al. (1991) described the presence of two types of marine black shales in Pennsylvanian strata; one deposited in a nearshore environment and one in an offshore environment. They documented nearshore black shales in the Desmoinesian strata only. Offshore black shales are found throughout the Pennsylvanian cyclothems.

Coveney, et al. (1991) asserted that nearshore black shales were deposited in an "acidic peat bog" environment where the slightly acidic waters promoted the oxidation of sulfides to produce "organic acids or $H_2SO_4$ (Coveney et al., 1991, p. 149). This in turn allowed the "fixation of Mo, Se, and V by organic debris" (Coveney et al., 1991, p. 149). The authors documented molybdenum amounts of more than 1000 ppm in the Desmoinesian nearshore black shales. However, the offshore black shales deposited westward of the nearshore black shales, lacked these concentrations of molybdenum.

Coveney, et al. (1991) disagree with Heckel's upwelling model to explain the presence of the phosphatic black shales of the Pennsylvanian. They agreed with Parrish (1982) who wrote that the landlocked nature of the Midcontinent epeiric seas would have prohibited the upwelling process. Instead, they agree with Schlinsog and Angino (1983) who noted that "terrestrial plants would have been a prolific source of organic matter and phosphorus for Pennsylvanian seas" (Coveney et al., 1991, p. 148). "However, because of acidic conditions in pore fluids, phosphate was not retained in the nearshore environment, but was flushed seaward to be...offshore, mainly during diagenesis, along with phosphate resulting from the extreme productivity in estuarine environ-

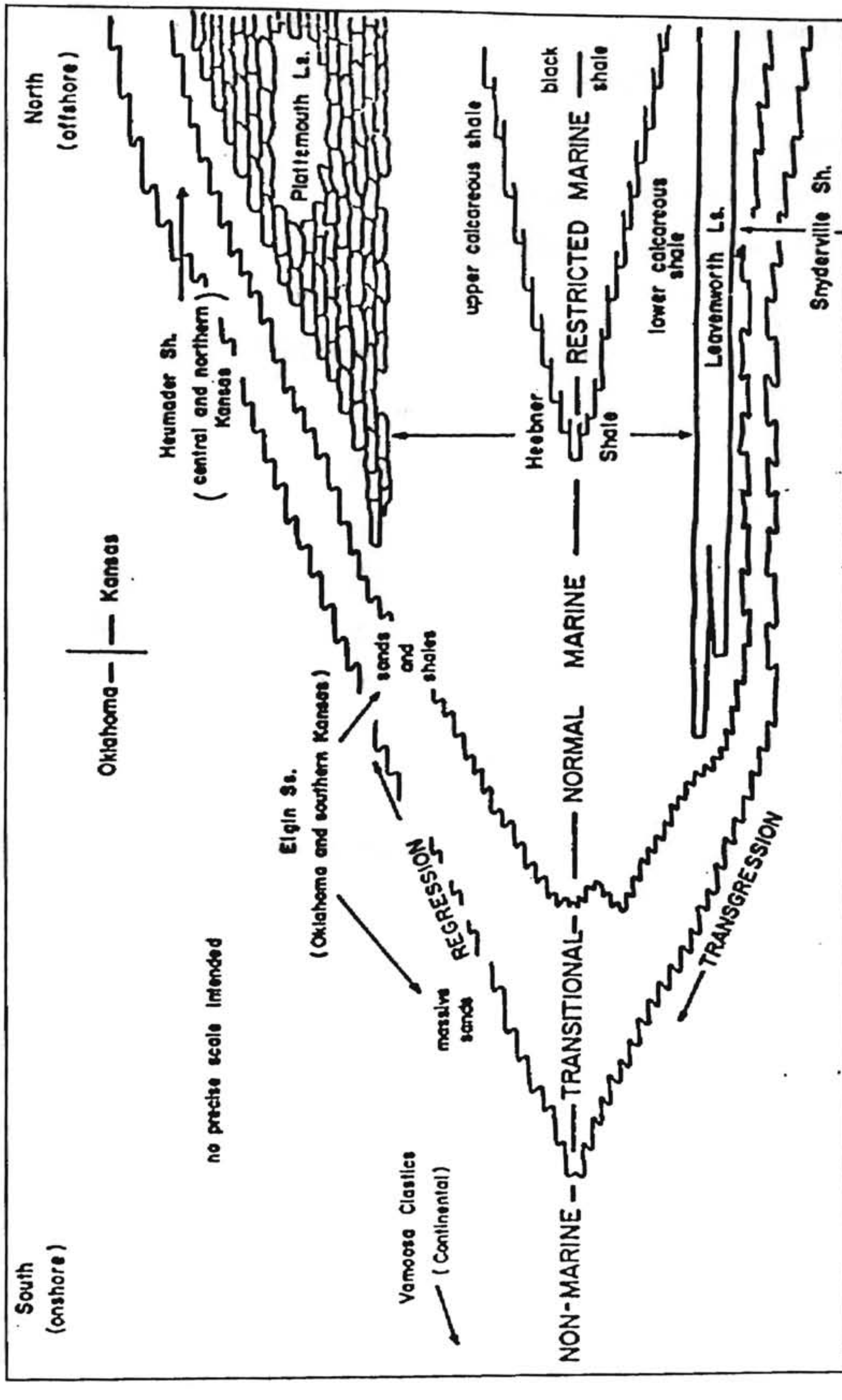


Figure 46. Evans' (1966) interpreted facies relationships in southern Kansas and northern Oklahoma.

ments. (e.g., Pevear, 1966). Thus the formation of phosphatic Pennsylvanian black shales was probably independent of upwelling bottom waters" (Coveney, et al., p. 148).

According to Watney et al. (1995), the Middle Pennsylvanian nearshore black shales were deposited rapidly "over a relatively short term...in the Illinois and Appalachian basins" (Watney et al., 1995, p. 150). These nearshore shales correlate with the offshore shales further west.

Watney et al. (1995) interpreted the Pennsylvanian black shales to be condensed sections. They noted the presence of "conodonts, ammonids (from the southern exposures), and dissociated fish debris, suggesting very slow sediment accumulation rates. Minor elements such as uranium and various other metals are also abundant in the black shales along with phosphate. Nonskeletal phosphate (apatite) is common as nodules and laminae in black shales. Abundant and diverse radiolarians, nautiloids, and fish debris have been found in the nodules in black shales in eastern Kansas (Kidder, 1985). The source of the phosphate could be planktonic organisms, fecal material, or perhaps solution and suspension from river water. Heckel (1977, 1994) proposed that the water column in which black shale accumulated contained a thermocline leading to quasi-estuarine circulation and upwelling, which accounts for the conspicuous phosphate. Water depths would necessarily be deep to accommodate formation of a long-term, stable thermocline" (Watney et al., 1995, p. 151).

Watney et al. (1995) concluded that black shales are condensed sections, containing the maximum flooding surface of the cyclothem. They noted that the water depths during maximum flooding periods "exceeded the total thickness of the cyclothem" (Watney et al., 1995, p. 151). Black shales contain abundant conodonts and fish debris but "generally lack benthic marine invertebrates" (Watney et al., 1995, p. 151). "Uranium concentrations in black shales range from <20 ppm to more than 250 ppm, accounting for most of the high natural gamma radiation emitted by black shales. Greatly reduced sedimentation rates are suggested by (1) commonly abundant phosphate, (2) high concentrations of normally sparse pelagic fossils, (3) horizontal orientation of clay minerals composing the shale (suggesting dilute suspension sedimentation; James, 1970), and (4) elevated concentrations of minor elements such as uranium" (Watney et al., 1995, p. 151).

Boardman et al. (1984) proposed a model relating dissolved oxygen to faunal communities of the Mic-Continent Pennsylvanian cyclothems (Boardman et al., 1984, p. 170). Oxygen declines at depth. Within the oxygen minimum zone, organic matter may slowly accumulate. Black shales often change to green or gray shale as they become more distant from the basin where they are deposited in environments with more oxygen.

Carter et al. (1986) presented an episodic transgressive model. They asserted that "the post-glacial transgressions in the SW Pacific was episodic in nature, with the shoreline migrating in a series of steps from its lowstand position at 20-18,000 yr BP until it started to stabilize about its modern level at about 6,500 yr BP" (Carter et al., 1986, p. 645).

Maximum flooding surfaces within black shales are recognized in the subsurface by hot streaks on gamma-ray-logs. Black shales containing condensed sections and phosphate also contain radioactive elements which cause the off-scale gamma-ray-log readings. Another usefulness of these black shales is their lateral extent. They extend further distances than other cyclothem units.

## V.

## SURFACE STUDY

The author chose thirteen surface exposures from Parsons, Kansas to Tulsa, Oklahoma, to study the Marmaton Group. The formations studied are the Labette Shale (upper part), Pawnee Limestone, Bandera Shale, Altamont Limestone, Nowata Shale, and Lenapah Limestone (lower part). Appendix A contains a list of these locations, each identified by a number one through 13, from north to south. Figure 47 shows the units

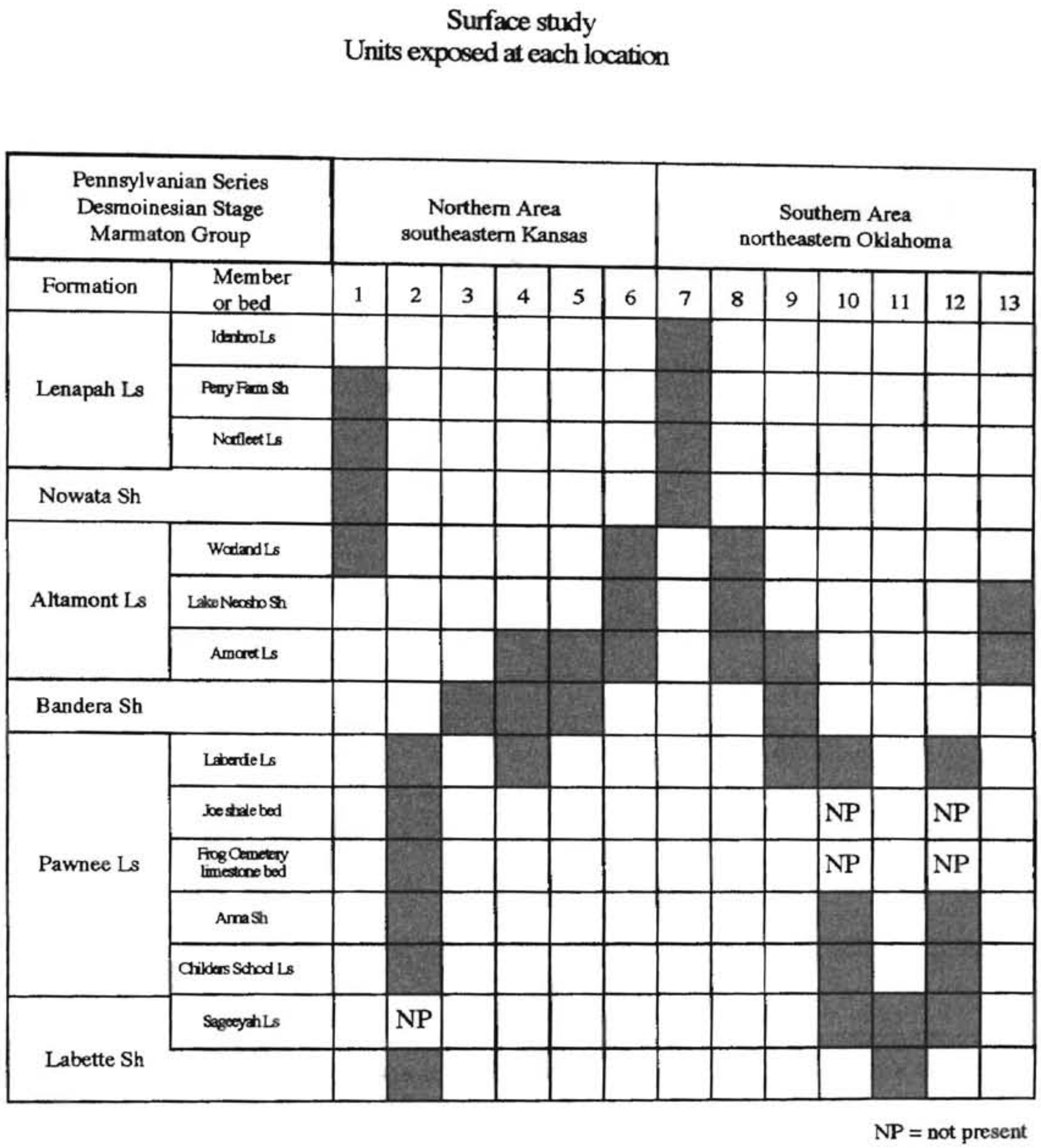


Figure 47. The units exposed at each of the 13 surface study locations are indicated. The location numbers correspond with the numbers in Appendix A.

exposed at each location, identified by the numbers corresponding to the list in Appendix A. After a discussion of the data collected and observations made at each location, interpretations will be presented. The discussion of the data includes a descriptive measured section for each location and photographs (when needed) of outcrops and thin-sections. Measured sections include thin-section sample numbers and descriptions based on these thin-sections and field observations. Interpretations of the data are based on the author's observations and previous works discussed in Chapters III and IV. Interpretations include systems tracts and a sea-level curve for each measured section. Figure 48 provides a key to the symbols presented with the measured sections in this chapter.

## Data

Location 1, Parsons Quarry

This quarry is located south of Parsons, on the west side of Highway 59, at NE, NW, Sec. 36, T. 31 S., R. 19 E., Labette County, Kansas. The Worland Limestone Member, Nowata Shale, Norfleet Limestone Member, and Perry Farm Shale Member (in ascending order) are exposed at this section. The location map is shown in Figure 49. Figure 50 is the Parsons Quarry measured section, including unit descriptions and thin-section sample numbers. The author measured a total thickness of 7 feet 8 inches (2.34 meters) from the base of the uppermost Worland bed to about the middle of the Perry Farm Shale. Figure 51 is a photograph of the section, showing the variable thickness of the Nowata Shale.

The Worland Limestone is at least 10 feet thick here. See Figure 52. The author includes only the top bed of the Worland in this study (unit 1) which is a light to medium gray fossiliferous oolitic grainstone. It weathers light tan to light gray and contains echinoderms and other fossil fragments. There is evidence of algal micritization. It has been cemented with sparry calcite. The ooids contain baroque dolomite. Figure 53 is a photograph of thin-section sample PQ1 from the Worland Limestone. The contact

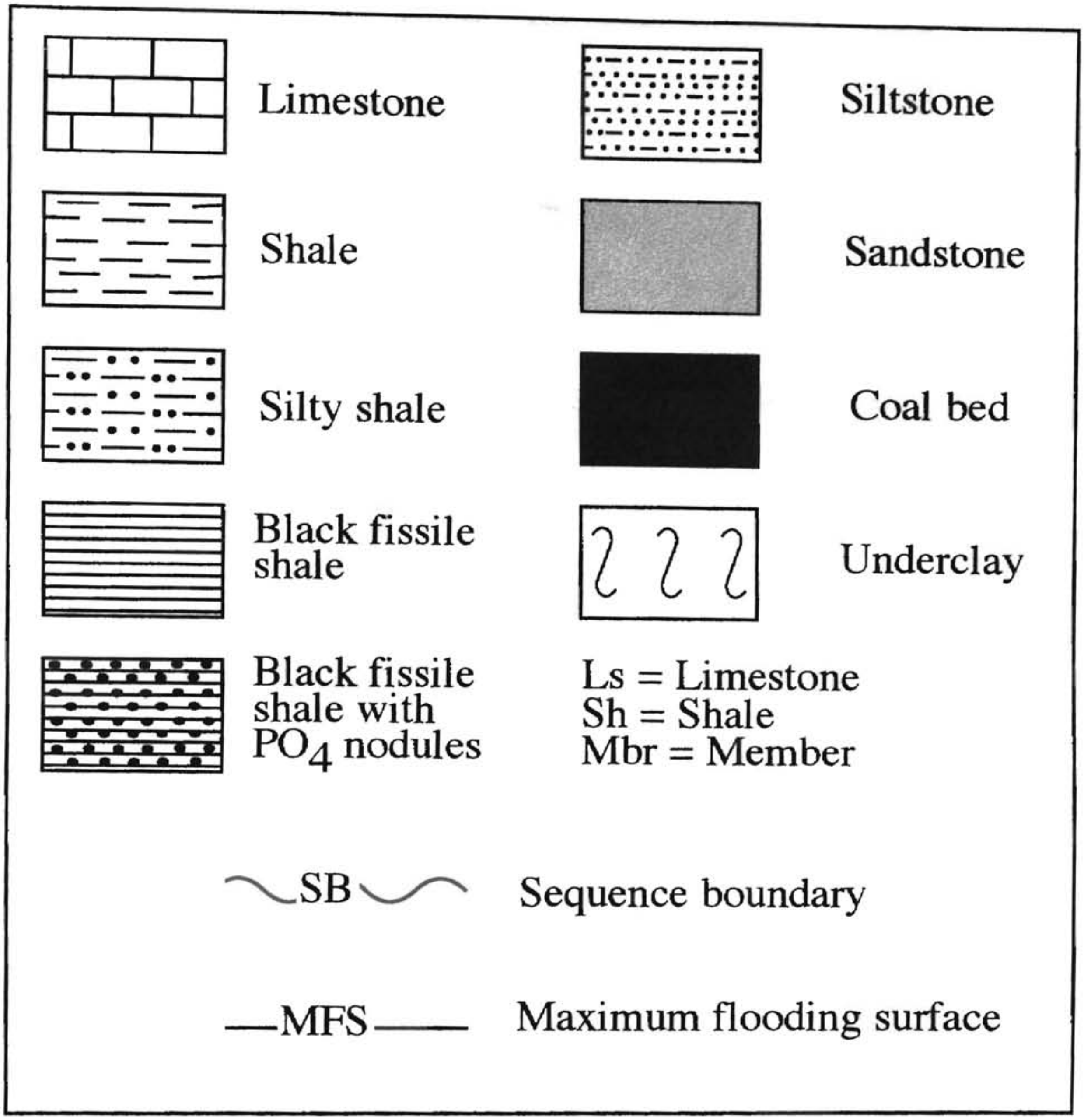


Figure 48. Key to symbols and abbreviations in measured sections of surface study.

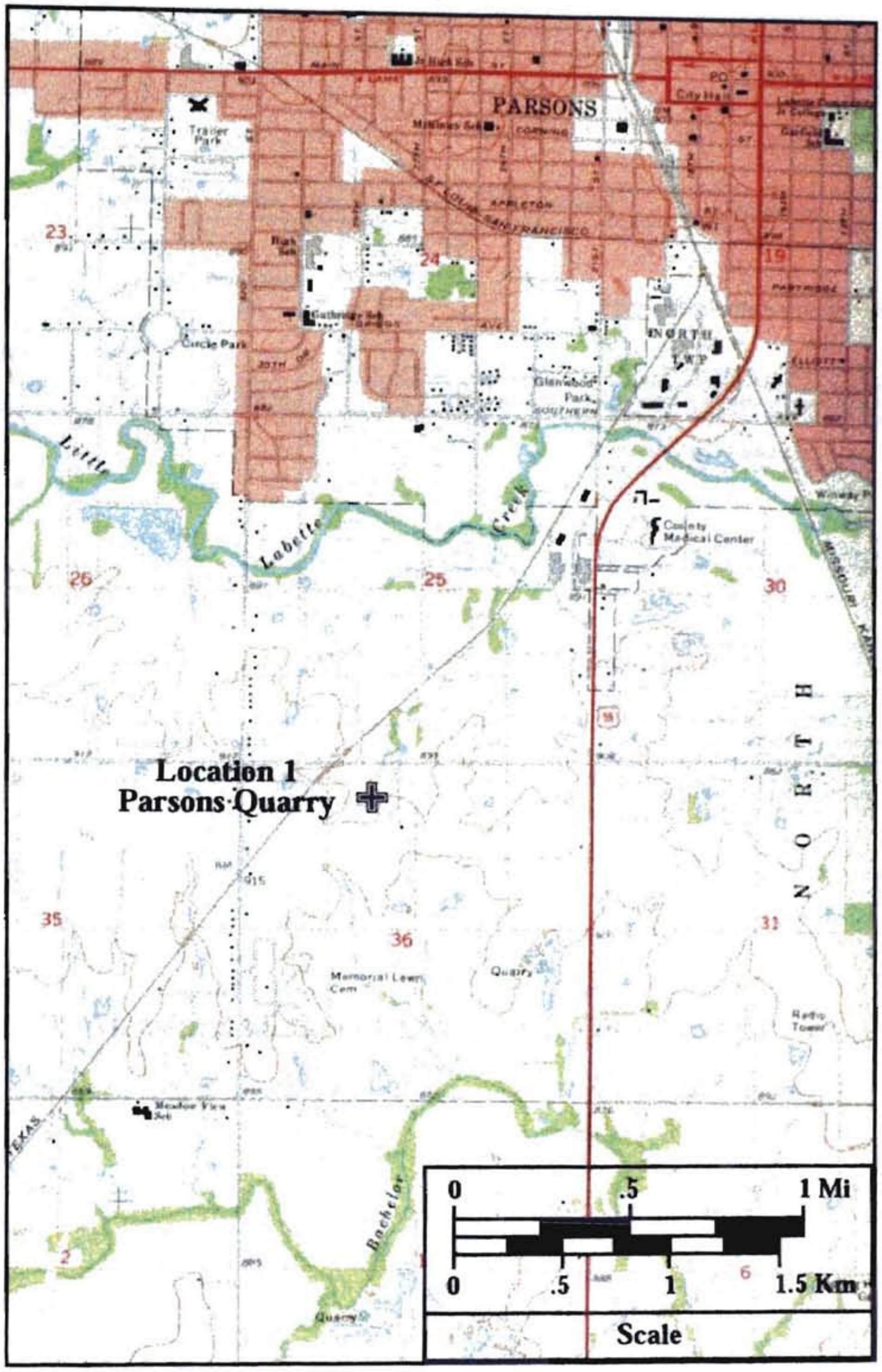


Figure 49. Location 1, Parsons Quarry, at NE, NW, Sec. 36, T. 31 S., R. 19 E., on the west side of Highway 59, south of Parsons, Labette County, Kansas.

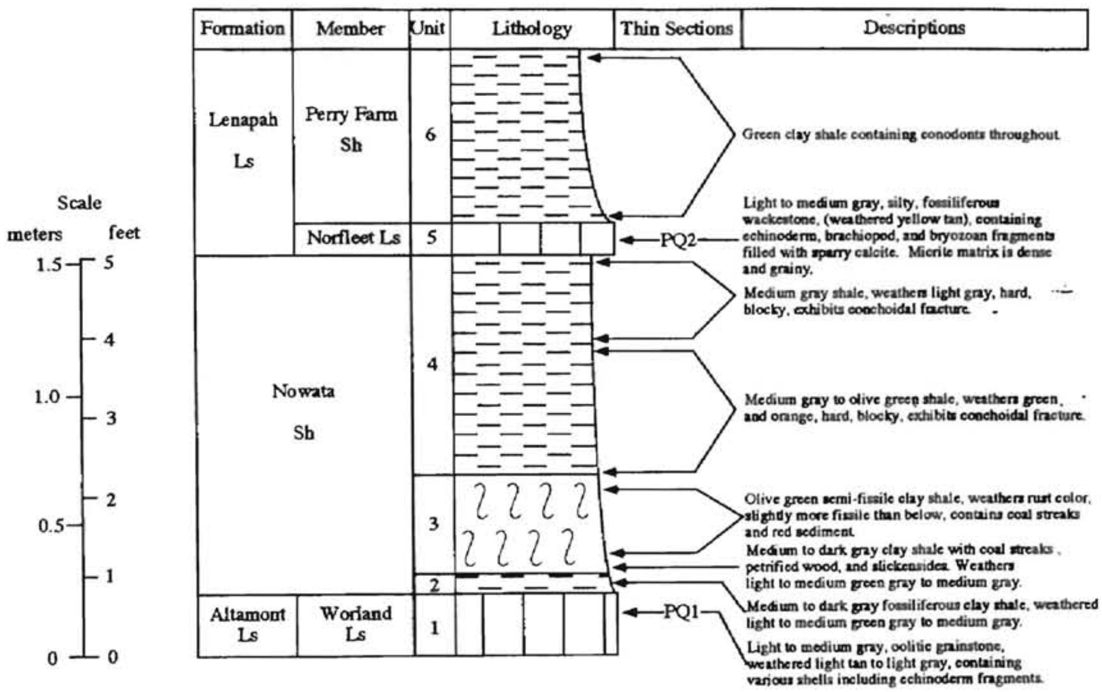


Figure 50. Measured section of Location 1, Parsons Quarry at NE, NW, Sec. 36, T. 31 S., R. 19 E., Labette County, Kansas.

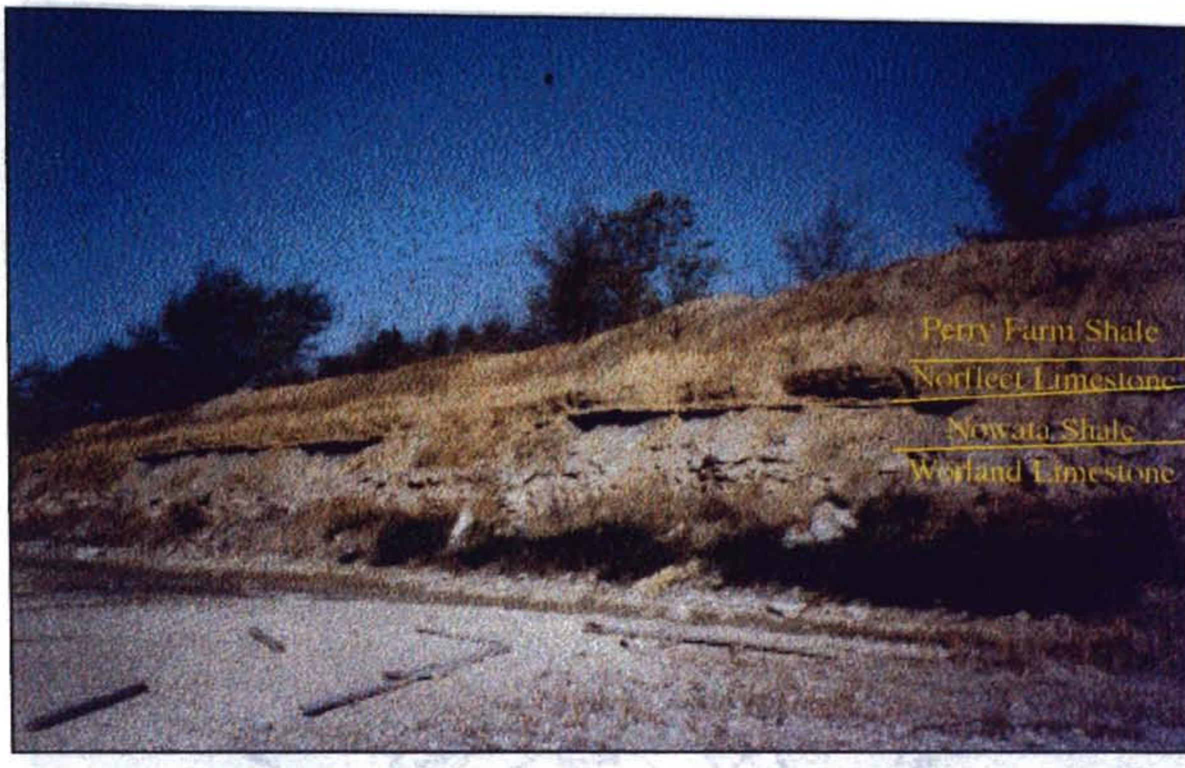


Figure 51. Photograph of Location 1, Parsons Quarry.

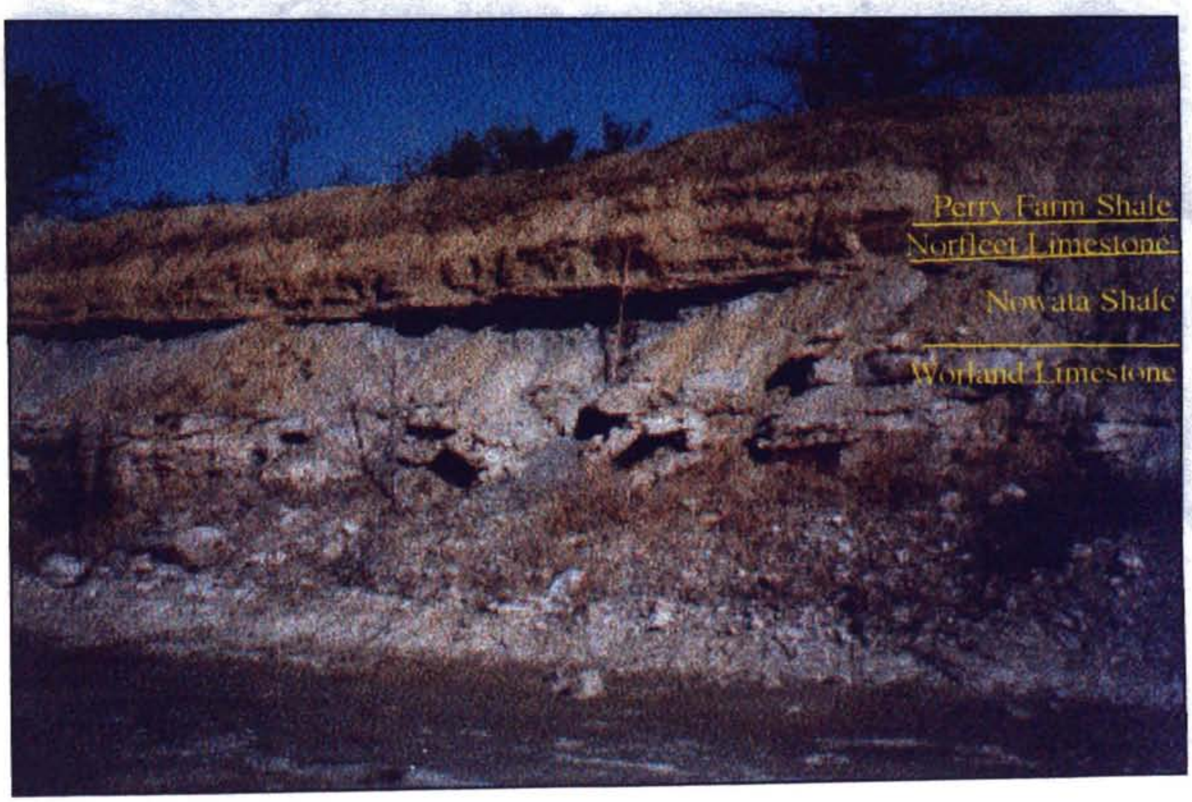


Figure 52. Photograph of Location 1, Parsons Quarry.

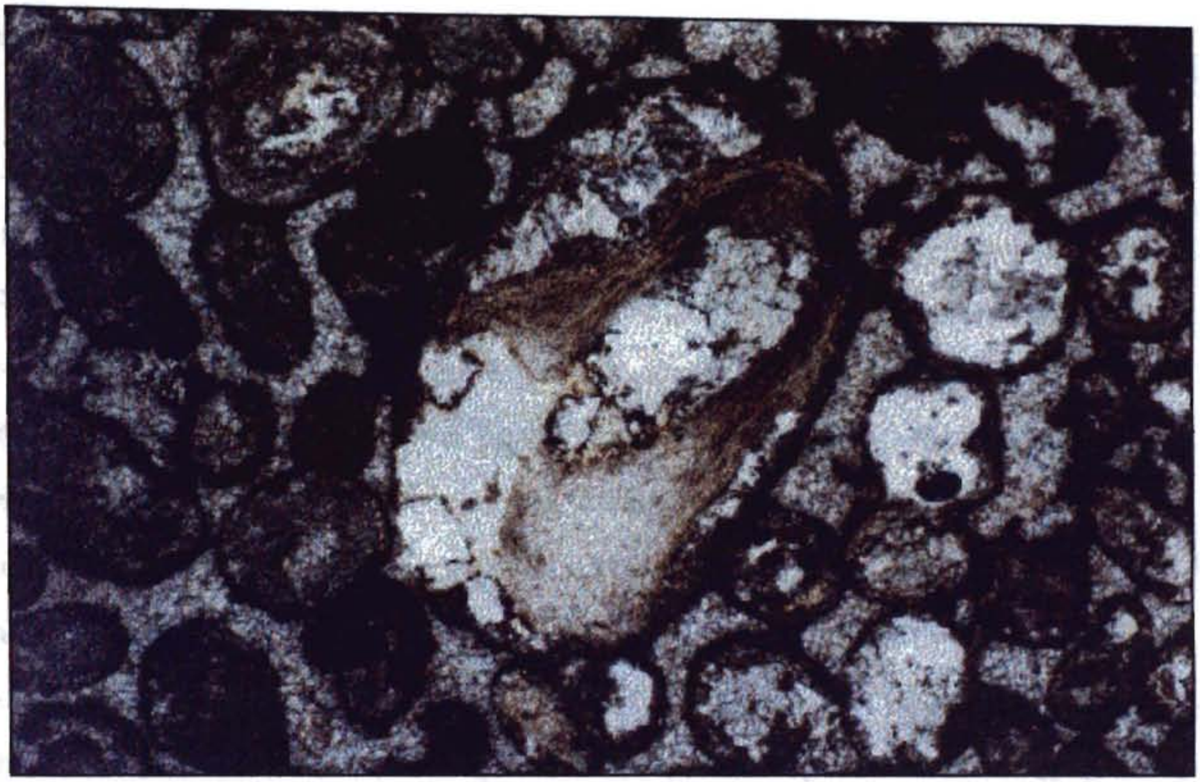

Figure 53. Thin section sample PQ1 (top of Worland), oolitic grainstone. Ooids are filled with baroque dolomite.

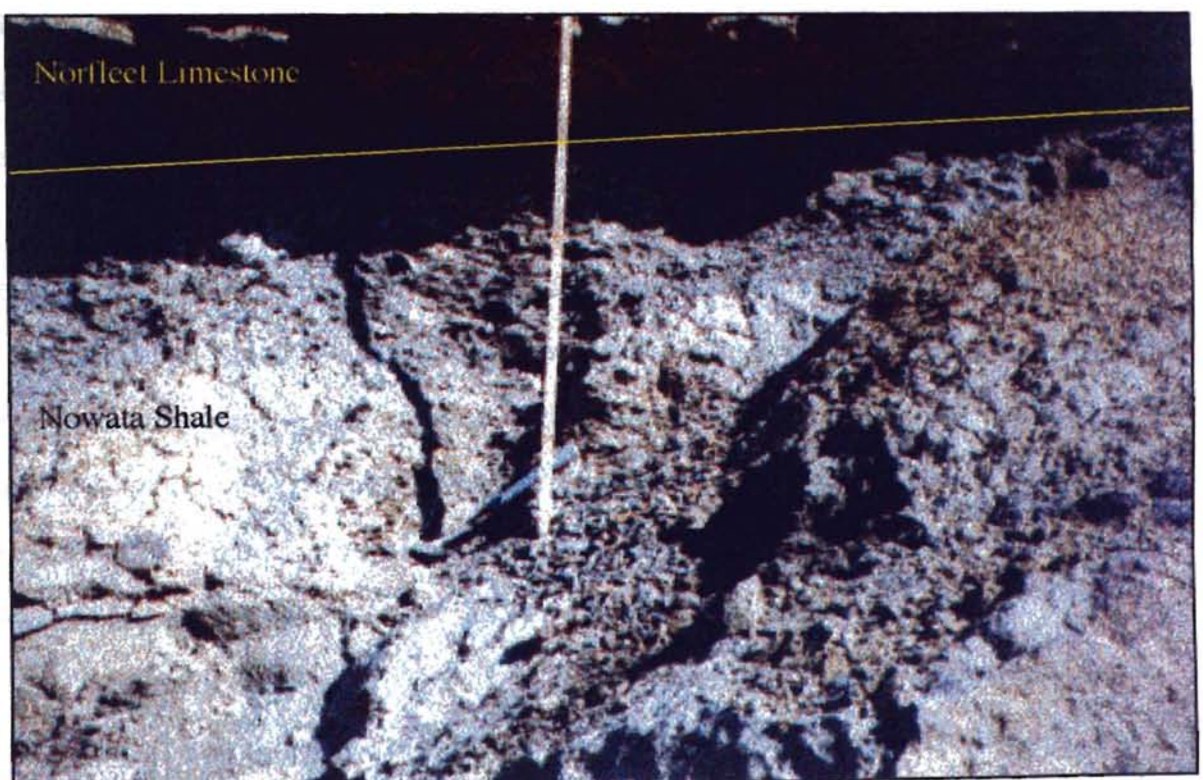


Figure 54. Close-up photograph of Nowata Shale at Location 1, Parsons Quarry.

between the Worland Limestone and the overlying Nowata Shale is sharp but irregular.

The Nowata Shale at this location varies laterally from two to four feet (.61 to 1.22 meters) thick. The author measured 3 feet 9 inches (1.14 meters) where data was collected. Figure 54 is a close-up photograph of the Nowata Shale. The lower 3 inches (7.6 centimeters) of the Nowata, Unit 2, is a medium to dark gray fossiliferous shale which weathers light to medium green gray. Three to 5 inches (7.6 to 12.7 centimeters) above the Nowata base is the lower part of Unit 3, an olive green, semi-fissile clay shale that weathers to a rust color. Coal streaks, slickensides, and petrified wood were found in this interval. Five to 18 inches (12.7 to 45.8 centimeters) above the Nowata base is the upper part of Unit 3, an olive green semi-fissile clay shale which weathers rust. No coal streaks were found in this interval. Eighteen to 30 inches (45.8 to 76.2 centimeters) above the Nowata base is the lower part of Unit 4, an olive green to medium gray, hard, blocky shale which weathers green and orange. The interval 30 to 45 inches (76.2 to 114 centimeters) above the Nowata base is the upper part of Unit 4, a medium gray, hard, blocky shale which weathers light to medium olive gray. The contact here between the Nowata Shale and the overlying Norfleet Limestone is sharp and straight.

The Norfleet Limestone (Unit 5) is 3.5 to 5 inches (8.9 to 12.7 centimeters) thick here. It is a light to medium gray, silty, fossiliferous wackestone, weathered yellow tan. It is a carbonate which has altered to a clay. It contains echinoderm fragments, brachiopod shells and spines, and bryozoans. Fossil shells are filled with sparry calcite (blocky) and dolomite rhombs. The matrix is mosaic sparry calcite. Sample PQ2 was taken from the Norfleet for thin-section analysis (Figure 55). The contact between the Norfleet Limestone and the overlying Perry Farm Shale is sharp and straight.

The Perry Farm Shale (Unit 6) is at least 2 feet (.61 meters) thick here. It is a green, semi-fissile clay shale containing conodonts and other fossils throughout.

Location 2, Labette SW

This locality was first studied and referred to as "Labette SW" by Price (1981).

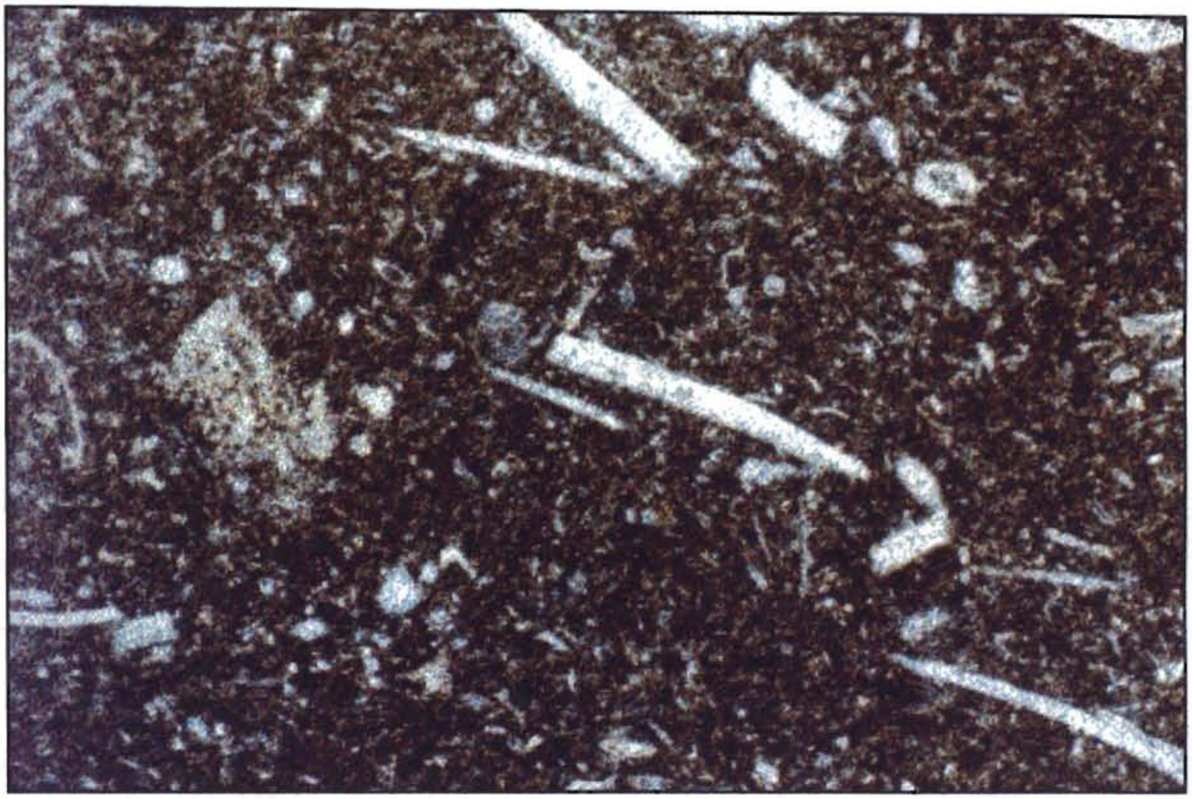

Figure 55. Thin section of Norfleet Limestone (sample PQ2) at Location 1 showing a silty, fossiliferous wackestone containing echinoderm, brachiopod, and bryozoan fragments filled with sparry calcite.

The roadcut near a creek at the center of W. line, NW, Sec. 3, T. 33 S., R. 20 E., Labette County, Kansas exposes the following units in ascending order: the upper part of the Labette Shale, Childers School Limestone Member, Anna Shale Member, Frog Cemetery limestone bed, Joe shale bed, and the lower few beds of the Laberdie Limestone Member. Figure 56 is the location map for this exposure. Figure 57 is the measured section for Location 2, including unit descriptions and thin-section sample numbers. This is the only exposure in this study which contains the Frog Cemetery limestone bed and the Joe shale bed. The outcrop varies laterally, making it difficult to get a good photo of the outcrop as a whole. The author measured a total thickness of 17 feet 2 inches (5.24 meters).

Here, the Labette Shale is 9.5 feet (2.9 meters) thick, most of which is green-brown silty shale (Unit 1). Unit 2 is a two inch (5.08 centimeter) thick underclay, lying eight to 10 inches (20.3 to 25.4 centimeters) below the top of the Labette. Overlying the underclay, five to eight inches (12.7 to 20.3 centimeters) below the top of the Labette, is a three inch (7.6 centimeter) thick bed of coal. The photograph in Figure 58 shows this coal bed just above the head of the rock hammer. The upper five inches (12.7 centimeters) of the Labette is a green clay shale. The contact between the Labette Shale and the overlying Childers School Limestone is sharp and straight.

Since the Childers School is lenticular here, it is difficult to see without looking at the entire exposure laterally. The Childers School (Unit 5) is a one to two inch (2.54 to 5.08 centimeter) thick, lenticular, dark gray, fossiliferous wackestone which weathers medium orange tan. It contains pyritized gastropods and other fossil shell fragments filled with sparry calcite (blocky and drusy) in a micrite matrix. Figure 59 is a photograph of thin-section sample LSW1 (Childers School). The contact between the Childers School Limestone and the overlying Anna Shale is sharp and straight.

The Anna Shale lies above the Childers School Limestone. It is 28 inches (71.2 centimeters) thick and contains five units based on lithology. The lower 12 inches (30.5

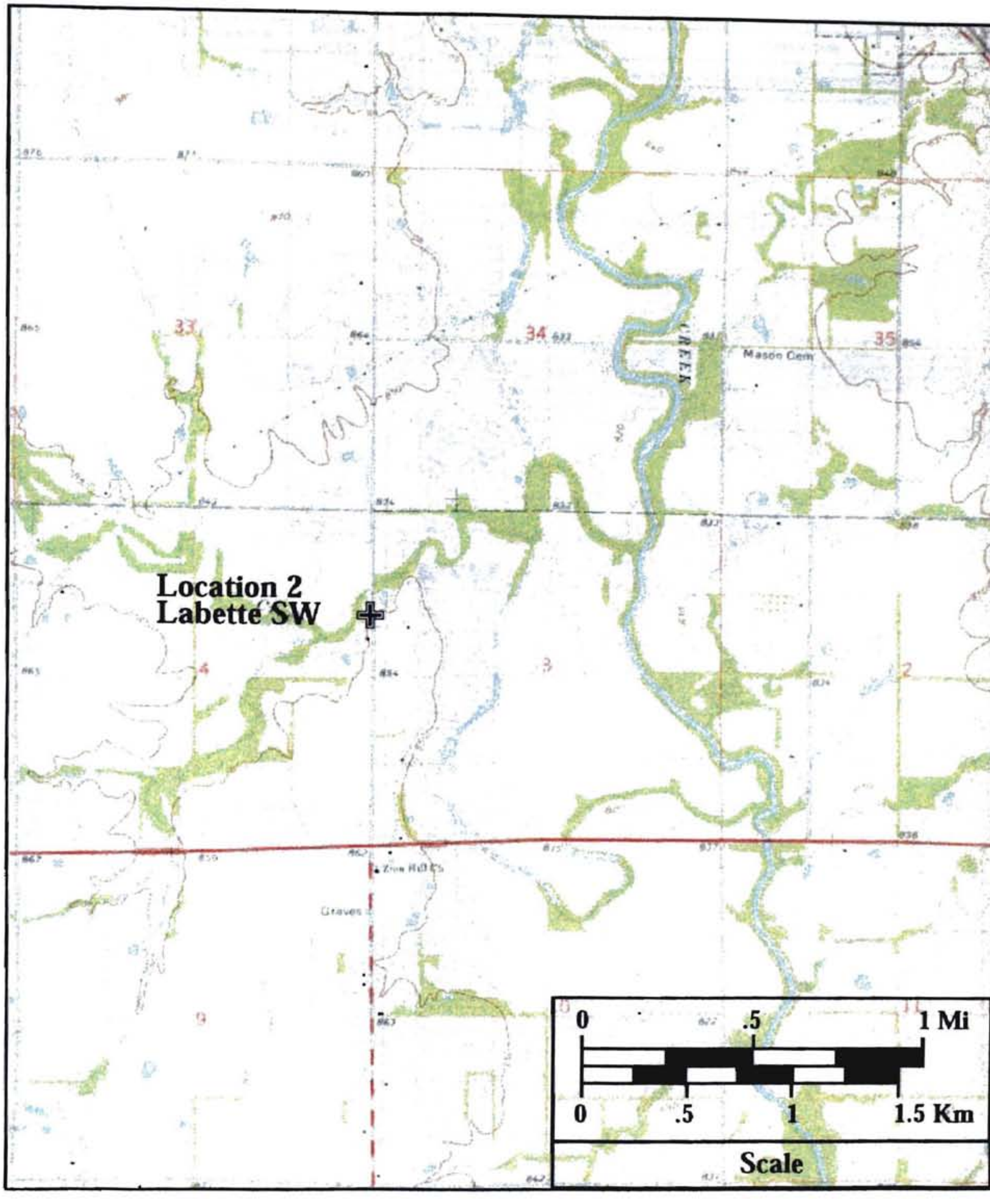


Figure 56. Map showing Location 2, Labette SW, center of W. line, NW, Sec. 3, T. 33 S., R. 20 E., Labette County, Kansas.

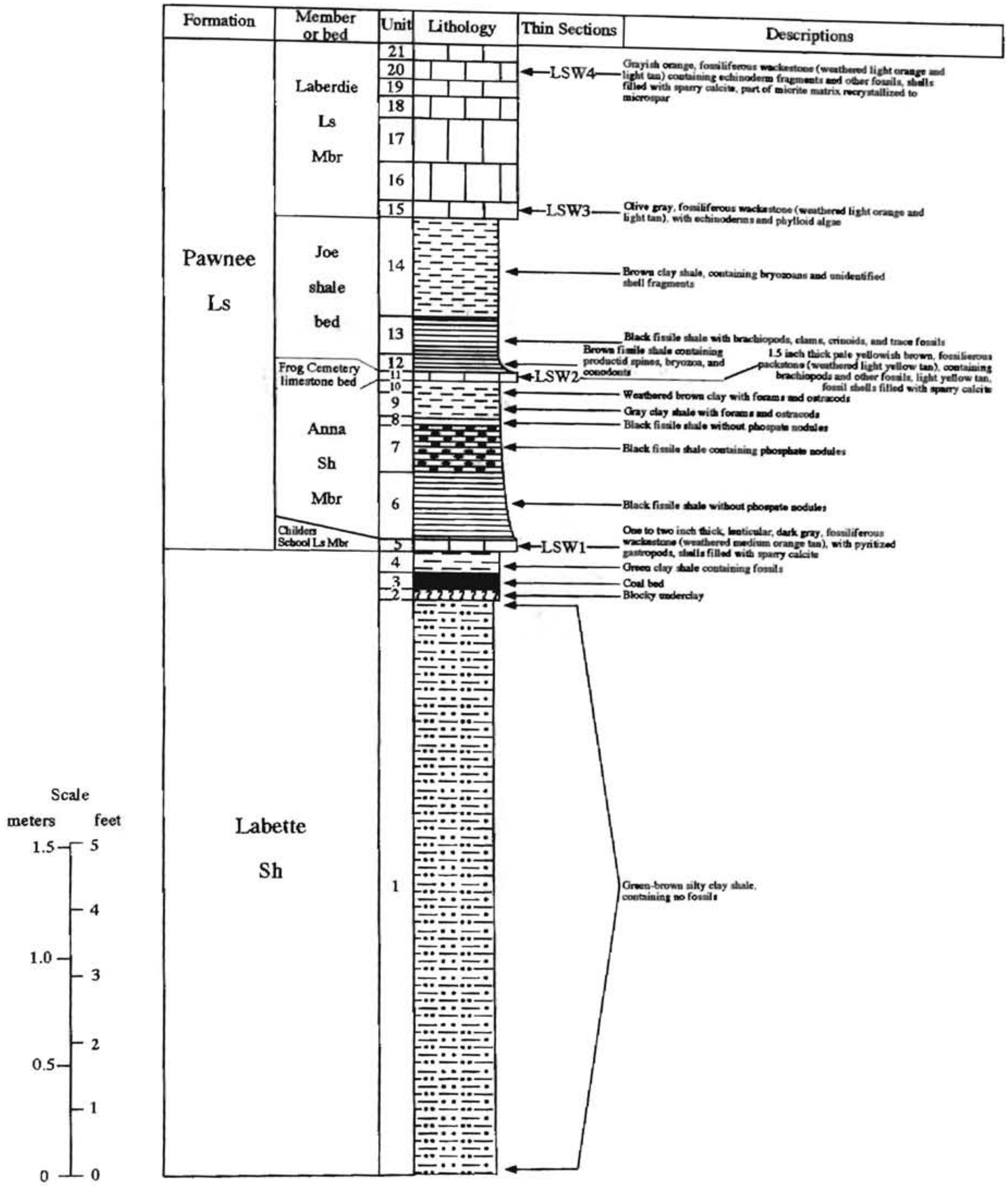


Figure 57. Measured section for Location 2, Labette SW at the center of W. line, NW, Sec. 3, T. 33 S., R. 20 E., Labette County, Kansas.

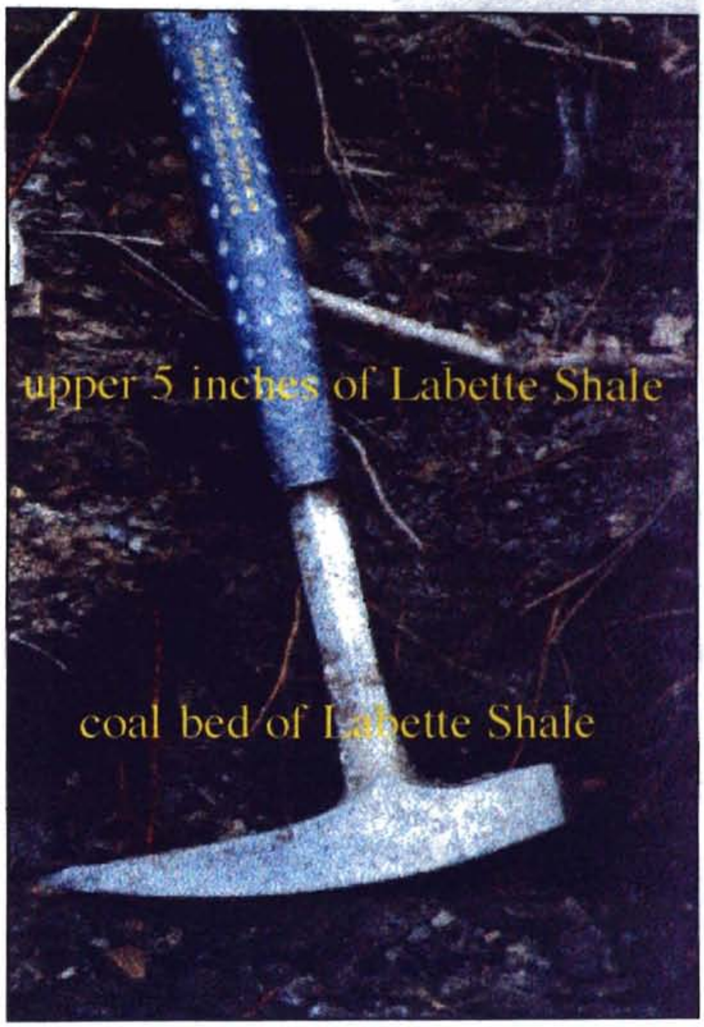


Figure 58. Photo of Location 2 exposure showing coal within Labette Shale at the level of the hammer head.

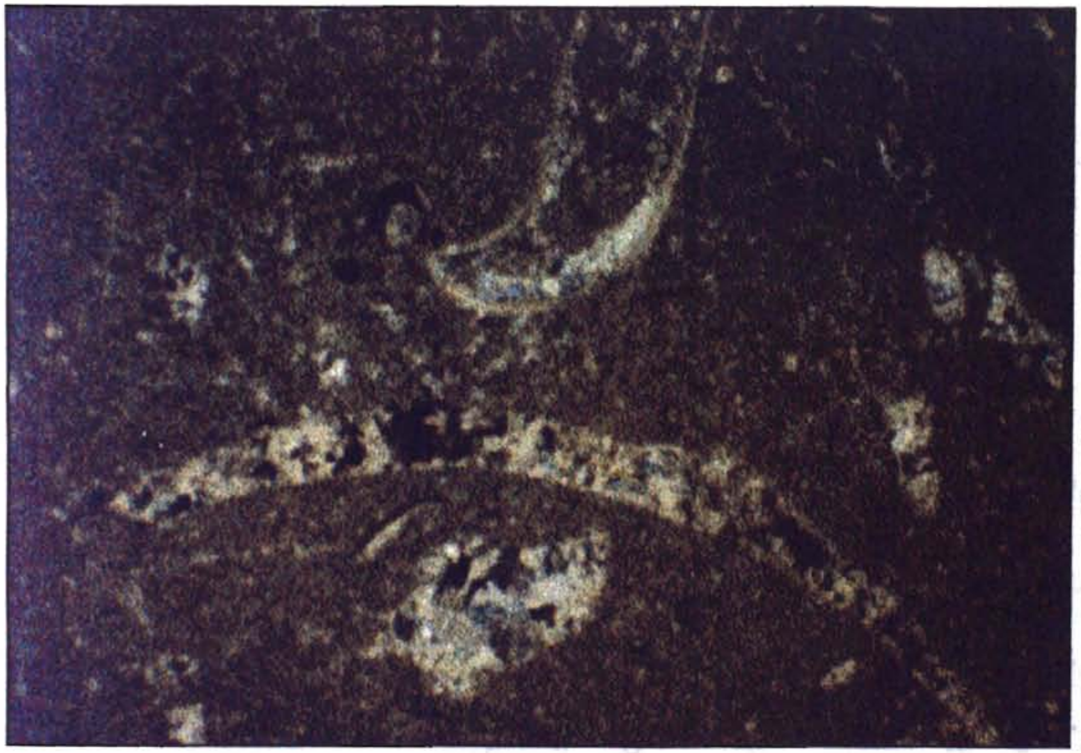

Figure 59. Thin section photograph of the Childers School Limestone at Location 2, Labette SW. Fossiliferous wackestone containing pyritized gastropods. Shells are filled with sparry calcite.

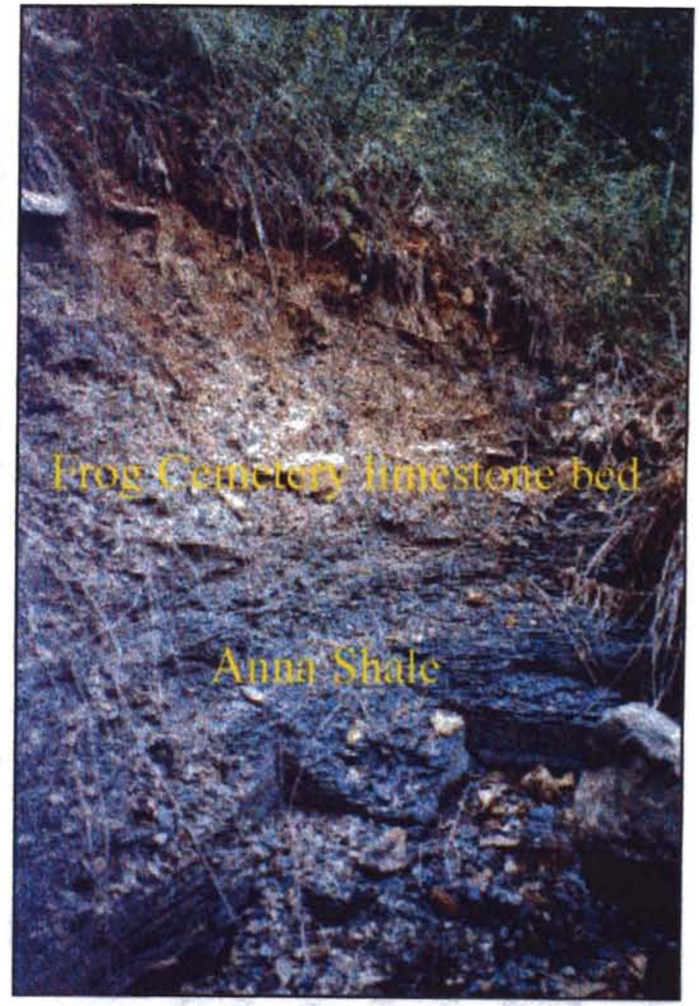


Figure 60. Photograph of interval containing Anna Shale and Frog Cemetery limestone bed at Location 2, Labette SW.

centimeters) is unit 6, a black fissile shale. Twelve to 20 inches (30.5 to 50.8 centimeters) above the Anna base is unit 7, a black fissile shale with phosphate nodules. The 20 to 22 inches (50.8 to 55.9 centimeters) above the Anna base is unit 8, a black fissile shale without phosphate nodules. The interval 22 to 26 inches (55.9 to 66.1 centimeters) above the Anna base is unit 9, a gray clay and 26 to 28 inches (55.9 to 71.2 centimeters) above the Anna base is unit 10, a weathered brown clay. Figure 60 shows the Anna Shale at the outcrop. It contains forams, ostracods, and conodonts throughout its thickness. The contact between the Anna and the Frog Cemetery limestone bed above is sharp and straight.

The Frog Cemetery limestone bed (unit 11) is shown in Figure 61. It is about 1.5 inches (3.81 centimeters) thick here. It is a pale yellowish brown fossiliferous packstone with brachiopods and other fossils filled with sparry calcite. It weathers light yellow tan. Figure 62 is a photo of the Frog Cemetery thin-section sample number LSW2. The contact between the Frog Cemetery limestone bed and the Joe shale bed is sharp and straight.

The 28 inch (71.2 centimeter) thick Joe shale bed lies on top of the Frog Cemetery limestone bed. See Figure 61. The Joe shale bed contains two lithologic units. The lower three inches (7.6 centimeters), unit 12, is a fossiliferous, brown, fissile shale. Three to 10 inches (7.6 to 25.4 centimeters) above the Joe base is a seven inch thick black fissile shale (unit 13) containing brachiopods, clams, crinoids, and trace fossils. Ten to 28 inches (25.4 to 45.8 centimeters) above the Joe base (unit 14) is a brown clay shale. The contact between the Joe and the Laberdie is sharp and straight.

The Laberdie Limestone is 27 inches (68.6 centimeters) thick here. Figure 63 shows the Laberdie Limestone beds (units 15 - 21). Here, only the lowermost seven beds are present which are 3 (7.6), 7 (17.8), 8 (20.3), 4 (10.1), 3 (7.6), 3.5 (8.90), and 3 (7.6) inches (centimeters) thick, in ascending order. The lower part of the Laberdie here is an olive gray fossiliferous wackestone which weathers light orange and light tan. It


Figure 61. Photo showing the Anna Shale, the lenticular Frog Cemetery limestone bed, and the Joe shale bed at Location 2, Labette SW.

Figure 62. Thin section photograph of the Frog Cemetery limestone bed (sample LSW2) from Location 2, Labette SW. Fossiliferous packstone containing brachiopods and other fossils. Shells filled with sparry calcite.

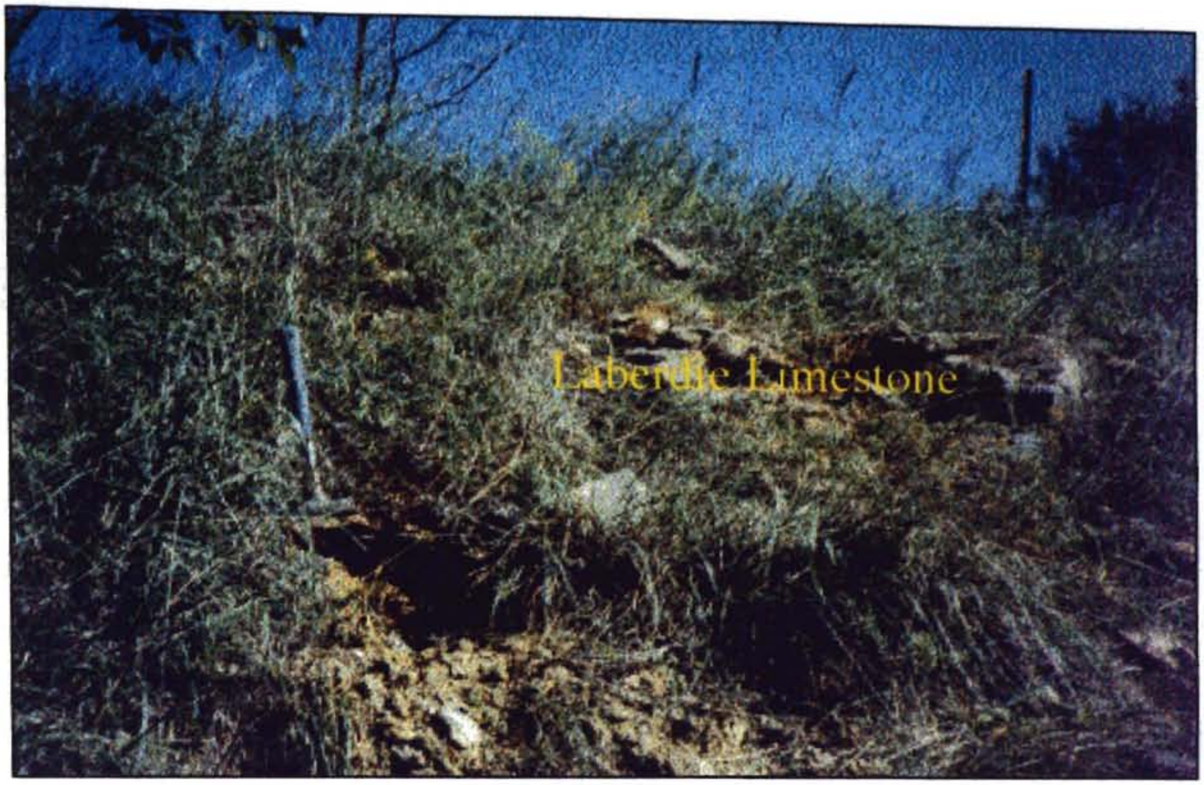


Figure 63. Laberdie Limestone at Location 2, Labette SW.

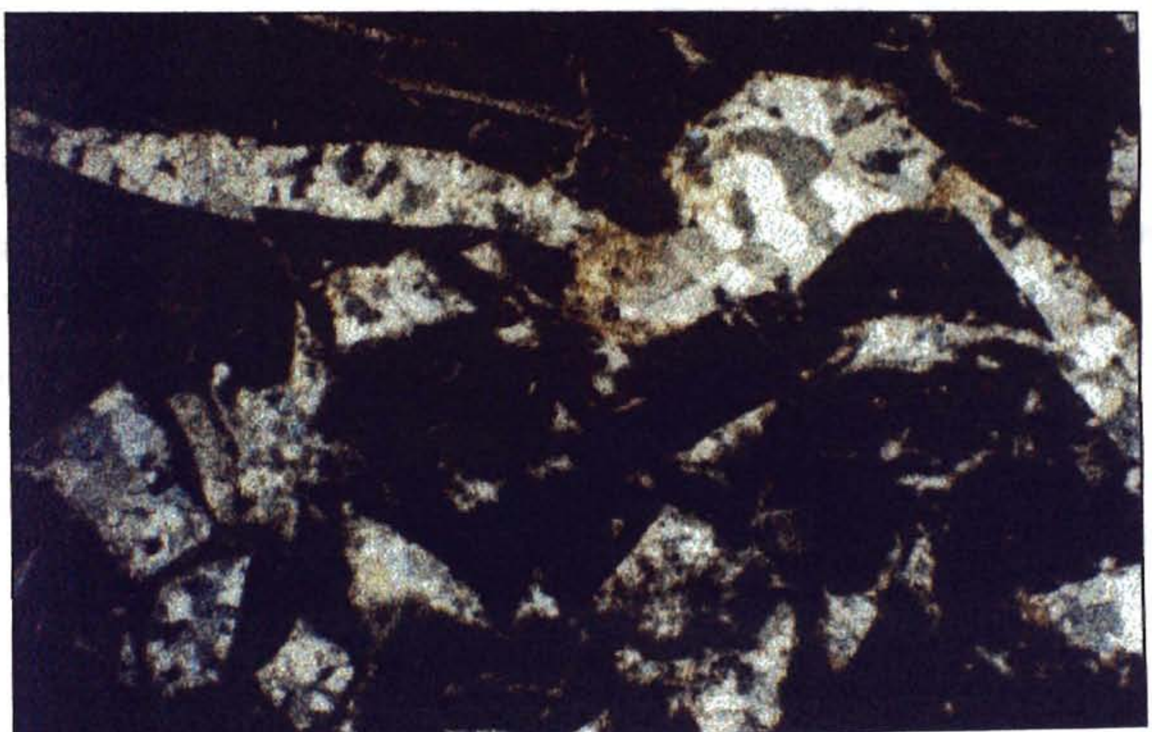

Figure 64. Photograph of thin section sample LSW3 from base of Laberdie Limestone at Location 2 , Labette SW. Fossiliferous wackestone containing echinoderms and phylloid algae filled with sparry calcite.

contains echinoderm fragments and phylloid algae. Figure 64 is a photo of thin-section sample LSW3 taken from the base of the Laberdie Limestone. The upper part is a grayish orange fossiliferous wackestone which weathers light orange and light tan. It contains echinoderms and other fossils. The shells are filled with sparry calcite. Figure 65 shows thin-section sample LSW4 from the top of the Laberdie Limestone.

Location 3, Lower Bandera

The outcrop at NW, NW, NW, Sec. 9, T. 33 S., R. 20 E., east of Altamont, Labette County exposes a 13 inch (33.0 centimeter) thick portion of the lower part of the Bandera Shale. Figure 66 shows the location map. A portion of the Bandera Shale is exposed here. The author divided the Bandera Shale here into 5 lithologic units (Figure 67). Photographs of this outcrop were of no help. The lower 5 inches (12.7 centimeters) of the section is unit 1, a coal streaked clay shale. Five to 7 inches (12.7 to 17.8 centimeters) to above the outcrop base is unit 2, a two inch (5.08 centimeter) thick fossiliferous clay shale. Seven to 9 inches (17.8 to 22.9 centimeters) above the outcrop base is a two inch thick medium gray fossiliferous wackestone to packstone which weathers light tan to medium gray. It contains many brachiopods, echinoderm fragments, and bryozoans. Figure 68 is a photograph of thin-section sample LB1. Nine to 11 inches (22.9 to 28.0 centimeters) above the outcrop base is a medium brown fossiliferous clay shale which weathers to an orange and medium brown color. Eleven to 13 inches (28.0 to 33.0 centimeters) above the outcrop base is a two inch thick medium gray fossiliferous wackestone to packstone with many brachiopods, echinoderm fragments, and bryozoans. It weathers light tan to medium gray.

Location 4, Bandera Section

A thick section of Bandera Shale, including the contacts with the Amoret Limestone Member and Laberdie Limestone Member, is exposed along a road which crosses the Kansas-Oklahoma border for about half a mile. The locations where samples were taken are along the line dividing Sec. 17 and 18, T. 35 S., R. 19 E., Labette

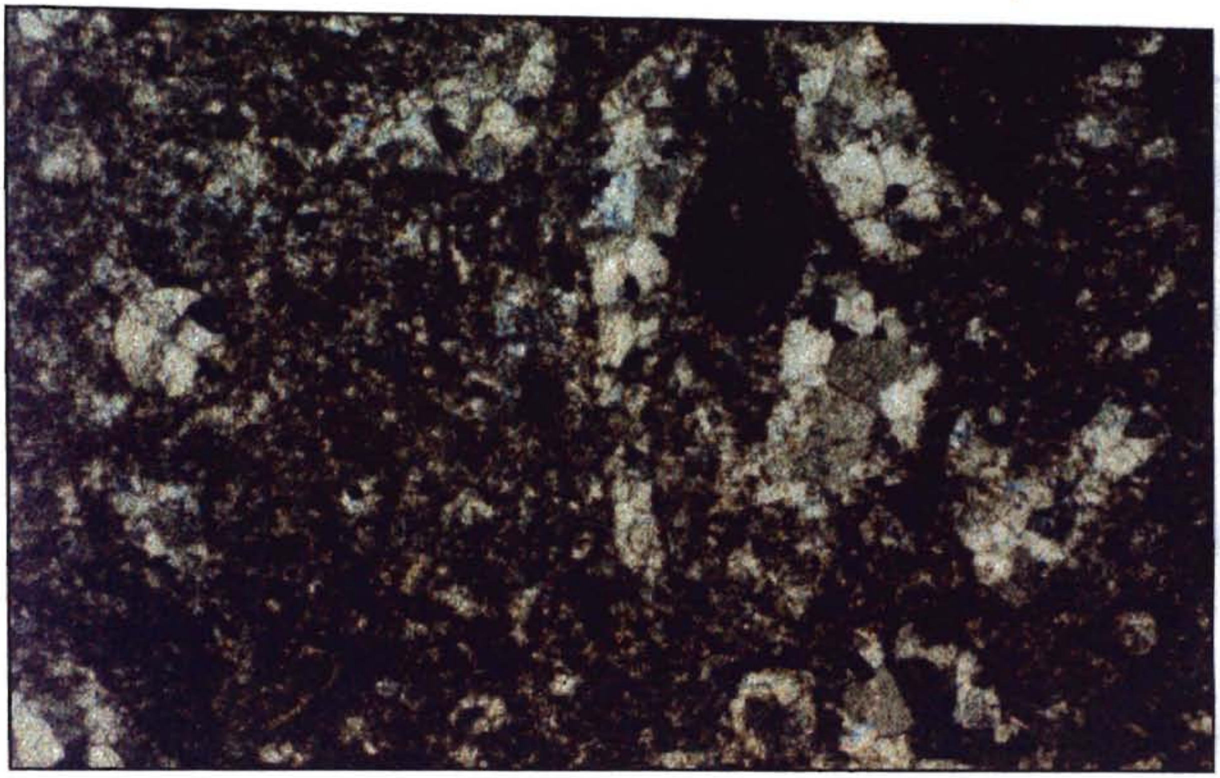

Figure 65. Photograph of thin section sample LSW4 from top of Laberdie Limestone at Location 2, Labette SW. Fossiliferous wackestone containing echinoderm fragments and other fossils. Shells are filled with sparry calcite. Part of micrite matrix recrystallized to microspar.

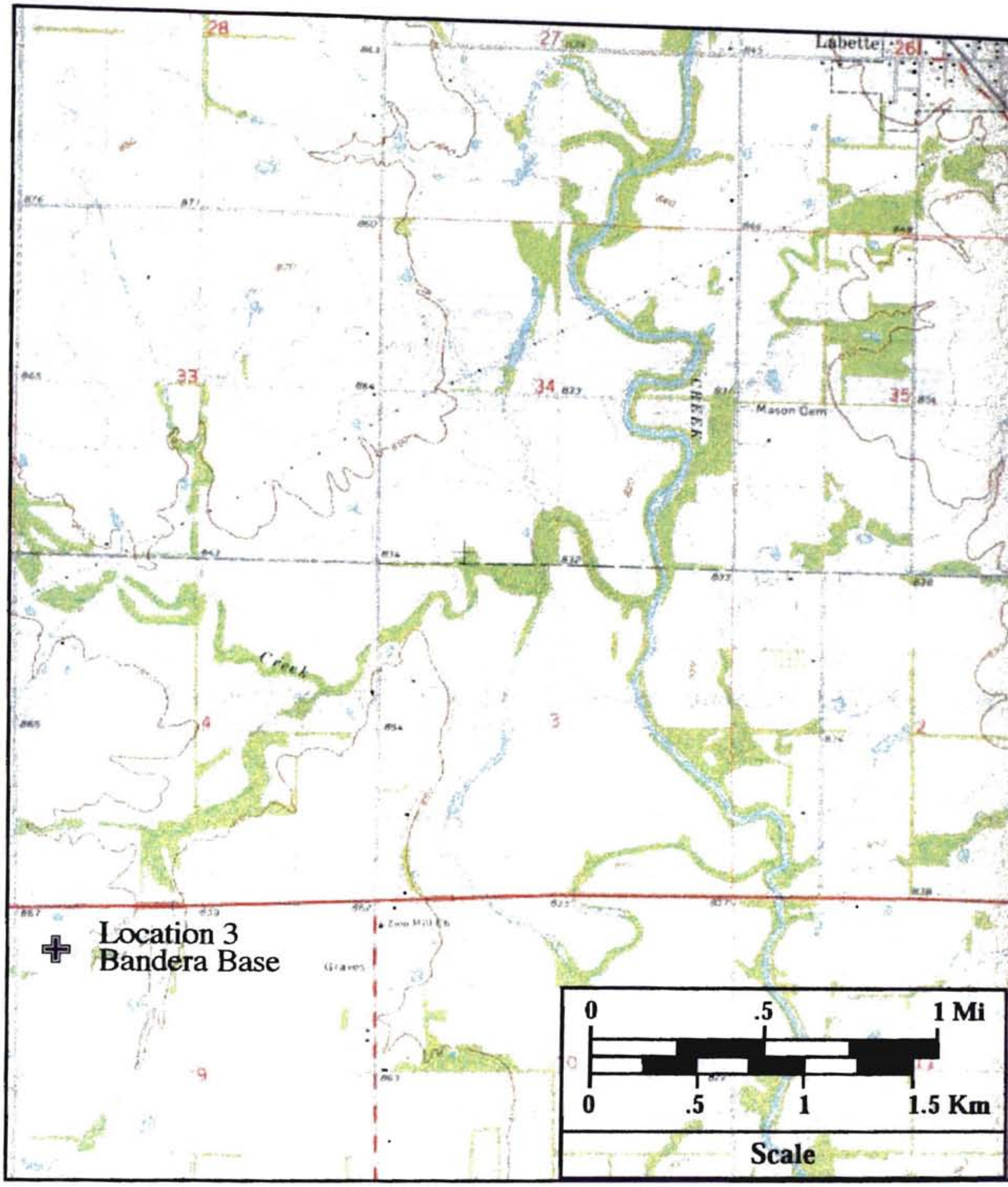


Figure 66. Map showing Location 3, Lower Bandera, NW, NW, NW, Sec. 9, T. 33 S., R. 20 E., Labette County, Kansas.

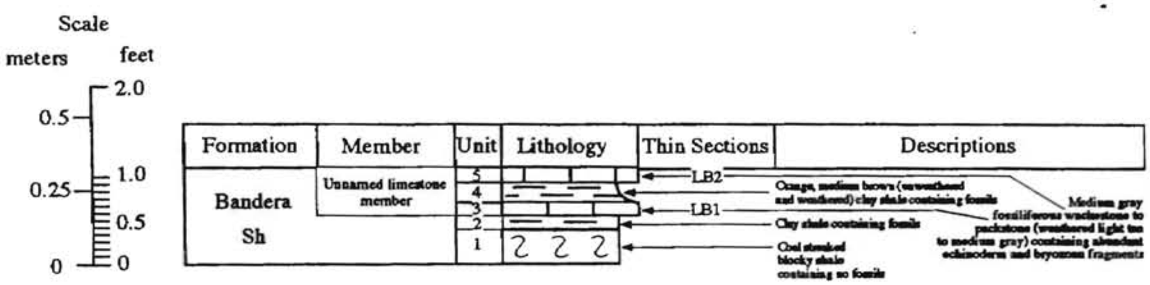


Figure 67. Measured section of Location 3, Lower Bandera at NW, NW, NW, Sec. 9, T. 33 S., R. 20 E.

Figure 68. Photograph of sample BB1 from Location 3. Fossiliferous wackestone to packstone containing abundant gastropods, echinoderm, brachiopod, and bryozoan fragments. Sample BB2 is very similar.

County, Kansas and at the E. line, NE, NE, Sec. 16, T. 29 N., R. 18 E., Nowata County, Oklahoma (Figure 69). The Bandera contact with the Amoret is exposed in Kansas while the contact with the Laberdie Limestone is in Oklahoma . The author sampled the top of the Laberdie Limestone, the base and the top of the Bandera Shale, and the base of the Amoret Limestone. Figure 70 shows the measured section for Location 4. The author measured a total thickness of about 135 feet (41.2 meters) from the top part of the Laberdie Limestone to the lower bed of the Amoret Limestone. Figure 71 is a photo of the exposure. The very top of the Laberdie Limestone (thin-section sample BB1) is a fossiliferous wackestone. Directly above this is 88 feet (26.8 meters) of green and brown semi-fissile silty shale. The base of this shale is visible in the ditch along the road. Most of this silty shale is covered. It is visible in spots. Above this lies a 20 foot (6.1 meters) thick massive sandstone. Above this is a covered zone which is probably highly weathered shale. A nine foot (2.74 meter) thick sandstone bed overlies this. A two foot (.61 meter) thick medium brown clay shale with orange weathered streaks lies above this and below the Amoret Limestone. The Amoret (thin-section sample BS2) is a light gray packstone, weathered yellow tan to light gray. It contains brachiopods, ostracods, and other fossil fragments filled with sparry calcite. It is algal in part and contains red sediment in parts. See Figure 72.

Location 5, Harper Road

The Bandera Shale-Amoret Limestone contact is exposed at this section located on Harper Road at SE, SW, SE, Sec. 11, T. 35 S., R. 18 E., Labette County, Kansas (Figure 73). The contact is sharp and straight. The author measured a total thickness of 6 feet 3 inches (1.91 meters). Figure 74 shows the measured section for this location, including unit descriptions and the thin-section sample number. Figure 75 is a photograph of the outcrop. The Bandera Shale is divided into 6 units here, based on lithology. The lowest unit of the Bandera is a sandstone (unit 1, 51 inches (1.30 meters) below the Amoret base). Forty to 51 inches (1.02 to 1.30 meters) below the Amoret/Bandera

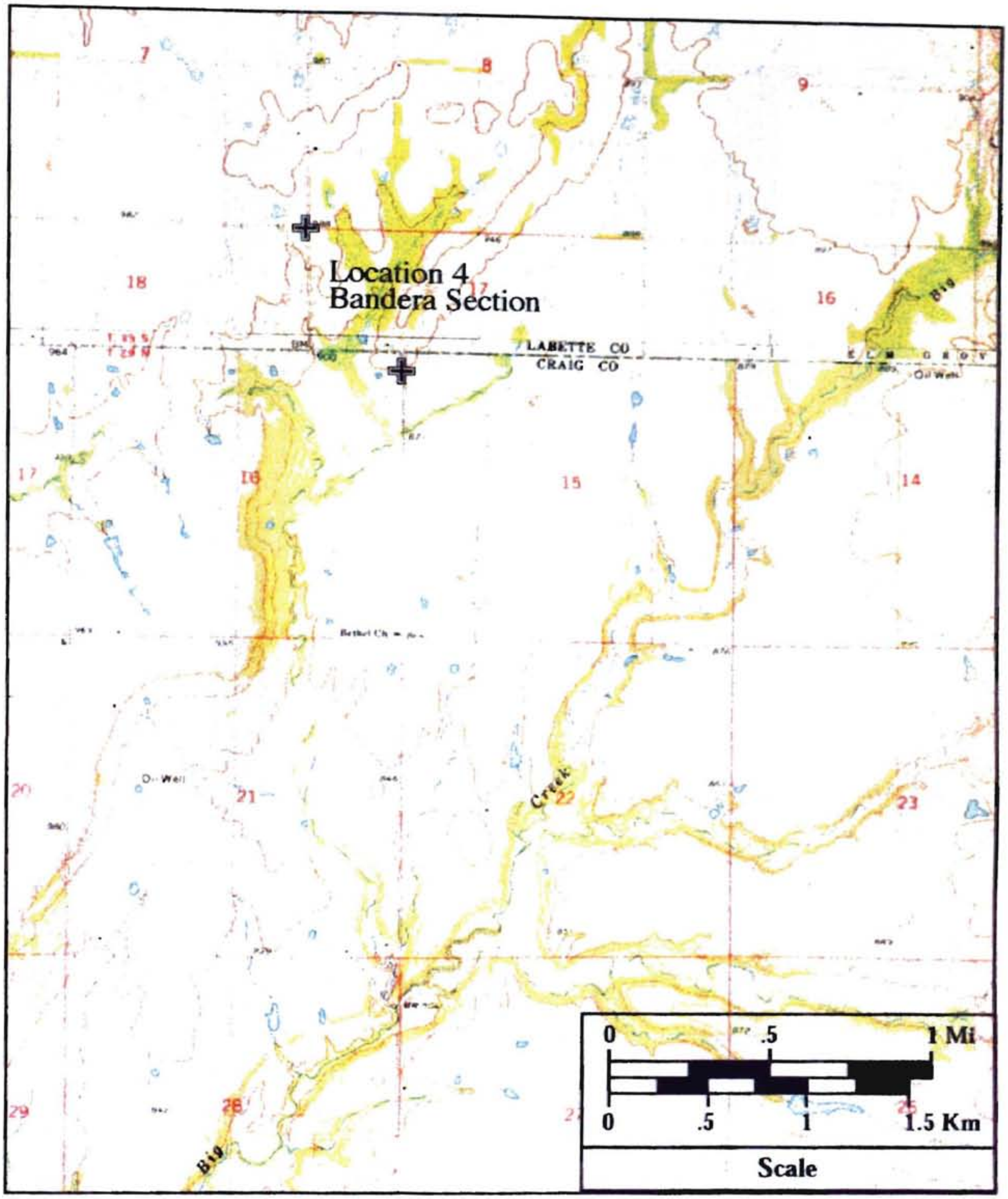


Figure 69. Map showing Location 4, Bandera Section, along line between Sec. 17 and 18, T. 35 S., R. 19 E., Labette County, Kansas, and at the East line, NE, NE, Sec. 16, T. 29 N., R. 18 E., Nowata County, Oklahoma.

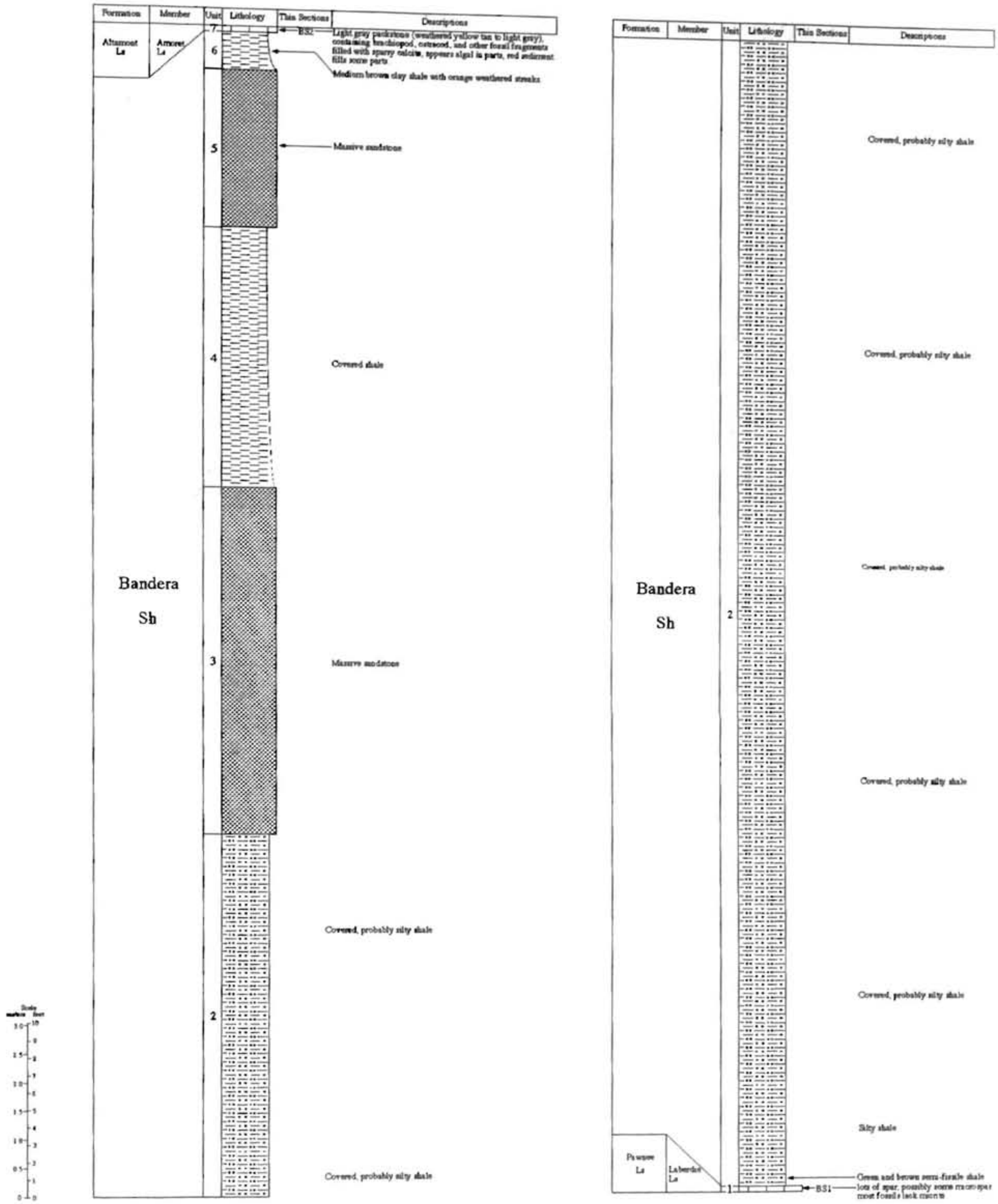


Figure 70. Measured section of Location 4, Bandera Section, along line between Sec. 17 and 18, T. 35 S., R. 19 E., Labette County, Kansas, and at the East line, NE, NE, Sec. 16, T. 29 N., R. 18 E., Nowata County, Oklahoma.


Figure 71. Photograph of Location 4, Bandera Section location.

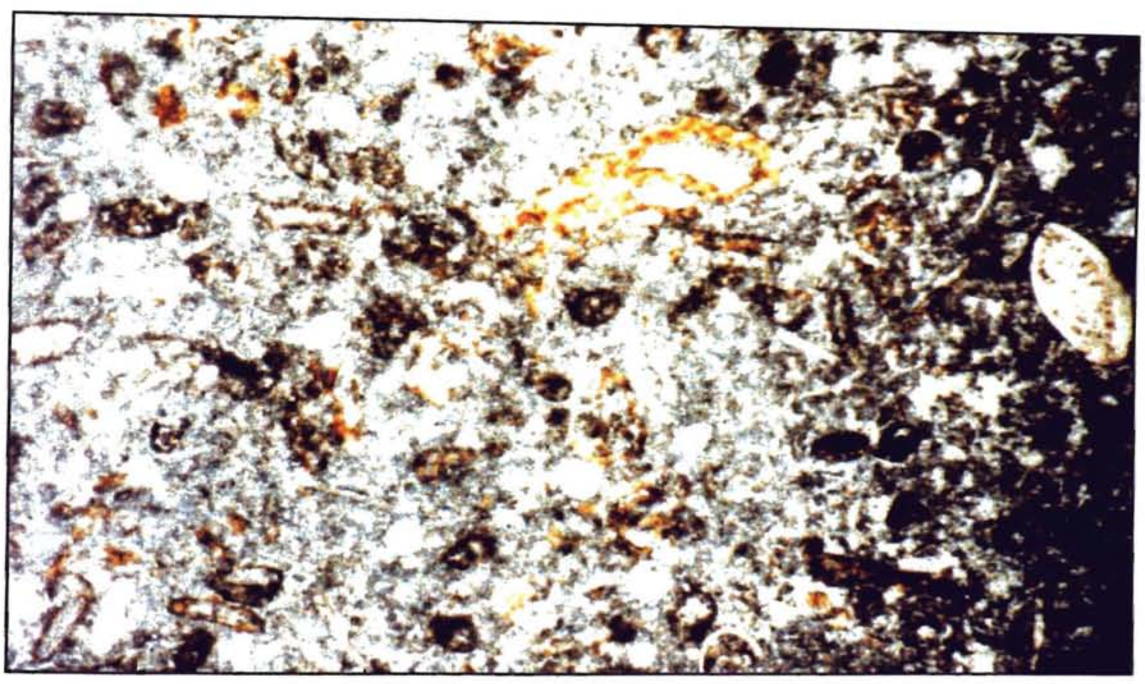

Figure 72. Photograph of thin section sample BS2 (Amoret Limestone) from Location 4, Bandera Section location. Fossiliferous packstone containing brachiopod, ostracod, and other fossil fragments filled with sparry calcite.

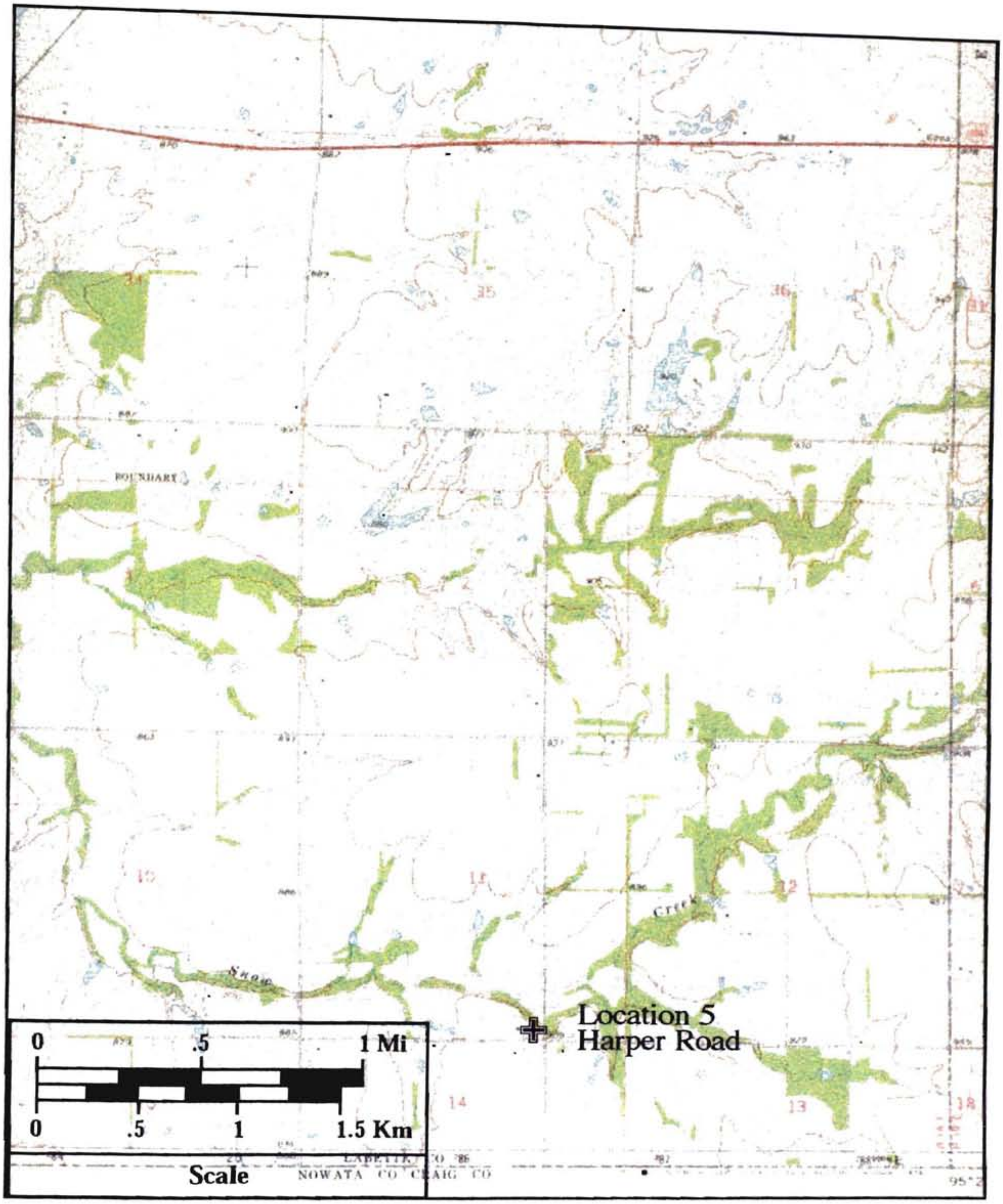


Figure 73. Location 5, Harper Road at SE, SW, SE, Sec. 11, T. 35 S., R. 18 E., Labette County, Kansas.

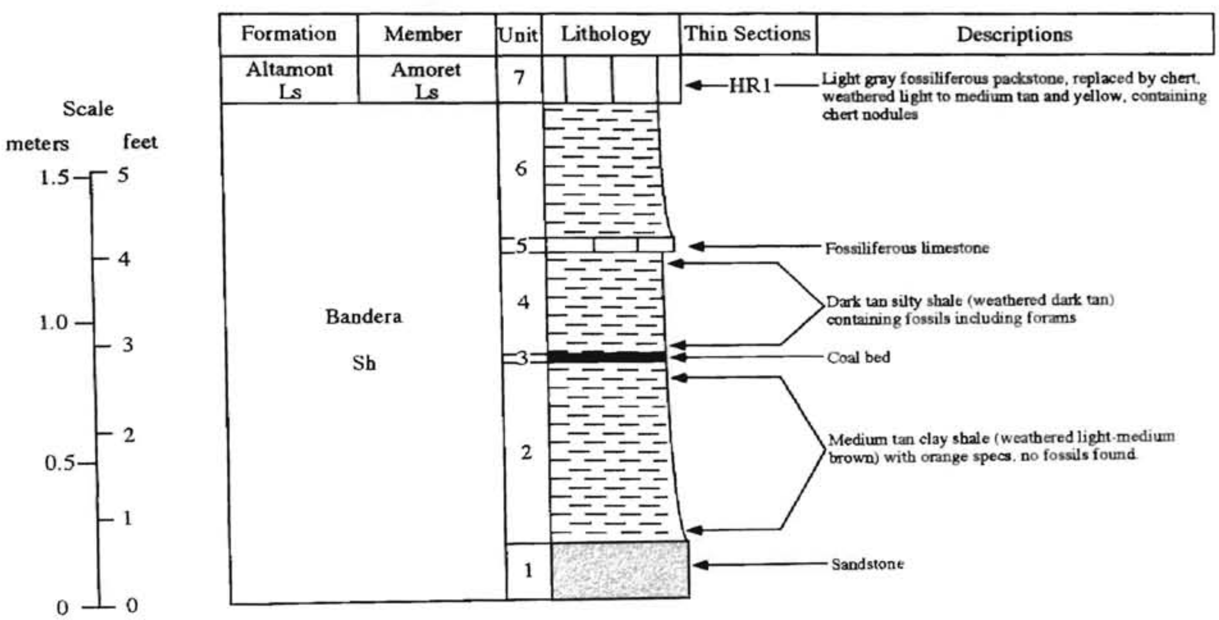


Figure 74. Measured section of Location 5, Harper Road at SE, SW, SE, Sec. 11, T. 35 S., R. 18 E., Labette County, Kansas.

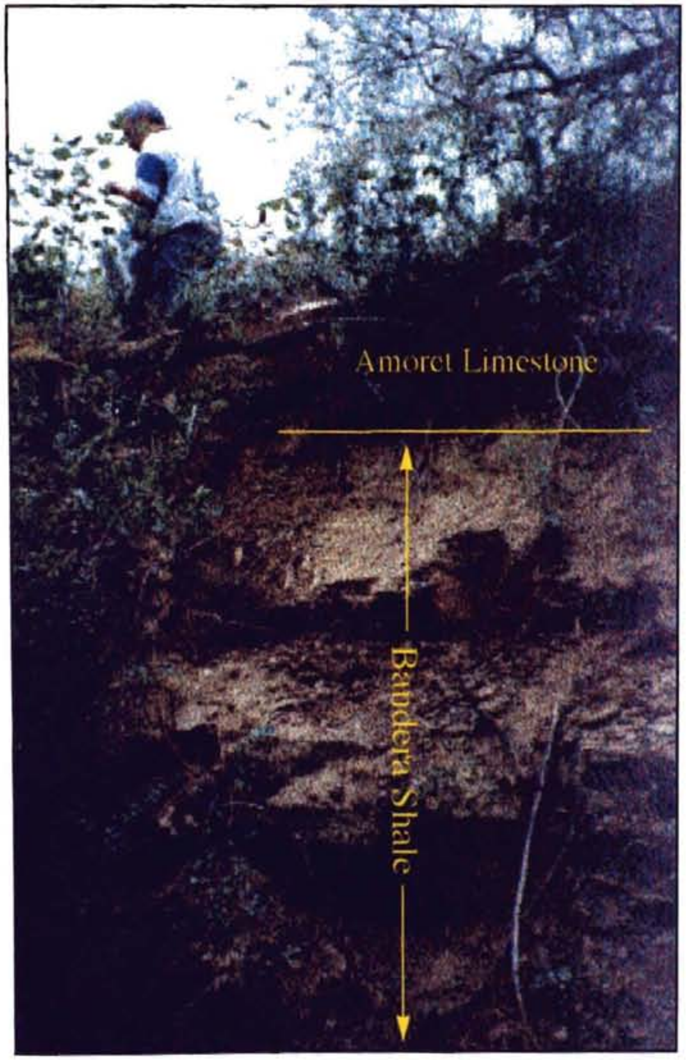


Figure 75. Photograph of Location 5, Harper Road exposure at SE, SW, SE, Sec. 11, T. 35 S., R. 18 E., Labette County, Kansas.

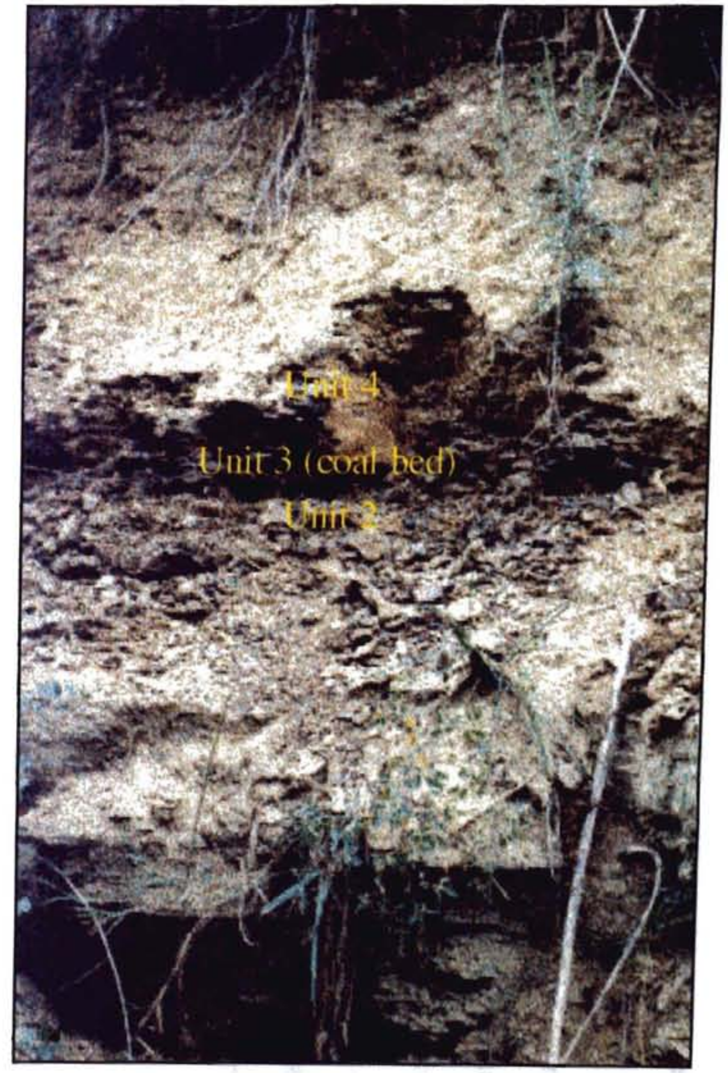


Figure 76. Photograph of Location 5, Harper Road exposure at SE, SW, SE, Sec. 11, T. 35 S., R. 18 E., Labette County, Kansas.

contact is unit 2, a medium tan clay shale, weathered light to medium brown), containing orange specs and no fossils. 39 to 40 inches (.99 to 1.02 meters) below the contact is unit 3, a one inch thick coal bed (Figure 76). 18 to 39 inches (.45 to .99 meters) below the contact is unit 4, a dark tan silty shale, which weathers dark tan and contains forams and other fossils. The interval 16 to 18 inches (.41 to .45 meters) below the contact is unit 5, a fossiliferous limestone (Figure 77). Zero to 16 inches (0 to .41 meters) below the contact is unit 6, a silty, fossiliferous shale. The Amoret Limestone (unit 7) is a fossiliferous packstone containing chert nodules. Figure 78 is a photograph of thin-section sample HR1 (Amoret).

Location 6, Coffeyville Quarry

This quarry is located at SE, SW, NW, SW, Sec. 35, T.34 S., R.17 E., east of the Montgomery-Labette County line in southeastern Kansas. The units exposed here are, in ascending order, the Amoret Limestone, Lake Neosho Shale, and Worland Limestone. Figure 79 shows the location map for the exposure. The measured section is in Figure 80. Only part of the Amoret Limestone is visible here, due to the water level in the quarry. The complete thickness of the Lake Neosho Shale is present and all or at least most of the Worland Limestone is present. The total thickness of visible Altamont Limestone at the time the author measured it was 13 feet, 6.5 inches (4.13 meters). Figure 81 and 82 are photographs of the outcrop.

The basal few feet of the Amoret Limestone are hidden by water in the quarry. At this quarry section, where the author measured 6 feet 2 inches (1.88 meters) of Amoret, it is probably thicker than 10 feet (3.05 meters) thick, perhaps as much as or more than 20 feet (6.10 meters). Here, it is a massive buildup with no bedding planes except for the 8 inch (20.3 centimeter) thick bed (unit 3) at the top. Unit 1 is a light olive gray fossiliferous packstone which weathers medium gray. The author measured it to be 5 feet 3 inches (1.60 meters) but it is probably greater than this. It contains forams, brachiopods, and echinoderms. Micritic lined shells are filled with drusy and

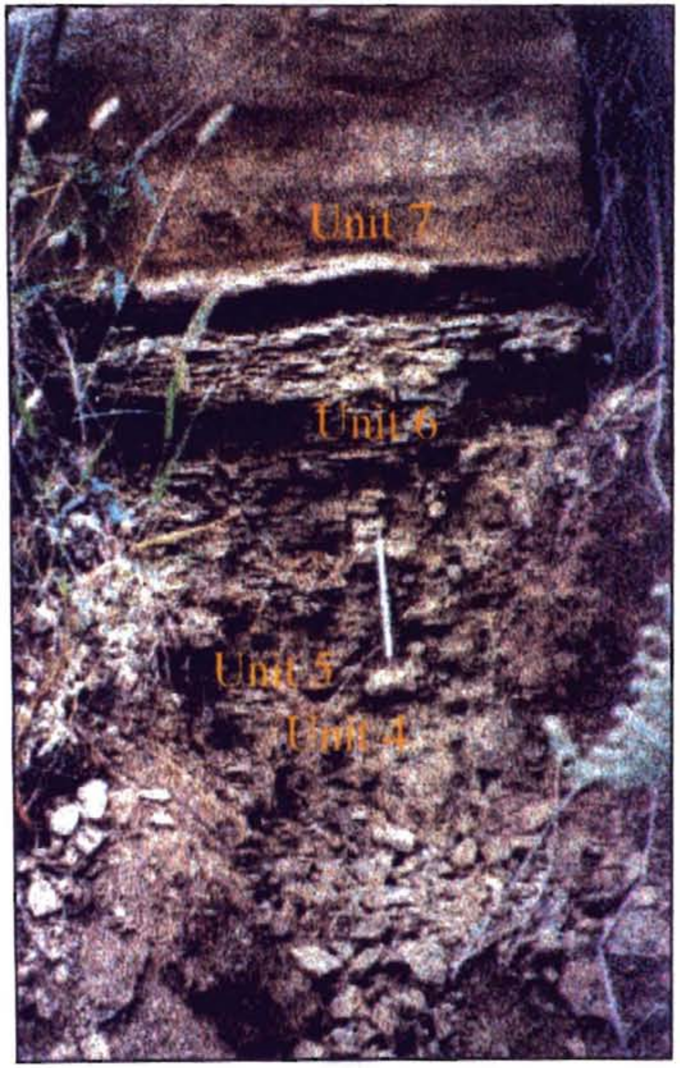


Figure 77. Photograph of Location 5, Harper Road exposure at SE, SW, SE, Sec. 11, T. 35 S., R. 18 E., Labette County, Kansas.

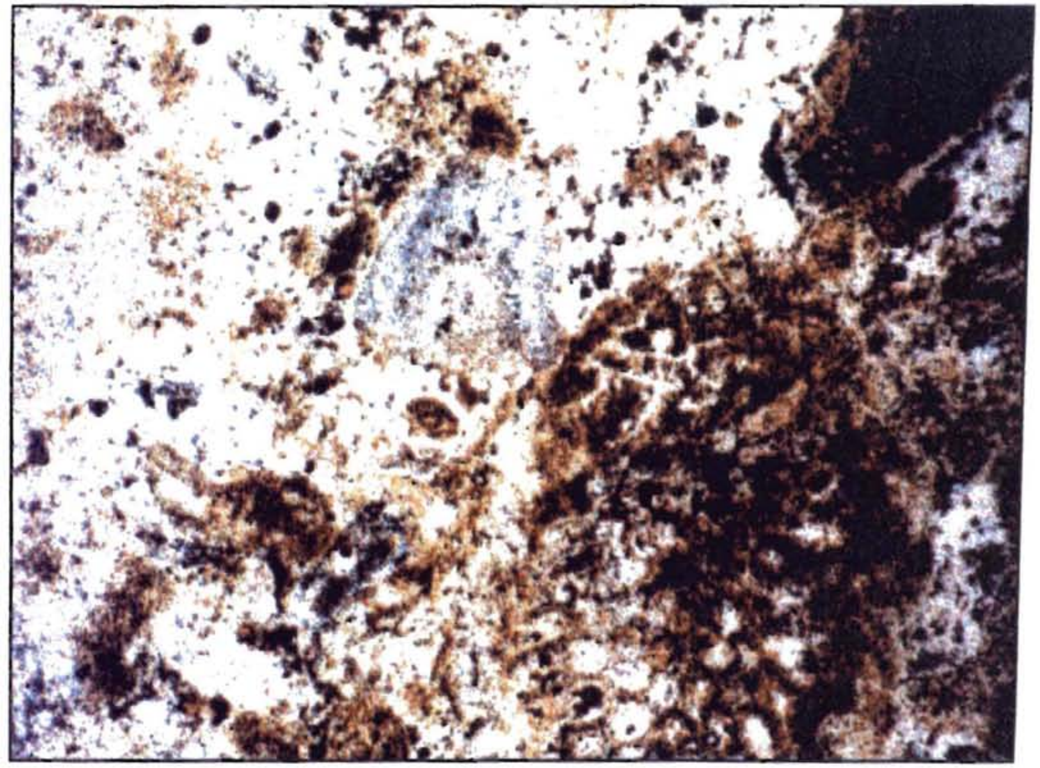

Figure 78. Photograph of thin section sample HR1 (Amoret Limestone) from Location 5, Harper Road. Fossiliferous packstone, replaced by chert and containing chert nodules.

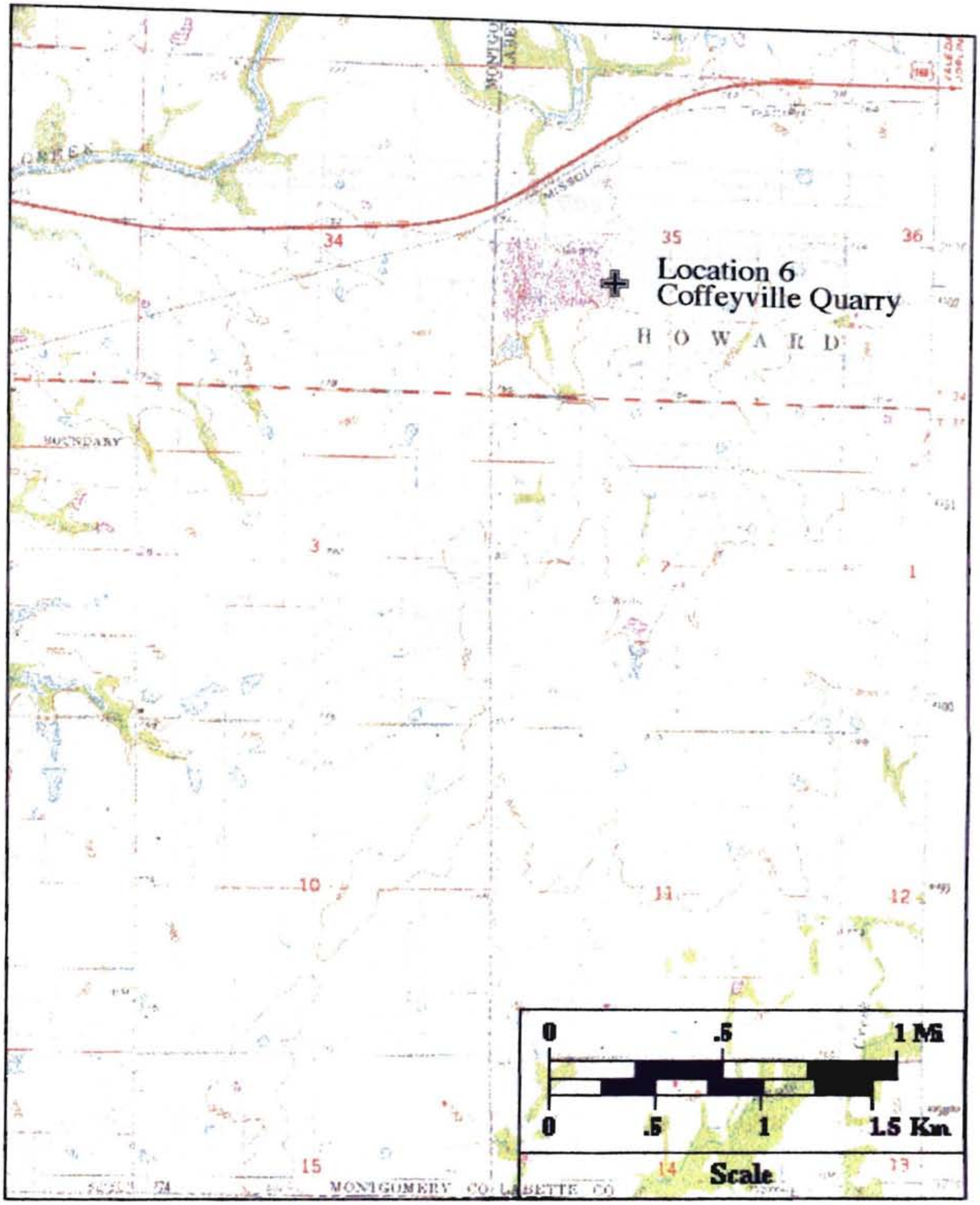


Figure 79. Map of Location 6, Coffeyville Quarry, NE, SW, Sec. 35, T. 34 S., R. 17 E., Labette County, Kansas.

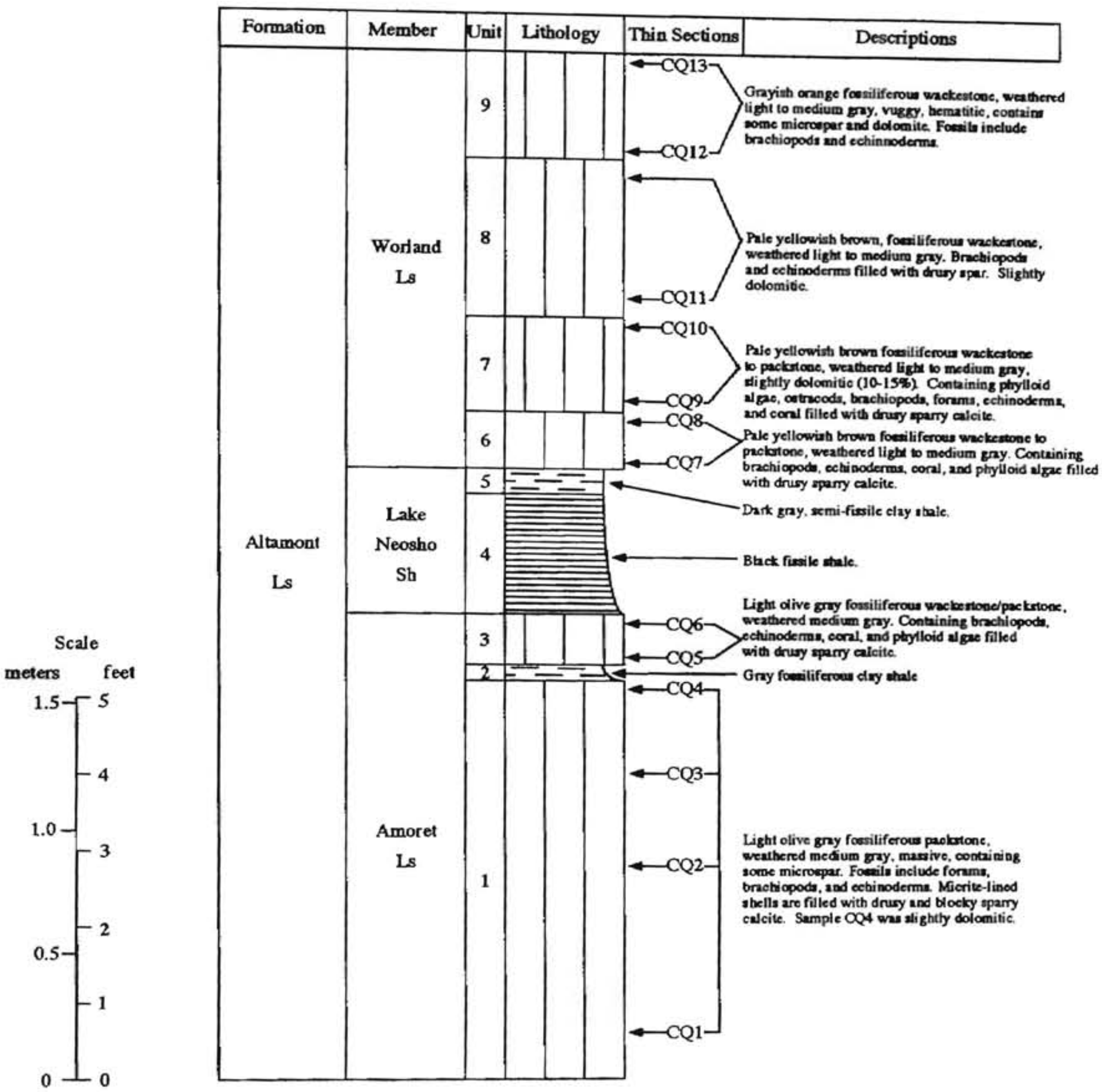


Figure 80. Measured section of Location 6, Coffeyville Quarry, NE, SW, Sec. 35, T. 34 S., R. 17 E., Labette County, Kansas.


Figure 81. Photograph of Location 6 exposure, Coffeyville Quarry.


Figure 82. Photograph of Location 6 exposure, Coffeyville Quarry.

blocky sparry calcite (Figures 83 and 84). In sample CQ1, over half of the micrite matrix recrystallized to microspar (Figure 85). thin-section CQ4, also from unit 1, indicates the sample is slightly dolomitic (Figure 86). Unit 2 is a 3 inch (7.62 centimeter) thick gray, fossiliferous, clay shale. Unit 3 is an 8 inch (20.3 centimeter) thick light olive gray fossiliferous wackestone/packstone which weathers medium gray. It contains brachiopods, echinoderms, corals, bryozoans, and some phylloid algae. Drusy and blocky calcite spar fills the fossil shells. The micrite is mottled due to algae. Figure 87 is a photograph of thin-section sample CQ6 from the Amoret, showing coral filled with drusy and blocky sparry calcite. The contact between the Amoret and the Lake Neosho is sharp and straight.

The Lake Neosho Shale is 1 foot 11 inches (.58 meters) thick here (Figure 88). The author divided it into two units based on lithology. The lower part (unit 4) is a 1 foot 7 inches (.48 meters) thick black, fissile shale. The upper 4 inches (.10 meters) (unit 5) is a dark gray, semi-fissile clay shale. The Lake Neosho contains no phosphate nodules here. The Lake Neosho/Worland contact is sharp and straight.

The Worland is made of laterally continuous beds ranging in thickness between one and two feet (.30 to .61 meters). See Figure 89. The bed 0 to 9 inches (22.9 centimeters) above the Worland base (unit 6) is a pale yellowish brown fossiliferous phylloid algal wackestone/packstone, which weathers light to medium gray. It contains brachiopods, echinoderms, phylloid algae, and a coral. Drusy spar infills fossils. A small amount of the micrite matrix has recrystallized to microspar. Thin-sections CQ7 and CQ8 were taken from this bed (Figure 90). Unit 7, 9 to 24 inches (22.9 to 61.0 centimeters above the Worland base is a pale yellowish brown fossiliferous phylloid algal wackestone/packstone, weathering light to medium gray. This bed is slightly dolomitic (Figure 91). It contains brachiopods, forams, echinoderms, coral, and ostracods, many of which are broken (Figures 92, 93). A geopetal structure within a brachiopod shell was observed in thin-section CQ10 (Figure 94). About 10% of the micrite matrix has

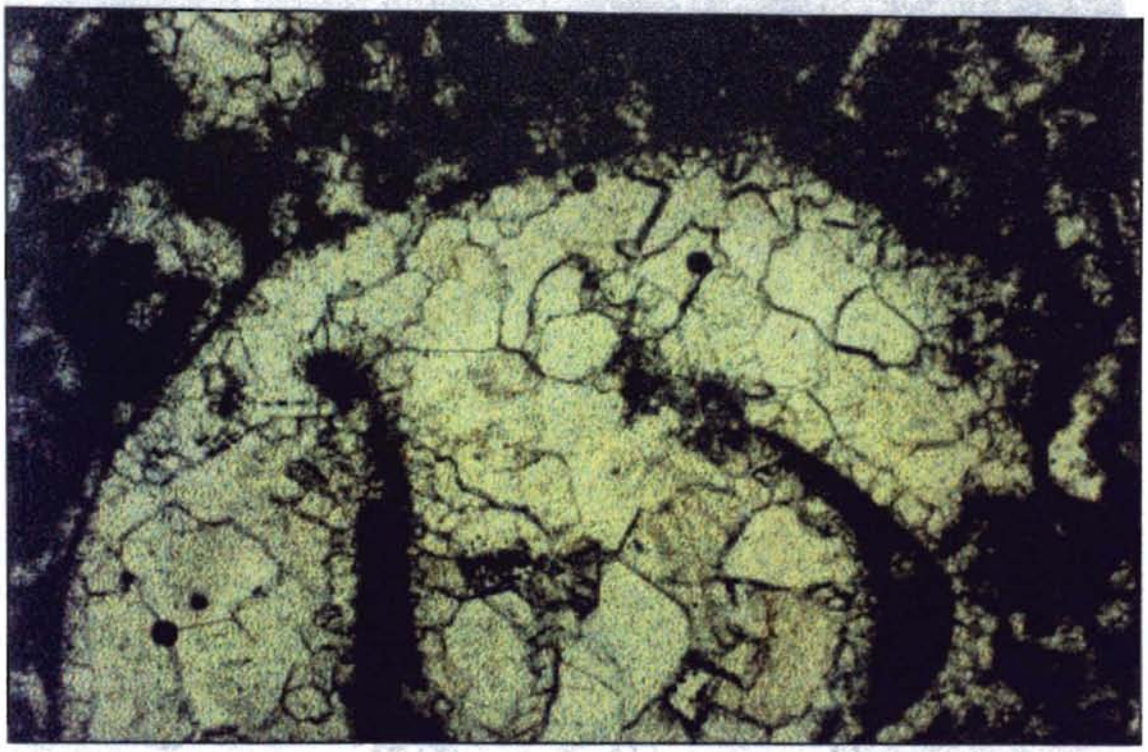

Figure 83. Thin section sample CQ2 from Location 6, Coffeyville Quarry. Fossiliferous packstone containing ostracods.

Figure 84. Thin section sample CQ4 from Location 6, Coffeyville Quarry. Fossiliferous packstone containing ostracods.

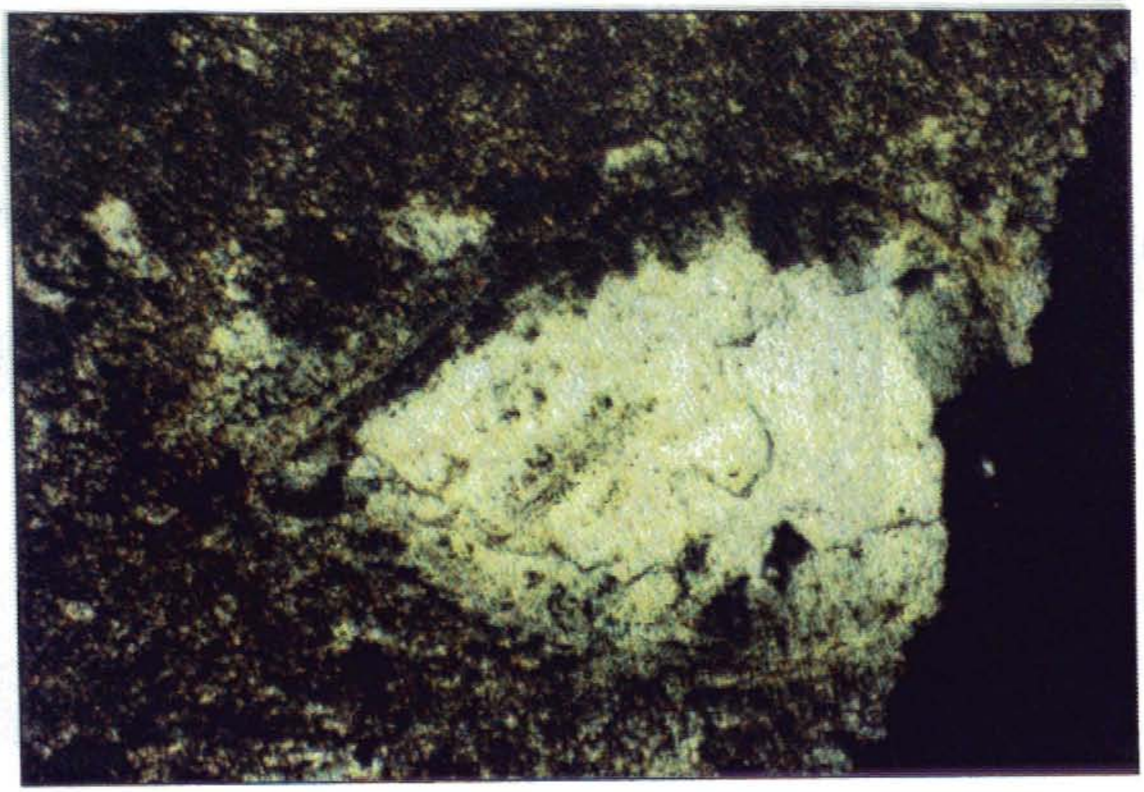

Figure 85. Thin-section sample CQ1 from Location 6, Coffeyville Quarry showing an ostracod shell filled with drusy sparry calcite.

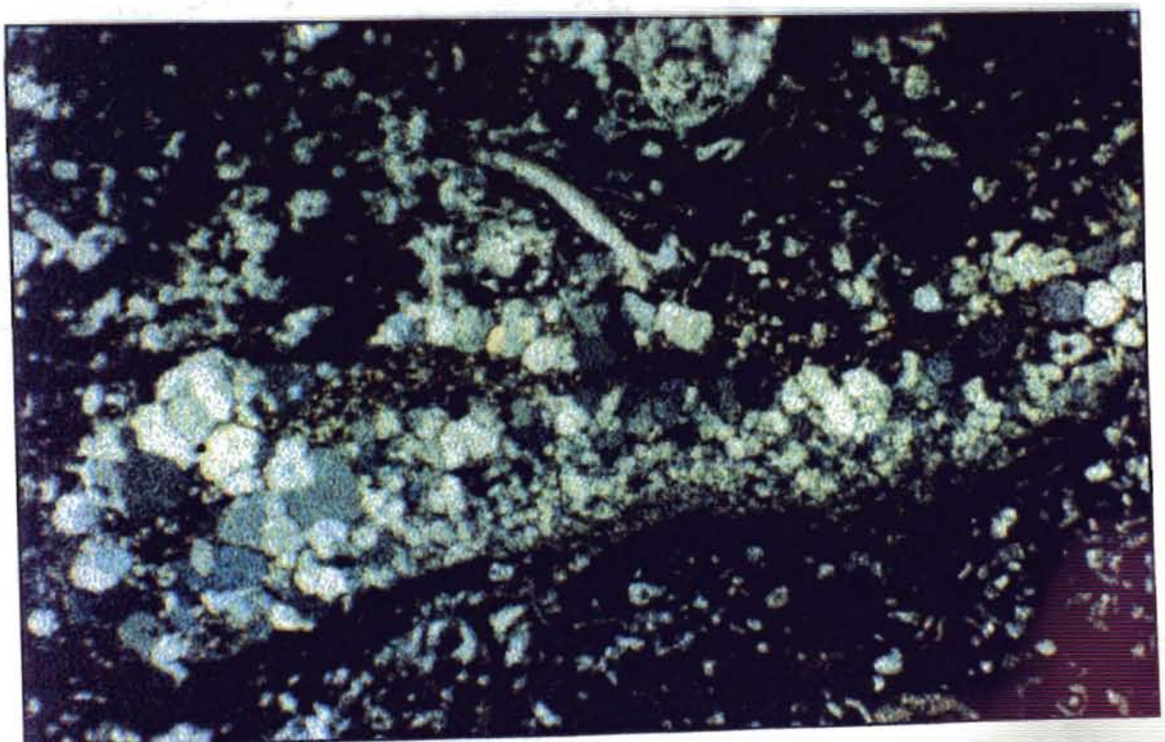

Figure 86. Thin-section sample CQ4 from Location 6, Coffeyville Quarry showing sparry calcite and grainy dolomite.

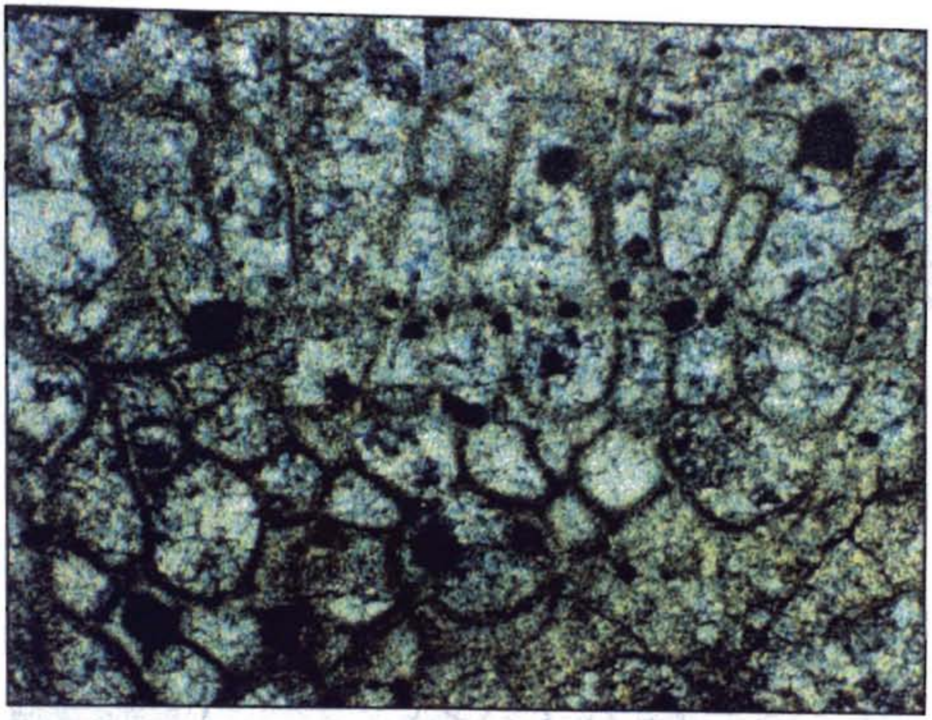

Figure 87. Thin section sample CQ6 from Location 6, Coffeyville Quarry showing doral filled with drusy and blocky sparry calcite.

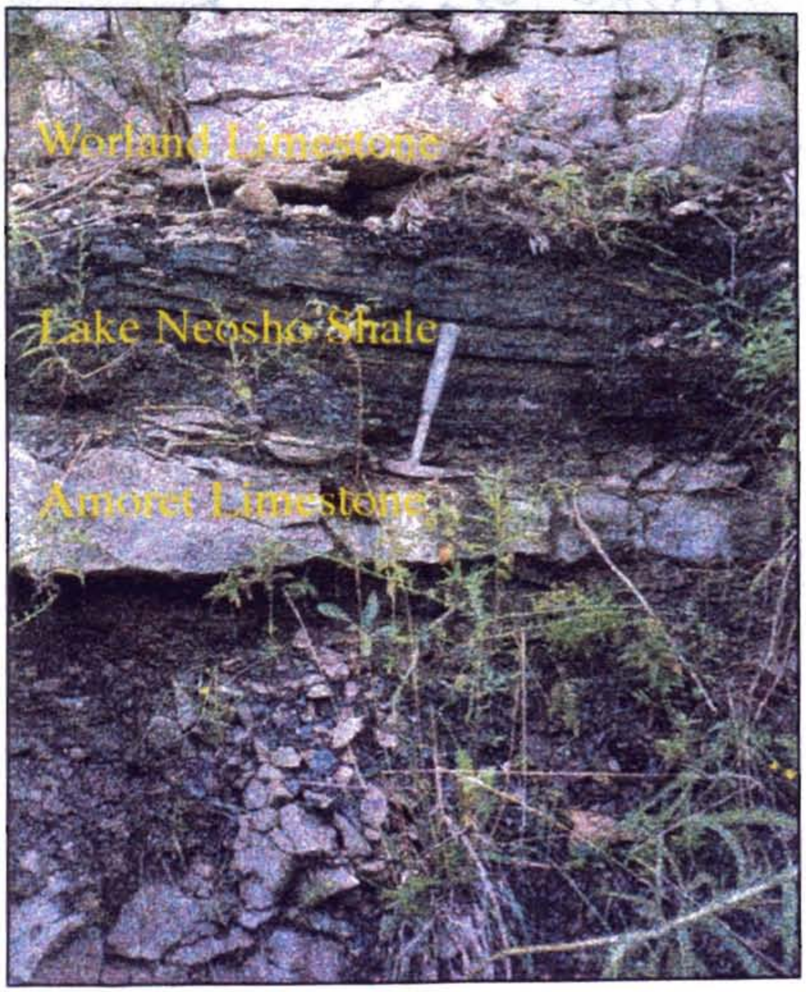


Figure 88. Photograph of Lake Neosho Shale at Location 6, Coffeyville Quarry.


Figure 89. Photograph showing Worland Limestone at Location 6, Coffeyville Quarry.

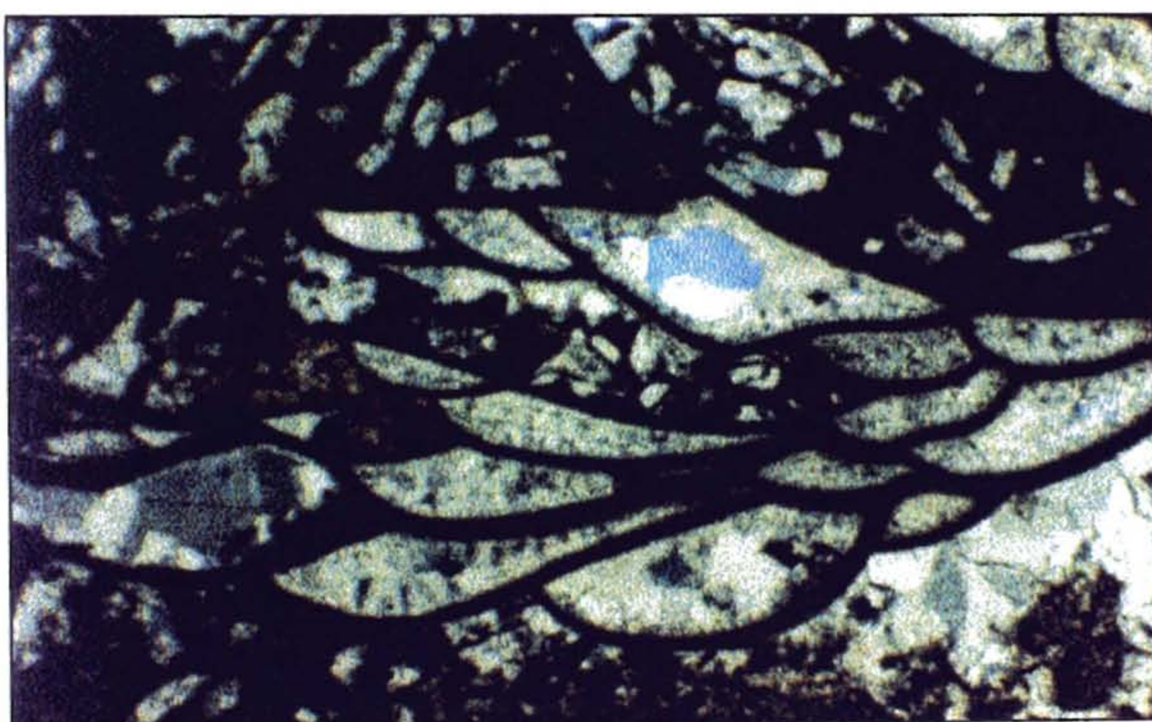

Figure 90. Thin section CQ8 (top of unit 6) from Location 6, Coffeyville Quarry showing coral filled with sparry calcite.

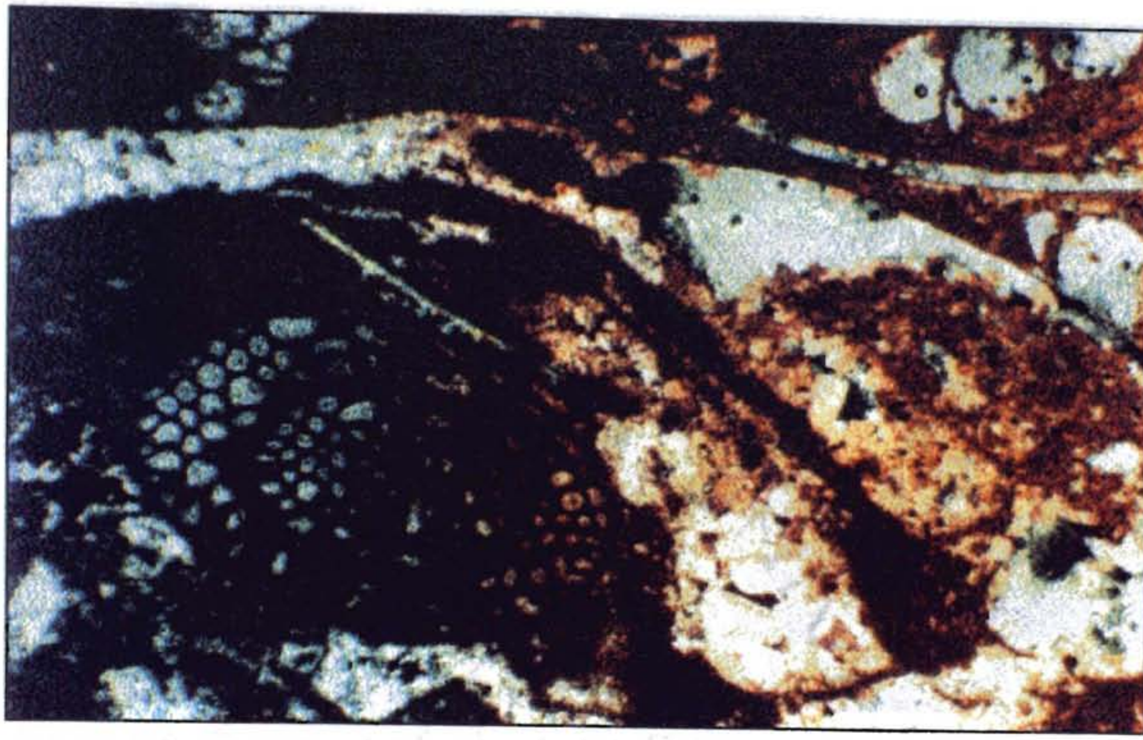

Figure 91. Photograph showing thin-section CQ10 (unit 7) from Location 6, Coffeyville Quarry partly stained with Alizuran Red S to indicate dolomite presence.

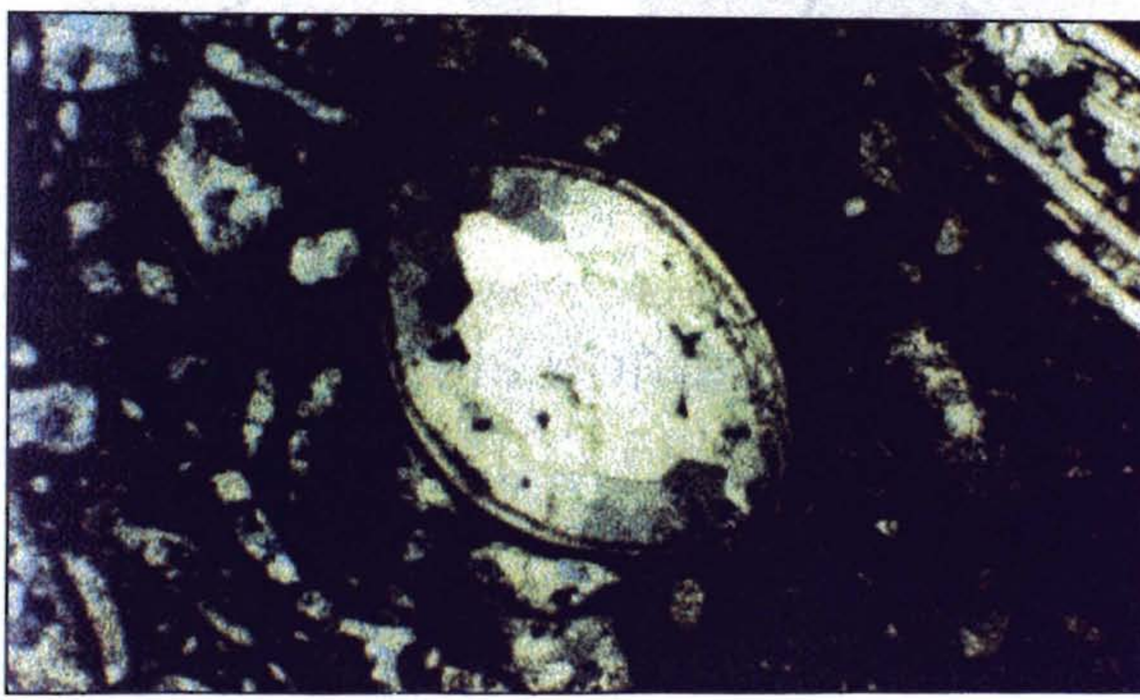

Figure 92. Thin-section CQ9 (unit 7) from Location 6, Coffeyville Quarry showing ostracod filled with drusy sparry calcite.

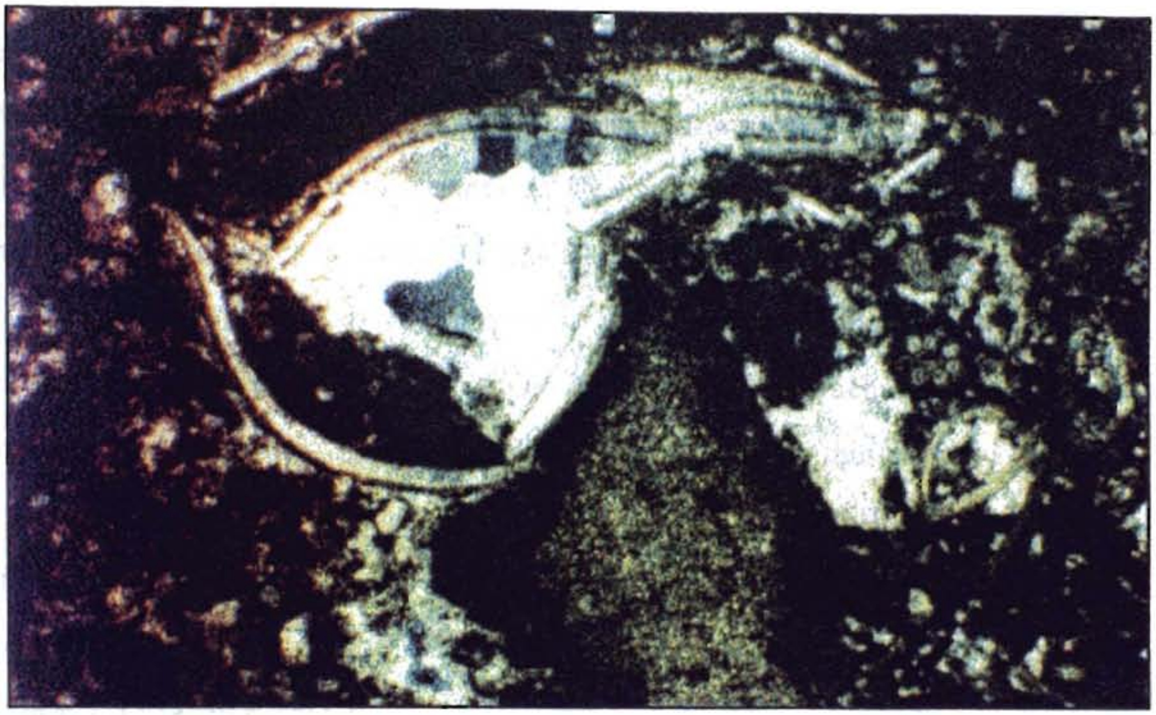

Figure 93. Photograph of thin-section CQ9 (unit 7) from Location 6, Coffeyville Quarry showing broken shell filled with drusy sparry calcite and geopetal structure.

Figure 94. Photograph of thin-section CQ10 (unit 7) from Location 6, Coffeyville Quarry showing geopetal structure within a brachiopod shell.

recrystallized to microspar (samples CQ9 and CQ10). Unit 8, 24 to 50 inches (61.0 to 127 centimeters) above the Worland base is a pale yellowish brown, fossiliferous wackestone which weathers light to medium gray. This bed contains brachiopods and echinoderms filled with drusy spar. Sample CQ11 is slightly dolomitic. Unit 9, 50 to 66 inches (127 to 168 centimeters) above the Worland base is a grayish orange fossiliferous wackestone which weathers light to medium gray. It contains brachiopods, echinoderms, and some hematite. About 70% of the micrite matrix in thin-section CQ12 has recrystallized to microspar. Thin-section CQ13 (Figure 95) was difficult to cut because it underwent extensive dissolution. The fossils in it are completely dissolved out and lined with sparry calcite. It also contains some dolomite.

Location 7, Lenapah Road Cut

This thick road cut along Highway 169 at the W. line, NW, SW, Sec. 20, T. 28 N., R. 16 E., Nowata County, Oklahoma exposes the Nowata Shale, Norfleet Limestone Member, Perry Farm Shale Member, and Idenbro Limestone Member, in ascending order (Figures 96, 97). The author measured a total thickness of 19 feet (5.80 meters). Six feet 8 inches (2.03 meters) of Nowata Shale are exposed at this road cut. Most of the Nowata (unit 1) here is a semi-fissile, medium brown and medium to dark gray, silty shale, weathered to a medium brown and light to medium gray. A three inch thick sandstone bed (unit 2) lies 18 to 21 inches (45.8 to 53.4 centimeters) below the top of the Nowata. The upper 18 inches (45.8 centimeters) of the Nowata (unit 3) is a green clay shale which weathers light gray.

The Norfleet Limestone Member is a single bed 14 inches (35.6 centimeters) in thickness. It is a medium gray silty carbonate, in which no fossils were found. The Perry Farm Shale Member is a 2 foot 11 inch (89.0 centimeter) thick green clay shale containing fossils, including conodonts, throughout. The Idenbro Limestone Member is present as several crumbly, irregular beds. These beds are a light olive to medium gray mudstone, weathered olive green to light tan. No fossils were found in the Idenbro.

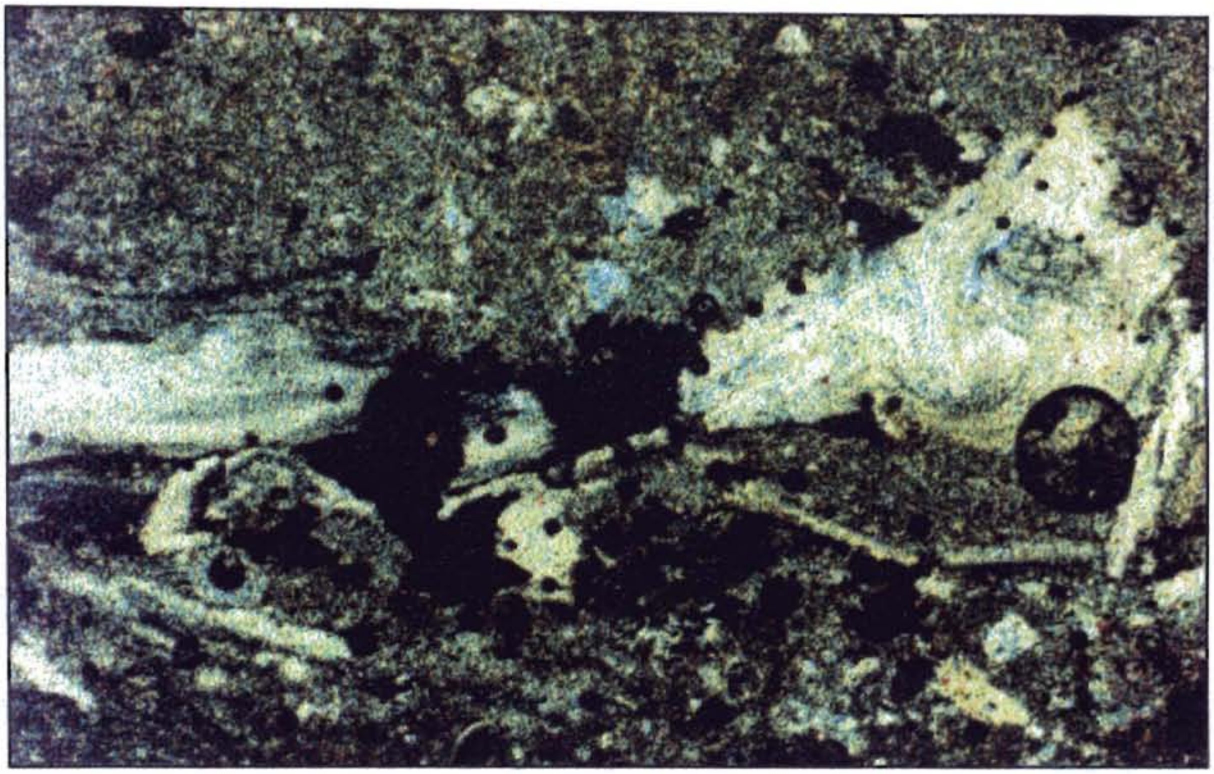

Figure 95. Photograph of thin-section CQ13 (unit 9) from Location 6, Coffeyville Quarry showing brachiopod shell in a micrite and microspar matrix. Extensive dissolution occurred in this sample.

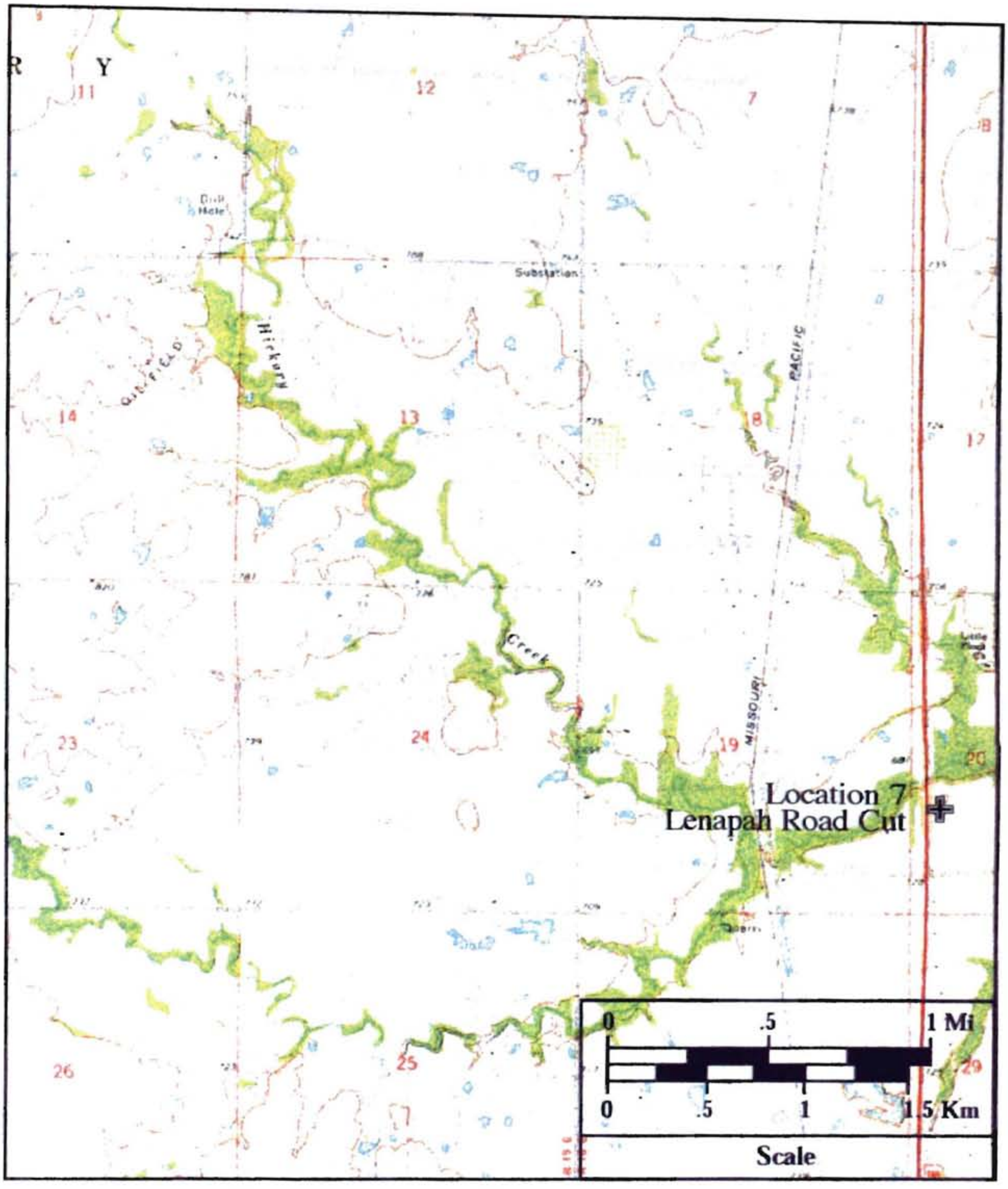


Figure 96. Location 7, Lenapah Road Cut, along Highway 169 at the W. line, NW, SW, Sec. 20, T. 28 N., R. 16 E., Nowata County, Oklahoma.

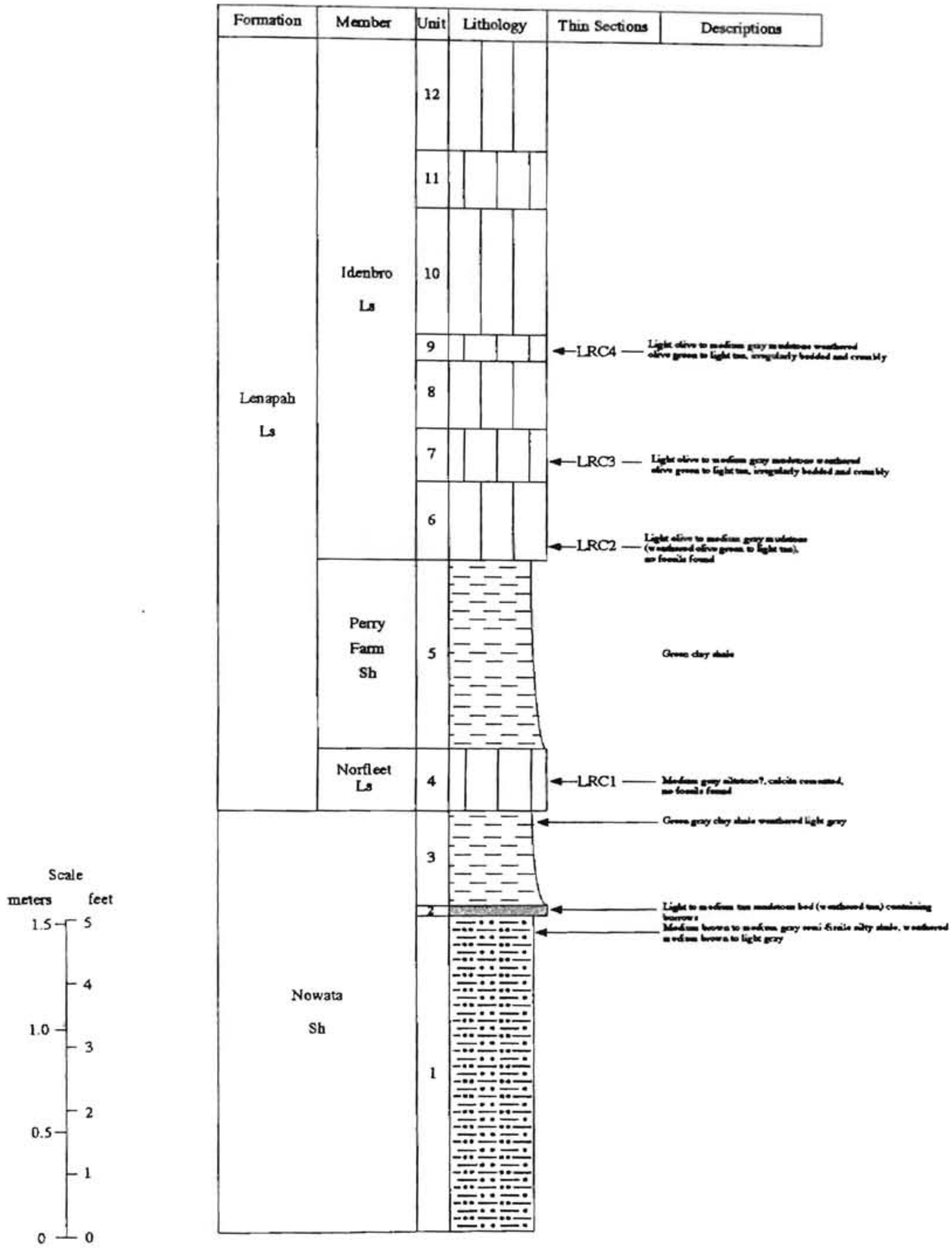


Figure 97. Measured section of Location 7, Lenapah Road Cut along E. line, W/2, W/2, W/2, SW, Sec. 20, T. 28 N., R. 16 E., 2.7-2.9 miles north of HW10 (East) on HW169, Nowata County, Oklahoma.

Location 8, Hancock Bridge

The creek at SW, SE, Sec. 10, T. 27 N., R. 16 E., Nowata County, Oklahoma, exposes in ascending order, the Amoret Limestone Member, Lake Neosho Shale Member, and Worland Limestone Member (Figure 98). The Bandera Shale and the Nowata Shale are not seen at this exposure. The measured section with descriptions and thin-section sample numbers is in Figure 99. This location is surrounded by trees, making photographs dark (Figure 100).

The Amoret Limestone Member is 2 feet 4 inches (71.2 centimeters) thick. It is divided into two lithologic units. See Figure 101. The lower bed (unit 1) of the Amoret is a 1 foot 6 inch (45.8 centimeter) thick very hard, black, semi-fissile mudstone, weathered dark gray to black. The uppermost bed (unit 2) of the Amoret is a 10 inch (25.4 centimeter) thick, very thin bedded (.5 inch (1.5 centimeter) beds) hard, dense, medium to dark gray mudstone, weathered medium brown to olive brown (Figure 102). No fossils were observed in unit 2.

The Lake Neosho Shale Member is eight feet (2.8 meters) thick. It is divided into two lithologic units. The lower part (unit 3), is a 4 foot 5 inch (1.35 meter) thick black fissile shale (Figure 103). The upper part (unit 4), is a 4 foot 9 inch (1.45 meter) thick, dark gray, semi-fissile clay shale, weathered olive green to medium gray.

The Worland Limestone Member is 5 feet 4 inches (1.63 meters) thick and has been divided into 4 units by the author based on bedding (Figure 104). The lowest bed (unit 5) of the Worland is a 10 to 12 inch (.25 to .30 meter) thick light gray and yellowish brown fossiliferous wackestone weathered light to medium gray. It contains brachiopod, ostracod, echinoderm, and bryozoan fragments. The fossils are filled with sparry calcite (Figure 105). Unit 6 is a 10 to 12 inch (.25 to .30 meter) thick light gray and tan fossiliferous algal wackestone, weathered light to medium gray. It contains brachiopod, bryozoan, echinoderm, and ostracod fragments filled with sparry calcite. Unit 7 is a 9 to 10 inch (.23 to .25 meter) thick bed. Unit 8 is a 3 foot (.92 meter) thick inter-

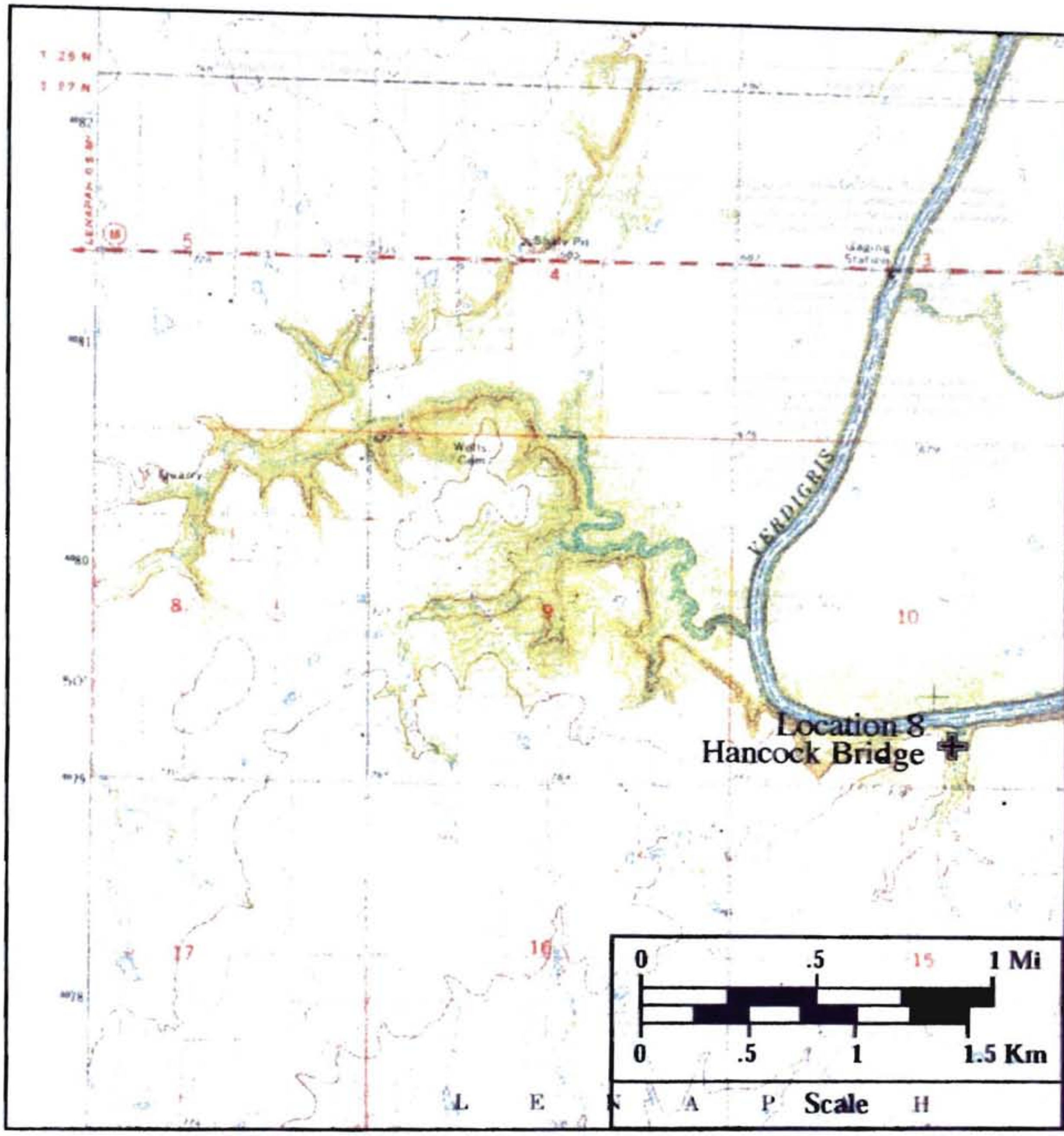


Figure 98. Location 8, Hancock Bridge along creek at SW, SE, Sec. 10, T. 27 N., R. 16 E., Nowata County, Oklahoma.

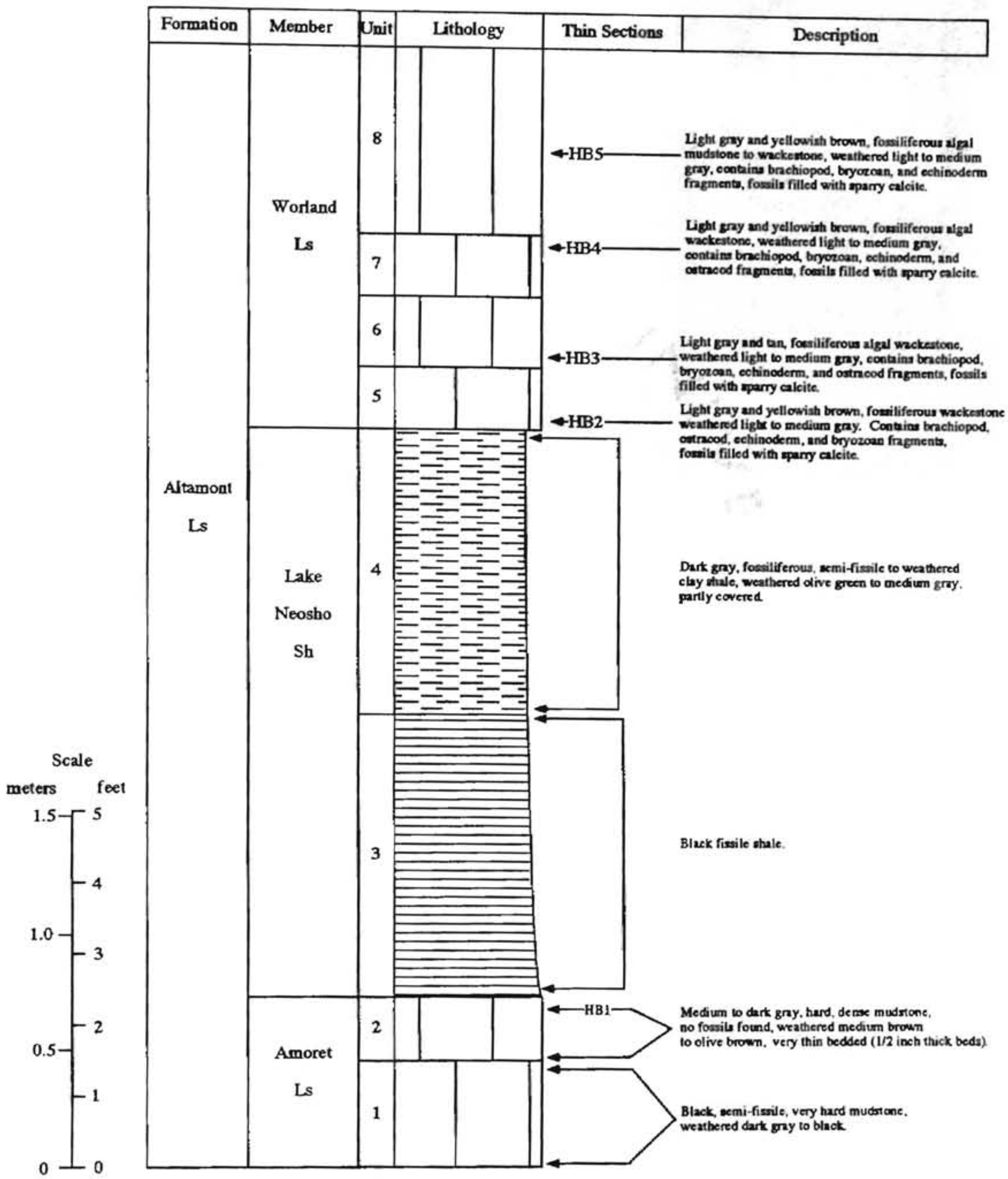


Figure 99. Measured section of Location 8, Hancock Bridge along creek at SW, SE, Sec. 10, T. 27 N., R. 16 E., Nowata County, Oklahoma.

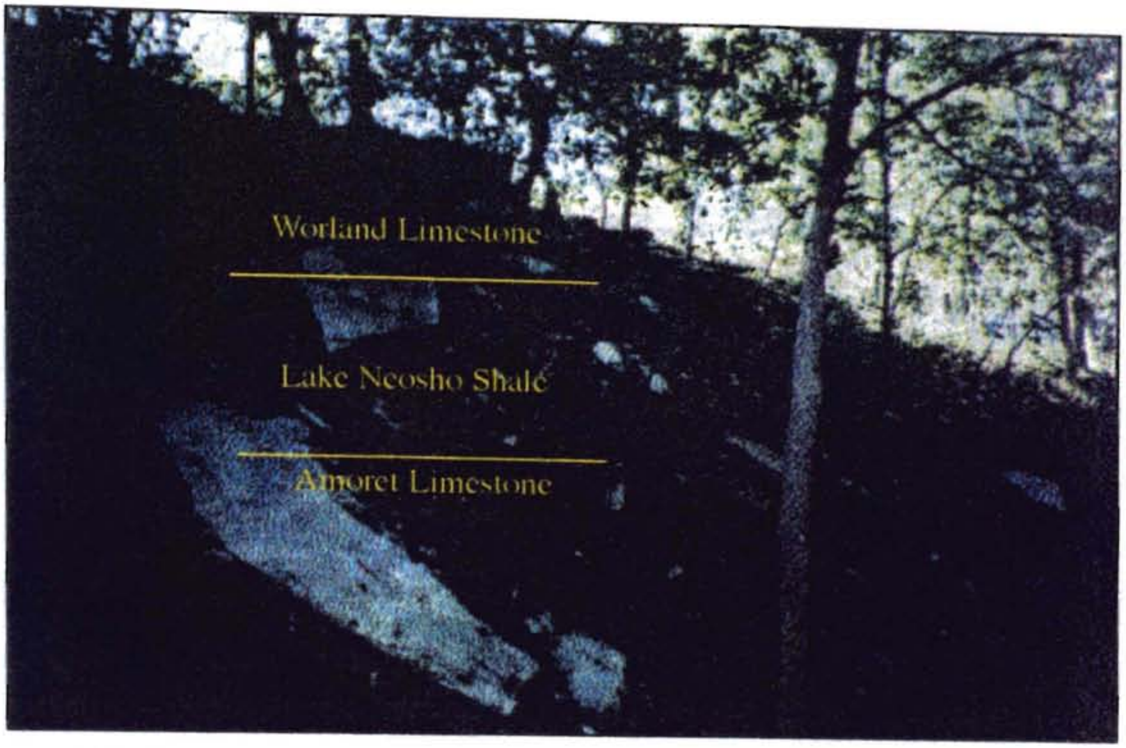


Figure 100. Photograph of Location 8, Hancock Bridge.


Figure 101. Amoret Limestone at Location 8, Hancock Bridge.

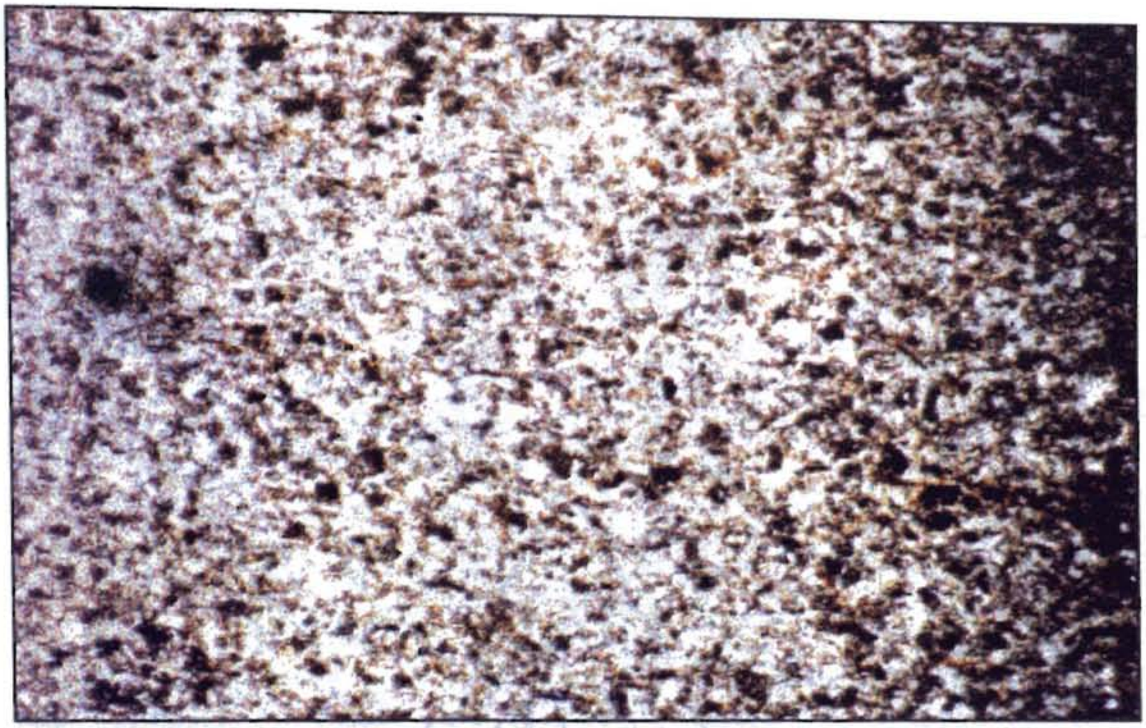

Figure 102. Thin section HB1 (unit 2, Amoret Limestone) from Location 8, Hancock Bridge.

Figure 103. Lake Neosho Shale at Location 8, Hancock Bridge.

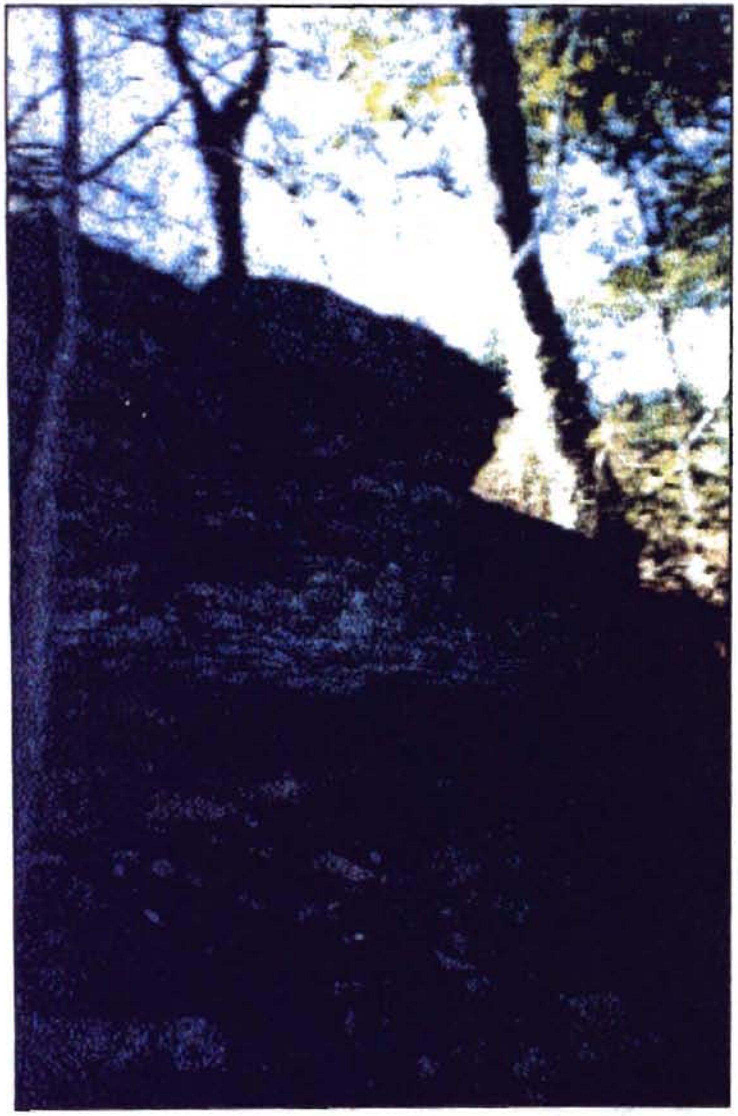

Figure 104. Worland Limestone at Location 8, Hancock Bridge.

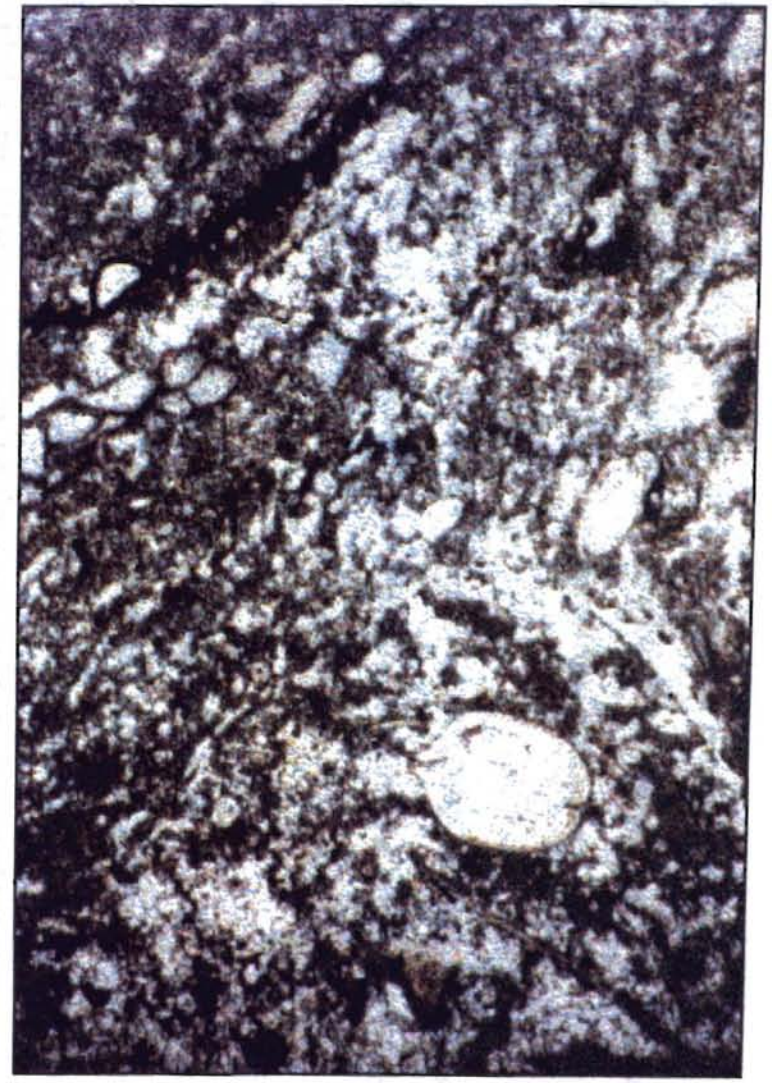

Figure 105. Worland Limestone thin section sample HB2 Location 8, Hancock Bridge.

val of thin and irregular beds. This interval is a light gray and yellowish brown fossiliferous algal mudstone to wackestone weathered light to medium gray. It contains brachiopod, bryozoan, and echinoderm fragments filled with sparry calcite.

Location 9, Bellco Quarry

The units exposed in the quarry at the C. of W/2, W/2, SW, Sec. 26, T. 26 N., R. 16 E., Nowata County, Oklahoma (Figure 106) are the Laberdie Limestone Member, Bandera Shale, and Amoret Limestone Member (Figure 107). See Figure 108 for photograph of Bellco Quarry.

The Laberdie Limestone Member was measured to be 15 feet 10 inches (4.83 meters) thick here (Figure 109). The author started measurements from the quarry floor. The Laberdie is certainly much thicker here than the author's measurement. The author divided it into 10 units based on lithology and bedding. It is made of straight and laterally continuous limestone beds, some of which are separated by thin shale partings.

The Bandera Shale is 24 inches (.61 meters) thick in the quarry (Figure 110). The author sampled the Bandera in detail and divided it into 3 units based on lithology. Unit 11, 22 to 24 inches (.56 to .61 meters) below the top of the Bandera, is an orange clay shale containing a few brachiopods and molluscs which are not pyritized. Unit 12, 12 to 22 inches (.31 to.56 meters) below the top of the Bandera is an orange clay shale containing no fossils. Unit 12 contains coal streaks in the upper 8 inches (20.3 centimeters). See Figure 111. Unit 13, 0 to 12 inches (0 to 30.5 centimeters) below the top of the Bandera, is a dark gray semi-fissile clay shale containing phosphatic inarticulate brachiopods, the amounts of which increase upwards in this unit.

The Amoret Limestone Member is very thin at this location (Figure 112). The author measured a total of 8 inches (20.3 centimeters) of Amoret and divided it into two units based on bedding. Both units are light gray weathered light gray to light tan. Unit 14, the lowest bed of the Amoret, is 3 inches (7.6 centimeters) thick. It is a fossiliferous wackestone containing brachiopods, echinoderms, and phylloid algae. Unit 15 is a 5

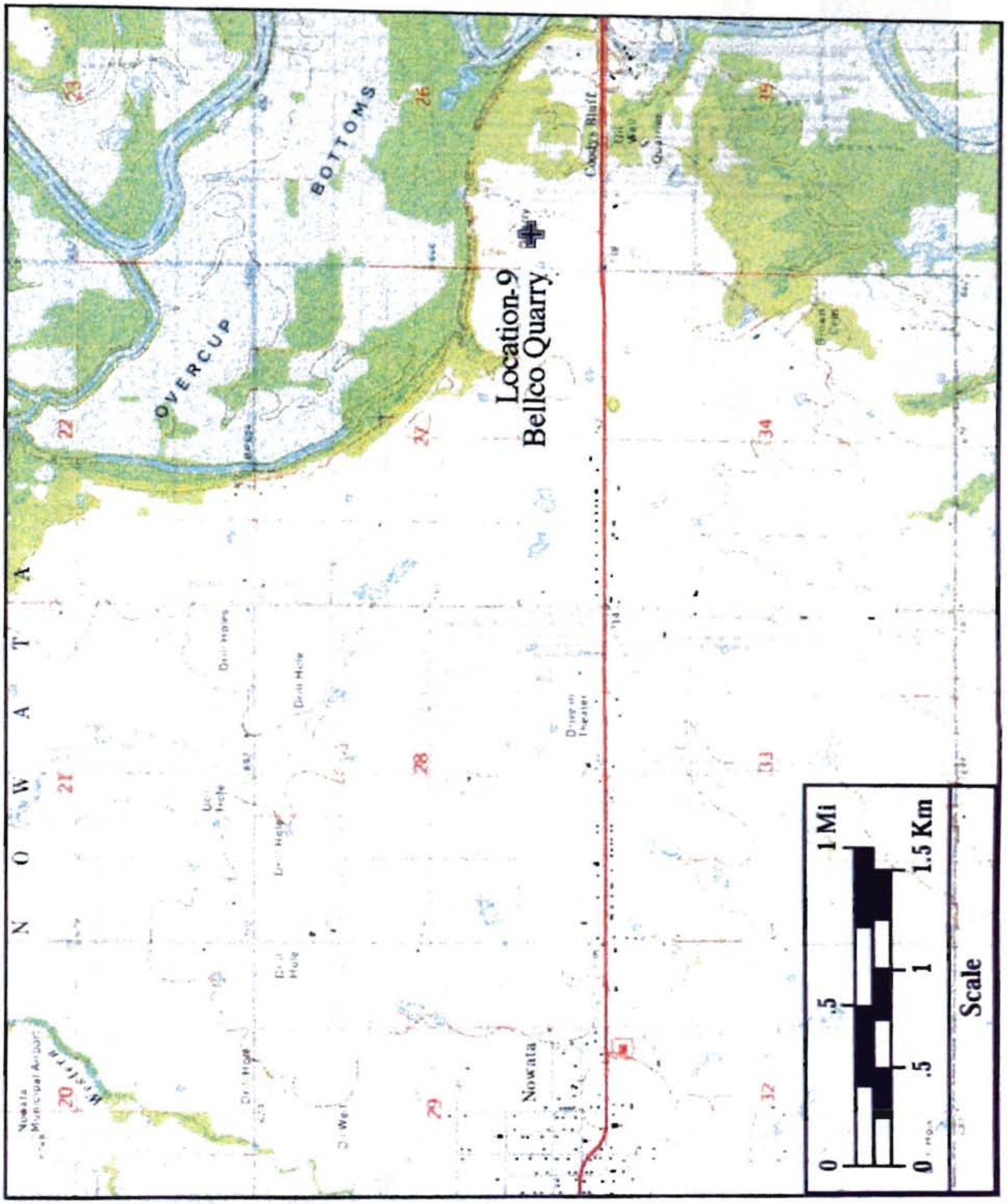


Figure 106. Location 9, Bellco Quarry, C. of W/2, W/2, SW, Sec. 26, T. 26 N., R. 16 E., Nowata County, Oklahoma.

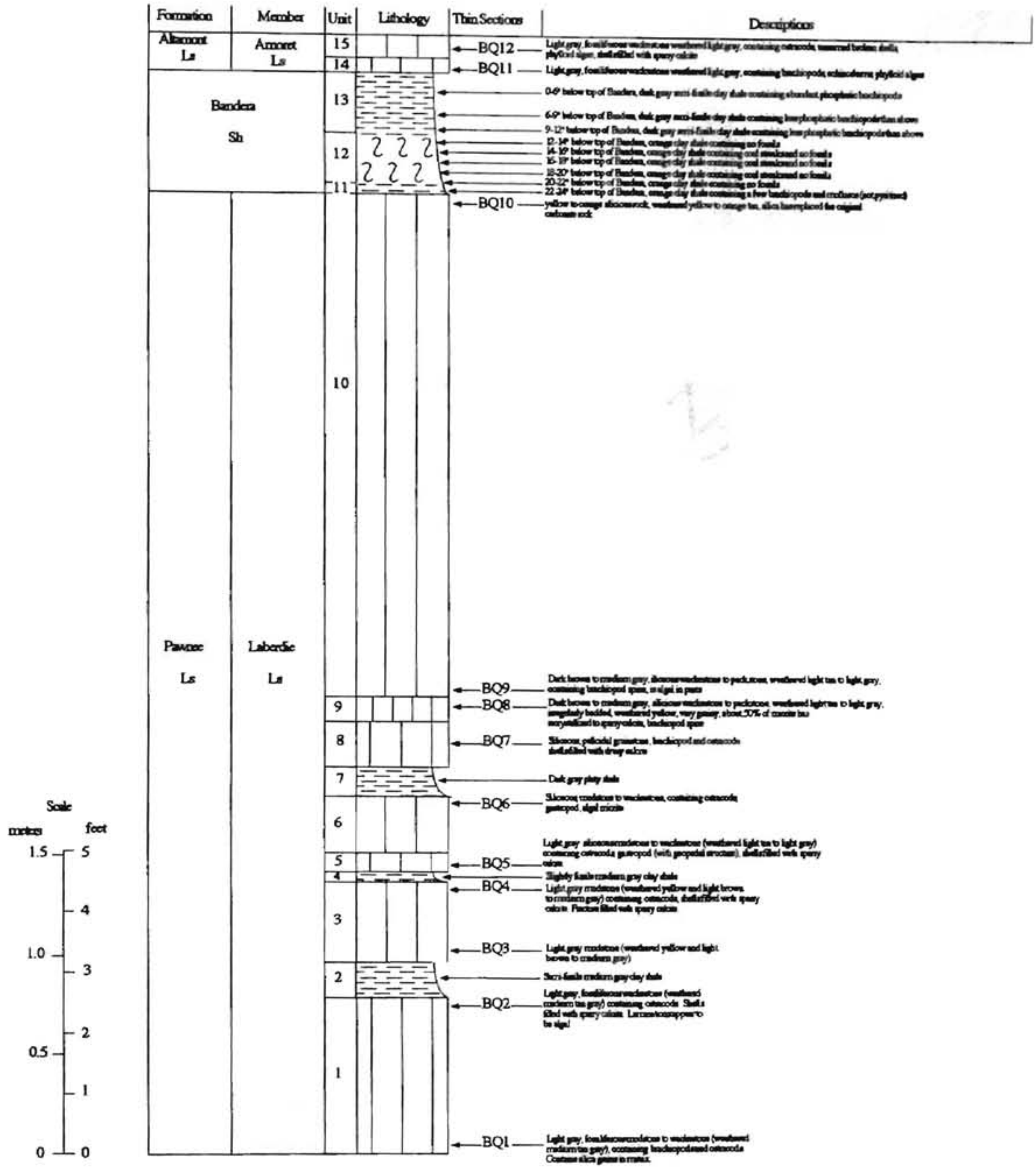

Figure 107. Measured section for Location 9, Bellco Quarry, C. of W/2, W/2, SW, Sec. 26, T. 26 N., R. 16 E., Nowata County, Oklahoma.

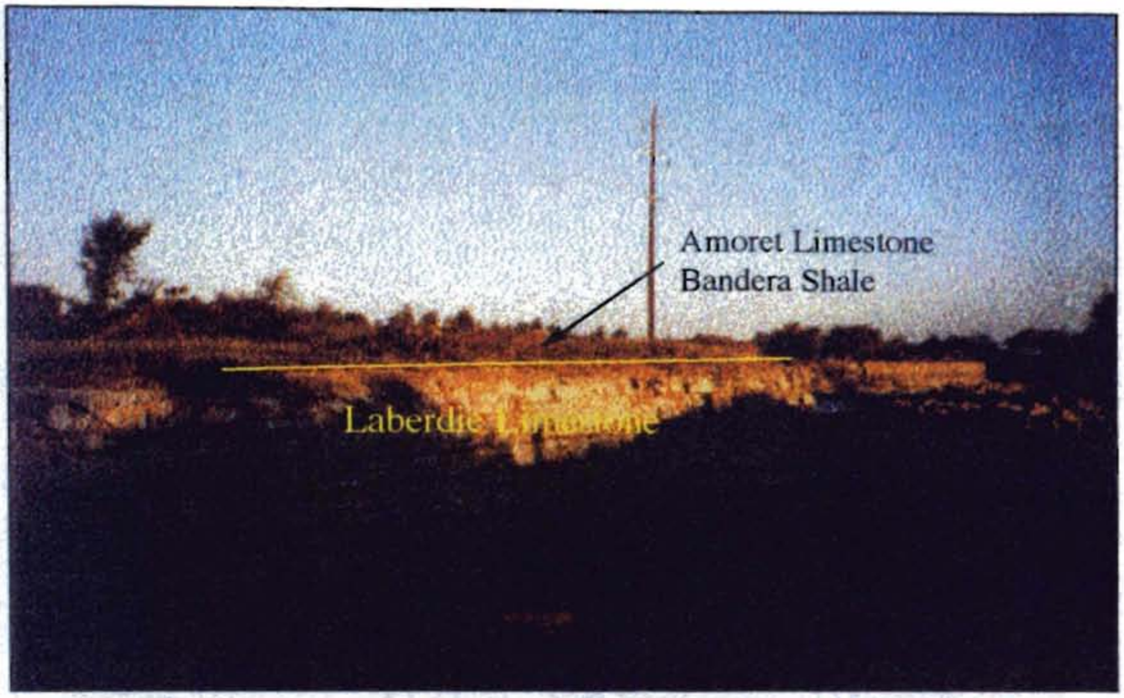


Figure 108. Location 9, Bellco Quarry, C. of W/2, W/2, SW, Sec. 26, T. 26 N., R. 16 E., Nowata County, Oklahoma.

Figure 109. Laberdie Limestone at Location 9, Bellco Quarry.

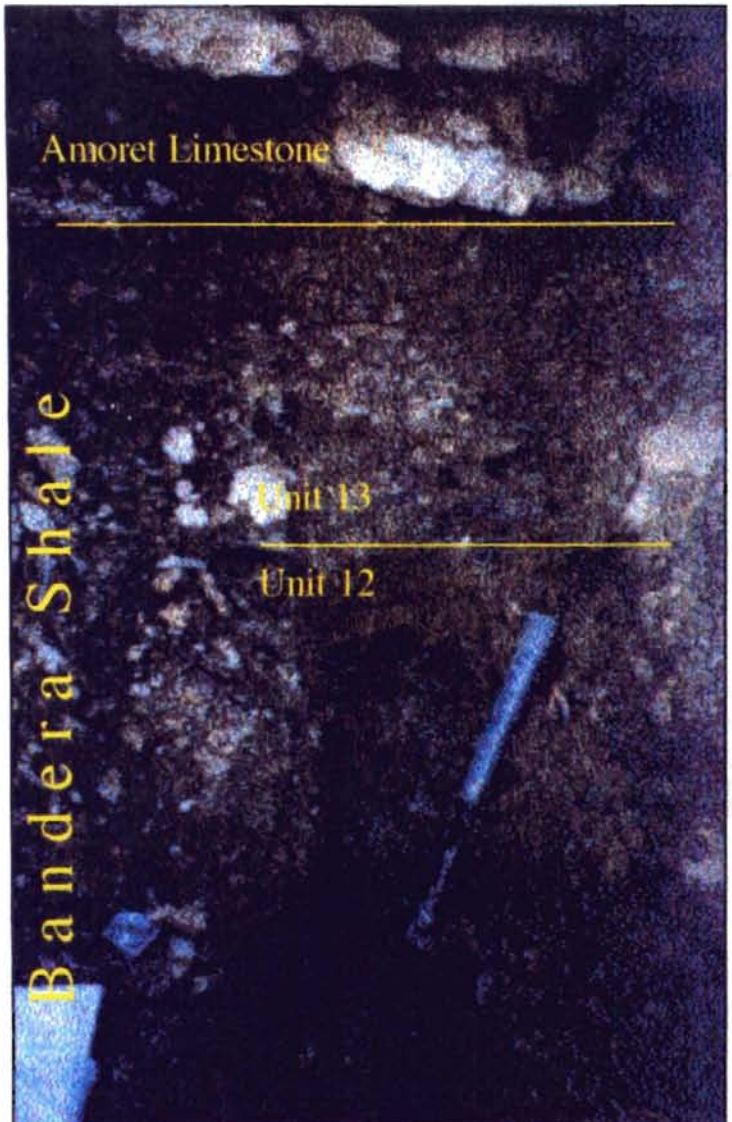


Figure 110. Bandera Shale at Location 9, Bellco Quarry.

Figure 111. Bandera Shale at Location 9, Bellco Quarry.

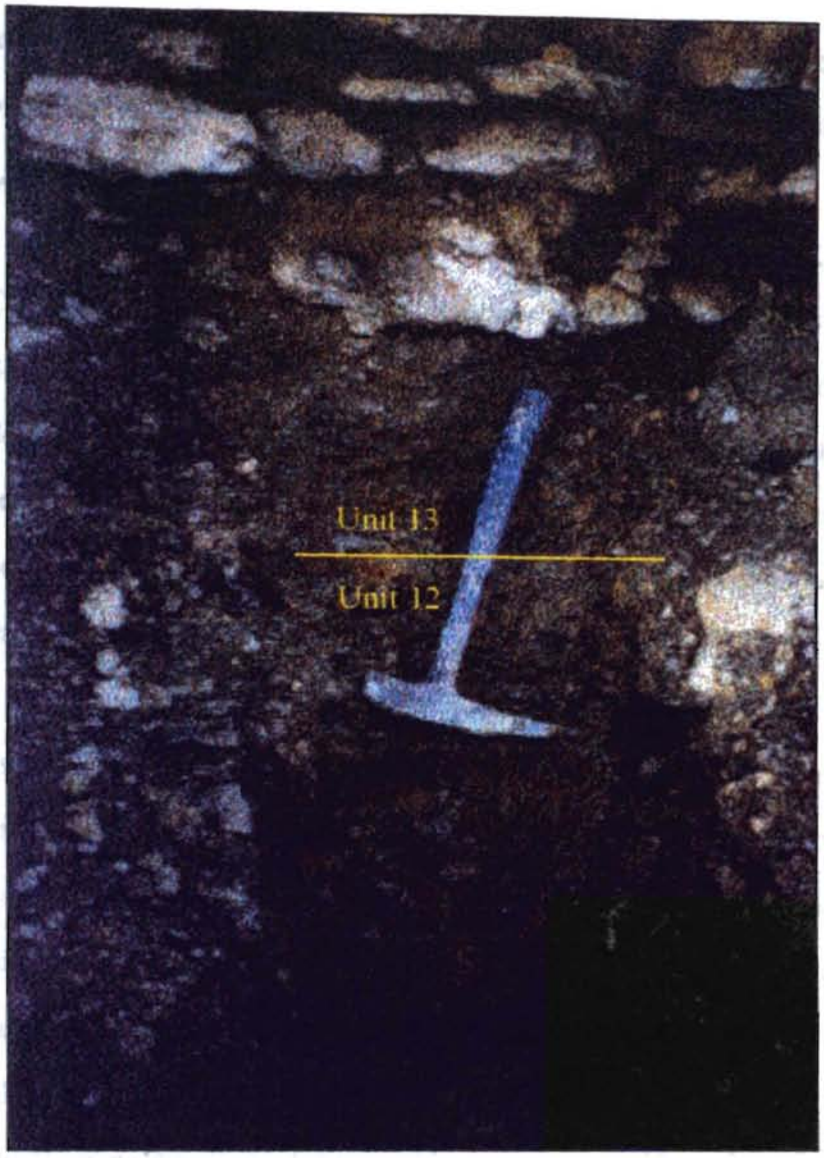


Figure 112. Bandera Shale and Amoret Limestone at Location 9, Bellco Quarry.

inch (12.7 centimeter) thick fossiliferous wackestone, containing ostracods, unnamed broken shells, and phylloid algae. Sparry calcite fills the shells.

Location 10. Oologah Dam

The dam on Lake Oologah at SW, NW, NE, Sec. 2, T. 22 N., R. 15 E., Rogers County, Oklahoma (Figure 113) exposes the Sageeyah Limestone Member, Childers School Limestone Member, Anna Shale Member, and Laberdie Limestone Member. See Figure 114. The Sageeyah Limestone Member of the Labette Shale is not present in any of the outcrops used in this study north of here. This section exhibits a distinctive vertical profile (Figure 115). The Sageeyah and Childers School Limestone Members protrude further than the Laberdie Limestone.

The author measured the Sageeyah Limestone to be 15 feet 5 inches (4.7 meters) thick. The lake level prevented any measurement greater than this. The thick Sageeyah exhibits irregular, sharp bedding planes between its massive beds (Figure 116). These beds contain hummocky fracture patterns within them. The author divided the massive Sageeyah into three units based on bedding. Unit 1 is 3 feet 10 inches (1.2 meters) thick. Unit 2 is 5 feet (1.5 meters) thick. Unit 3 is 6 feet 7 inches (2.0 meters) thick. The Sageeyah (all three units) is a very light gray fossiliferous, algal wackestone which weathers pale yellowish brown. It contains brachiopods, echinoderms, forams, and green algae. Drusy spar infills fossils. The Sageeyah-Childers School contact is sharp and irregular (wavy) (Figure 117).

The Childers School Limestone Member is a 2 feet 3 inch (68.6 centimeter) thick bed (Figure 117). It is light to medium gray and weathers light gray and pale yellowish brown. Two thin-sections were made from the Childers School. Thin-section sample OD7 was taken at the Childers School base. This sample is a fossiliferous grainstone, containing brachiopods, echinoderms, and forams. Thin-section sample OD8, taken from the top of the Childers School bed, is a fossiliferous grainstone containing brachiopods, echinoderms, and forams.

inch (12.7 centimeter) thick fossiliferous wackestone, containing ostracods, unnamed broken shells, and phylloid algae. Sparry calcite fills the shells.

Location 10, Oologah Dam

The dam on Lake Oologah at SW, NW, NE, Sec. 2, T. 22 N., R. 15 E., Rogers County, Oklahoma (Figure 113) exposes the Sageeyah Limestone Member, Childers School Limestone Member, Anna Shale Member, and Laberdie Limestone Member. See Figure 114. The Sageeyah Limestone Member of the Labette Shale is not present in any of the outcrops used in this study north of here. This section exhibits a distinctive vertical profile (Figure 115). The Sageeyah and Childers School Limestone Members protrude further than the Laberdie Limestone.

The author measured the Sageeyah Limestone to be 15 feet 5 inches (4.7 meters) thick. The lake level prevented any measurement greater than this. The thick Sageeyah exhibits irregular, sharp bedding planes between its massive beds (Figure 116). These beds contain hummocky fracture patterns within them. The author divided the massive Sageeyah into three units based on bedding. Unit 1 is 3 feet 10 inches (1.2 meters) thick. Unit 2 is 5 feet (1.5 meters) thick. Unit 3 is 6 feet 7 inches (2.0 meters) thick. The Sageeyah (all three units) is a very light gray fossiliferous, algal wackestone which weathers pale yellowish brown. It contains brachiopods, echinoderms, forams, and green algae. Drusy spar infills fossils. The Sageeyah-Childers School contact is sharp and irregular (wavy) (Figure 117).

The Childers School Limestone Member is a 2 feet 3 inch (68.6 centimeter) thick bed (Figure 117). It is light to medium gray and weathers light gray and pale yellowish brown. Two thin-sections were made from the Childers School. Thin-section sample OD7 was taken at the Childers School base. This sample is a fossiliferous grainstone, containing brachiopods, echinoderms, and forams. Thin-section sample OD8, taken from the top of the Childers School bed, is a fossiliferous grainstone containing brachiopods, echinoderms, and forams.

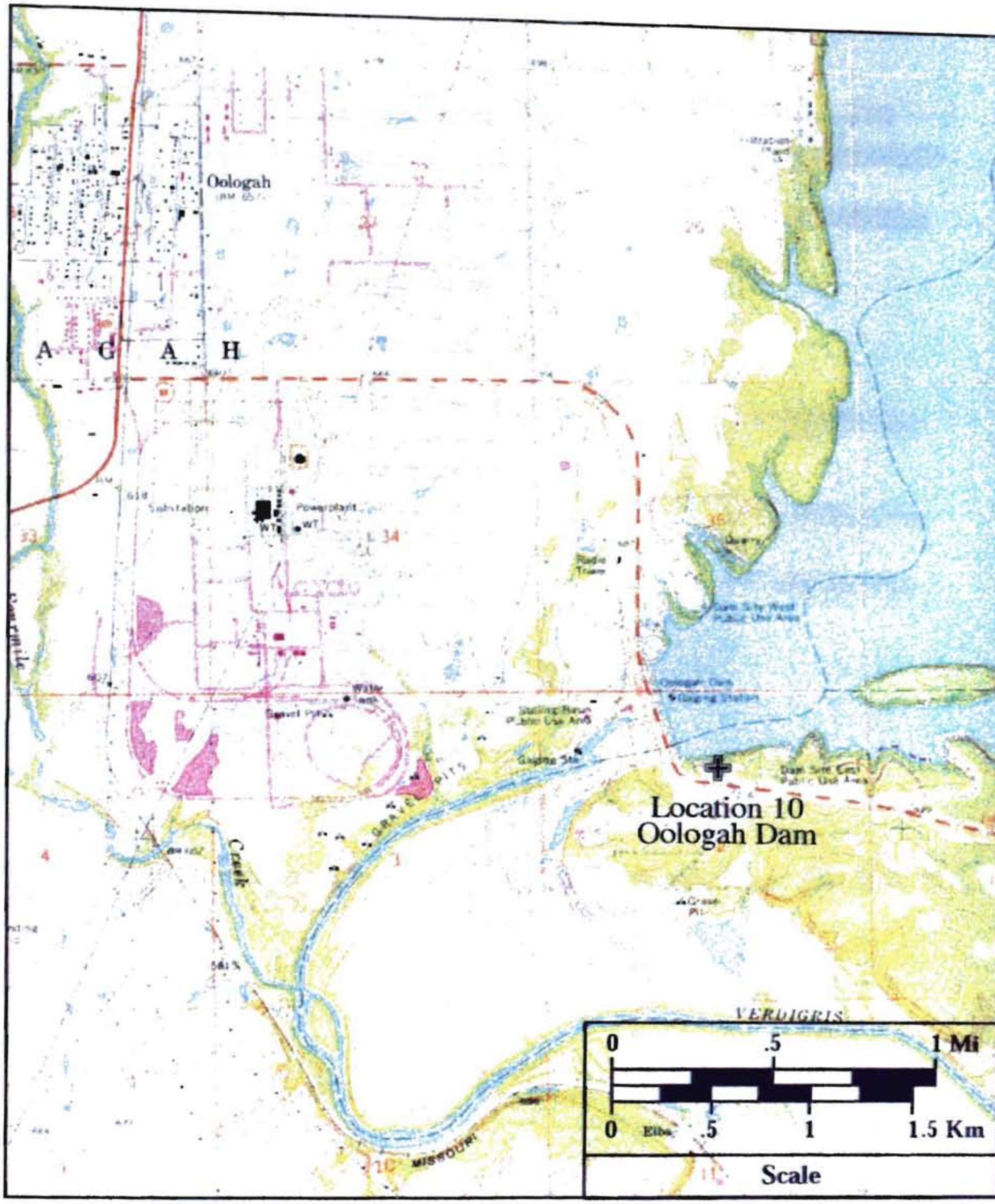


Figure 113. Location 10, Oologah Dam, SW, NW, NE, Sec. 2, T. 22 N., R. 15 E., Rogers County, Oklahoma.

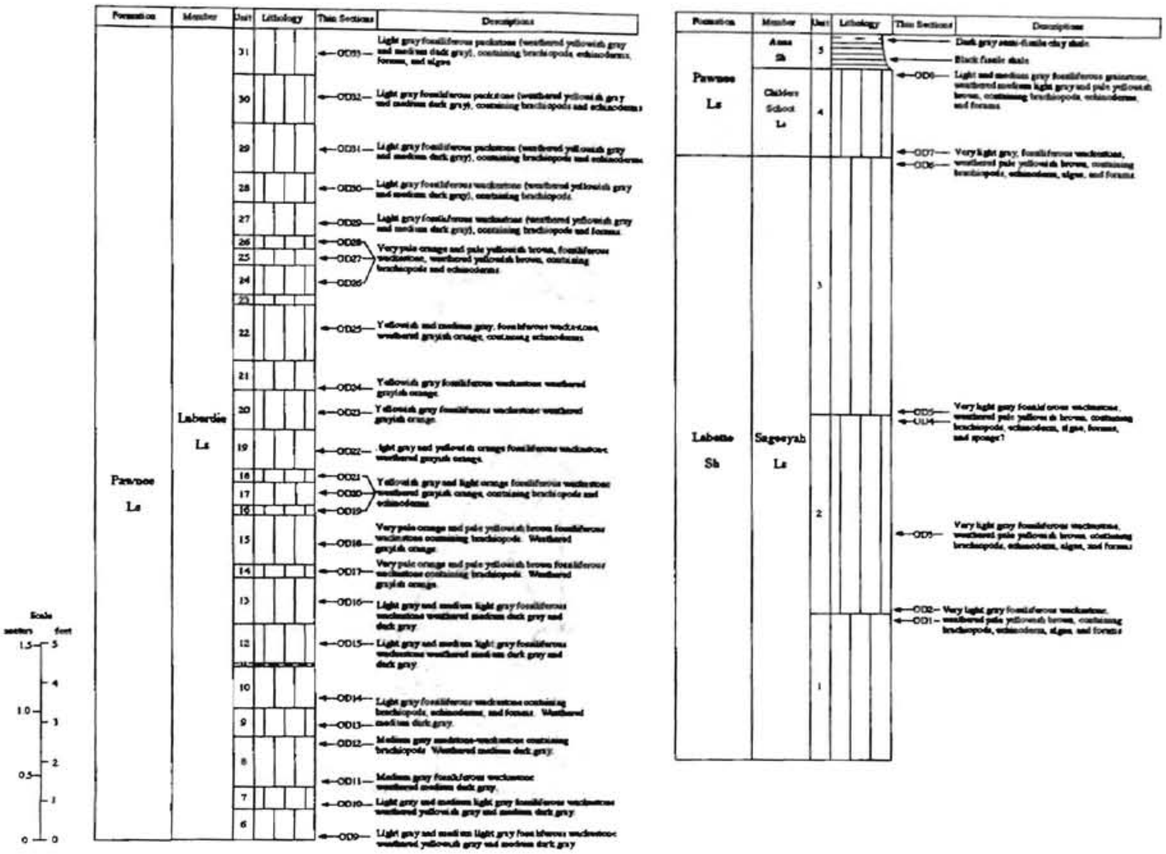

Figure 114. Measured section for Location 10, Oologah Dam, SW, NW, NE, Sec. 2, T. 22 N., R. 15 E., Rogers County, Oklahoma.

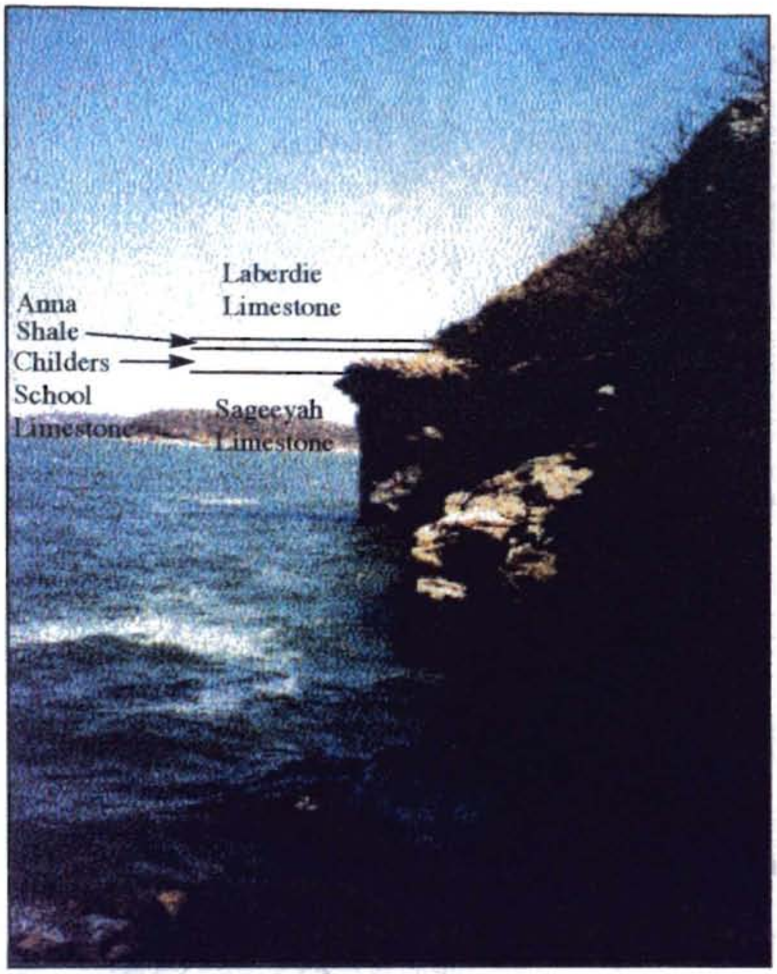


Figure 115. Photograph of vertical profile at Location 10.

Figure 116. Bedding plane within the Sageeyah Limestone at Location 10, Oologah Dam.

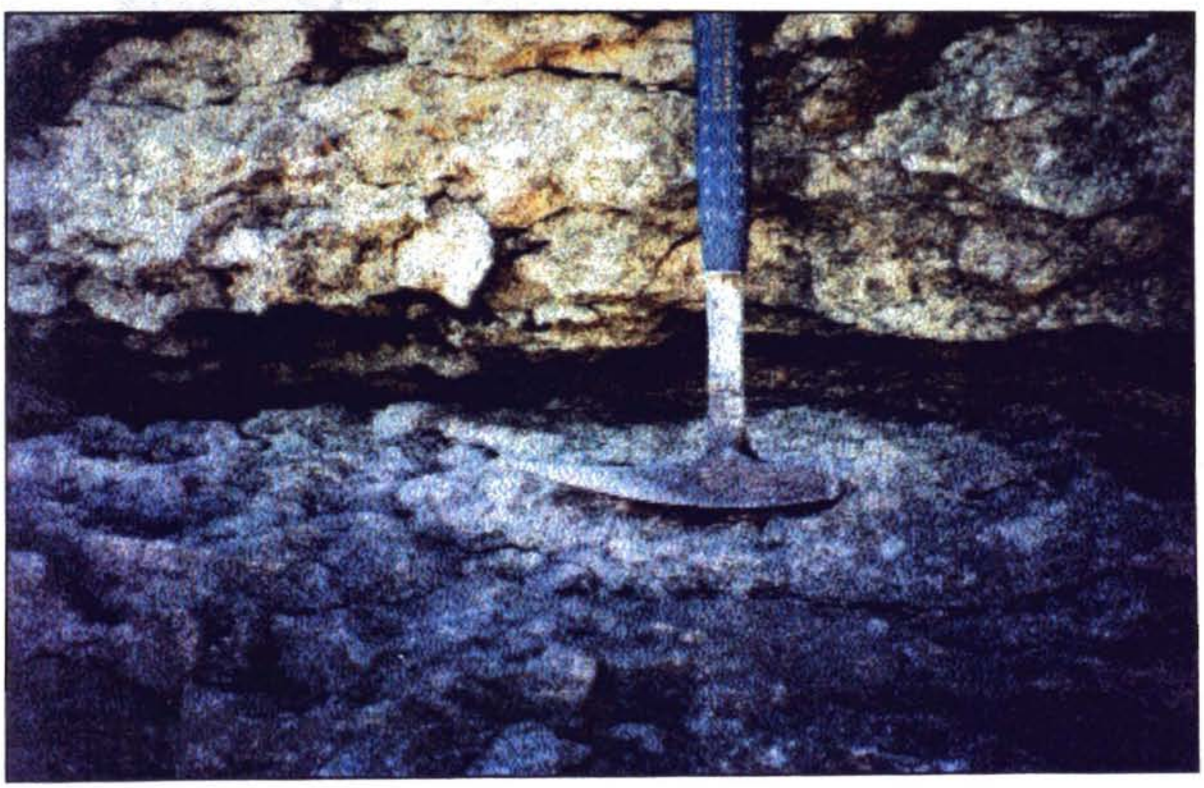

Figure 117. Contact between the Sageeyah Limestone and Childers School Limestone at Location 10, Oologah Dam.

The Anna Shale Member is one foot (30.5 centimeters) thick (Figure 118). The author divided it into two units based on lithology. The lower part, unit 5, is an eight inch (20.3 centimeter) thick black fissile shale. Unit 6 is a four inch (10.2 centimeter) thick dark gray semi-fissile clay shale.

The Laberdie Limestone Member was measured to be 20 feet 7 inches (6.28 meters) thick. See Figures 119 and 120. The author divided it into 26 units based on bedding and lithology. The Laberdie exhibits sharp, wavy bedding planes between its relatively thin beds. It is a fossiliferous wackestone in all of the beds except the upper three (units 30-32) which are fossiliferous packstones. In general, the weathered color of the Laberdie Limestone lightens upward from medium dark gray and dark gray to medium dark gray and grayish orange. Drusy spar infills fossils. Blocky calcite, vugs, and chert are present in parts of the Laberdie Limestone. No dolomite was found in units of the Laberdie. The unweathered color of the Childers School Limestone (medium light gray) is darker than the unweathered color of the Sageeyah Limestone (very light gray) and the Laberdie Limestone (light gray/medium light gray/yellowish gray and brown).

Location 11, Oologah Road Cut

This exposure is on the south side of Highway 88, southeast of the Oologah Dam at the middle of the N. line of NW, SW, Sec. 6, T. 22 N., R. 16 E., Rogers County, Oklahoma (Figure 121). The contact between the shale facies and the Sageeyah Limestone Member of the Labette Shale is exposed here. See Figure 122. The author examined the upper 2 feet (.61 meter) of the shale for microfossils and the very base of the Sageeyah Limestone for thin-section analysis. Two feet six inches (.76 meter) below the shale-Sageeyah Limestone Member contact, is a fossiliferous olive gray to medium brown shale weathered light yellow brown with orange streaks. Eight to 14 inches (20.3 to 35.6 centimeters) below the contact is a yellow-orange and light gray silty massive shale weathered yellow-orange and brown. One to 2 inches (2.5 to 5.1 centimeters)

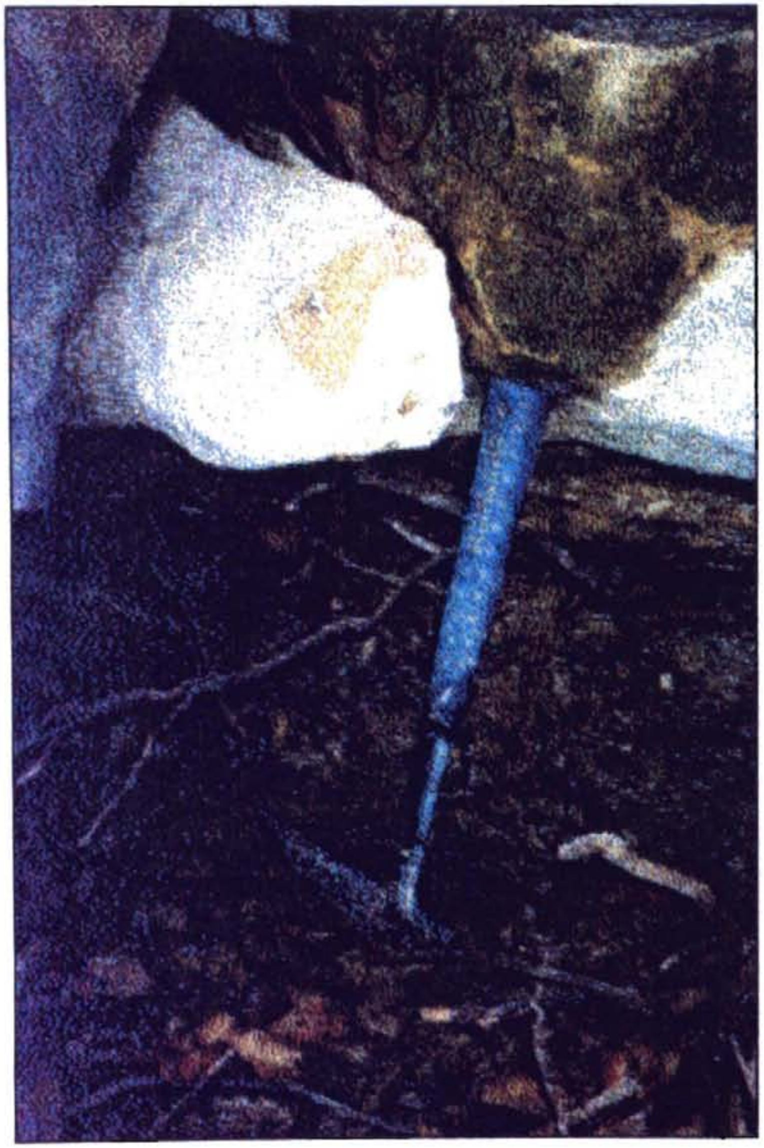

Figure 118. Anna Shale at Oologah Dam.

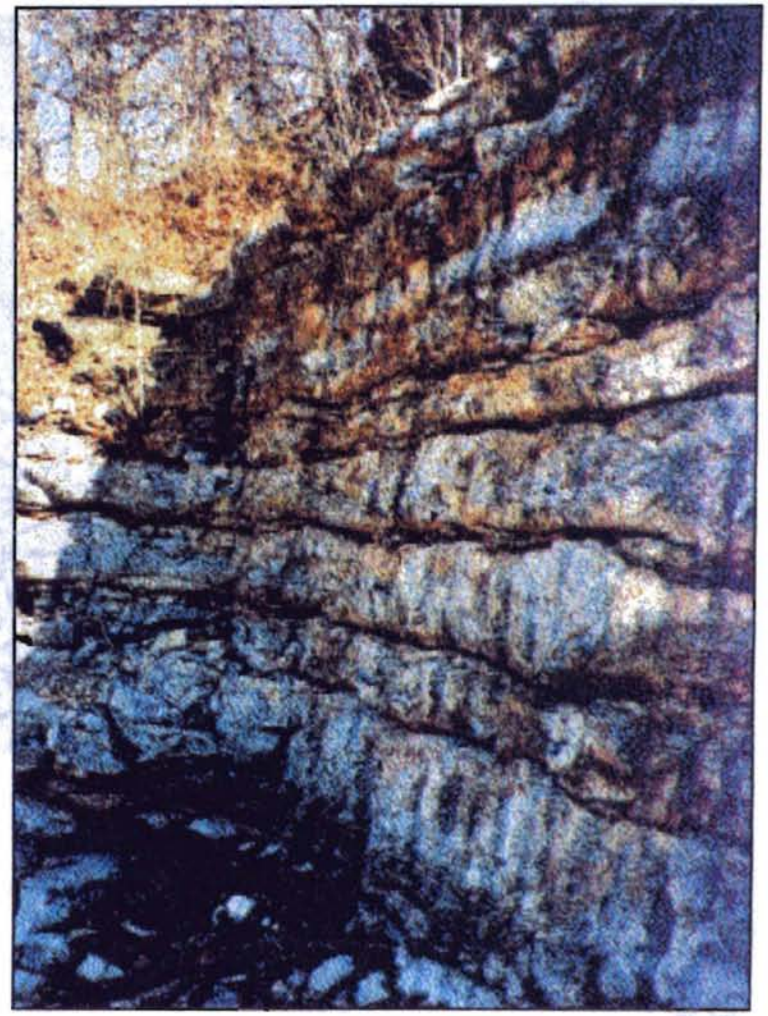

Figure 119. Lower part of Laberdie Limestone at Oologah Dam.

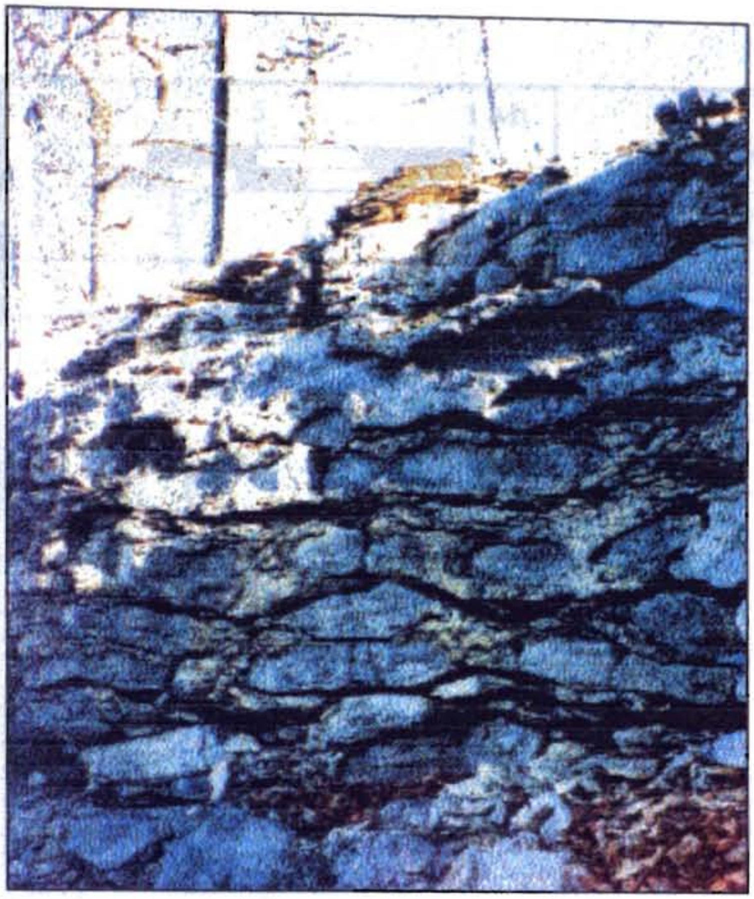

Figure 120. Upper part of Laberdie Limestone at Oologah Dam.


Figure 121. Location 11, Oologah Road Cut, middle of N. line, NW, SW, Sec. 6, T. 22 N., R. 16 E., Rogers County, Oklahoma.

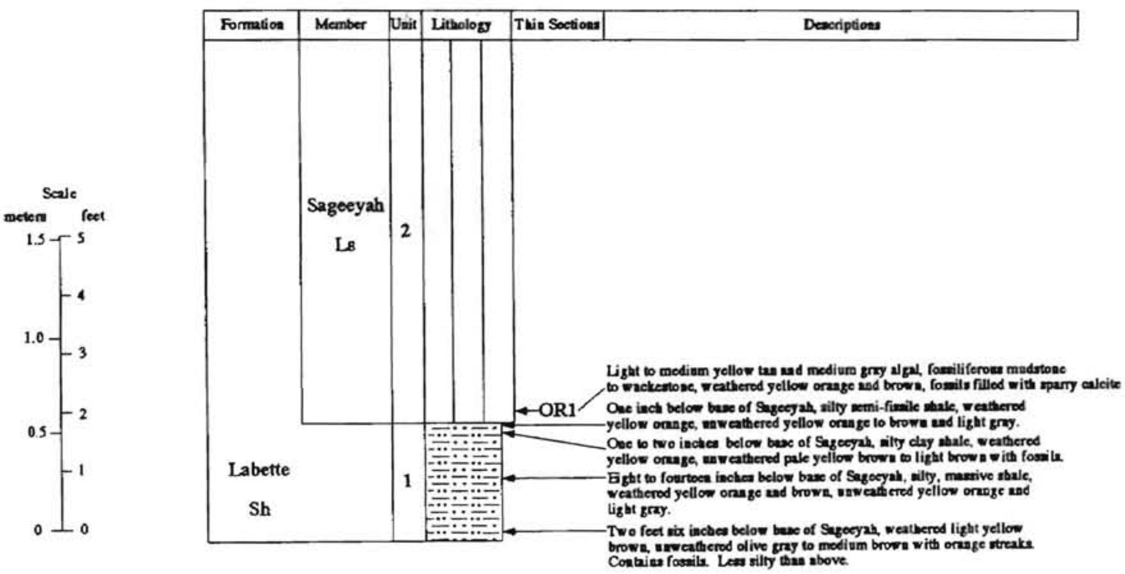


Figure 122. Measured section for Location 11, Oologah Road Cut, middle of N. line, NW, SW, Sec. 6, T. 22 N., R. 16 E., Rogers County, Oklahoma.

below the contact is a fossiliferous pale yellow-brown to light brown silty clay shale weathered yellow-orange. Zero to 1 inch (2.0 to 2.5 centimeters) below the contact is a yellow-orange to brown and light gray silty semi-fissile shale weathered yellow-orange.

The author measured 6 feet 7 inches (2.0 meters) of the massive Sageeyah Limestone. The base of this bed is a light to medium yellow tan and medium gray, algal, fossiliferous mudstone to wackestone which weathers yellow-orange and brown. Fossils are filled with sparry calcite. Figure 123 is a photograph of the thin-section sample OR1.

Location 12, Tulsa Road Cut

Location 12 is at the E. line of NE, Sec. 9, T. 20 N., R. 14 E., Tulsa County, Oklahoma (Figure 124). This is a thick exposure of the Sageeyah Limestone Member, Childers School Limestone Member, Anna Shale Member, and Laberdie Limestone Member. This location was blasted to build a new road. Since the author studied this location, the road has been paved and the rock face covered with a safety fence. The total thickness measured here ranges from 57.5 to 59 feet (17.5 to 18.0 meters). See Figure 125. The author collected samples from this section while walking up the slope of the dirt road before it was paved (Figures 126 and 127).

The Sageeyah Limestone Member is 37 feet (11.3 meters) thick here. The author has divided the Sageeyah into 27 units. A change in color and bedding characteristics occurs between units 14 and 15 of the Sageeyah. The lower part of the Sageeyah (units 1 through 14) is a medium to dark gray fossiliferous wackestone containing silica and weathering medium to dark gray. These units contain brachiopod spines, echinoderm fragments, and forams. Shells are filled with drusy and blocky sparry calcite. The bedding planes in these units are straight. Additionally, chert was found in the matrix in units 4 through 14. The upper part (units 15 through 27) is a light to medium gray fossiliferous wackestone weathered light gray and medium brownish yellow. These units contain forams, brachiopods, echinoderms, bryozoans, and coral. Shells are filled with

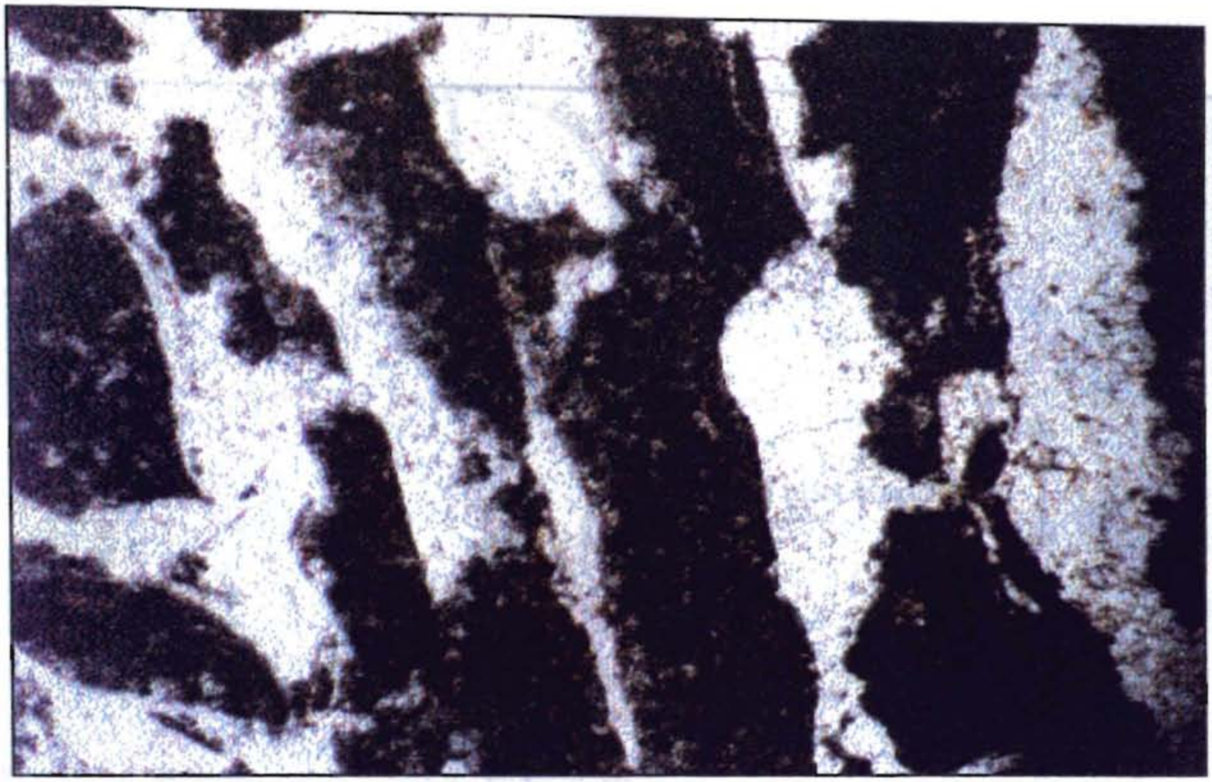

Figure 123. Thin-section OD1 from Location 11, Oologah Road Cut.

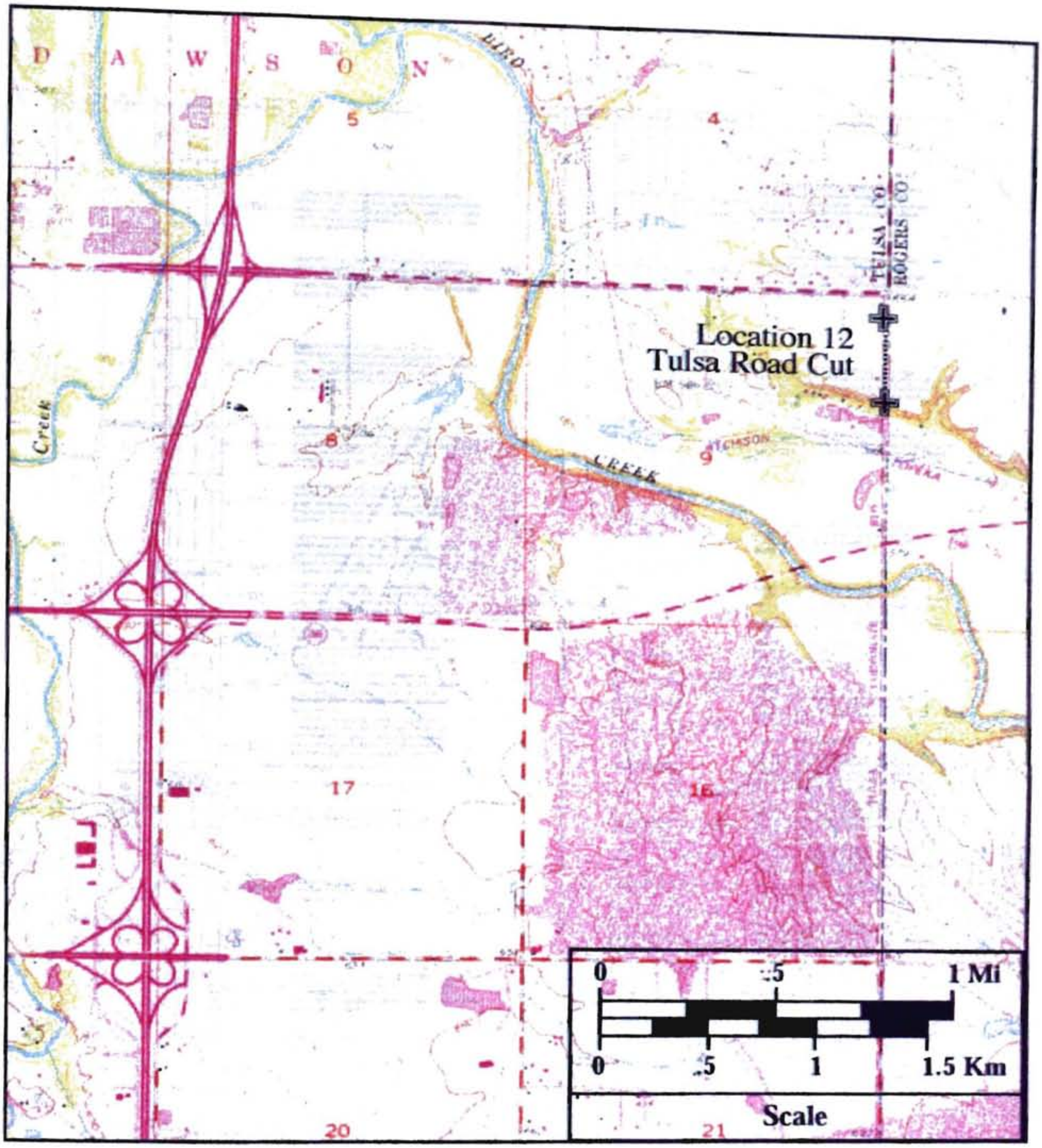


Figure 124. Location 12, Tulsa Road Cut, E. line of NE, Sec. 9, T. 20 N., R. 14 E., Tulsa County, Oklahoma.

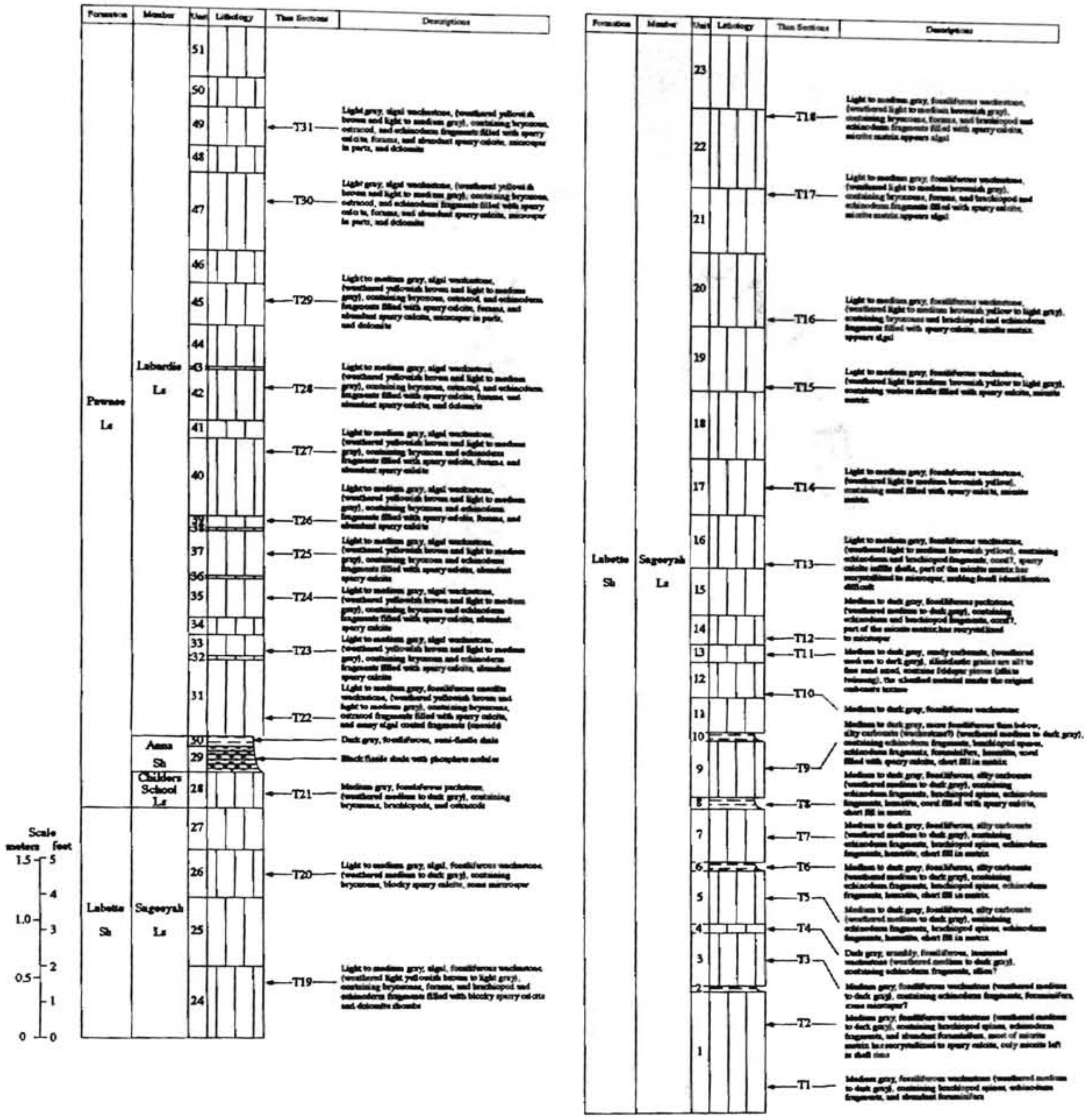

Figure 125. Measured section of Location 12, Tulsa Road Cut, E. line of NE, Sec. 9, T. 20 N., R. 14 E., Tulsa County, Oklahoma.

Figure 126. Location 12, Tulsa Road Cut.


Figure 127. Location 12, Tulsa Road Cut.

sparry calcite. The bedding planes in these units are slightly irregular. Microspar was found in units 15 and 16.

The Childers School Limestone Member varies between one inch and one foot (2.54 to 30.5 centimeters) thick here. It is a medium gray fossiliferous packstone weathered medium to dark gray. Fossils found in the Childers School include bryozoans, brachiopods, and ostracods. These are filled with sparry calcite.

The Anna Shale Member is between 8 and 12 inches (20.3 to 30.5 centimeters) thick here. It is divided into two units based on lithology. Unit 29 is a fossiliferous black fissile shale containing phosphate nodules. Unit 30 is a fossiliferous dark gray semi-fissile clay shale.

The Laberdie Limestone Member is 19 feet 10 inches (6.05 meters) thick and is divided into 21 units here. The Laberdie is a light to medium gray fossiliferous algal wackestone weathered yellowish brown and light to medium gray. It contains brachiopods, echinoderms, ostracods, and bryozoans filled with sparry calcite. Units 41 through 51 contain dolomite rhombs.

<u>Location 13, Garnett Plaza</u>

The creek at SE, SW, SW, Sec. 17, T. 19 N., R. 14 E., Tulsa County, Oklahoma (Figure 128), has exposed the top of the Amoret Limestone Member and the lower portion of the Lake Neosho Shale Member. See Figure 129.

The Amoret forms the creek bottom. Its mound-like form is exposed when the water level is not too high. It is a hematite-stained chaetetes rock. Figure 130 is a photograph of thin-section GP1 from the Amoret. The Lake Neosho contains two facies, a fossiliferous black fissile shale overlain by a fossiliferous dark gray clay shale.

## Interpretation of Data

Interpretations of the 13 surface study locations follows. Interpretations are presented using Heckel's (1977), Mitchum et al.'s (1977), Vail et al.'s (1977), Van Wagoner et al.'s (1988), and Posamentier et al.'s (1992) terminology. Included with interpreta-

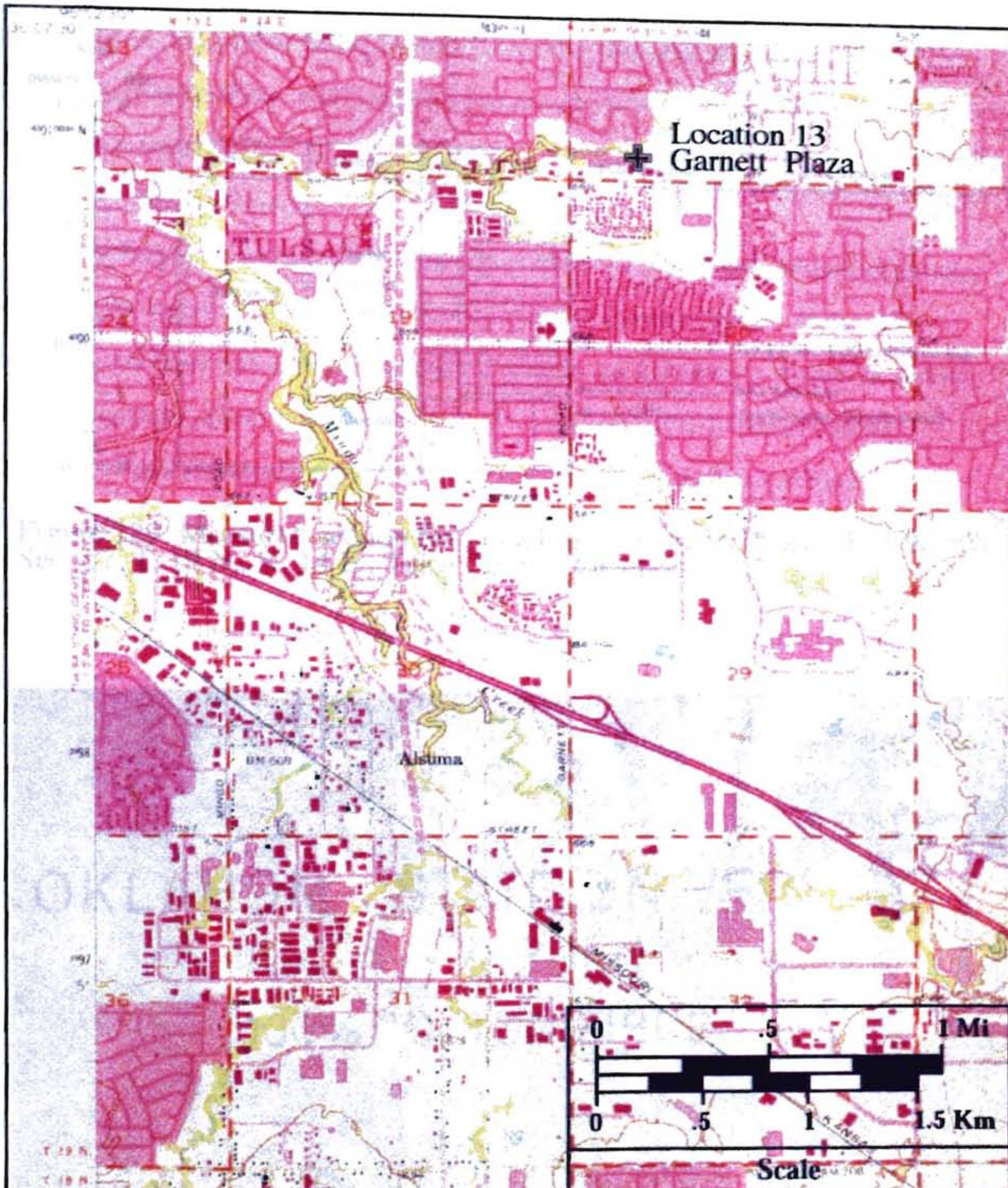


Figure 128. Location 13, Garnett Plaza, SE, SW, SW, Sec. 17, T. 19 N., R. 14 E., Tulsa County, Oklahoma.

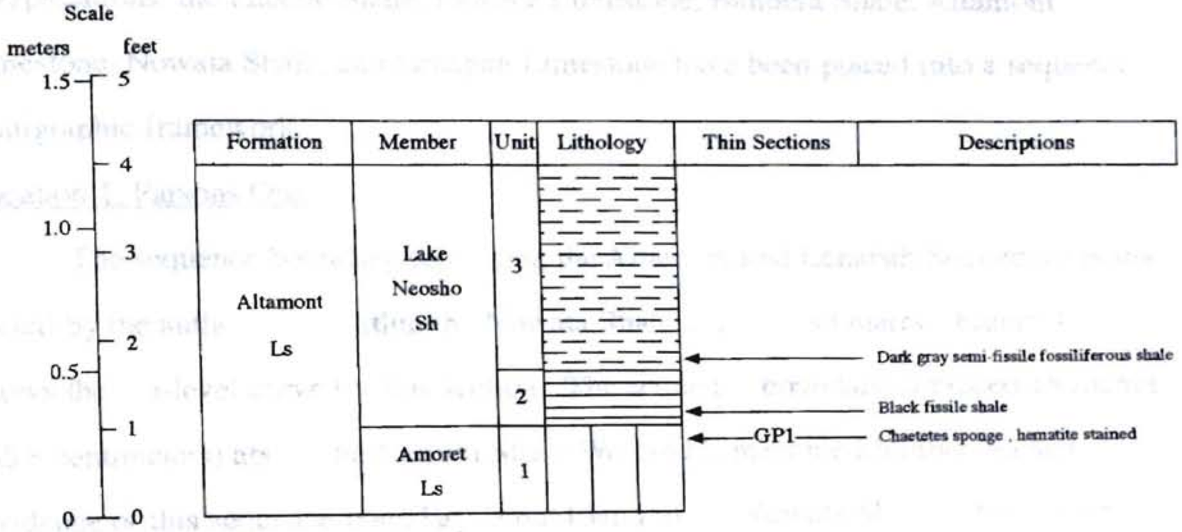


Figure 129. Measured section for Location 13, Garnett Plaza, SE, SW, SW, Sec. 17, T. 19 N., R. 14 E., Tulsa County, Oklahoma.

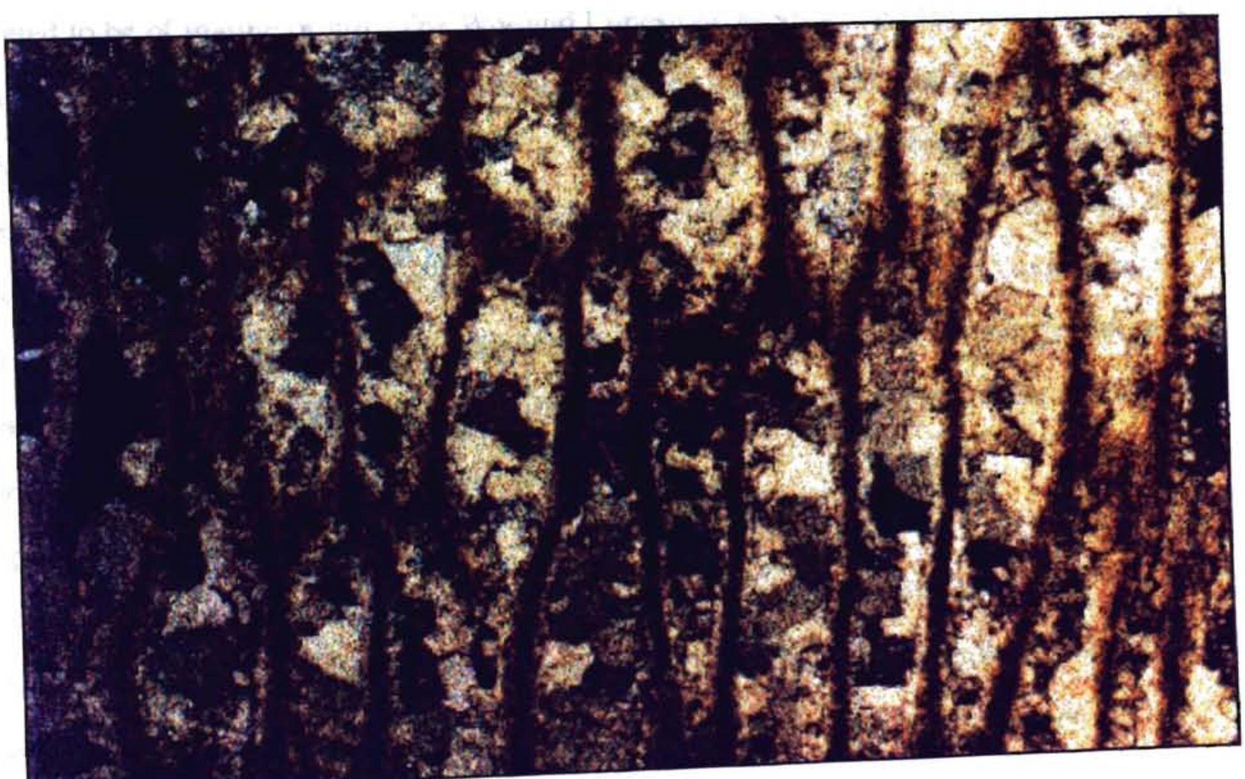

Figure 130. Thin section GP1 (Amoret Limestone) from Location 13, Garnett Plaza.

tions is a systems tract and sea-level curve for each measured section. Based on the interpretations, the Labette Shale, Pawnee Limestone, Bandera Shale, Altamont Limestone, Nowata Shale, and Lenapah Limestone have been placed into a sequence-stratigraphic framework.

Location 1, Parsons Quarry

The sequence boundary separating the Altamont and Lenapah Sequences is interpreted by the author to lie within the Nowata Shale at Parsons Quarry. Figure 131 shows the sea-level curve for this section. The sequence boundary is placed 18 inches (45.8 centimeters) above the Nowata Shale-Worland Limestone Member contact. Evidence of this sequence boundary is not found in the Nowata Shale at the Lenapah Road Cut exposure (Location 7) in Oklahoma. The lower five inches (12.7 centimeters) of the Nowata contains coal streaks, slickensides, and petrified wood, all of which are evidence of a paleosol. The Nowata Shale above this interval is fossiliferous, and interpreted to be of marine origin. The Worland Limestone Member and the lower 18 inches (45.8 centimeters) of the Nowata Shale represent the highstand (forced regressive) systems tract of the Altamont Sequence. The Nowata Shale above the sequence boundary represents the transgressive systems tract of the Lenapah Sequence. The maximum flooding surface of the Lenapah Sequence lies at the base of the Norfleet Limestone, dividing the transgressive from the highstand systems tract above. This interpretation is based on Greenberg (1986). The fossiliferous Perry Farm is interpreted to be of marine origin and lie within the highstand systems tract.

Location 2, Labette SW

The Labette SW section represents a nearly complete Pawnee Sequence. The transgressive surface of the Pawnee Sequence is interpreted to lie at the top of the coal bed, separating the highstand (forced regressive) systems tract of the Fort Scott Sequence from the transgressive systems tract of the Pawnee Sequence. Figure 132 is the sea-level curve for this exposure. The underclay in the Labette is evidence of a

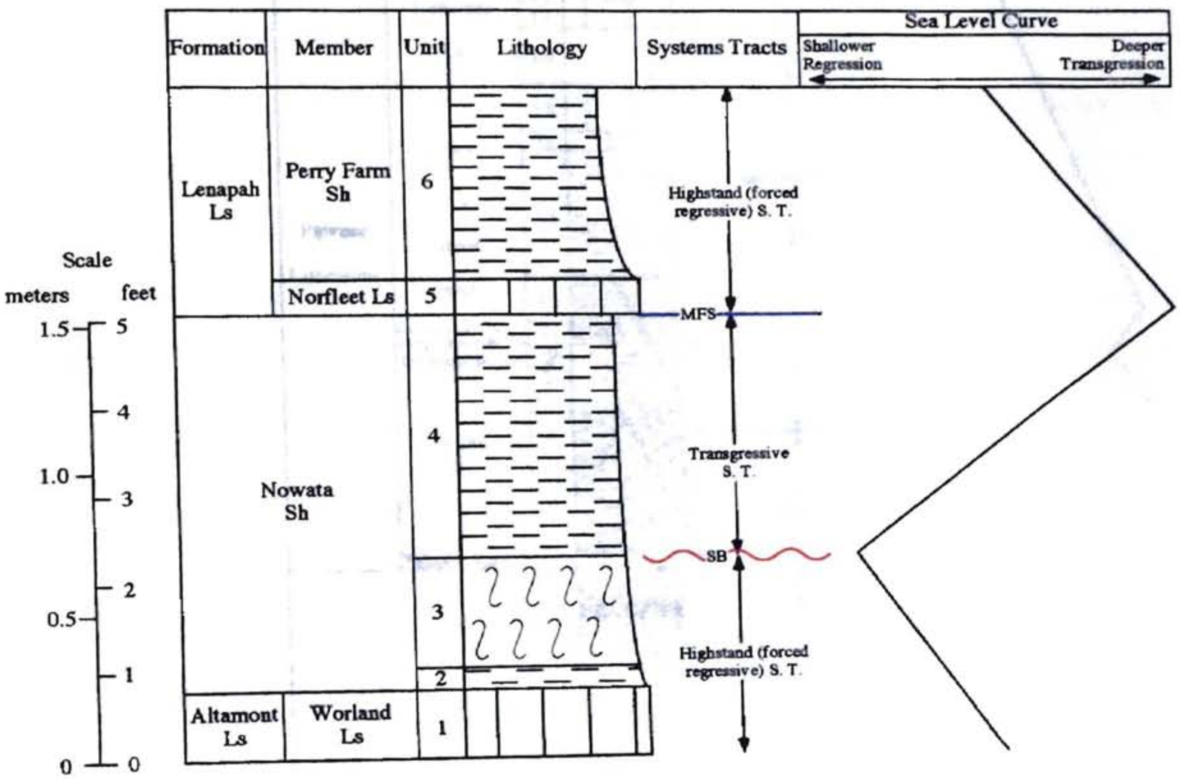


Figure 131. Interpretations of Location 1, Parsons Quarry.

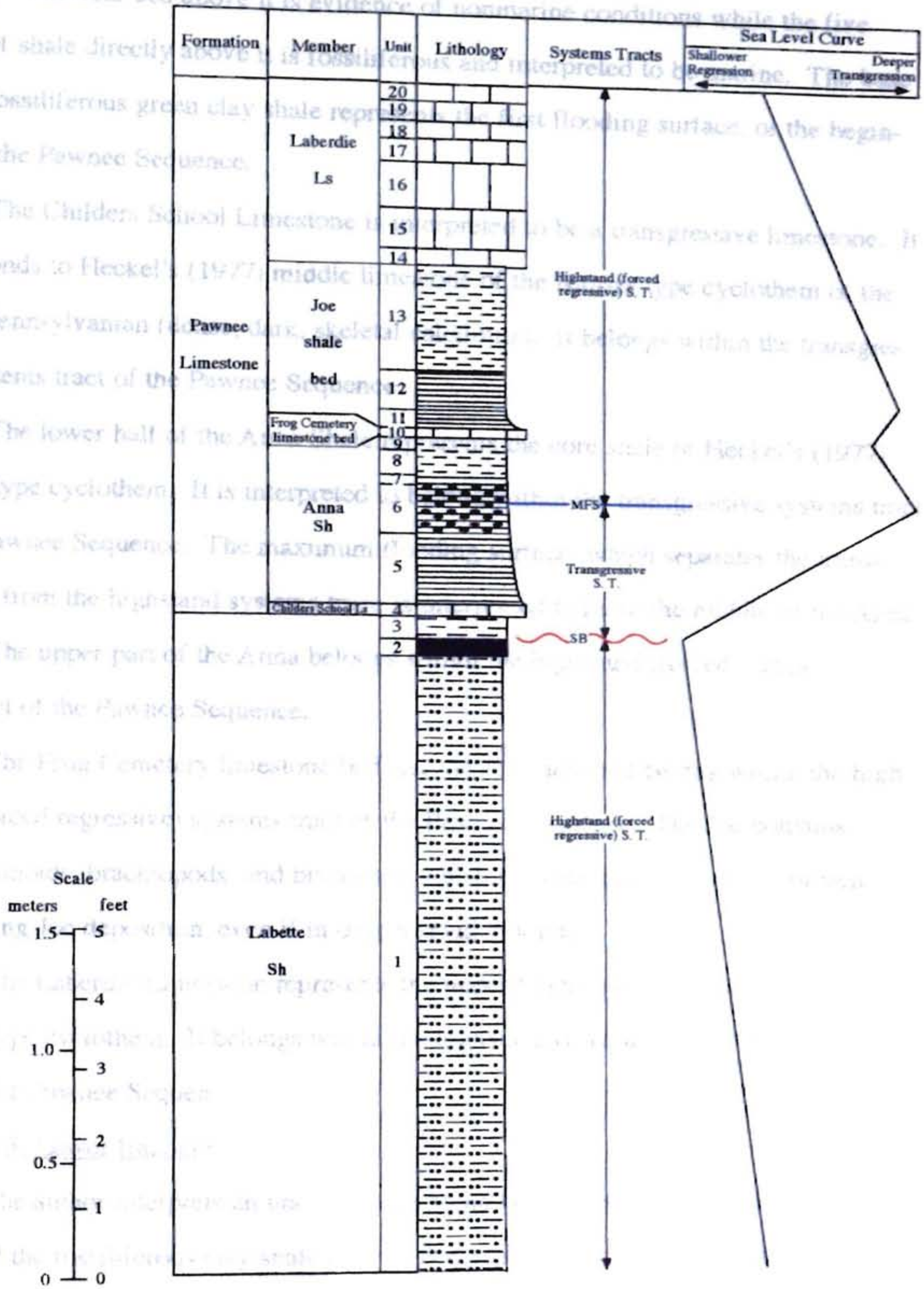


**Figure 132. Interpretations of Location 2, Labette SW.**

paleosol. The coal bed above it is evidence of nonmarine conditions while the five inches of shale directly above it is fossiliferous and interpreted to be marine. The base of this fossiliferous green clay shale represents the first flooding surface, or the beginning of the Pawnee Sequence.

The Childers School Limestone is interpreted to be a transgressive limestone. It corresponds to Heckel's (1977) middle limestone of the Kansas type cyclothem of the Upper Pennsylvanian (dense, dark, skeletal calcilutite). It belongs within the transgressive systems tract of the Pawnee Sequence.

The lower half of the Anna Shale represents the core shale of Heckel's (1977) Kansas type cyclothem. It is interpreted to belong within the transgressive systems tract of the Pawnee Sequence. The maximum flooding surface, which separates the transgressive from the highstand systems tract, is interpreted to lie in the middle of the Anna Shale. The upper part of the Anna belongs within the highstand (forced regressive) systems tract of the Pawnee Sequence.

The Frog Cemetery limestone bed and the Joe shale bed belong within the highstand (forced regressive) systems tract of the Pawnee Sequence. The Joe contains clams, crinoids, brachiopods, and bryozoans which indicate that oxygen was present here during Joe deposition, even if in only a small amount.

The Laberdie Limestone represents the upper limestone of Heckel's (1977) Kansas type cyclothem. It belongs within the highstand (forced regressive) systems tract of the Pawnee Sequence.

Location 3, Lower Bandera

The author interprets an unconformity to lie between the coal streaked blocky shale and the fossiliferous clay shale above. See Figure 133. The coal is interpreted to be a paleosol (nonmarine origin) while the fossiliferous shale is interpreted to be marine. The limestone and shale beds (Units 3 through 5) above these are interpreted to be marine because of the presence of fossils. The boundary separating the Pawnee and

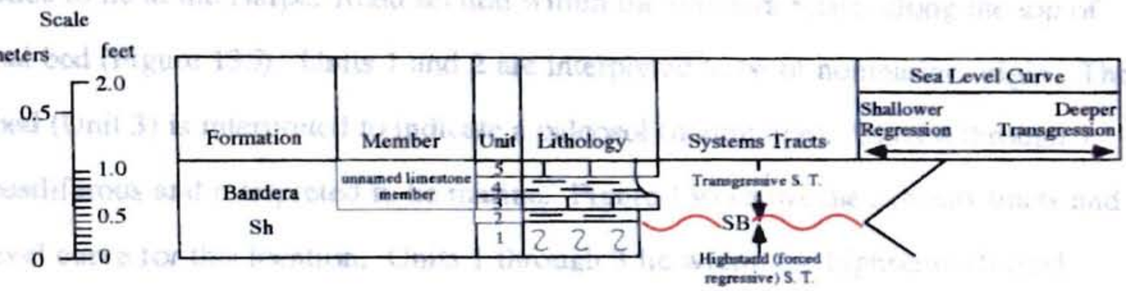


Figure 133. Interpretations of Location 3, Bandera Base.

Altamont Sequences could possibly be placed here. The author discusses the possibility of placing this boundary further up within the Bandera (Location 5).

Location 4, Bandera Section

Figure 134 shows the sea-level curve and systems tracts for Location 4.

Location 5, Harper Road

The author interprets the boundary separating the Pawnee from the Altamont Sequence to lie at the Harper Road section within the Bandera Shale, along the top of the coal bed (Figure 135). Units 1 and 2 are interpreted to be of nonmarine origin. The coal bed (Unit 3) is interpreted to indicate a paleosol (nonmarine). Units 4 through 7 are fossiliferous and interpreted to be marine. Figure 136 shows the systems tracts and sea-level curve for this location. Units 1 through 3 lie within the highstand (forced regressive) systems tract of the Pawnee Sequence. Units 4 through 7 are interpreted to lie within the transgressive systems tract of the Altamont Sequence. The Amoret Limestone represents the transgressive limestone of Heckel's (1977) Kansas type cyclothem.

Location 6, Coffeyville Quarry

The section at the Coffeyville Quarry represents a nearly complete marine portion of the Altamont Sequence. All of the units in this section are fossiliferous and interpreted to be of marine origin. Figure 136 is the systems tracts and sea-level curve for the exposure.

The Amoret is thicker here than in the Oklahoma exposures. In all of the locations (including ones not included in this study) in northeastern Oklahoma where the Amoret was found during field work, it was less than 10 feet thick. However at this quarry section where it is partly covered by water, it is probably greater than 10 feet thick, perhaps as much as or more than 20 feet. Where visible, it is a massive buildup with no bedding planes except for the 8 inch thick bed (unit 3 ) at the top. This suggests that at this location, the Amoret was deposited as a mud mound (bioherm) on top of the

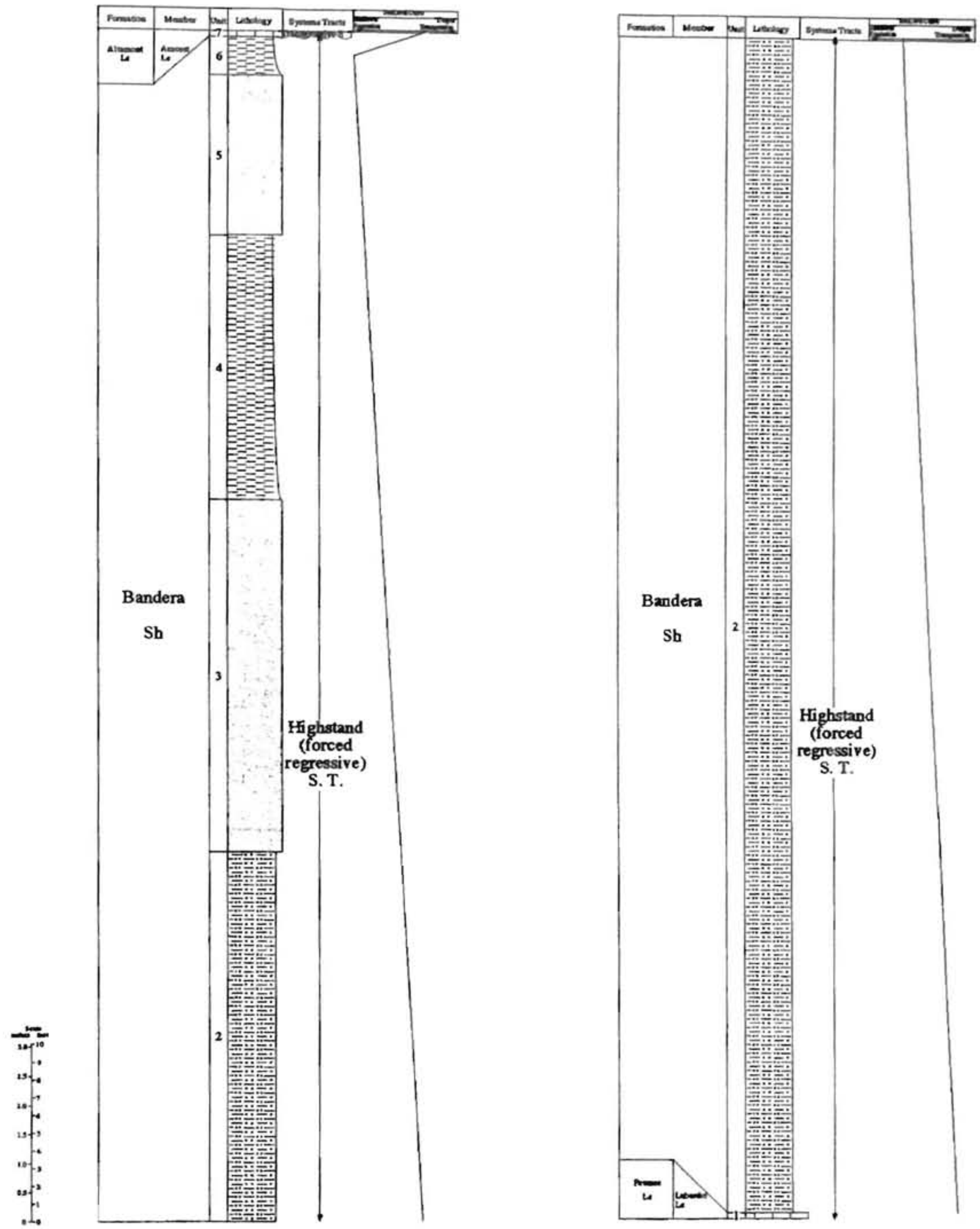


Figure 134. Interpretations of Location 4, Bandera Section.

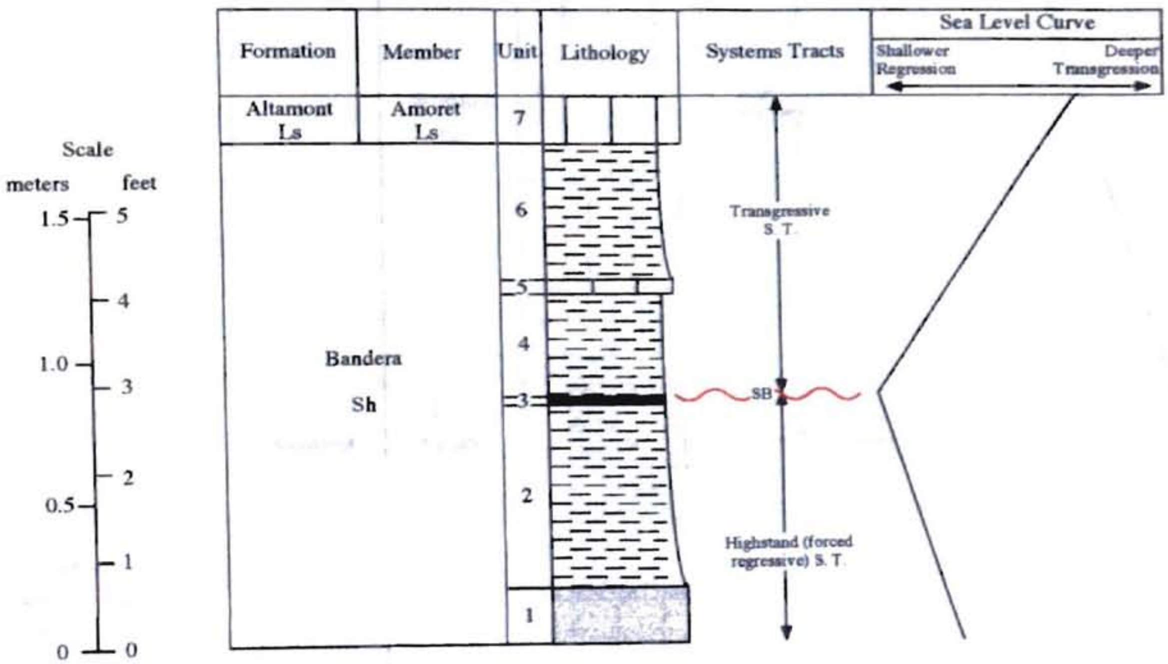


Figure 135. Interpretations of Location 5, Harper Road.

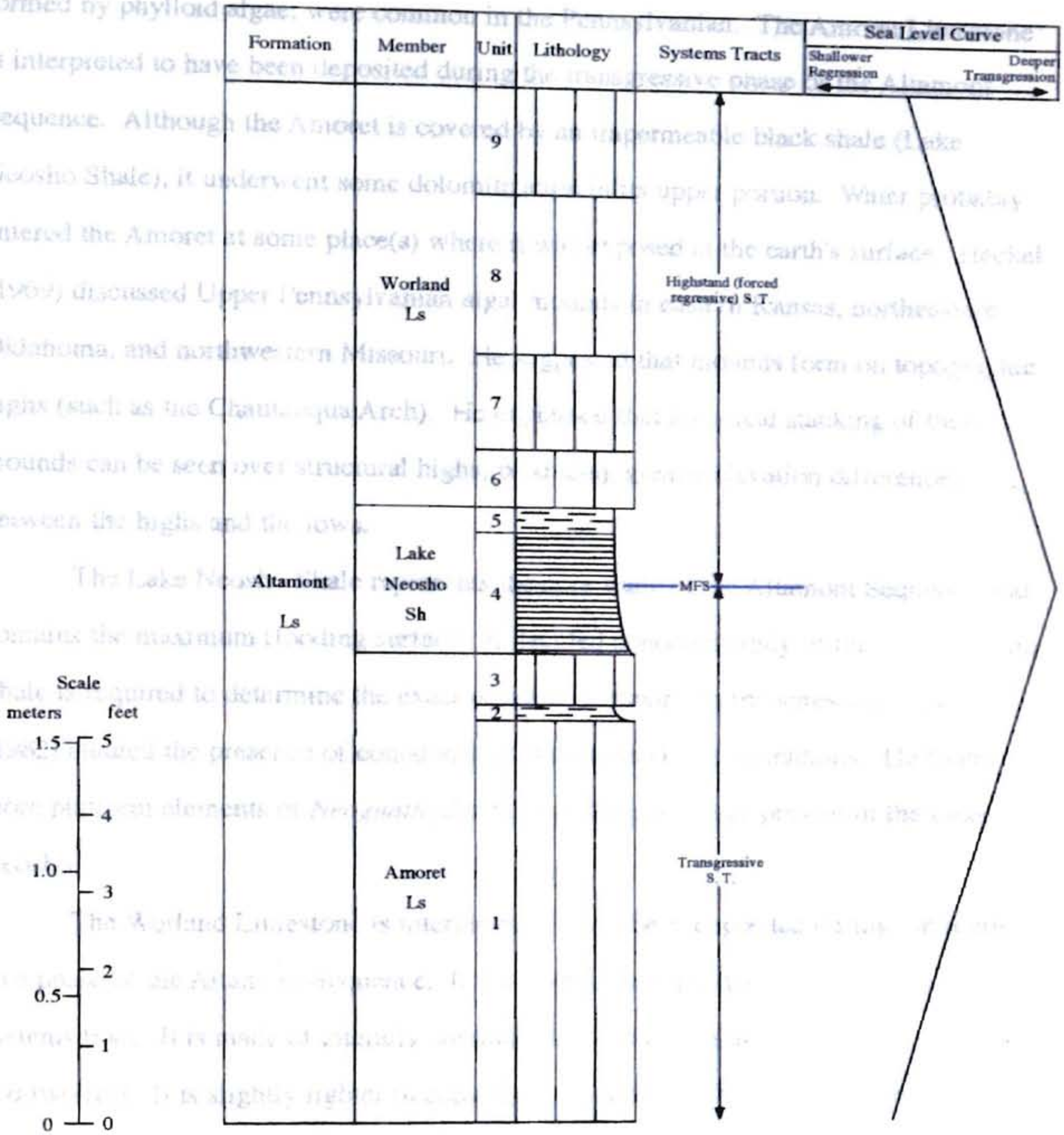


**Figure 136. Interpretations of Location 6, Coffeyville Quarry.**

Chautauqua Arch. According to Wilson and Jordan (1983), buildups such as this, formed by phylloid algae, were common in the Pennsylvanian. The Amoret Limestone is interpreted to have been deposited during the transgressive phase of the Altamont Sequence. Although the Amoret is covered by an impermeable black shale (Lake Neosho Shale), it underwent some dolomitization in its upper portion. Water probably entered the Amoret at some place(s) where it was exposed at the earth's surface. Heckel (1969) discussed Upper Pennsylvanian algal mounds in eastern Kansas, northeastern Oklahoma, and northwestern Missouri. He suggested that mounds form on topographic highs (such as the Chautauqua Arch). He explained that a vertical stacking of these mounds can be seen over structural highs, producing greater elevation differences between the highs and the lows.

The Lake Neosho Shale represents the core shale of the Altamont Sequence and contains the maximum flooding surface. A detailed conodont study of the Lake Neosho Shale is required to determine the exact position of maximum transgression. Swade (1982) studied the presence of conodonts in Marmaton Group formations. He found more platform elements of *Neognathodus* than of *Idiognathodus* present in the Lake Neosho.

The Worland Limestone is interpreted to have been deposited during the regressive phase of the Altamont Sequence. It lies within the highstand (forced regressive) systems tract. It is made of laterally continuous beds ranging in thickness between one and two feet. It is slightly lighter in color than the Amoret. It weathers to an almost yellow-gray color while the Amoret weathers medium to dark gray. The presence of phylloid algae in samples CQ8 and CQ10 suggest that during the beginning of the regressive phase of Altamont deposition, a reef grew on top of the topographically high Amoret of the study site.

There are signs of fresh water phreatic zone diagenesis (drusy spar) throughout both limestones. The upper part of the Worland Limestone underwent extensive fresh water phreatic zone diagenesis, shown by the upward increase in vugular porosity (5-15%), hematite, and dolomite. Another indicator of extensive diagenesis is that much of the micrite in the upper part of the Worland has neomorphosed to microspar. The uppermost thin-section (sample CQ13) underwent so much dissolution that the billet had to be examined in order to identify its specific lithology. The fossils in this sample had been completely dissolved out and then infilled with spar and hematite.

Based on the petrographic analysis it appears that the Amoret Limestone Member of the Altamont Limestone was deposited on the outer ramp in a subtidal to intertidal zone as a mud mound (at the study site). Micritization due to algae occurred in this marine environment as the Amoret was being deposited. The growth kept pace with the rise in sea-level, until the water was too deep for light to penetrate. At that time deposition of the Lake Neosho Shale Member occurred in the basin (subtidal zone). The regression of the sea resulted in deposition of the Worland Ls, probably in the upper subtidal to lower intertidal zone of the ramp. This hypothesis is supported by the broken nature of the fossils (indicating a shoal facies).

Later, the Altamont was subjected to a fresh water phreatic zone environment. This occurred either by structural uplift of the rock body or by the drop in sea-level. The entire Altamont in my study experience diagenesis in this environment, shown by the presence of drusy calcite spar. The indications of phreatic zone fresh water diagenesis increase upwards towards the top of the Worland. These indications include drusy calcite spar, secondary vugular porosity, dolomite, hematite, and microspar. It makes sense that the upper portions of the sequence would experience more diagenesis than the lower portions.

Location 7, Lenapah Road Cut

There is no evidence of an unconformity in the Nowata Shale here as there was at Location 1 in Kansas. It is possible that one lies lower in the section (covered at this location) or there may not be one. This may be due to elevation differences between the two locations. In Kansas, the Nowata was probably higher in elevation than in Oklahoma, and was subaerially exposed. This location in Oklahoma, however, was probably covered by water even during the lowest sea-level. Since there was more accommodation space in Oklahoma than Kansas, the Nowata is thicker in Oklahoma than Kansas. Figure 137 is the measured section with the systems tracts and sea-level curve.

Although it contains no fossils, the Norfleet Limestone is interpreted to be the transgressive limestone of the Lenapah Sequence. The fossiliferous Perry Farm Shale is interpreted to be the core shale (of marine origin) of the Lenapah Limestone. The maximum flooding surface of the Lenapah lies within the Perry Farm, separating the transgressive systems tract from the highstand (forced regressive) systems tract. The Idenbro Limestone contains no fossils but is interpreted to be a regressive limestone.

Location 8, Hancock Bridge

This section is similar to Location 6 in that it represents a nearly complete marine portion of the Altamont Sequence. However, the Amoret Limestone is different here. The Amoret represents the transgressive limestone and lies within the transgressive systems tract of the Altamont Sequence. See Figure 138. The maximum flooding surface of the Altamont lies within the Lake Neosho Shale, separating the transgressive from the highstand (forced regressive) systems tract. The Lake Neosho represents the core shale. The Worland represents the regressive limestone.

Location 9, Bellco Quarry

This outcrop exposes the sequence boundary between the Pawnee and Altamont Sequences that is within the Bandera Shale (Figure 139). The fossiliferous Laberdie Limestone is interpreted to be of marine origin, represents the regressive limestone of the Pawnee Sequence, and lies within the highstand (forced regressive) systems tract. The Bandera Shale is divided into three units. The lower zone (unit 11) contains a few brachiopods and molluscs which are not pyritized. It is interpreted to be marine. The

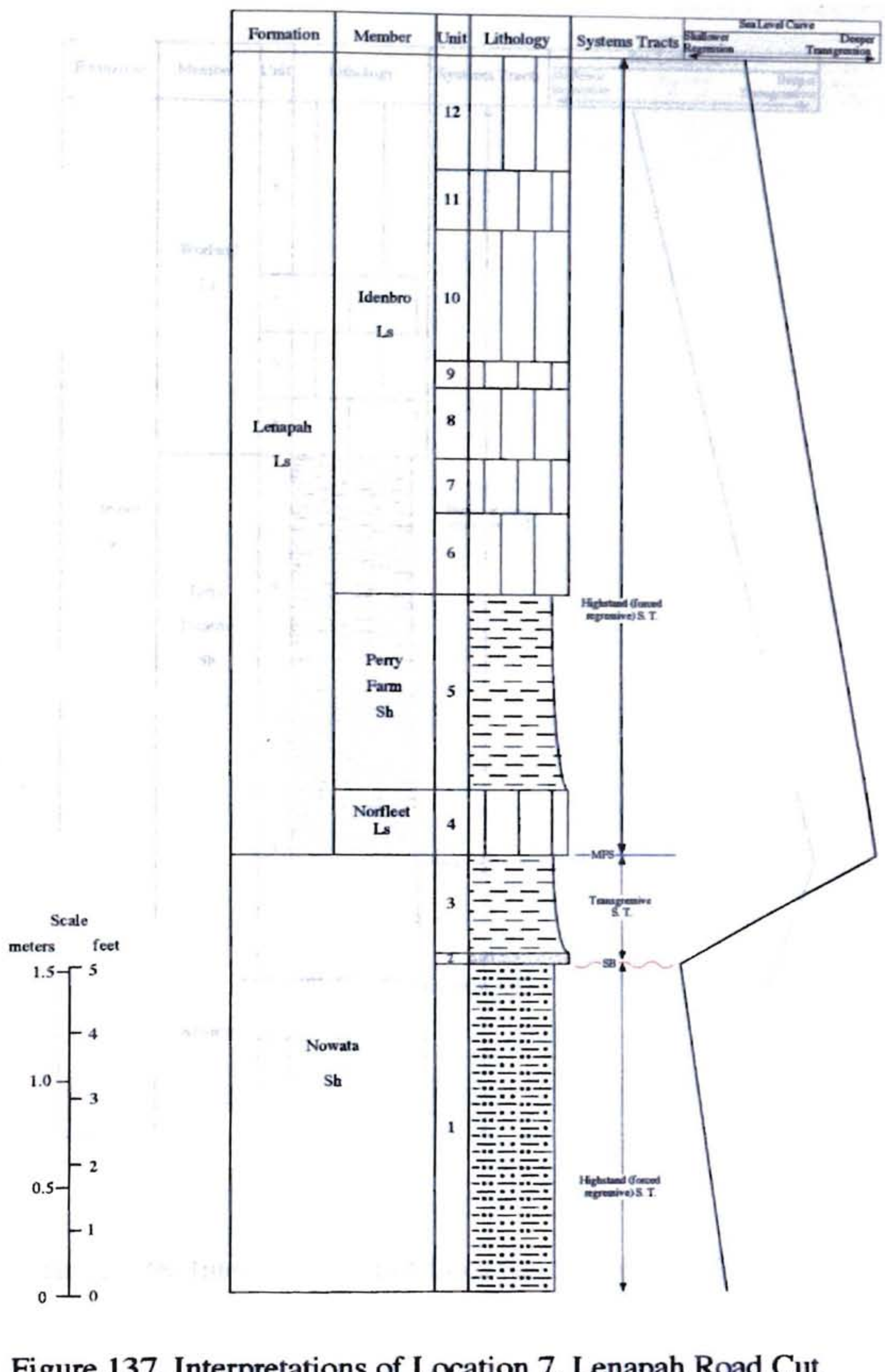


Figure 137. Interpretations of Location 7, Lenapah Road Cut.

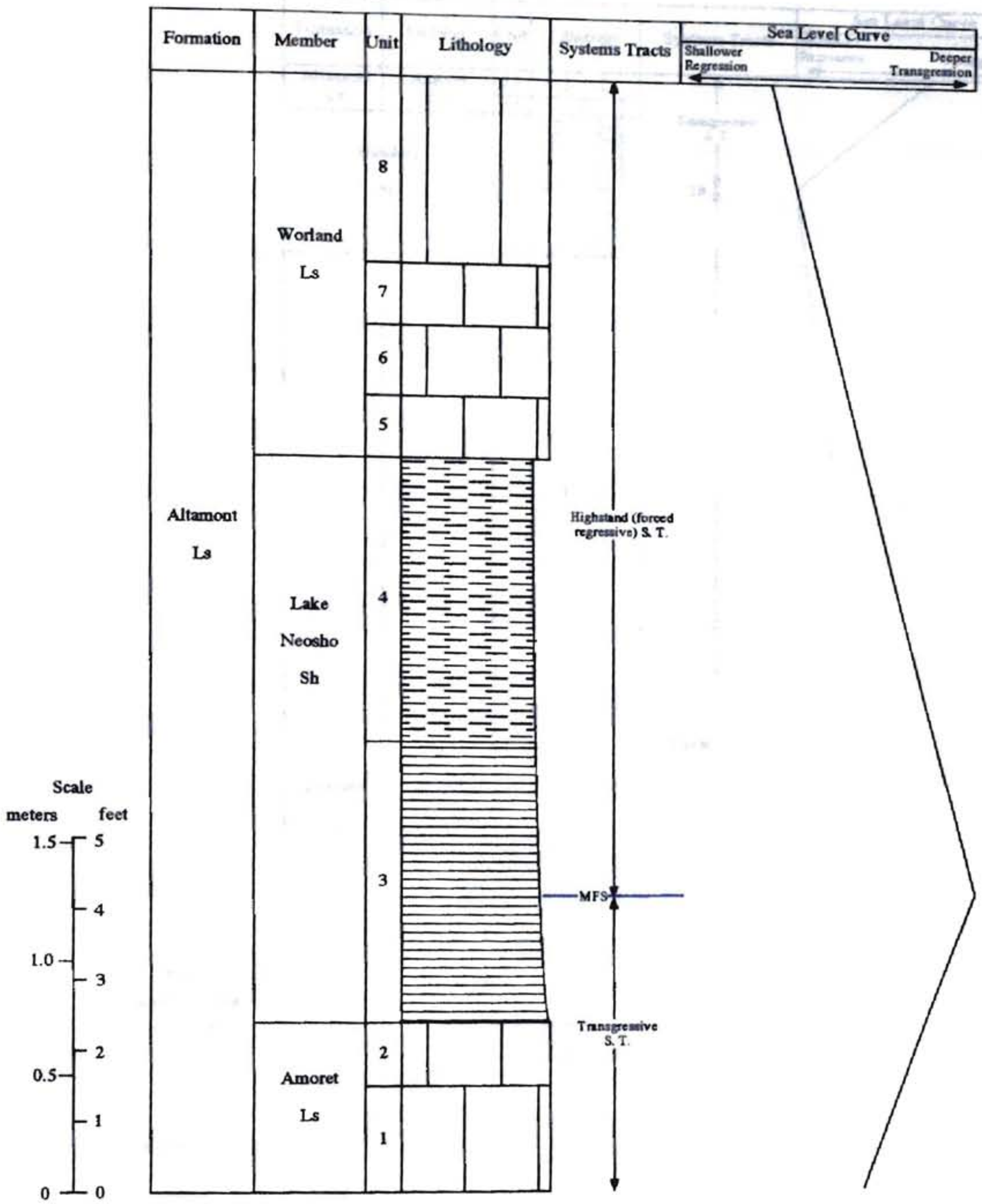


Figure 138. Interpretations of Location 8, Hancock Bridge.

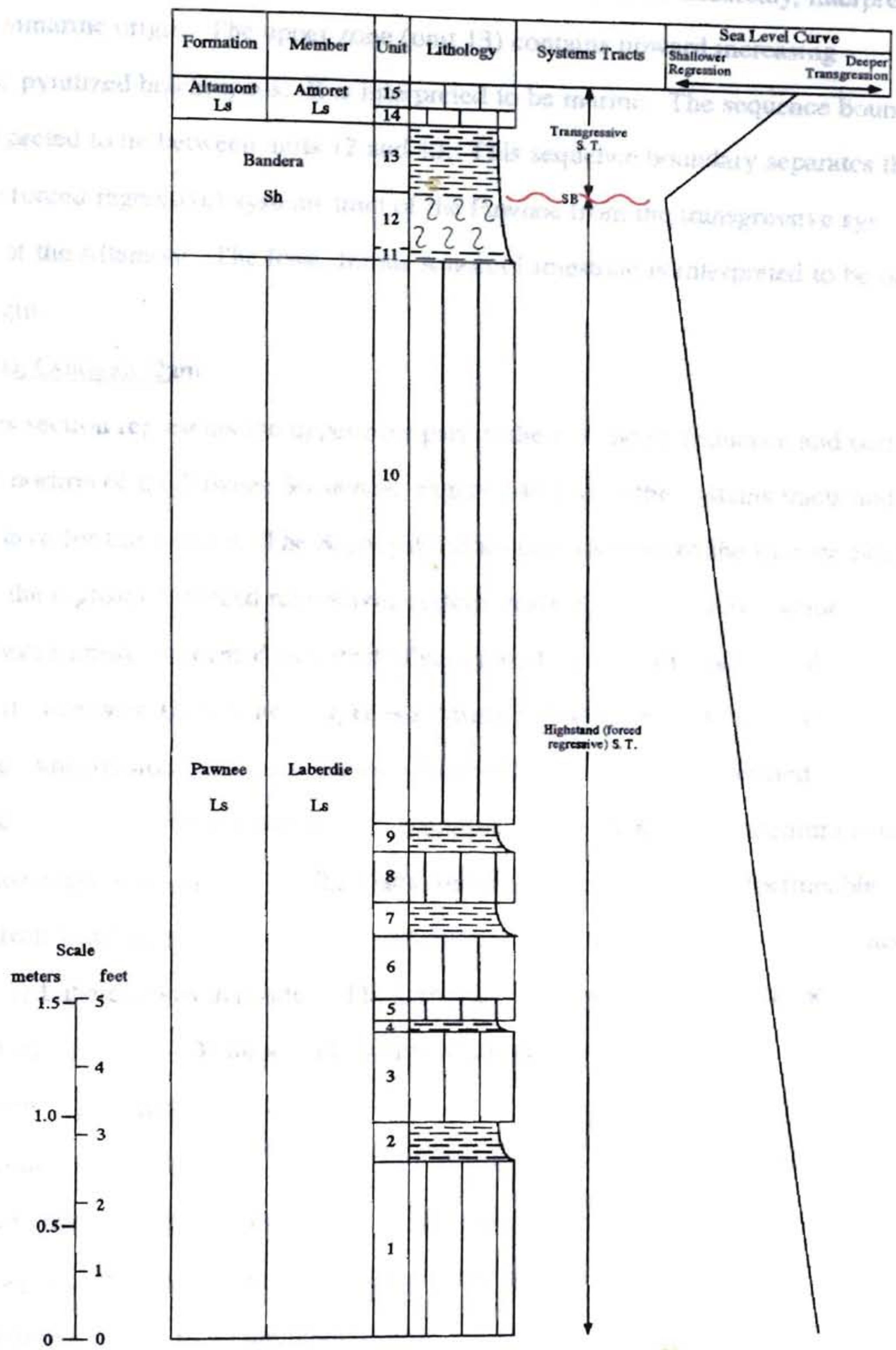


Figure 139. Interpretations of Location 9, Bellco Quarry.

middle zone (unit 12) contains coal streaks and no fossils. It is an underclay, interpreted to be of nonmarine origin. The upper zone (unit 13) contains upward increasing amounts of pyratized brachiopods. It is interpreted to be marine. The sequence boundary is interpreted to lie between units 12 and 13. This sequence boundary separates the highstand (forced regressive) systems tract of the Pawnee from the transgressive systems tract of the Altamont. The fossiliferous Amoret Limestone is interpreted to be of marine origin.

Location 10, Oologah Dam

This section represents the uppermost part of the Fort Scott Sequence and part of the marine portion of the Pawnee Sequence. Figure 140 shows the systems tracts and sea-level curve for this section. The Sageeyah Limestone Member of the Labette Shale lies within the highstand (forced regressive) systems tract of the Fort Scott Sequence. The Sageeyah Limestone formed as a thick algal mound on the Northeast Oklahoma Platform. It underwent fresh water diagenesis during stillstand or slow regression. Then as the transgression began, the Childers School Limestone was deposited. Childers School deposition stopped as the transgression approached its maximum extent and the Anna Shale was deposited. The black, fissile Anna acted as an impermeable barrier to fresh water diagenesis for the Childers School. Then the sea slowly retreated again and the Laberdie was deposited. The Laberdie became thick due to the positive structure of the Northeast Oklahoma Platform (which was probably higher then relative to the surrounding basins than it was earlier due to the Sageeyah deposition).

In general, the weathered color of the Laberdie Limestone lightens upward from medium dark gray/dark gray to medium dark gray/grayish orange. Usually, the better a carbonate is preserved, the darker its color is. Fresh water tends to lighten the original color of the limestone. Due to the relatively slow nature of Pennsylvanian regressions, the Sageeyah Limestone was probably exposed long enough for diagenesis to occur before the Childers School Limestone was deposited during the following transgression.

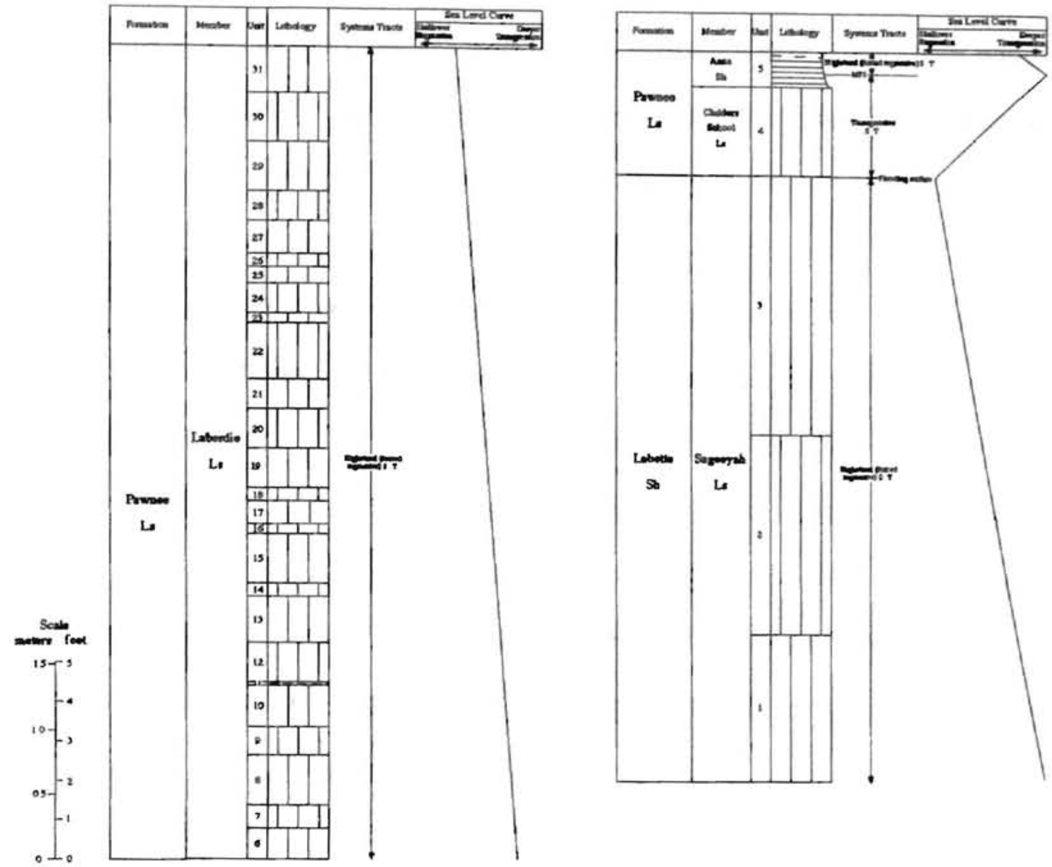


Figure 140. Interpretations of Location 10, Oologah Dam.

This may be a reason for the lighter color of the Sageeyah. During rapid transgression, the Childers School Limestone and then the Anna Shale were deposited. This black fissile shale acted as a seal to the Childers School and probably prevented fresh water diagenesis of the Childers School, allowing the Childers School to retain its original color. The Laberdie Limestone was probably exposed frequently to fresh water due to the slow nature of the regression during which it was deposited.

All of the limestones except the Childers School contain drusy spar which is indicative of fresh water diagenesis. Blocky calcite, vugs, and chert are present in parts of the Laberdie Limestone. The author found no dolomite in any unit. Brachiopods, echinoderms, forams, bryozoan are present throughout all three of the limestones. Green algae is present in the Childers School Limestone but especially in the Sageeyah Limestone (wackestone). According to Wilson (1983), bioherms during the Pennsylvanin were generally formed by phylloid algae. The Sageeyah probably represents a bioherm.

Location 11, Oologah Road Cut

Figure 141 shows the interpretations for this exposure.

Location 12, Tulsa Road Cut

This thick road cut north of Tulsa represents a nearly complete Pawnee Sequence and the top of the Fort Scott Sequence. Figure 142 shows the interpreted systems tracts and sea-level curve for the section. The Sageeyah Limestone Member of the Labette Shale lies within the highstand (forced regressive) systems tract of the Fort Scott Sequence.

The fossiliferous Childers School is interpreted to represent the transgressive limestone (of marine origin) of Heckel's (1977) Kansas type cyclothem. It lies within the transgressive systems tract of the Pawnee Sequence.

The maximum flooding surface which separates the transgressive and highstand (forced regressive) systems tracts of the Pawnee Sequence lies within the Anna Shale.

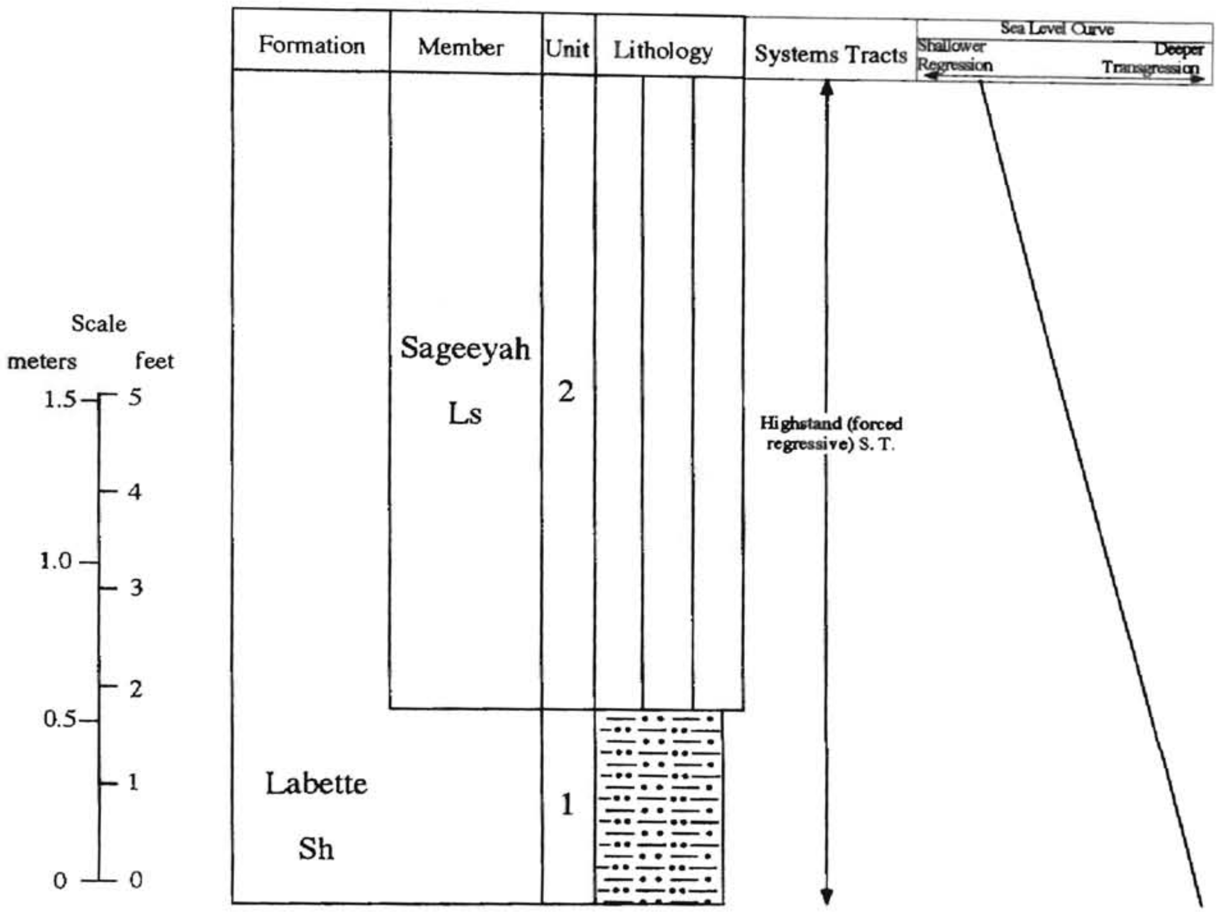


Figure 141. Interpretations of Location 11, Oologah Road Cut.

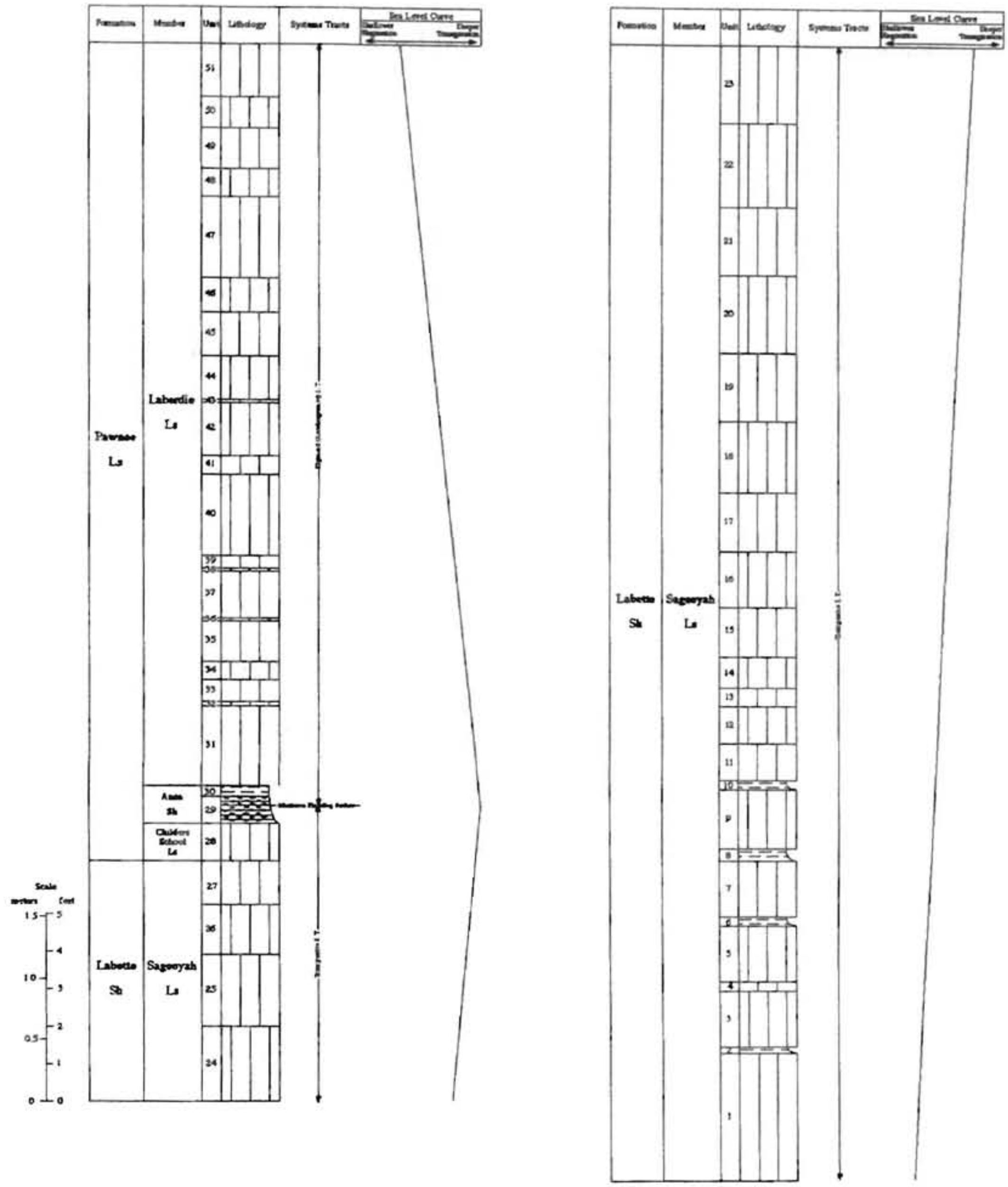

Figure 142. Interpretations of Location 12, Tulsa Road Cut.

The Anna represents Heckel's core shale.

The Laberdie Limestone represents the regressive limestone of Heckel's terminology and lies within the highstand (forced regressive) systems tract of the Pawnee Sequence.

Location 13, Garnett Plaza

This creek exposure represents the middle part of the Altamont Sequence. Figure 143 shows the systems tracts and sea-level curve for this section. The Amoret represents the transgressive limestone of the Altamont. The maximum flooding surface of the Altamont lies within the black fissile shale unit of the Lake Neosho. The dark gray semi-fissile shale of the Lake Neosho lies within the highstand (forced regressive) systems tract of the Altamont Sequence and represents a highstand delta. The Worland appears to have been pinched out by the accumulation of a highstand delta. This area was probably topographically low enough to accommodate the accumulation of sediment while higher areas were shallow enough for carbonate (Worland Limestone) deposition. Evidence for deposition of a highstand delta includes the additional facies of the Lake Neosho (dark gray clay shale) and the absence of the Worland Limestone.

# V.

# SUBSURFACE STUDY

## Data

The subsurface component of the present study is a vertical expansion of the surface study units to include, in ascending order, the Excello Shale of the Senora Formation, Fort Scott Limestone, Labette Shale, Pawnee Limestone, Bandera Shale, Altamont Limestone, Nowata Shale, Lenapah Limestone, Holdenville Shale, Seminole Formation, Checkerboard Limestone, and Tacket Shale. Figure 2 shows the unit interval of the subsurface study. The subsurface study utilizes 119 well logs from Osage, Washington, and Nowata Counties, 12 to 50 miles west of the surface study. The author collected gamma-ray and resistivity-logs to construct six stratigraphic cross sections, six

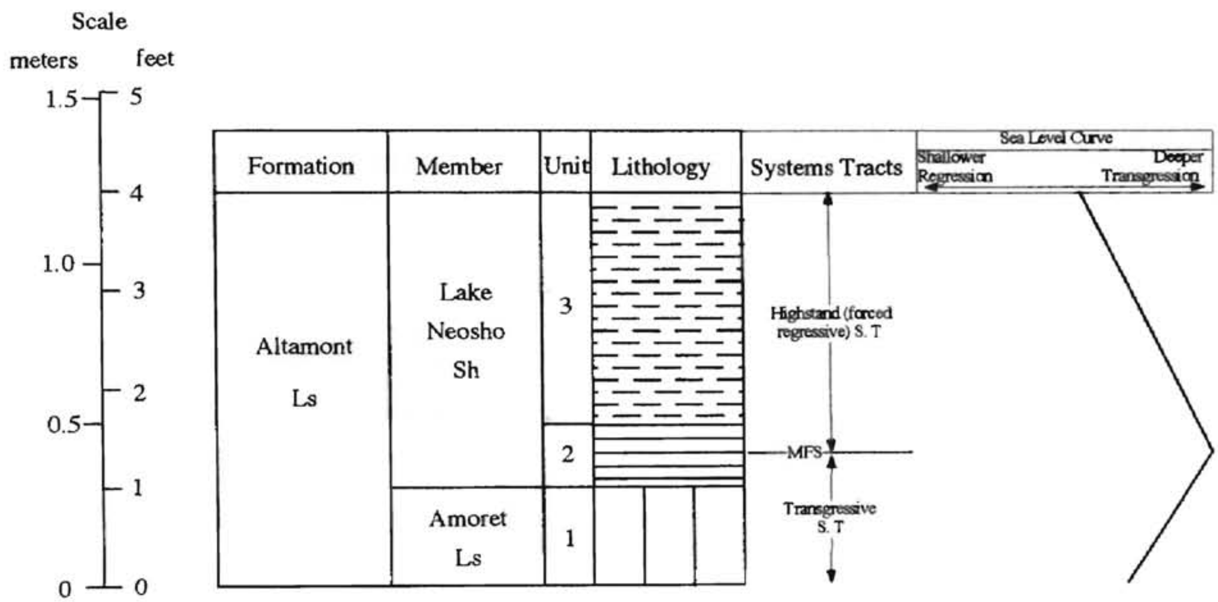


Figure 143. Interpretations of Location 13, Garnett Plaza.

structural contour maps, and five isopach maps. The structural and isopach maps cover a 36 by 36 square mile grid in Osage County, Oklahoma, from Townships 23 North to 28 North and from Ranges 7 East to 12 East. The stratigraphic cross sections are in the same area as the maps but extend further east to Range 15 East as the author attempted to get the cross sections as close as possible to the area of the surface study. Enclosure 1 shows the location of the subsurface study.

The objectives of the subsurface study were to first define and correlate cyclothemic-scale depositional sequences of the Pennsylvanian Marmaton Group and second, compare the quality of correlations based on the depositional sequence and GSU methods. The first method, developed by workers at Exxon, places depositional sequence boundaries at unconformities (or their correlative conformities). The second method being tested places GSU boundaries at maximum flooding surfaces (condensed sections).

## Well Logs

The radioactive elements, such as uranium and thorium, within the laterally persistent core black shales produces "hot streaks" on the gamma-ray-logs. These black shales are also more laterally persistent than the other units and are therefore reliable subsurface markers. Other units, such as carbonate rocks and shales, were more variable laterally, and their correlation more interpretive. After determining unit boundaries, depositional sequences and GSUs (genetic stratigraphic units) were defined on the stratigraphic cross sections.

## Stratigraphic Cross Sections

The author constructed six stratigraphic cross sections using the top of the black shale of the Tacket Shale as the datum. Units were correlated based on lithology from the top of the Tacket Shale down to the base of the Excello Shale of the Senora Formation. Krumme's (1981) cross sections were used as a guide for this study's lithologic unit correlations. Stratigraphic cross section numbers 1 through 3 run west-east and parallel the general depositional strike of the units. Stratigraphic cross sections 4 through 6 run north-south and approximately parallel the depositional dip of the units. Enclosure 1 shows where the cross sections are located.

Black shales were correlated first using gamma-ray hot streaks. Then other lithologic units were correlated using the already correlated black shale hot streaks as guides. Finally, the author correlated sequences using both Exxon's and Galloway's methods. Depositional sequences are correlated with red and are shown on Enclosures 2 and 4. GSUs are correlated with blue and are shown on Enclosures 3 and 5. Lithologic, sequence, and GSU boundaries are dashed, rather than solid, where the author had to infer them.

The Pawnee and Altamont Limestones vary laterally in thickness only slightly. The intervening Bandera Shale thins southward and achieves maximum thickness in the northeast. Chenoweth (1966, p. 193) writes that the Bandera "thins rapidly and irregularly both southward along the outcrop and westward in the subsurface...".

The upper part of the Labette Shale is sandy in some parts (cross section 1, well 9; cross section 2, well 7; cross section 3, well 7; cross section 4, well 5; cross section 5, well 7; and cross section 6, wells 3, 4, and 5). The Labette Shale contains limestone beds in some parts (cross section 2, well 4; and cross section 4, wells 2 and 3). The Labette thickens to east in cross sections 1, 2, and 3. At well 8 of cross section 6, in the southeastern part of the study area, the Labette Shale thins by half its thickness in adjacent well 7, while the Pawnee and Altamont Limestones double their thicknesses. The Lenapah Limestone is absent in southern and eastern areas.

All depositional sequence boundaries are inferred, and therefore are dashed lines. The gamma-ray and resistivity-logs used do not indicate subaerial exposure surfaces. The author put these boundaries in approximately where they were observed at outcrop. GSU boundaries, however were identified by the presence of gamma-ray hot streaks. Where maximum flooding surfaces are not within black fissile shales, the author dashed in the GSU boundaries.

## Structural Maps

Six structural contour maps were constructed of the: 1) top of the Tacket Shale, 2) top of the Altamont Limestone, 3) base of the Lake Neosho Shale, 4) top of the Pawnee Limestone, 5) base of the Anna Shale, and 6) top of the Fort Scott Limestone. These six maps indicate that the units they are based upon generally strike to the north, northeast and dip to the west at about 50 feet per mile.

The reason structure maps were constructed along both the tops of the limestone formations and the bases of their black shale members was to compare their results. The maps based on limestone formations are based on lithology and do not provide a clear picture of paleostructure. The maps based on black shales (maximum flooding surfaces) are time relevant and give a truer picture of paleostructure and paleotopography of the area.

The complex area at T. 25 N., R. 9 E. presented difficulties. The author collected additional well data in this area, hoping it would clear the confusion, but it did not. The author used Oswego lime structural maps published by the U.S.G.S., which are based on many more wells than collected for this study, to guide contours. There also appears to be a possible shelf structure striking north/south. The topographic map for that area does not hint at any ancient structure there.

## Isopach Maps

Isopach maps were constructed for the Altamont Limestone, Bandera Shale, Pawnee Limestone, Altamont through Pawnee Limestone interval, and Labette Shale. The thickness of both the Altamont and Pawnee Limestones increased in the southern part of the study area. The Altamont increased in thickness in the north also. The two limestones and the intervening Bandera Shale exhibited maximum thicknesses at the very north and very south of the study area. The Bandera Shale exhibited its maximum thickness at the very north part of the study area. The Labette Shale thickened to the east.

An increase in the thickness of carbonates would probably take place on a topographic high where the biota could thrive in shallower water, producing more carbonate sediment. An increase in the thickness of shales would probably take place in topographic lows where more sediment could accumulate.

## Interpretation of Data

Exxon's depositional sequence method is difficult to use at the scale of the well logs. The unconformities in this study (disconformities) are not visible on the well logs, as far as the author can detect. The author put the depositional sequence boundaries in the upper parts of the shale formations below the transgressive limestones on the cross sections (where these boundaries were observed at outcrop). If the lower limestone member of the limestone formation was missing, the boundary was put at the base of the core shale.

The GSU method provides a higher degree of confidence when choosing sequence boundaries. The boundaries of the GSUs in this study are usually within the middle of the core shales (maximum flooding surfaces). The exception is the Lenapah Limestone, in which the GSU boundary is placed at the base of the Norfleet Limestone Member, based on Greenberg (1986). In this study most of the core shales are of black fissile facies and produce hot streaks on the gamma-ray-logs. These are easy to correlate. Where the core shales do not contain a black fissile facies, boundaries were dashed in.

# VII.

# SUMMARY OF SURFACE AND SUBSURFACE STUDIES

Significant sequence-stratigraphic surfaces were interpreted at outcrop and in the subsurface. Subaerial exposure surfaces, flooding surfaces, and condensed sections (maximum flooding surfaces) were interpreted within the Marmaton Group units based on the data collected for this study. Textural trends were observed and used to interpret variations in sea-level.

Subaerial exposure surfaces were interpreted at outcrop locations 1, 2, 3, 5, and 9 based on the observance of the following paleosol indicators: petrified wood, slickensides, coal beds and streaks, and underclays. Petrified wood is evidence of vegetative processes which occur within a soil during subaerial exposure. Slickensides are caused during burial processes as peds are compressed against each other (Retallack, 1989, p. 9). Coal beds and streaks are formed as the O horizon of soil zones. They are referred to as histosols (Figure 41). Not all subaerial exposure surfaces are used to bound depositional sequences. The subaerial exposure surfaces at locations 1, 2, and 9 are interpreted as sequence boundaries by the author. The subaerial exposure surfaces within the Bandera Shale at locations 3 and 5 are most likely not correlatable with each other. The Bandera Shale in the area of locations 3 and 5 (southeastern Kansas) is quite thick (88 feet thick at location 4). The paleosol interpreted at location 3 is near the base of the Bandera while the one interpreted at location 5 is near the top of the Bandera. This illustrates the difficulty of determining sequence boundaries at outcrop scale where onlap onto a surface is not visible. The author could place the sequence boundary separating the Pawnee and Altamont Limestones at either of these two locations.

Subaerial exposure surfaces were not identified in the subsurface of this study. The resistivity and gamma-ray-logs used to construct stratigraphic cross sections showed no visible evidence of subaerial exposure. Since these surfaces were ambiguous in the subsurface data used, the author dashed in all depositional sequence boundaries on the stratigraphic cross sections. These boundaries were placed at approximately the same places within the units that they were interpreted to lie at outcrop.

Flooding surfaces were recognized at the surface. At outcrop location 2, a flooding surface was interpreted at the base of the Frog Cemetery limestone bed. This surface separated parasequences within the highstand (forced regressive) systems tract of the Pawnee Limestone. Other flooding surfaces recognized at outcrop were overlying interpreted paleosols and were used as sequence boundaries, separating highstand (forced regressive) systems tracts from transgressive systems tracts.

Condensed sections were recognized at the surface and subsurface. At outcrop, maximum conodont abundance and diversity, phosphate nodules, and high shale fissility were evidence of marine condensed sections. Previous authors (Swade, 1982; Greenberg, 1986) provided conodont data for the Marmaton Group. The author observed phosphate nodules and high fissility in the units containing maximum conodont abundance and diversity. Maximum flooding surfaces (condensed sections) were interpreted at locations 1, 2, 6, 7, 8, 10, 12, and 13. Most of these surfaces lie within black fissile shales.

Condensed sections (maximum flooding surfaces) were interpreted in the subsurface based on the presence of hot streaks on gamma-ray-logs. These hot streaks were observed within the same units which were found to contain condensed sections at the surface. The hot streaks are caused by the high concentrations of radioactive elements found in condensed sections.

Textural trends in carbonates were documented at outcrop based on thin-sections. At location 2, the Childers School Limestone is interpreted to be the transgressive limestone (Heckel, 1977). The Frog Cemetery limestone bed is interpreted to be a shallower limestone formed during a second, smaller flooding than the one which formed the Childers School. Evidence which agrees with this interpretation is that the Childers School is a fossiliferous wackestone and the Frog Cemetery limestone bed is a fossiliferous packstone. At location 6, The Amoret Limestone (transgressive by Heckel's nomenclature) exhibits a deepening upward trend in texture. The base is a fossiliferous packstone while the top is a fossiliferous wackestone to packstone. The Worland Limestone (regressive by Heckel's nomenclature) is a fossiliferous wackestone, texturally shallower than the top of the Amoret. At location 9, the Laberdie Limestone exhibits shallowing upward trends in texture. The base is a fossiliferous wackestone while the upper part is a fossiliferous, siliceous wackestone to packstone.

In addition to significant sequence-stratigraphic surfaces and carbonate textural trends, an interesting stratigraphic feature was observed at surface and in subsurface. A highstand delta was interpreted to be present at the top of the Altamont Limestone at outcrop location 13, in Tulsa, Oklahoma. The Amoret Limestone is overlain by an unusual Lake Neosho Shale composed of two facies. The Worland Limestone is absent here. It appears that a highstand delta was deposited here during the time the Worland was being deposited in outcrop locations north of location 13. A highstand delta was interpreted at the top of the Fort Scott Limestone at well number 8 of stratigraphic cross section 6. The Higginsville Limestone Member gradually thins southward from well number 6 to number 7 until it is no longer visible on the resistivity and gamma-ray-logs from well number 8. The Higginsville also thins southward from well number 6 to number 7 in cross section 5 and eastward from well number 5 to numbers 6, 7, and 8 in cross section 3. One explanation is that a highstand delta was deposited at the location of well number 8 during the time that the Higginsville was being deposited. The influx of sediment would have prevented carbonate production.

The author applies Heckel's (1977) Kansas type cyclothem nomenclature to lithologic units and sequence-stratigraphic nomenclature to significant surfaces and the strata between in this study. These two sets of terminology do not coincide with each other. Heckel's nomenclature does not describe strata in sequence-stratigraphic terms. Heckel's (1977) transgressive limestone (middle limestone) is not necessarily deposited during a transgression. If it was deposited during a transgression, one should observe evidence of upward deepening throughout the limestone. It may be deposited during a transgression or a stillstand. The offshore shale (core shale) is deposited during late transgression and early regression. The regressive limestone (upper limestone) may be deposited during regression or stillstand. There may be a flooding surface(s) within the regressive limestone, dividing it into more than one shallowing upward packages, called parasequences in sequence-stratigraphic terminology). The nearshore shale (outside shale) is deposited during late regression and possibly early transgression. It may contain one or more flooding surfaces. Carter et al. (1986) provide an alternative to Heckel's model. Carter et al. studied post-glacial shorelines east of South Island, New Zealand and on the Great Barrier Reef shelf, off Queensland, Australia. They concluded that "sea-level stabilized at some shorelines for a considerable period of time (up to 1-2000 yr); and the intervening rises of sea-level, estimated to have been at least 10-12 m 10{3}yr{-1}, were too rapid to allow the reworking of the wedges into a transgressive sediment sheet, as favoured in some current models" (Carter et al., 1986, p. 629). In their episodic transgressive model, they assert that post-glacial transgressions have been episodic, in which sea-level rises in rapid spurts, pausing when conditions make it stable.

# VIII.

# CONCLUSIONS

Cyclothemic-scale depositional sequences of the Marmaton Group in southeastern Kansas and northeastern Kansas can be identified at outcrop and correlated into the subsurface. Both Exxon's depositional sequence method and the GSU method work well in outcrop. Sequence boundaries can be placed at subaerial exposure surfaces. GSU boundaries can be placed where marine condensed sections are observed.

In the subsurface, however, the GSU method was superior. Using the available gamma-ray and resistivity-logs to correlate Exxon depositional sequences in the subsurface is ambiguous. Most unconformities of this study are not visible on these logs. Since most of the maximum flooding surfaces of this study are within black fissile shales that are associated with gamma-ray hot streaks, the GSU method works well when correlating in the subsurface.

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APPENDIX A

Surface study locations

1. Parsons Quarry
   NE, NW, Sec. 36, T. 31 S., R. 19 E.
   Labette County, KS

2. Labette SW
   Center W. line, NW, Sec. 3, T. 33 S., R. 20 E.
   Labette County, KS

3. Lower Bandera
   NW, NW, NW, Sec. 9, T. 33 S., R. 20 E.
   Labette County, KS

4. Bandera Section
   along line dividing Sec. 17 & 18, T. 35 S., R. 19 E.
   Labette County, KS
   E. line, NE, NE, Sec. 16, T. 29 N., R. 18 E.
   Craig County, OK

5. Harper Road
   SE, SW, SE, Sec. 11, T. 35 S., R. 18 E.
   Labette County, KS

6. Coffeyville Quarry
   SE, SW, SE, SW, Sec. 35, T. 34 S., R. 17 E.
   Labette County, KS

7. Lenapah Road Cut
   along W. line, NW, SW, Sec. 20, T. 28 N., R. 16 E.
   Nowata County, OK

8. Hancock Bridge
   SW, SE, Sec. 10, T. 27 N., R. 16 E.
   Nowata County, OK

9. Bellco Quarry
   C. of W/2, W/2, SW, Sec. 26, T. 26 N., R. 16 E.
   Nowata County, OK

10. Oologah Dam
    SW, NW, NE, Sec. 2, T. 22 N., R. 15 E.
    Rogers County, OK

11. Oologah Road Cut
middle of N. line of NW, SW, Sec. 6, T. 22 N., R. 16 E.
Rogers County, OK

12. Tulsa Road Cut
E. line of NE, Sec. 9, T. 20 N., R. 14 E.
Tulsa County, OK

13. Garnett Plaza
SE, SW, SW, Sec. 17, T. 19 N., R. 14 E.
Tulsa County, OK

# APPENDIX B

# WELL LOG SPREADSHEET

| x-sec | Location | Location | Well Name |
|---|---|---|---|
| no | 36-23N-7E | SE/2,NE,SW | Drummond #3-2 |
| no | 7-23N-8E | NE | Mary L. Wister no. 1-A |
| no | 13-23N-8E | 990'FSL,990'FWL,SW | MP no. 7 |
| 003-1,004-8 | 30-23N-8E | 1200'FSL,300'FEL,NE | Rafter "D" Company no. 3 |
| no | 6-23N-9E | 300'FNL,1650'FEL,SW | Manion no.7-B |
| no | 9-23N-9E | SE/4,300'FSL,900'FWL | Priscilla no.2 |
| no | 14-23N-9E | SW,SW,NW | Drummond no.1 |
| no | 18-23N-9E | NW,SW,SW | MP no. 12 |
| no | 21-23N-9E | 700'FNL,900'FEL,NW | Blackbear no. 1-21 |
| no | 31-23N-9E | SE,1320'FNL,990'FWL | Hominy Northeast no. 1 |
| no | 34-23N-9E | 770'FEL,990'FSL | Mahala no.1 |
| 003-4 | 3-23N-10E | 660'FNL,330'FWL | No. Canyon Creek #1 |
| no | 32-23N-10E | 1200'FSL,500'FWL,SE | Jewell #1 |
| 003-6 | 13-23N-11E | 315'FNL,830'FEL,NE | Forbes #10 |
| no | 17-23N-11E | 300'FSL,1290'FWL | Narango no. 1-17 |
| 003-7 | 24-23N-12E | C NE of SE/4 | Blue Williams #1 |
| no | 30-23N-12E | S/2,NW,SE | Coone no. 1 |
| 006-8 | 31-23N-12E | SW,NW,SE | Well 7-31-23-12 |
| no | 36-23N-12E | SW/4,782'FSL,1980'FEL | Vaughn no. 1 |
| no | 10-24N-7E | 965'FNL,870'FWL,NE | Bassinger no. 3 |
| no | 17-24N-7E | NW,SW,NE | Naval Reserve Unit Tract no. 6-9 |
| 004-6 | 22-24N-8E | 600'FEL,1090'FSL | East Berry SE-22-24-8 no. 11 |
| no | 32-24N-8E | 2604'FNL,1275'FEL | Osage 10B no. 4A |
| 004-7 | 32-24N-8E | SE/4,1960FSL,1035FEL | Osage Roe no.11-A |
| no | 7-24N-9E | SE/4,500'FNL,330'FEL | Stuart no. 1 |
| no | 29-24N-9E | 900'FWL,330'FSL | Fields no. 2 |
| no | 4-24N-10E | SW | Penwell "E" no. 1 |
| 005-6 | 29-24N-10E | NE,NE,SE | Drummond no. 3 |
| no | 36-24N-10E | 1070'FSL,990'FEL,SE/4 | Southwest Barnsdall no. 1-A |
| 006-5 | 1-24N-11E | NW | Oklahoma Land & Cattle no. 1-1 |
| no | 20-24N-11E | 330'FSL,330'FEL,SE/4 | Humphrey no. 20-1 |
| no | 8-24N-12E | 330'FSL,940'FWL,SW | Little Creek no. 8-7 |
| no | 17-24N-12E | 990'FSL,990'FEL,NW | S. Little Creek no. 17-1 |
| 006-6 | 19-24N-12E | 330'FSL,2310'FWL | La Bodie no. 11 Al Lot 64 |
| no | 2-25N-7E | NW,SW,SW, 990'FSL,300'FWL | Wayne no. 1 |
| no | 3-25N-7E | 330'FSL,1320'FEL,NE | Clear Creek no. 1 |
| no | 4-25N-7E | 660'FWL,660'FSL,SE | Virginia no. 1-A |
| 002-2 | 13-25N-7E | NW,SE,SE | Eleanor no. 1 |
| 002-1 | 29-25N-7E | 1225'FWL,190'FNL,NE,NW,NW | Bigheart no. 8 |
| no | 34-25N-7E | 330'FSL,330'FEL,NE | Alred no. 1-34 |
| no | 3-25N-8E | 900'FNL,1050'FWL,SW | Drummond no. 1-3 |
| 002-3 | 10-25N-8E | SW,SE,SW | Bruce no. 5 |
| 004-5 | 28-25N-8E | NE,NE,SE | Chess no. 2 |
| no | 36-25N-8E | SW,SW,SE | Vivian no. 1-36 |
| no | 6-25N-9E | NE,NW,NW | East Thomas no. 1 |
| 002-4 | 8-25N-9E | 990'FWL,330'FNL,SE | Yates no. 1-A |
| no | 24-25N-9E | 650'FNL,300'FEL,SW | OSU no. 83-1 |
| no | 13-25N-10E | NW,SW,NE | Tate no. 30 |
| 002-5 | 21-25N-10E | | no. 1-21 Dickson |
| no | 1-25N-11E | 330'SNL,480'EWL | Ballew no. 7 |
| 002-6 | 16-25N-11E | 760'FSL,660'FEL,NW | Natl. Zinc 11-16-25-11 |
| no | 20-25N-11E | 660'FSL,30'FEL,SW | Harmon Et. Al. no. 3-20 |
| no | 29-25N-11E | 1050'FSL,990'FEL,NW | Williams no. 2-29 |
| 002-7,006-4 | 8-25N-12E | 990'FNL,760'FEL,SW | E. Woolaroc no. 1 |
| 004-3 | 21-26N-8E | 660'FNL,660'FWL,SE | Brave no. 1 |
| no | 34-26N-8E | 330'FNL,330'FEL,NW | South Myers no. 1 |
| no | 36-26N-8E | 990'FSL,330'FEL,NW | OK no. 2-36 |
| no | 31-26N-9E | NE | Smith no. 31-9 |
| no | 34-26N-9E | 330'FNL,1400'FEL,NE | Pawhuska no. 5 |
| no | 2-26N-10E | SE,330'FSL,330'FEL | Osage Hills no. 102 |
| no | 3-26N-10E | 1980'FNL,890'FEL | TR 8 Well No. 14 |
| no | 9-26N-10E | C N/2,NE,SE,SE | Lane No. 1-A |

| Company | Field | County | State | Log Meas.from | Map 1 Tackett Sh |
|---|---|---|---|---|---|
| Rickelson Oil & Gas | | Osage | OK | 921 | -894 |
| Great Southwestern Exploration | Osage Hominy | Osage | OK | 1125 | -712 |
| Southland Energy Corp. | Bandwheel | Osage | OK | 837 | -498 |
| Golden Oil Co. | Pettit Dome | Osage | OK | 1051 | -797 |
| Nadel & Gussman & J.M. Graves | Manion | Osage | OK | 804 | -538 |
| DCK Resources, Ltd. | Wildcat | Osage | OK | 873 | -579 |
| Juniper Petroleum | Wildcat | Osage | OK | 846 | -545 |
| Bandwheel Investors Fund | Bandwheel | Osage | OK | 778 | -590 |
| William R. Lynn | Signal Hills | Osage | OK | 845 | -531 |
| Centennial Petroleum Inc. | Wildcat | Osage | OK | 793 | -665 |
| C.N. Operating Co. | Wildcat | Osage | OK | 749 | -517 |
| Federal Energy Development Co. | Wildcat | Osage | OK | 859 | -279 |
| Nadel & Gussman | Canyon Creek | Osage | OK | 873 | -337 |
| Wachtman, Shroeder-B&J Investment | | Osage | OK | 729 | 121 |
| Strata Energy Inc. | S. Barnsdall | Osage | OK | 841 | -25 |
| BBR Oil Corp. | W.C. | Washington | OK | 744 | 290 |
| L.E.C. LTD. | blank | Osage | OK | 938 | 251 |
| Dyco Petroleum Corp. | So. Avant | Osage | OK | 918 | 243 |
| BBR Oil Corp. | blank | Washington | OK | 735 | 287 |
| Nadel and Gussman | West Dalton | Osage | OK | 930 | -973 |
| Texaco Inc. | Naval Reserve | Osage | OK | 1005 | -1113 |
| Sun Production Co. | Tidal Osage | Osage | OK | 1012.5 | -634.5 |
| Energy Reserves Group | Osage Hominy | Osage | OK | 899 | -723 |
| Energy Reserves Group | Osage Hominy | Osage | OK | 882 | -726 |
| Ferguson Oil Company | Post Oak | Osage | OK | 895 | -560 |
| Continental Oil and Ref. | Speedway | Osage | OK | 1002 | -585 |
| Narmac Resources Company | Pershing | Osage | OK | 889 | -355 |
| Siosi Oil & Gas Company | North Birch | Osage | OK | 801 | -382 |
| Centennial Petroleum Inc. | Barnsdall | Osage | OK | 786 | -44 |
| V.J.Huff | Wildcat | Osage | OK | 904 | 21 |
| Golden Oil Co. & Silver Pet. | S. Barnsdall | Osage | OK | 720 | -72 |
| Federal Energy Development Co. | Candy Creek | Osage | OK | 788 | 110 |
| Federal Energy Development Co. | Candy Creek | Osage | OK | 721 | 103 |
| Solar Petroleum, Inc. | N. Avant | Osage | OK | 753 | 76 |
| Trans Atlantic Resource Corp. | Wildcat | Osage | OK | 1077 | -1001 |
| DCX Resources, Ltd. | Wildcat | Osage | OK | 1012 | -1017 |
| Golden Eagle Resources Corp. | Stone | Osage | OK | 1076 | -988 |
| | | Osage | OK | 1063 | -862 |
| Callmet Oil Co. | blank | Osage | OK | 1080 | -1100 |
| Bill J. Barbee | Wildcat | Osage | OK | 973 | -982 |
| Strata Energy Inc. | W. Pawhuska | Osage | OK | 1067 | -710 |
| Rickelson Oil and Gas Company | blank | Osage | OK | 961 | -680 |
| J. M. Graves | | Osage | OK | 1063 | -683 |
| James W. Wise | South Atlantic | Osage | OK | 1054 | -670 |
| Great Southwestern Exploration | Atlantic | Osage | OK | 992 | -672 |
| | | Osage | OK | 759 | -701 |
| Ron and Dan Oil, Ltd. | N. Pershing | Osage | OK | 878 | -447 |
| Class Petroleum Corp. | Tate | Osage | OK | 948 | -165 |
| Dance Oil Company | | Osage | OK | 848 | -322 |
| Cambrian Petroleum | N. Woolaroc | Osage | OK | 930 | 47 |
| | | Osage | OK | 1016 | -114 |
| John Swank | Quapaw | Osage | OK | 906 | -104 |
| John B. Swank | South Quapaw | Osage | OK | 801 | -81 |
| Wichita Industries, Inc. and Antares Oil Corp. | blank | Osage | OK | 950 | 66 |
| B.B.R. Oil Corporation | Wildcat | Osage | OK | 1040 | -722 |
| Bruner Oil and Gas, Inc. | Wildcat | Osage | OK | 965 | -774 |
| Fox Oil & Gas Company | Bluestem Lake | Osage | OK | 998 | -650 |
| C.N. Operating Co. | West Pawhuska | Osage | OK | 986 | -671 |
| Centennial Petroleum Inc. | Pawhuska | Osage | OK | 998 | -538 |
| ZCA Gas Gathering Co., Inc. | S.W. Domes | Osage | OK | 885 | -284 |
| Petroleum Reserve Corporation | Domes Unit | Osage | OK | 851 | -349 |
| K.W.B. Oil Property Mgmt., Inc. | S.W. Domes | Osage | OK | 881 | -361 |

| Checkerboard Ls | Seminole Formation | Nuyaka Creek Shale | Lenapah Ls. | Nowata Sh. | Worland Ls. | Lake Neosho Sh. | Amoret Ls. | Bandera Sh. | Edna ls bed |
|---|---|---|---|---|---|---|---|---|---|
| -903 | | | | | -1122 | -1132 | -1136 | -1147 | |
| -715 | | | | | -890 | -916 | -919 | -923 | |
| -500 | | | | | -703 | -725 | -729 | -734 | |
| -799 | | -872 | | | -1004 | -1023 | -1027 | -1030 | no |
| -542 | | | | | -736 | -758 | -763 | -776 | |
| -585 | | | | | -821 | -831 | -835 | -839 | |
| -551 | | | | | -784 | -794 | -796 | -800 | |
| | | | | | -816 | -834 | -838 | -842 | no |
| | | | | | -771 | -782 | -783 | -789 | no? |
| | | -808 | | | -922 | ? | ? | ? | ? |
| -521 | | | | | -780 | not shown | not shown | not shown | |
| -286 | | -397 | | | -504 | -515 | -517 | -521 | no |
| -345 | | -492 | | | -627 | not shown | not shown | not shown | |
| 107 | | | | | -132 | -144 | -149 | -153 | |
| -31 | | | | | -292 | -299 | -303 | -309 | |
| 280 | | | | | 9 | 1 | -2 | -7 | |
| 248 | | | | | -25 | -29 | -32 | -35 | |
| 235 | | 74 | | | -64 | ? | ? | -115 | no |
| 275 | | | 207? | | -31 | gr not devel. | | | |
| -977 | | | | | -1130 | -1170 | -1174 | -1178 | |
| -1119 | | | | | -1274 | -1305 | -1314 | -1317 | |
| -639.5 | | | | | -794.5 | -826.5 | -830.5 | -834.5 | |
| -732 | | | | | -889 | -922 | -926 | -929 | |
| -732 | | | | | -892 | -924 | -928 | -931 | |
| -566 | | | | | -725 | -757 | -761 | -765 | |
| | | | | | -761 | -787 | -793 | -798 | no |
| -365 | | -446 | | | -544 | -572 | -578 | -583 | no |
| -389 | | -495 | | | -582 | -606 | -609 | -619 | no |
| -50 | | | | | -274 | -290 | -294 | -300 | |
| 4 | | | | | -172 | -200 | -209 | -214 | |
| -85 | | | | | -284 | -310 | -314 | -324 | no |
| ? | | | | | -100 | -128 | -133 | -139 | |
| 87 | | | | | -107 | -132 | -136 | -142 | |
| 60 | | | | | -129 | -156 | -160 | -170 | |
| -1009 | | -1048 | | | -1135 | -1173 | -1182 | -1186 | |
| -1026 | | -1050 | | | -1147 | -1183 | -1195 | -1198 | |
| -994 | | -1025 | ? | -1054 | -1116 | 1146 | -1158 | -1164 | |
| -874 | | -917 | -935 | -952 | -1007 | -1042 | -1050 | -1060 | no |
| -1116 | | -1143 | -1160 | -1172 | -1244 | -1273 | -1282 | -1292 | no |
| -987 | | | | | -1130 | -1164 | -1179 | -1183 | |
| -721 | | | | | -848 | -873 | -890 | -896 | |
| -689 | | -729 | -744 | -759 | -816 | -850 | -854 | not shown | not shown |
| -692 | | | | | -827 | -867 | -872 | -878 | |
| -680 | | -736 | -728 | | -824 | -848 | -862 | -866 | |
| | | -730 | | | -820 | -851 | -855 | -865 | no |
| -712 | | -760 | -780 | -800 | -862 | -890 | -896 | -906 | no |
| -460 | | | | | -617 | -646 | -649 | -658 | no |
| -177 | | -244 | ? | | -342 | -368 | -374 | -383 | |
| -332 | | -402 | | | -510 | -535 | -539 | -549 | no |
| 39 | | -26 | | | -133 | -159 | -172 | -177 | |
| -126 | | -193 | | | -294 | -312 | -326 | -336 | no |
| -114 | | -186 | | | -293 | -321 | -326 | -333 | |
| -95 | | -163 | | | -275 | -302 | -310 | -315 | |
| 50 | | -16 | | | -126 | -151 | -162 | -167 | no |
| -733 | | -768 | -778 | -795 | -866 | -894 | -904 | -909 | yes |
| | | -829 | | | -920 | -956 | -959 | -975 | no |
| | | -699 | | | -790 | -822 | -826 | -838 | no |
| | | -717 | | | -818 | -846 | -856 | -867 | no |
| -548 | | -607 | | | -695 | -720 | -726 | -736 | |
| | | -343 | | | -452 | -479 | -485 | -498 | no |
| | | -409 | | | -512 | -538 | -543 | -555 | no |
| | | -419 | | | -516 | -542 | -547 | -554 | yes? |

| Laberdie Ls. | Joe Sh. | Frog Cemetery Ls. | Anna Sh. | Childers School Ls. | Sageeyah Ls. | Labette Sh. | Map 2 Higginsville L | Little Osage Sh. | Blackjack Creek Ls. |
|---|---|---|---|---|---|---|---|---|---|
| -1161 | | | -1182 | -1186 | absent | -1204 | -1250 | -1267 | -1268 |
| -929 | | | -955 | -958 | absent | -965 | -1020 | -1045 | -1049 |
| -737 | | | -763 | -767 | absent | -785 | -891 | -915 | -919 |
| -1034 | ? | ? | -1057 | -1062 | absent | -1072 | -1161 | -1183 | -1188 |
| -782 | | | -798 | -802 | absent | -808 | -920 | -938 | -943 |
| -844 | | | -870 | -873 | -883 | -904 | -980 | -996 | -1001 |
| -807 | | | -834 | -838 | -846 | -866 | -939 | -958 | -962 |
| -848 | | | -875 | -879 | ? | -902 | -1005 | -1024 | -1029 |
| -794 | ? | ? | -822 | -824 | ? | -839 | -938 | -956 | -960 |
| ? | ? | ? | ? | ? | ? | -1017 | -1085 | -1104 | -1108 |
| not shown | | | not shown | not shown | absent | -909 | -943 | -961 | |
| -539 | -550 | -555 | -561 | -565 | absent | -571 | -701 | -720 | -723 |
| not shown | | | not shown | not shown | | -707 | -783 | -787 | -790 |
| -155 | | | -176 | -183 | absent | -193 | -344 | -353 | ? |
| -313 | | | -346 | -350 | -354 | -382 | -466 | -488 | -494 |
| -11 | | | -32 | -42 | absent | -50 | -226 | -231 | -236 |
| -39 | | | -68 | -76 | absent | -90 | -225 | -227 | -232 |
| -125 | ? | ? | ? | ? | ? | -182 | -256 | -262 | -266 |
| | | | gr not developed | | | | | | |
| -1183 | | | -1208 | -1214 | ? | -1230 | -1278 | -1312 | -1317 |
| -1320 | | | -1343 | -1349 | absent? | -1356 | -1415 | -1449 | -1453 |
| -836.5 | | | -867.5 | -870.5 | absent | -879.5 | -981.5 | -1013.5 | -1017.5 |
| -931 | | | -965 | -970 | absent | -977 | -1061 | -1089 | -1094 |
| -933 | | | -970 | -973 | absent | -978 | -1064 | -1091 | -1096 |
| -771 | | | -791 | -794 | absent | -796 | -911 | -943 | -947 |
| -799 | | | -832 | -834 | ? | -843 | -955 | -975 | -978 |
| -585 | | | -622 | -627 | absent | -632 | -747 | -764 | -768 |
| -621 | | | -645 | -649 | absent | -657 | -774 | -797 | -799 |
| -304 | | | -326 | -333 | absent? | -342 | -465 | -486 | -489 |
| -216 | | | -251 | -254 | | -258 | -405 | -427 | -432 |
| -326 | ? | ? | -349 | -354 | ? | -358 | -498 | -518 | -522 |
| -142 | | | -179 | -182 | absent | -188 | -343 | -364 | -369 |
| -146 | | | -181 | -183 | absent | -189 | -348 | -371 | -375 |
| -174 | -191 | -193 | -195 | -197 | absent | -203 | -340 | -363 | -367 |
| -1191 | | | -1213 | -1217 | absent | -1220 | -1280 | -1316 | -1323 |
| -1202 | | | -1223 | -1228 | absent | -1235 | -1292 | -1328 | -1336 |
| -1170 | | | -1189 | -1194 | absent | -1200 | -1254 | -1289 | -1297 |
| -1064 | | | -1085 | -1089 | | -1095 | -1157 | -1201 | -1205 |
| -1298 | | | -1320 | -1323 | | -1334 | -1374 | -1418 | -1423 |
| -1186 | | | -1209 | -1214 | absent | -1218 | -1277 | -1318 | -1322 |
| -899 | | | -920 | -925 | absent | -931 | -1006 | -1044 | -1049 |
| not shown | | | not shown | not shown | ? | -897 | -973 | -1017 | -1020 |
| -882 | | | -904 | -907 | absent | -912 | -1003 | -1039 | -1044 |
| -869 | | | -892 | -894 | absent | -900 | -946 | -1028 | -1034 |
| -869 | | | -888 | -891 | absent | -894 | -975 | -1013 | -1018 |
| -909 | | | -935 | -941 | | -946 | -1005 | -1038 | -1044 |
| -660 | | | -684 | -688 | absent | -690 | -796 | -828 | -832 |
| -386 | | | -410 | -413 | absent | -420 | -534 | -564 | -568 |
| -552 | | | -576 | -580 | | -588 | -690 | -722 | -725 |
| -181 | | | -203 | -206 | absent | -217 | -347 | -378 | -383 |
| -341 | | | -367 | -373 | | -378 | -487 | -518 | -524 |
| -340 | | | -368 | -371 | absent | -382 | -486 | -510 | -514 |
| -323 | | | -353 | -358 | absent | -370 | -473 | -497 | -502 |
| -170 | | | -194 | -198 | | -202 | -344 | -372 | -378 |
| -927 | | | -949 | -956 | ? | -960 | -1009 | -1044 | -1049 |
| -981 | | | -1003 | -1006 | ? | -1016 | -1068 | -1105 | -1110 |
| -840 | | | -861 | -865 | absent | -869 | -948 | -982 | -988 |
| -871 | | | -892 | -894 | ? | -896 | -976 | -1016 | -1019 |
| -740 | | | -760 | -762 | absent | -774 | -847 | -884 | -888 |
| -501 | | | -524 | -529 | absent | -535 | -614 | -648 | -652 |
| -557 | | | -579 | -585 | absent | -587 | -667 | -703 | -707 |
| -563 | | | -585 | -591 | ? | -593 | -674 | -709 | -714 |

| Excello Sh. | Breezy Hill Ls. | Map 3 Pawnee Isopach | Map 4 Altamont Isopach | Map 5 P&A Isopach | Map 6 Labette Isopach | Map 7 Bandera Isopach |
|---|---|---|---|---|---|---|
| -1297 | | 43 | 25 | 82 | 46 | 14 |
| -1073 | | 36 | 33 | 75 | 55 | 6 |
| -953 | | 48 | 31 | 82 | 106 | 3 |
| -1221 | -1225 | 38 | 26 | 68 | 89 | 4 |
| -978 | | 26 | 42 | 72 | 112 | 4 |
| -1031 | | 60 | 18 | 83 | 76 | 5 |
| -994 | | 59 | 16 | 82 | 73 | 7 |
| -1068 | -1071 | 54 | 26 | 86 | 103 | 6 |
| -997 | -1002 | 45 | 18 | 68 | 99 | 5 |
| -1146 | -1150 | #VALUE! | #VALUE! | 95 | 68 | #VALUE! |
| | | can't use | can't use | 129 | 34 | #VALUE! |
| -759 | | 32 | 17 | 67 | 130 | 18 |
| -837 | | can't use | can't use | 80 | 76 | #VALUE! |
| ? | | 38 | 21 | 61 | 151 | 2 |
| -522 | | 69 | 17 | 90 | 84 | 4 |
| -270 | | 39 | 16 | 59 | 176 | 4 |
| -268 | | 51 | 10 | 65 | 135 | 4 |
| -300 | | 57 | 51 | 118 | 74 | 10 |
| | | can't use | can't use | can't use | can't use | 0 |
| -1336 | | 47 | 48 | 100 | 48 | 5 |
| -1473 | -1477 | 36 | 43 | 82 | 59 | 3 |
| -1044.5 | | 43 | 40 | 85 | 102 | 2 |
| -1116 | -1121 | 46 | 40 | 88 | 84 | 2 |
| -1118 | -1122 | 45 | 39 | 86 | 86 | 2 |
| -971 | -975 | 25 | 40 | 71 | 115 | 6 |
| -1008 | -1013 | 44 | 37 | 82 | 112 | 1 |
| -796 | -801 | 47 | 39 | 88 | 115 | 2 |
| -829 | -837 | 36 | 37 | 75 | 117 | 2 |
| -525 | | 38 | 26 | 68 | 123 | 4 |
| -465 | | 42 | 42 | 86 | 147 | 2 |
| -558 | | 32 | 40 | 74 | 140 | 2 |
| -404 | | 46 | 39 | 88 | 155 | 3 |
| -408 | | 43 | 35 | 82 | 159 | 4 |
| -401 | | 29 | 41 | 74 | 137 | 4 |
| -1346 | -1350 | 29 | 51 | 85 | 60 | 5 |
| -1358 | -1363 | 33 | 51 | 88 | 57 | 4 |
| -1318 | -1324 | 30 | 48 | 84 | 54 | 6 |
| -1222 | -1226 | 31 | 53 | 88 | 62 | 4 |
| -1443 | -1448 | 36 | 48 | 90 | 40 | 6 |
| -1340 | | 32 | 53 | 88 | 59 | 3 |
| -1067 | | 32 | 48 | 83 | 75 | 3 |
| -1035 | -1039 | can't use | can't use | 81 | 76 | #VALUE! |
| -1063 | | 30 | 51 | 85 | 91 | 4 |
| -1056 | -1034 | 31 | 42 | 76 | 46 | 3 |
| -1028 | -1043 | 25 | 45 | 74 | 81 | 4 |
| -1061 | -1067 | 37 | 44 | 84 | 59 | 3 |
| -858 | -862 | 30 | 41 | 73 | 106 | 2 |
| -596 | -600 | 34 | 41 | 78 | 114 | 3 |
| -751 | -757 | 36 | 39 | 78 | 102 | 3 |
| -410 | 416 | 36 | 44 | 84 | 130 | 4 |
| -548 | -556 | 37 | 42 | 84 | 109 | 5 |
| -544 | -549 | 42 | 40 | 89 | 104 | 7 |
| -530 | -535 | 47 | 40 | 95 | 103 | 8 |
| -406 | -410 | 32 | 41 | 76 | 142 | 3 |
| -1074 | -1079 | 33 | 43 | 94 | 49 | 18 |
| -1134 | -1139 | 35 | 55 | 96 | 52 | 6 |
| -1010 | -1014 | 29 | 48 | 79 | 79 | 2 |
| -1036 | -1045 | 25 | 49 | 78 | 80 | 4 |
| -908 | -911 | 34 | 41 | 79 | 73 | 4 |
| -675 | -680 | 34 | 46 | 83 | 79 | 3 |
| -730 | -734 | 30 | 43 | 75 | 80 | 2 |
| -737 | -742 | 30 | 38 | 77 | 81 | 9 |

| x-sec | Location | Location | Well Name |
|---|---|---|---|
| no | 10-26N-10E | 330'FNL,330'FEL | Baker no. 1 'P' |
| no | 11-26N-10E | SE,330'FNL,2310'FEL | Osage Hills no. 111 |
| 005-4 | 29-26N-10E | 1315'FNL,1400'FWL,NW | Sand Creek no. 29-1 |
| no | 7-26N-11E | SE,990'FWL,300'FNL | Camp Creek no. 207 (307) |
| 006-3 | 4-26N-12E | 385'FNL,900'FWL | Swan "A" no. 1 |
| no | 6-27N-7E | 990'FSL&FWL,NW | SW Foraker "A" no. 1 |
| no | 35-27N-7E | 990'FSL,870'FWL,NE | Enfisco no. 2 |
| 004-2 | 23-27N-8E | 330'FSL,330'FEL,NE | Powell no. 1-23 |
| no | 19-27N-9E | 480'FNL,480'FWL,SW | Chapman no. 1-19 |
| no | 2-27N-10E | SE,SE,NE | Crain no. 1A |
| no | 11-27N-10E | 990'FNL,330'FWL,SW | Whiting no. 1-4 |
| no | 12-27N-10E | SW,990'FSL,330'FEL | Kane no. K-1 |
| no | 13-27N-10E | SW,990'FSL,330'FEL | Kane no. K-2 |
| no | 15-27N-10E | SE,990'FNL,330'FWL | Whiting no. 1-5 |
| no | 22-27N-10E | SE | Duffy no. 3-A |
| no | 23-27N-10E | SW,SW,SW | Doyle no. 8 |
| no | 24-27N-10E | SW,SW,SE | No. 73 |
| no | 25-27N-10E | NE | Dallas-Osage no. 86 |
| no | 27-27N-10E | 1410'FNL,600'FWL | Rick no. 2-B |
| 005-3 | 33-27N-10E | E/2,1320'FNL&FEL | NE 33 no. 3 |
| no | 34-27N-10E | SW,NW | Domes Unit no. 1-21 |
| no | 35-27N-10E | SE,NE | Fees no. 3 |
| no | 35-27N-10E | SE,NW,NW,NW | Domes Unit TR 3 no.28 |
| no | 36-27N-10E | 2590'FSL,1320'FWL | Domes Pond SW 36 no. W-1 |
| no | 7-27N-11E | C-SW/4 | Mike no. 6A |
| no | 8-27N-11E | 990'FNL,330'FEL,SE | Friend no. 8-1 |
| no | 30-27N-11E | 1020'FNL,1070'FEL | Domes no. 30-1 |
| 006-2 | 20-27N-12E | N/2,N/2,NW | City of Bartlesville no. 1 |
| no | 8-28N-7E | 990'FNL,990'FEL | Foraker no. 1-A |
| 001-1 | 27-28N-7E | 330'FSL/1650'FEL | Adam No.7-A |
| no | 7-28N-8E | 500'FNL,500'FEL,SE | Osage no. 2 |
| no | 7-28N-8E | SE | Osage-Robinson no. 1 |
| 001-2,004-1 | 26-28N-8E | NE,NE,SE | NW Barnard "A" Prosp. #1 |
| no | 23-28N-9E | 560'FSL,470'FWL,SE | no. 2-23-28-9 |
| no | 24-28N-9E | NE/4 | no. 15-24-28-9 |
| no | 25-28N-9E | C,SW,NE | Pond Creek no. 10-25-28-9 |
| 001-3 | 32-28N-9E | C S1/2,S1/2,NW | Osage #1-A |
| 001-4 | 36-28N-9E | NE, NW, NE | Pond Creek 15-36-28-9 |
| no | 1-28N-10E | 100'FSL,360'FEL,NE | Woodoo no. 5 |
| 005-1 | 2-28N-10E | 300'FSL,900'FEL,SE | S. Pond Creek |
| no | 5-28N-10E | 1320'FSL,420'FWL,SE | Kyler no. 1-5 |
| no | 12-28N-10E | 1010'FNL,400'FWL,NE | Hula Reservoir no. 1 |
| no | 22-28N-10E | 990'FNL,330'FEL,NW | Brandi no. 22-1 |
| no | 23-28N-10E | NW,NW,SW | Culver no. 1 |
| NO | 27-28N-10E | 380'FNL,330'FWL | Culver no. 1-27 |
| 001-5,005-2 | 34-28N-10E | NW | Culver no. 1-A |
| no | 8-28N-11E | SW,1795'FSL,990'FWL | Osage No. 1 |
| 001-6 | 21-28N-11E | NE, NE, SW | Wasson #2 |
| no | 23-28N-11E | 400'FSL,300'FWL,NE | Osage #1-23 |
| no | 30-28N-11E | 330'FWL,990'FSL,NW | McKinley no. 1 |
| no | 8-28N-12E | 2430'FNL,450'FWL | Mullendore #8-1 |
| no | 18-28N-12E | 1320'FNL,1320'FEL,NE | Mullendore no. 1 |

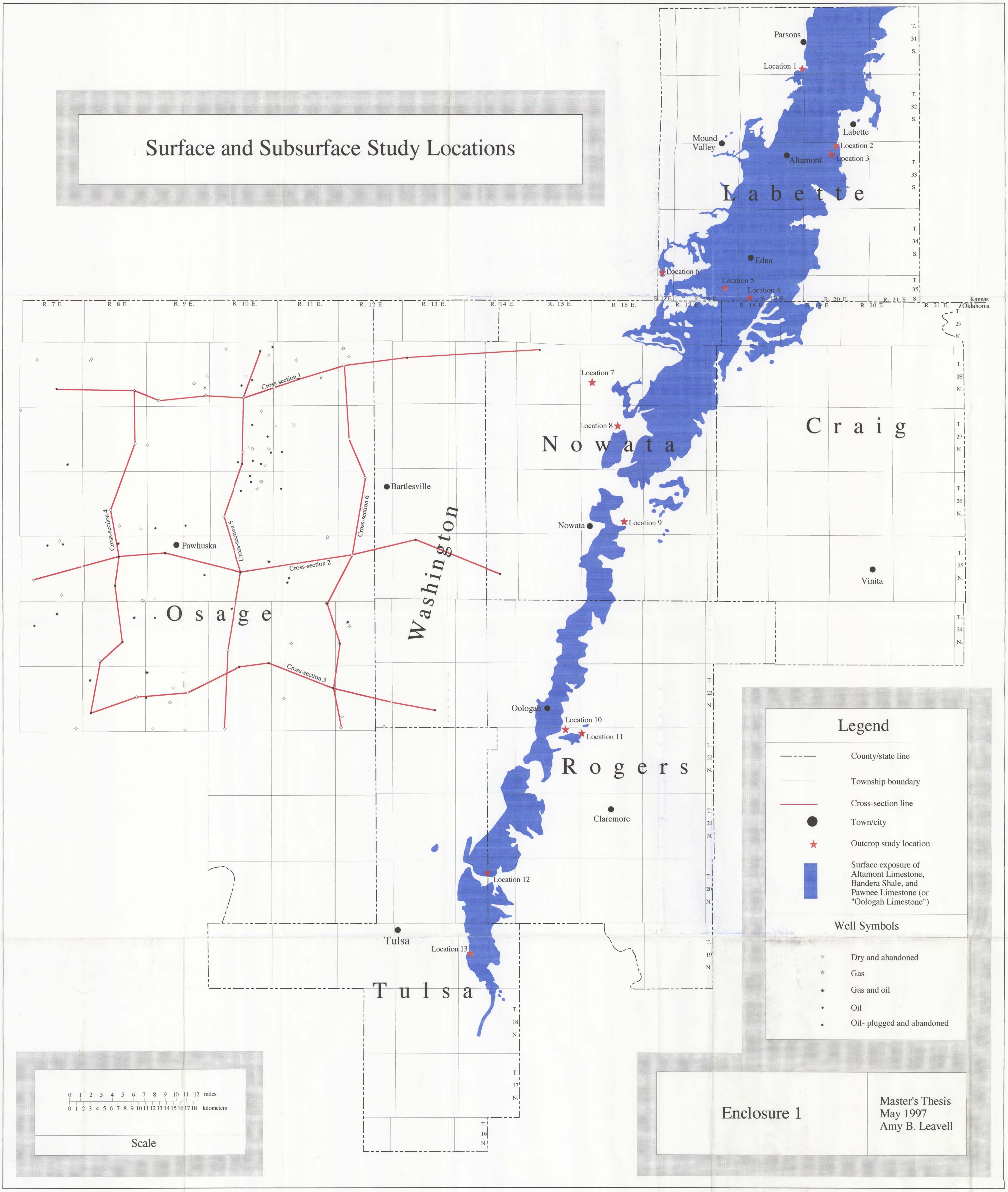
| Company | Field | County | State | Log Meas.from | Map 1 Tackett Sh |
|---|---|---|---|---|---|
| Phoenix Enterprises | Buck Creek | Osage | OK | 888 | -125 |
| ZCA Gas Gathering Co., Inc. | S.W. Domes | Osage | OK | 937 | -251 |
| Centennial Petroleum Inc. | Wildcat | Osage | OK | 903 | -475 |
| ZCA Gas Gathering Co., Inc. | Domes | Osage | OK | 856 | -224 |
| Phillips Petroleum Company | blank | Osage | OK | 750 | 74 |
| Taurus Oil | blank | Osage | OK | 1179 | -1146 |
| Wichita Industries, Inc. | Enfisco | Osage | OK | 1065 | -850 |
| Bill J. Barbee | Wildcat | Osage | OK | 1008 | -687 |
| Bill J. Barbee Expl. | Wildcat | Osage | OK | 885 | -671 |
| Wachtman and Schroeder Et Al | blank | Osage | OK | 960.5 | -148 |
| Four Brothers, Inc. | Domes Pond | Osage | OK | 973 | -212 |
| Four Brothers, Inc. | Domes Pond | Osage | OK | 938 | -251 |
| Four Brothers, Inc. | Domes Pond | Osage | OK | 838 | -252 |
| Four Brothers, Inc. | Domes Pond | Osage | OK | 944 | -261 |
| J. M. Graves | Sunset Lake | Osage | OK | 1000 | -252 |
| J. M. Graves | Wildcat | Osage | OK | 988 | -254 |
| National Petroleum Company | Domes Pond Creek | Osage | OK | 911 | -191 |
| J. M. Graves | blank | Osage | OK | 917 | -196 |
| J. M. Graves | Pond Creek | Osage | OK | 937 | -286 |
| Petroleum Reserve Co. | W.C. | Osage | OK | 834 | -346 |
| Petroleum Reserve Corporation | Wildcat | Osage | OK | 900 | -342 |
| Petroleum Reserve Corporation | Domes Unit | Osage | OK | 959 | -259 |
| Petroleum Reserve Corporation | Domes Pond | Osage | OK | 977 | -291 |
| Petroleum Reserve Corporation | Domes Pond Creek | Osage | OK | 1006 | -240 |
| J. M. Graves | Domes Pond Creek | Osage | OK | 922 | -238 |
| Golden Oil Company | Bowring | Osage | OK | 953 | -116 |
| Bruner Oil and Gas, Inc. | Wildcat | Osage | OK | 780 | -209 |
| Rickelson Oil & Gas Co. | Wildcat | Osage | OK | 790 | 17 |
| Wichita Industries, Inc. | Foraker | Osage | OK | 1260 | -976 |
| Liberty & Mid Central | Foraker | Osage | OK | 1273 | -907 |
| Lebreg, Inc. | Wildcat | Osage | OK | 1105 | -827 |
| Lebreg, Inc. | Wildcat | Osage | OK | 1084 | -816 |
| Wachtman, Shroeder, & Short | Wildcat | Osage | OK | 1072 | -690 |
| Revco Petroleum Corporation | blank | Osage | OK | 990 | -376 |
| Revco Petroleum Corporation | blank | Osage | OK | 1050 | -342 |
| Dyco Petroleum Corp. | blank | Osage | OK | 1055 | -369 |
| Dyco Petroleum Corp. | Wildcat | Osage | OK | 1028 | -596 |
| Dyco Petroleum Corp. | Wildcat | Osage | OK | 1093 | -334 |
| Frank Files | Turkey Creek | Osage | OK | 764 | -192 |
| Wachtman and Schroeder-Shakespear | blank | Osage | OK | 800 | -200 |
| James W. Wise | Semi-wildcat | Osage | OK | 834 | -348 |
| Bruner Oil and Gas | blank | Osage | OK | 740 | -208 |
| DBK Operating | Wildcat | Osage | OK | 851 | -261 |
| Santa Rosa Petroleum | Wildcat | Osage | OK | 921 | -259 |
| V.J.Huff and W-S | Wildcat | Osage | OK | 961 | -205 |
| Wachtman and Schroeder Et Al | blank | Osage | OK | 981 | -206 |
| Hambright and Noland | Semi-wildcat | Osage | OK | 766 | -267 |
| CN Operating Co. | Bowring | Osage | OK | 901 | -203 |
| Texas Pacific Oil Co. | Wildcat | Osage | OK | 745 | -138 |
| B.B.R. Oil Corporation | Wildcat | Osage | OK | | |
| Strata Energy Inc. | | Osage | OK | 718 | -16 |
| Bruner Oil and Gas | Wildcat | Osage | OK | 715 | -20 |

| Checkerboard | Seminole | Nuyaka | Lenapah | Nowata | Worland | Lake | Amoret | Bandera | Edna |
|---|---|---|---|---|---|---|---|---|---|
| Ls | Formation | Creek Shale | Ls. | Sh. | Ls. | Neosho Sh. | Ls. | Sh. | ls bed |
| -134 | | -181 | | | -318 | -342 | -346 | -349 | yes? |
| | | -312 | | | -419 | -445 | -449 | -463 | no |
| -482 | | -535 | ? | | -642 | -669 | -675 | -677 | ?yes? |
| | | | | | -397 | -422 | -426 | -439 | no |
| 60 | | 16 | 10 | -6 | -115 | -138 | -141 | -145 | |
| -1158 | | -1183 | | | -1259 | -1293 | -1301 | -1306 | |
| -865 | | -881 | | -913 | -991 | -1016 | -1022 | -1027 | |
| -697 | | -738 | | | -831 | -854 | -859 | -866 | yes |
| -678 | | ? | ? | | -818 | -845 | -847 | -856 | |
| | | | | | -321 | -350 | -355 | -372 | no |
| | | | | | -407 | -440 | -444 | -453 | no |
| | | -291 | | | -447 | -478 | -484 | -492 | no |
| | | -291 | | | -447 | -480 | -485 | -494 | no |
| | | | | | -442 | -471 | -478 | -486 | no |
| | | | | | -420 | -450 | -456 | -465 | no |
| | | | | | -424 | -453 | -460 | -468 | no |
| | | -240 | | | -376 | -405 | -411 | -419 | no |
| | | -247 | | | -379 | -406 | -411 | -421 | no |
| | | -334 | | | -443 | -473 | -479 | -487 | ? |
| -356 | | -398 | -406 | -435 | -502 | -531 | -537 | -546 | no |
| -350 | | -394 | -404 | | -501 | -526 | -532 | -535 | |
| -268 | | -312 | | | -431 | -469 | -461 | -473 | |
| -298 | | -338 | | | -455 | -481 | -487 | -495 | yes |
| -251 | | -294 | | | -416 | -442 | -446 | -452 | |
| | | -278 | | | -426 | -458 | -464 | -472 | no |
| | | | | | -327 | -358 | -361 | -377 | no |
| | | -258 | | | -394 | -421 | -426 | -438 | no |
| 4 | | -20 | -30 | -40 | -172 | -208 | -212 | -216 | |
| -992 | | ? | | | -1108 | -1127 | -1133 | -1139 | |
| -917 | | -934 | -939 | | -1047 | -1081 | -1084 | -1091 | |
| -841 | | ? | | | -963 | -1005 | -1011 | -1014 | |
| -828 | | ? | | | -970 | -991 | -998 | -1000 | |
| -706 | | -730 | | | -828 | -853 | -859 | -861 | |
| -390 | | ? | | | -533 | -557 | -580 | -582 | |
| -354 | | | | | -487 | -510 | -516 | -527 | yes |
| -377 | | | | | -522 | -549 | -557 | -568 | yes |
| -603 | | ? | | | -762 | -790 | -798 | -804 | |
| -344 | | | | | -483 | -507 | -518 | -536 | |
| ? | | | | | -302 | -306 | -310 | -343 | yes? |
| ? | | ? | | | -303 | -310 | -315 | -352 | |
| -361 | | -460 | | | -556 | -584 | -588 | -590 | |
| | | -229 | | | -322 | -328 | -338 | -363 | ? |
| | | | | | -390 | ? | ? | -461 | yes? |
| -268 | | -288 | | | -404 | -417 | -421 | -431 | yes? |
| -217 | | -239 | | | -364 | -384 | -389 | -399 | yes? |
| -214 | | | -244 | | -359 | -368 | -373 | -404 | yes |
| ? | | | | | -394 | -400 | -403 | -434 | yes? |
| ? | | ? | | | -378 | -403 | -410 | -419 | |
| -144 | | ? | | | -308 | -339 | -347 | -355 | |
| | | | | | | | | | |
| -22 | | ? | ? | | -177 | -194 | -207 | -210 | |
| ? | | -38 | | | -189 | -217 | -223 | -233 | |

| Laberdie Ls. | Joe Sh. | Frog Cemetery Ls. | Anna Sh. | Childers School Ls. | Sageeyah Ls. | Labette Sh. | Map 2 Higginsville L | Little Osage Sh. | Blackjack Creek Ls. |
|---|---|---|---|---|---|---|---|---|---|
| -356 | | | -386 | -391 | absent | -395 | -500 | -530 | -535 |
| -466 | | | -490 | -494 | ? | -513 | -581 | -613 | -619 |
| -691 | | | -711 | -716 | absent | -722 | -815 | -846 | -851 |
| -443 | | | -463 | -466 | absent | -469 | -554 | -588 | -592 |
| -154 | | | -184 | -188 | absent | -190 | -322 | -354 | -358 |
| -1323 | | | -1346 | -1354 | absent | -1358 | -1398 | -1435 | -1441 |
| -1036 | | | -1065 | -1072 | absent | -1078 | -1131 | ? | ? |
| -880 | | | -905 | -911 | ? | -917 | -958 | -987 | -995 |
| -860 | | | -889 | -898 | absent | -902 | -950 | -984 | -988 |
| -376 | | | -396 | -402 | ? | -406 | -480 | -510 | -516 |
| -457 | | | -477 | -484 | ? | -487 | -557 | -588 | -595 |
| -496 | ? | ? | ? | ? | ? | ? | -600 | -632 | -637 |
| -496 | | | -519 | -525 | ? | -528 | -602 | -633 | -639 |
| -488 | | | -510 | -516 | ? | -521 | -592 | -623 | -629 |
| -468 | | | -490 | -497 | ? | -501 | -571 | -603 | -609 |
| -472 | | | -494 | -500 | ? | -504 | -574 | -606 | -612 |
| -423 | | | -446 | -452 | ? | -457 | -531 | -564 | -571 |
| -426 | | | -447 | -453 | | -456 | -535 | -569 | -575 |
| -493 | | | -510 | -515 | ? | -521 | -583 | -618 | -623 |
| -550 | | | -570 | -574 | | -579 | -638 | -679 | -686 |
| -539 | | | -565 | -571 | absent | -574 | -640 | -673 | -678 |
| -476 | | | -498 | -503 | absent | -506 | -573 | -607 | -612 |
| -500 | | | -521 | -527 | ? | -541 | -597 | -630 | -635 |
| -460 | | | -484 | -488 | absent | -491 | -558 | -592 | -596 |
| -476 | | | -500 | -504 | ? | -508 | -588 | -621 | -626 |
| -379 | | | -401 | -406 | absent | -409 | -496 | -529 | -535 |
| -440 | ? | ? | ? | ? | ? | | -544 | -580 | -535 |
| -229 | | | -256 | -263 | absent | -265 | -378 | -409 | -416 |
| -1158 | | | -1184 | -1190 | absent | -1195 | -1226 | 1263 | -1268 |
| -1105 | | | -1132 | -1137 | -1149 | -1154 | -1181 | -1217 | -1226 |
| -1029 | | | -1058 | -1064 | absent | -1067 | -1104 | -1140 | -1145 |
| -1020 | | | -1043 | -1049 | absent | -1052 | -1089 | -1125 | -1132 |
| -876 | | | -900 | -907 | absent | -916 | -951 | -985 | -992 |
| -586 | | | -607 | -612 | -617 | -628 | -672 | -702 | -708 |
| -556 | | | -566 | -570 | ? | -585 | -644 | -675 | -683 |
| -578 | | | -599 | -603 | absent | -609 | -669 | -700 | -707 |
| -808 | | | -837 | -845 | absent | -850 | -891 | -922 | -929 |
| -538 | | | -558 | -562 | absent | -565 | -628 | -657 | -662 |
| -422 | | | -444 | -447 | ? | -462 | -529 | -556 | -563 |
| -420 | | | -442 | -446 | absent | -450 | -530 | -557 | -580 |
| -592 | | | -606 | -610 | ? | -622 | -650 | -684 | -687 |
| -438 | | | -458 | -463 | | -468 | -544 | -570 | -578 |
| -480 | | | -499 | -503 | ? | -507 | -579 | -607 | -614 |
| -483 | | | -501 | -504 | | -521 | -585 | -615 | -621 |
| -427 | | | -441 | -445 | ? | -451 | -516 | -545 | -552 |
| -414 | | | -432 | -434 | ? | -445 | -513 | -542 | -548 |
| -497 | | | -517 | -522 | ? | -537 | -617 | -644 | -651 |
| -448 | | | -474 | -479 | absent | -484 | not shown | not shown | not shown |
| -381 | | | -402 | -407 | -411 | -422 | -504 | -533 | -539 |
| | | | | | | | | | |
| -260 | | | -285 | -290 | absent | -305 | -386 | -412 | -418 |
| -261 | | | -287 | -293 | absent | -309 | -393 | -421 | -425 |

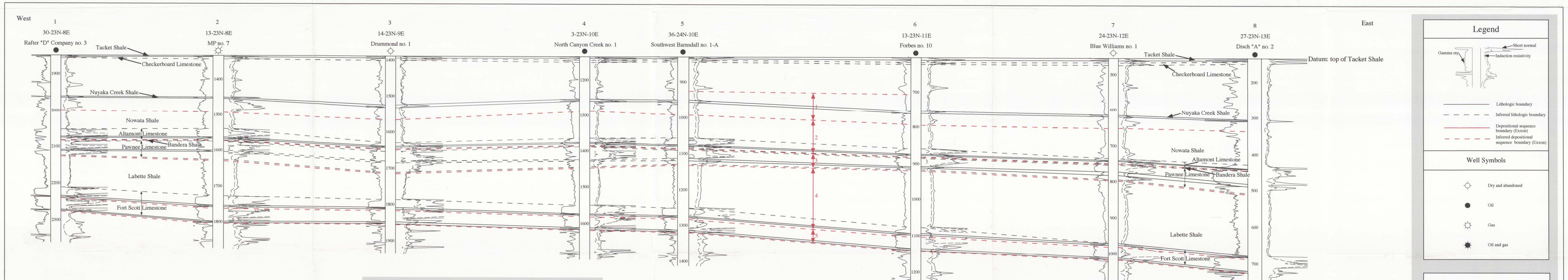
| Excello Sh. | Breezy Hill Ls. | Map 3 Pawnee Isopach | Map 4 Altamont Isopach | Map 5 P&A Isopach | Map 6 Labette Isopach | Map 7 Bandera Isopach |
|---|---|---|---|---|---|---|
| -556 | -519 | 39 | 31 | 77 | 105 | 7 |
| -641 | -646 | 47 | 44 | 94 | 68 | 3 |
| -875 | -881 | 31 | 35 | 80 | 93 | 14 |
| -612 | -617 | 26 | 42 | 72 | 85 | 4 |
| -381 | -386 | 36 | 30 | 75 | 132 | 9 |
| | | 35 | 47 | 99 | 40 | 17 |
| ? | ? | 42 | 36 | 87 | 53 | 9 |
| -1028 | -1022 | 37 | 35 | 86 | 41 | 14 |
| -1012 | -1017 | 42 | 38 | 84 | 48 | 4 |
| -538 | -543 | 30 | 51 | 85 | 74 | 4 |
| -617 | -621 | 30 | 46 | 80 | 70 | 4 |
| -660 | -665 | #VALUE! | 45 | #VALUE! | 600 | 4 |
| -662 | -666 | 32 | 47 | 81 | 74 | 2 |
| -652 | -656 | 33 | 44 | 79 | 71 | 2 |
| -632 | -637 | 33 | 45 | 81 | 70 | 3 |
| -632 | -637 | 32 | 44 | 80 | 70 | 4 |
| -595 | -599 | 34 | 43 | 81 | 74 | 4 |
| -598 | -605 | 30 | 42 | 77 | 79 | 5 |
| -643 | -646 | 28 | 44 | 78 | 62 | 6 |
| -705 | -712 | 29 | 44 | 77 | 59 | 4 |
| -699 | -704 | 35 | 34 | 73 | 66 | 4 |
| -633 | -637 | 30 | 42 | 75 | 67 | 3 |
| -657 | -661 | 41 | 40 | 86 | 56 | 5 |
| -616 | -620 | 31 | 36 | 75 | 67 | 8 |
| -650 | -654 | 32 | 46 | 82 | 80 | 4 |
| -559 | -565 | 30 | 50 | 82 | 87 | 2 |
| -608 | -612 | -440 | 44 | -394 | 544 | 2 |
| -435 | -442 | 36 | 44 | 93 | 113 | 13 |
| -1294 | -1299 | 37 | 31 | 87 | 31 | 19 |
| -1247 | -1250 | 49 | 44 | 107 | 27 | 14 |
| -1168 | -1173 | 38 | 31 | 84 | 37 | 15 |
| -1154 | -1159 | 32 | 30 | 82 | 37 | 20 |
| -1012 | -1018 | 40 | 33 | 88 | 35 | 15 |
| -728 | -733 | 42 | 49 | 95 | 44 | 4 |
| -702 | -707 | 29 | 40 | 98 | 59 | 29 |
| -727 | -731 | 31 | 46 | 87 | 60 | 10 |
| -945 | -955 | 42 | 42 | 88 | 41 | 4 |
| -683 | -699 | 27 | 53 | 82 | 63 | 2 |
| -580 | -584 | 40 | 41 | 160 | 67 | 79 |
| -594 | -598 | 30 | 49 | 147 | 80 | 68 |
| -706 | -712 | 30 | 34 | 66 | 28 | 2 |
| -596 | -601 | 30 | 41 | 146 | 76 | 75 |
| -633 | -637 | 27 | 71 | 117 | 72 | 19 |
| -639 | -644 | 38 | 27 | 117 | 64 | 52 |
| -570 | -574 | 24 | 35 | 87 | 65 | 28 |
| -565 | -569 | 31 | 45 | 86 | 68 | 10 |
| -672 | -678 | 40 | 40 | 143 | 80 | 63 |
| not shown | not shown | 36 | 41 | 106 | can't use | 29 |
| -561 | -566 | 41 | 47 | 114 | 82 | 26 |
| | | 0 | 0 | 0 | 0 | 0 |
| -439 | -444 | 45 | 33 | 128 | 81 | 50 |
| -445 | -450 | 48 | 44 | 120 | 84 | 28 |

Enclosures 1, 2, 3 , 4, 5, 6, 7 , 8, 9, 10, 11, 12, 13, 14, 15 and 16.


Surface and Subsurface Study Locations
Labette
Parsons
Location 1
Labette
Mound Valley
Altamont
Location 2
Location 3
Edna
Location 6
Location 5
Location 4
Kansas
Oklahoma
Craig
Vinita
Nowata
Location 7
Location 8
Nowata
Location 9
Osage
Pawhuska
Cross-section 1
Cross-section 2
Cross-section 3
Cross-section 4
Cross-section 5
Cross-section 6
Washington
Bartlesville
Rogers
Oologah
Location 10
Location 11
Claremore
Location 12
Tulsa
Tulsa
Location 13
R. 7 E.
R. 8 E.
R. 9 E.
R. 10 E.
R. 11 E.
R. 12 E.
R. 13 E.
R. 14 E.
R. 15 E.
R. 16 E.
R. 17 E.
R. 18 E.
R. 19 E.
R. 20 E.
R. 21 E.
T. 31 S.
T. 32 S.
T. 33 S.
T. 34 S.
T. 35 S.
T. 29 N.
T. 28 N.
T. 27 N.
T. 26 N.
T. 25 N.
T. 24 N.
T. 23 N.
T. 22 N.
T. 21 N.
T. 20 N.
T. 19 N.
T. 18 N.
T. 17 N.
T. 16 N.
Legend
County/state line
Township boundary
Cross-section line
Town/city
Outcrop study location
Surface exposure of Altamont Limestone, Bandera Shale, and Pawnee Limestone (or "Oologah Limestone")
Well Symbols
Dry and abandoned
Gas
Gas and oil
Oil
Oil- plugged and abandoned
0 1 2 3 4 5 6 7 8 9 10 11 12 miles
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 kilometers
Scale
Enclosure 1
Master's Thesis
May 1997
Amy B. Leavell


Stratigraphic Cross Section 1

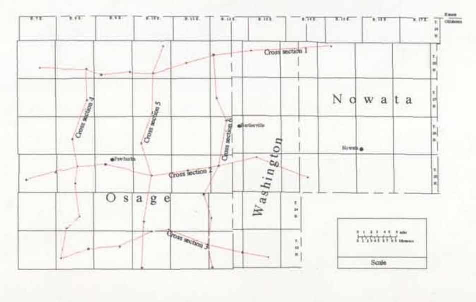

Stratigraphic Cross Section 2




Stratigraphic Cross Section 3

East-West Stratigraphic Cross Sections

Enclosure 2




Index map to cross sections

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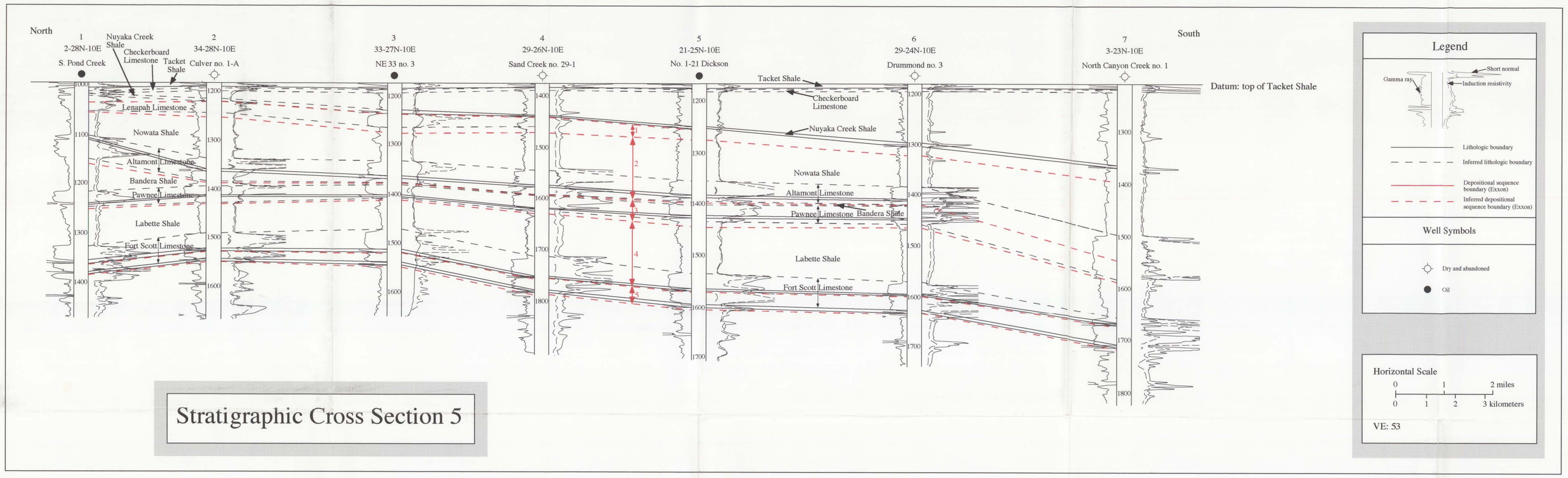
May 1997

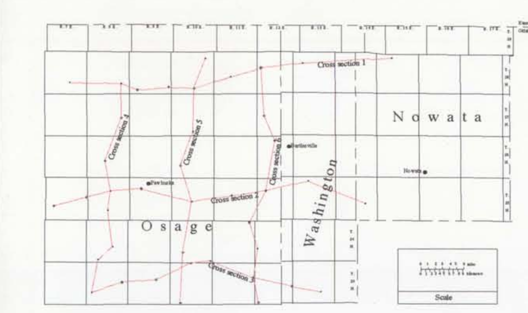

Stratigraphic Cross Section 4




Stratigraphic Cross Section 5

# North-South Stratigraphic Cross Sections

## Enclosure 3




Index map to cross sections

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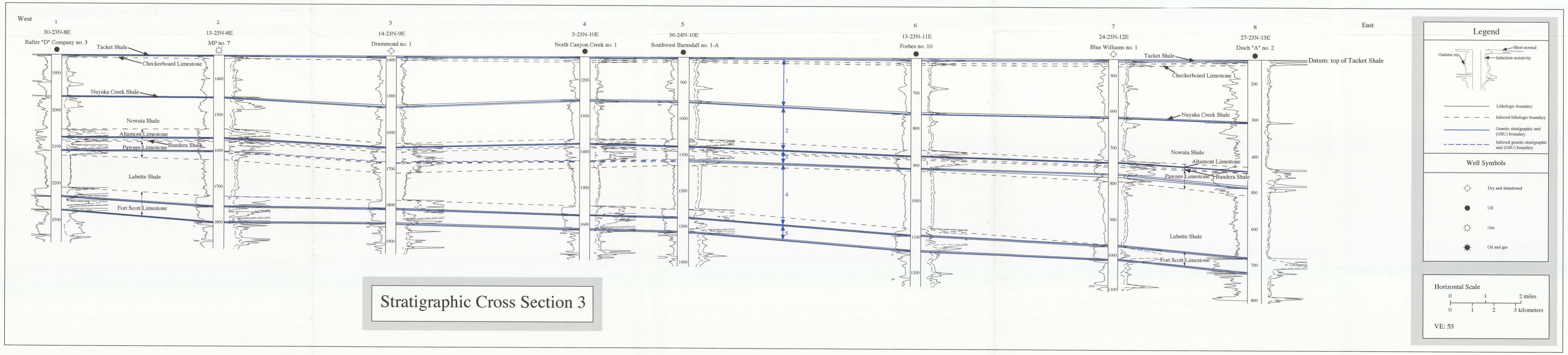
Stratigraphic Cross Section 6


Stratigraphic Cross Section 1


Stratigraphic Cross Section 2




Stratigraphic Cross Section 3

East-West Stratigraphic Cross Sections

Enclosure 4


Index map to cross sections

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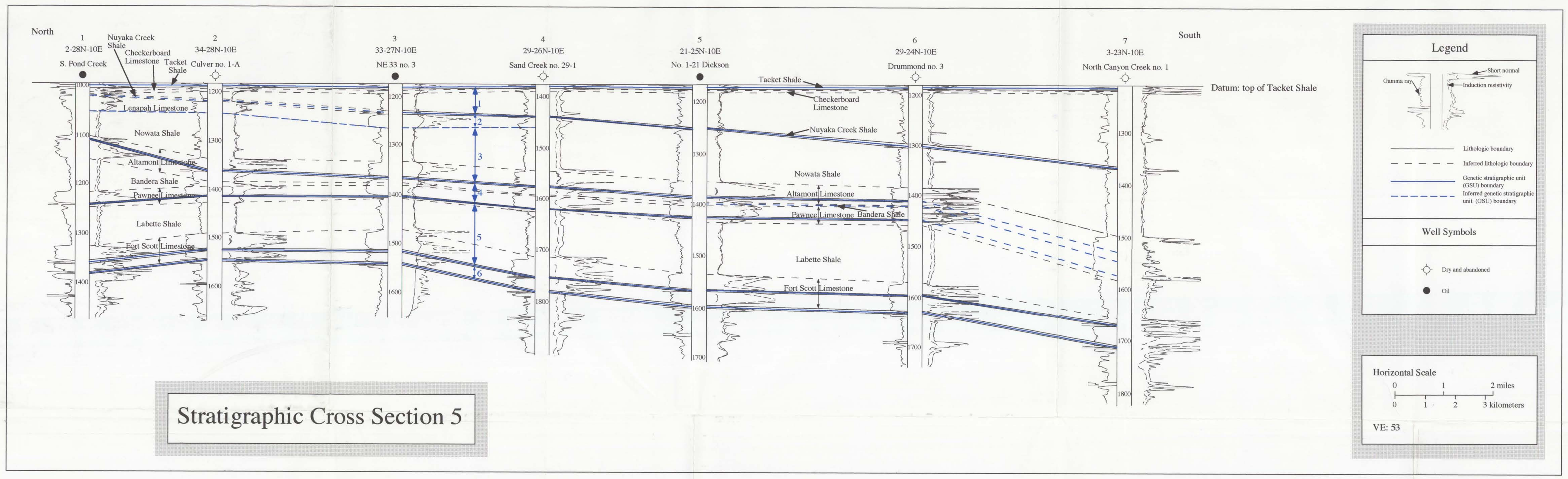
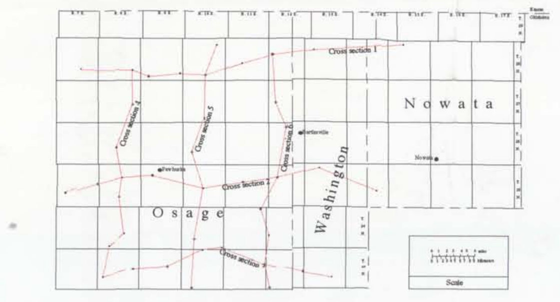



North-South Stratigraphic Cross Sections

Enclosure 5




Index map to cross sections

Amy B. Leavell
Master's Thesis
May 1997


Well symbols

- Dry, abandoned
- Gas
- Oil and gas
- Oil, abandoned
- Oil

Scale:

0 1 2 3 4 5 6 7 8 9 10 kilometers

0 1 2 3 4 5 6 miles

Enclosure 6

TOP OF TACKET SHALE
CONTOUR INTERVAL 100 FT.

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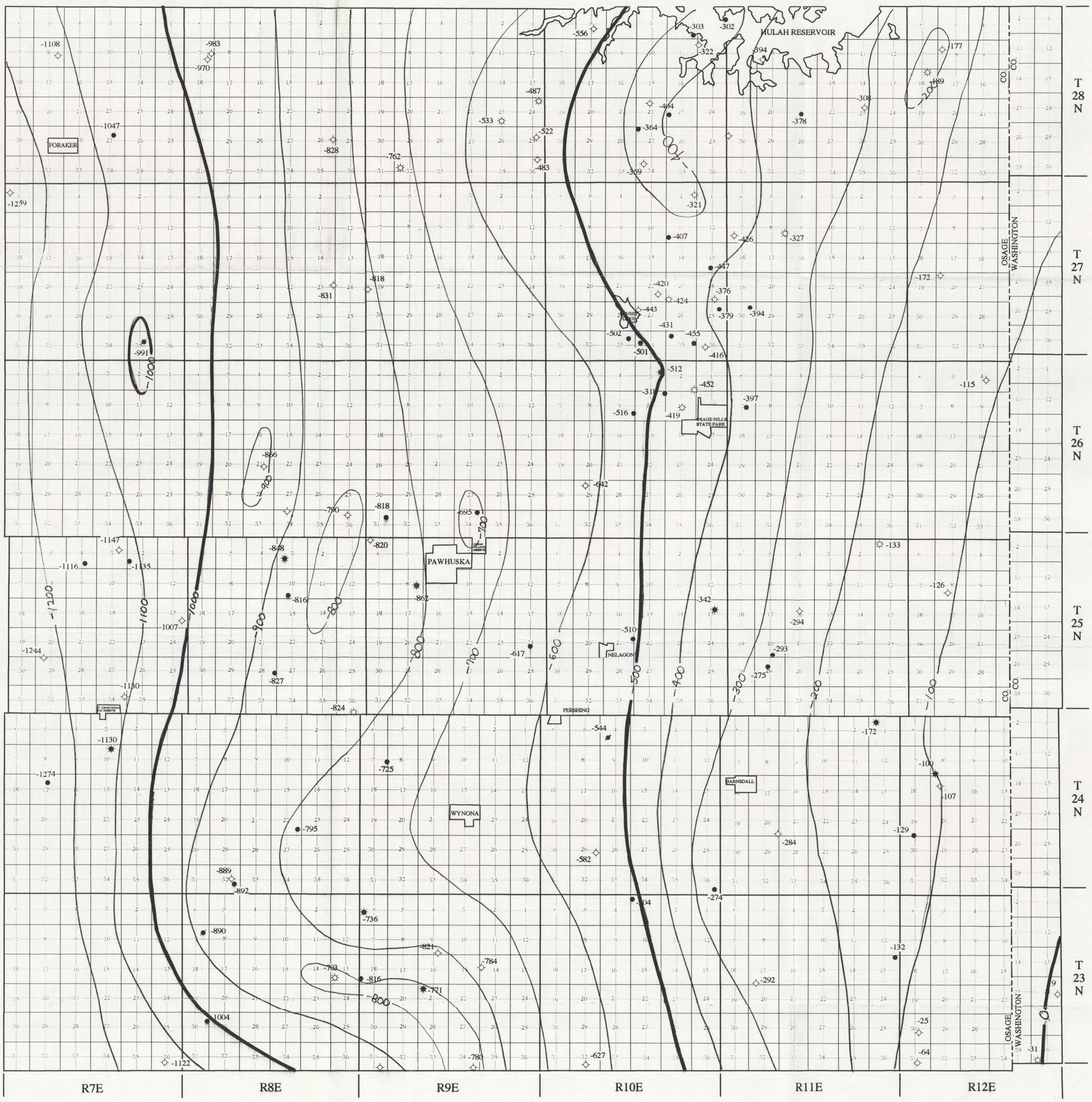


Well symbols

- Dry, abandoned
- Gas
- Oil and gas
- Oil, abandoned
- Oil

Scale:

0 1 2 3 4 5 6 7 8 9 10 kilometers

0 1 2 3 4 5 6 miles

Enclosure 7

Top of Altamont Limestone
Contour Interval = 100 ft

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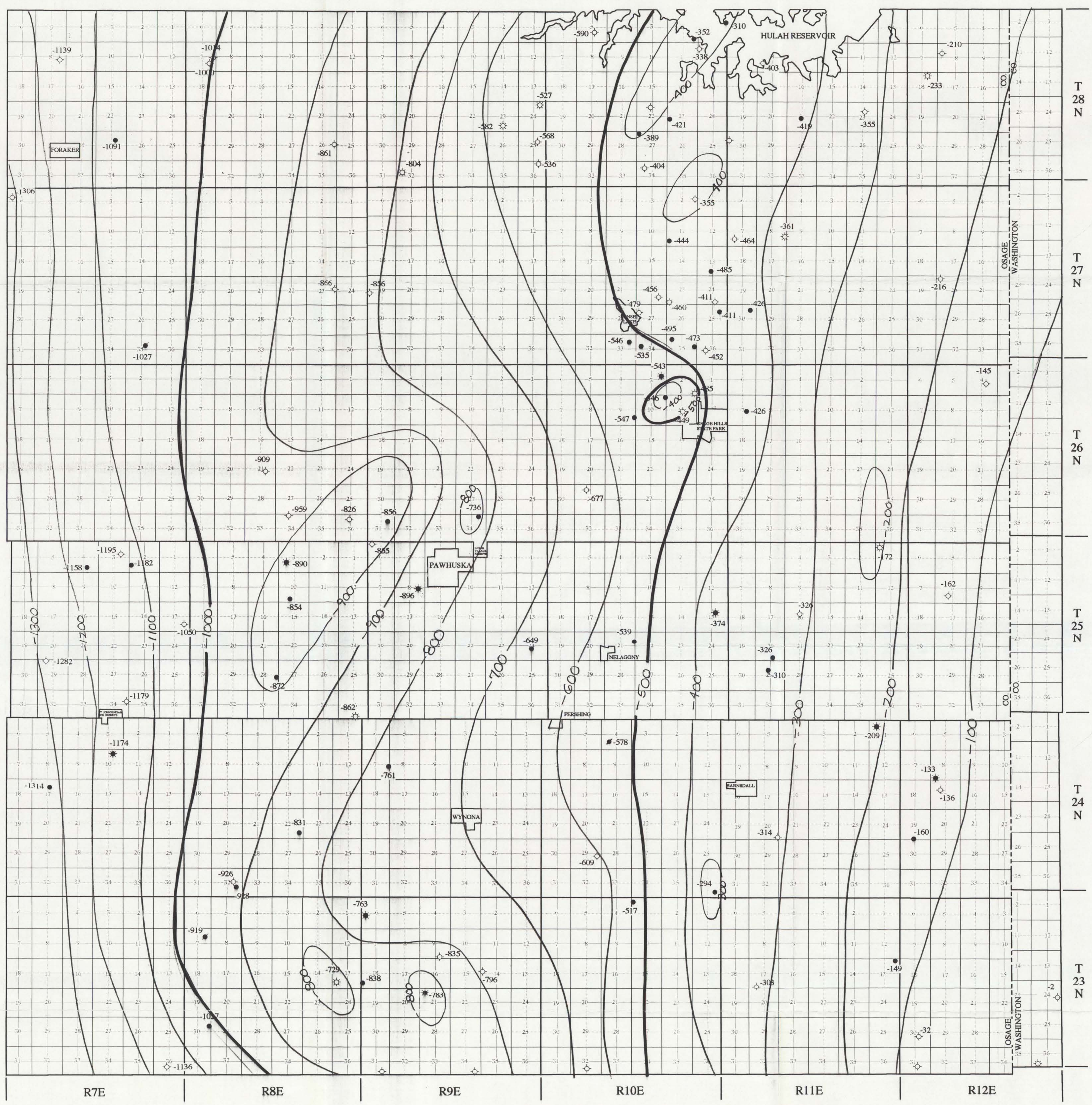
Master's Thesis
May 1997




Well symbols

Dry, abandoned

Gas

Oil and gas

Oil, abandoned

Oil

Scale:

0 1 2 3 4 5 6 7 8 9 10 kilometers

0 1 2 3 4 5 6 miles

## Enclosure 8

Base of Lake Neosho Shale Member
Contour Interval = 100 ft.

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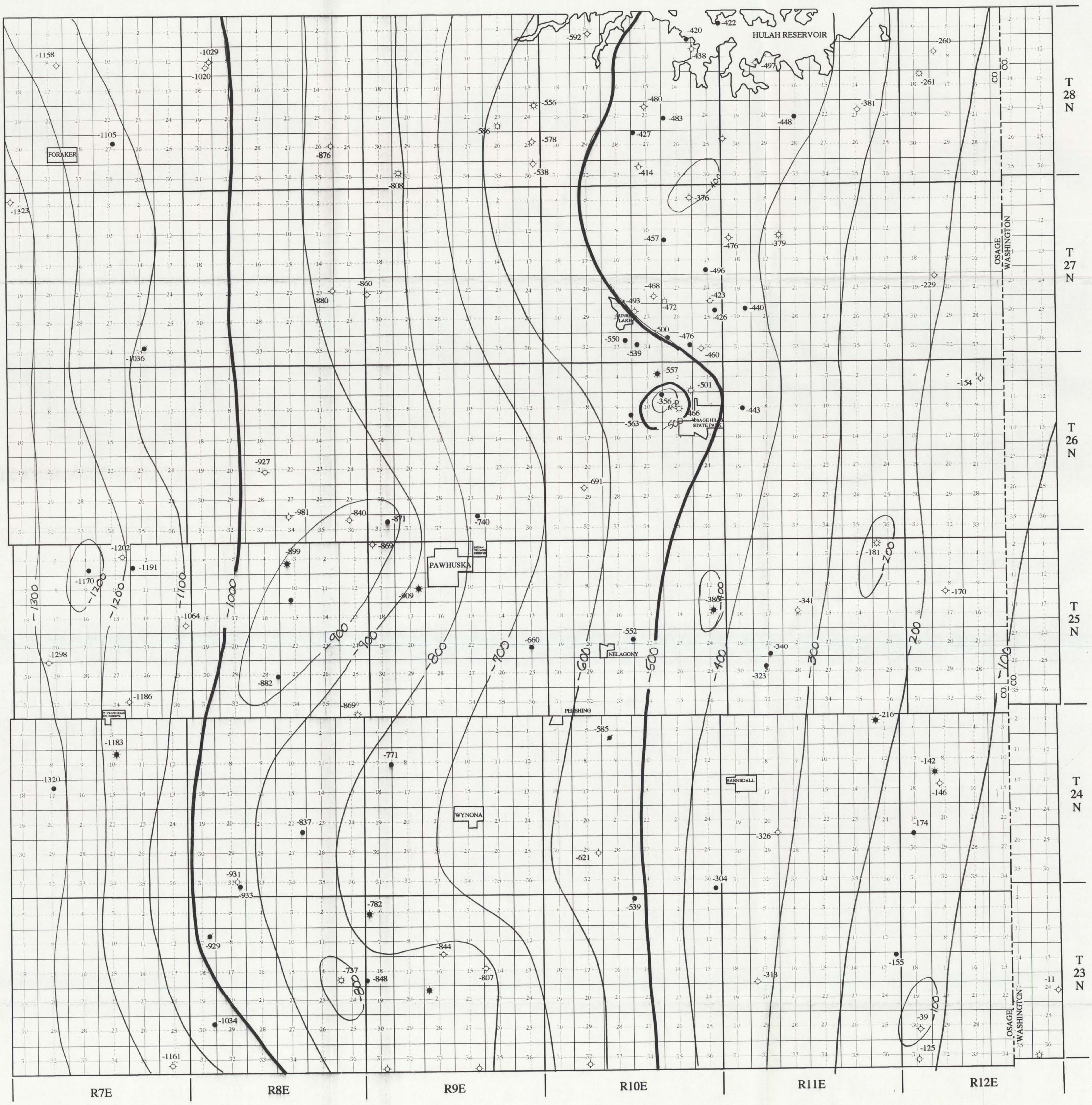
Master's Thesis
May 1997




Well symbols

- Dry, abandoned
- Gas
- Oil and gas
- Oil, abandoned
- Oil

Scale:

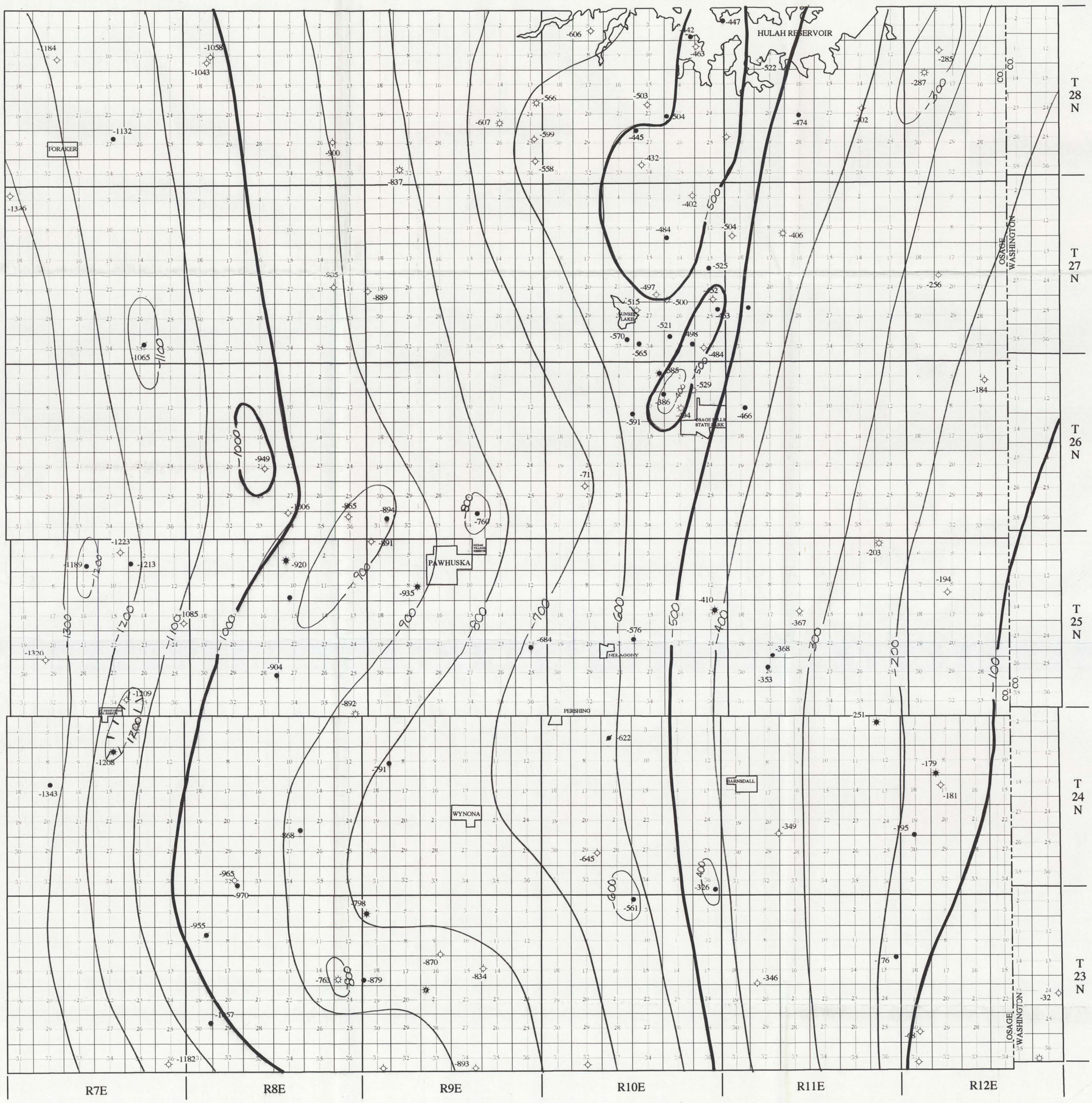
0 1 2 3 4 5 6 7 8 9 10 kilometers

0 1 2 3 4 5 6 miles

Enclosure 9

TOP OF PAWNEE LIMESTONE
CONTOUR INTERVAL 100 FT.

Amy B. Leavell
Master's Thesis
May 1997




Well symbols

- Dry, abandoned
- Gas
- Oil and gas
- Oil, abandoned
- Oil

Scale:

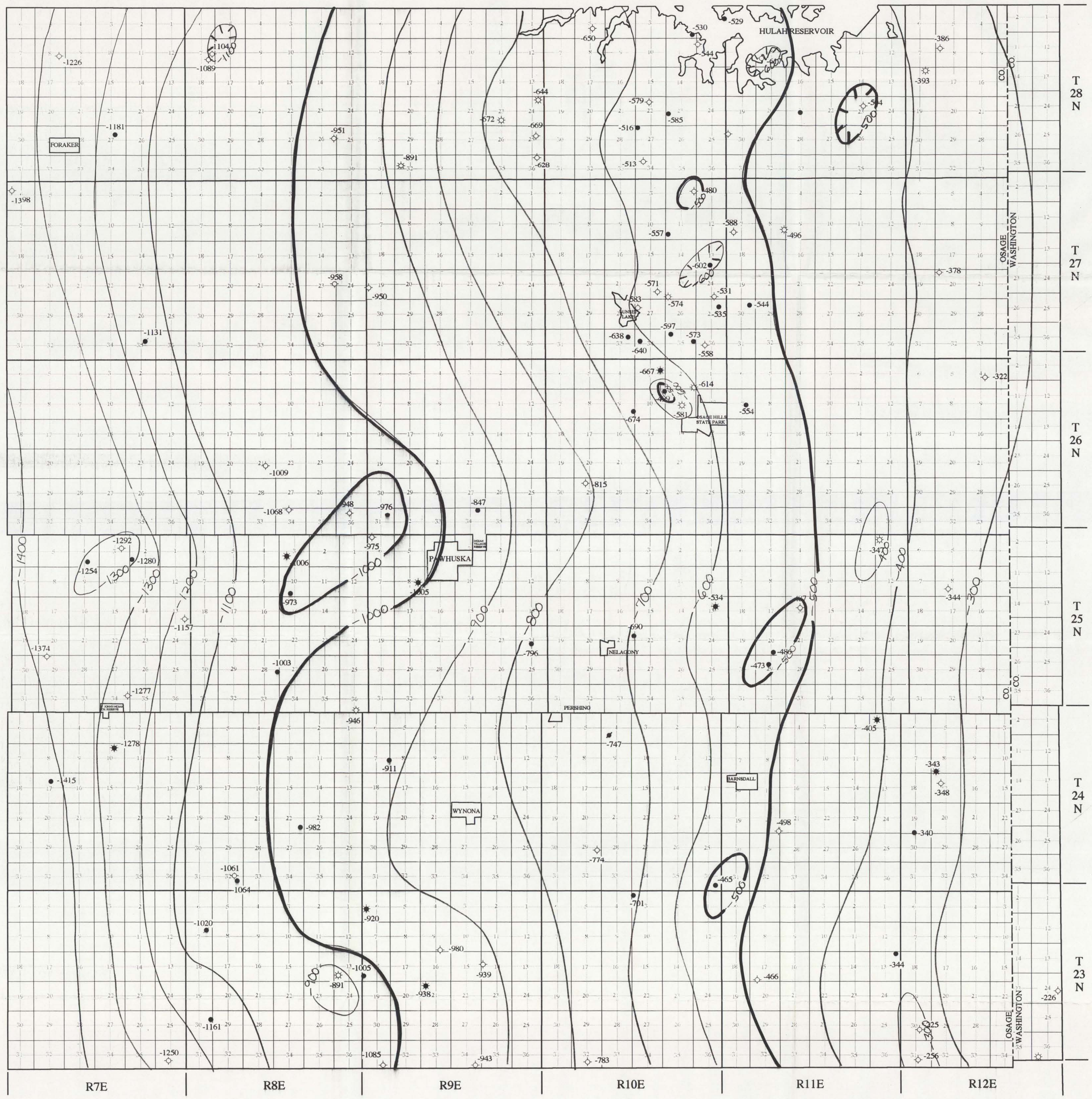
0 1 2 3 4 5 6 7 8 9 10 kilometers

0 1 2 3 4 5 6 miles

Enclosure 10

BASE OF ANNA SHALE MEMBER
CONTOUR INTERVAL 100 FT.

Amy B. Leavell
Master's Thesis
May 1997




Well symbols

- Dry, abandoned
- Gas
- Oil and gas
- Oil, abandoned
- Oil

Scale:

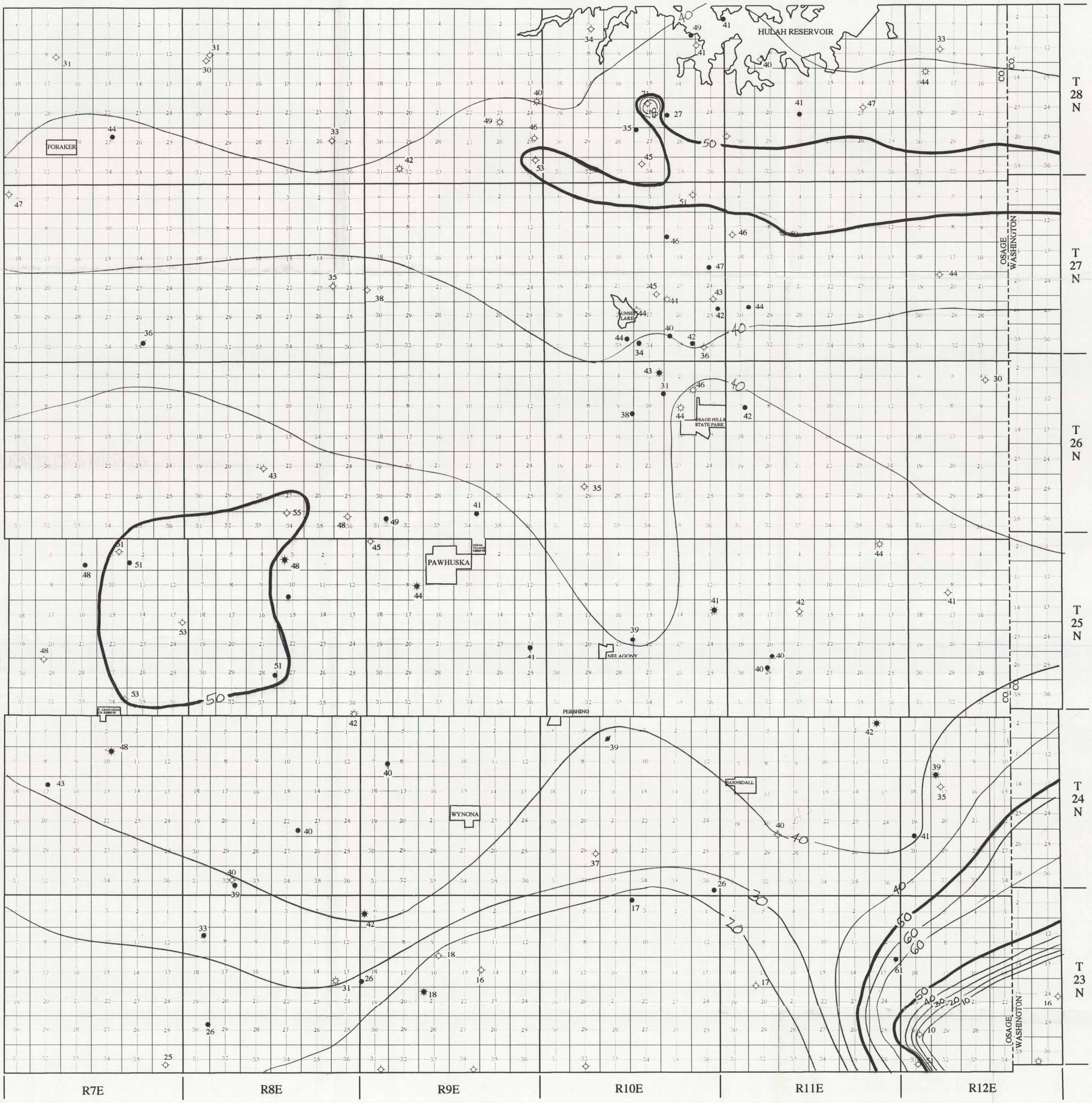
0 1 2 3 4 5 6 7 8 9 10 kilometers

0 1 2 3 4 5 6 miles

Enclosure 11

TOP OF HIGGINSVILLE LIMESTONE
CONTOUR INTERVAL 100 FT.

Amy B. Leavell
Master's Thesis
May 1997




Well symbols

- Dry, abandoned
- Gas
- Oil and gas
- Oil, abandoned
- Oil

Scale:

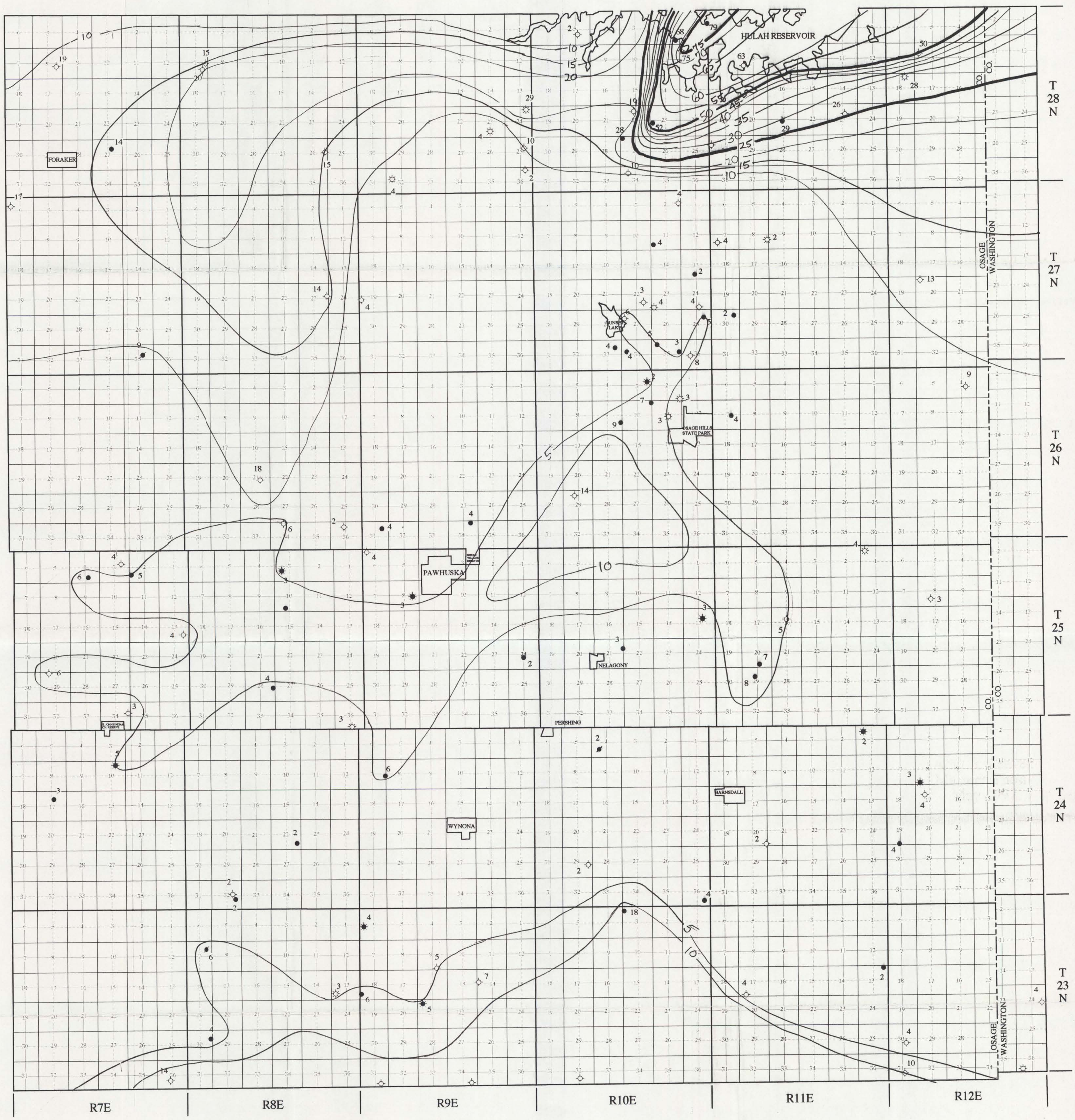
0 1 2 3 4 5 6 7 8 9 10 kilometers

0 1 2 3 4 5 6 miles

Enclosure 12

ALTAMONT LIMESTONE ISOPACH
CONTOUR INTERVAL 10 FT.

Amy B. Leavell
Master's Thesis
May 1997




Well symbols

- Dry, abandoned
- Gas
- Oil and gas
- Oil, abandoned
- Oil

Scale:

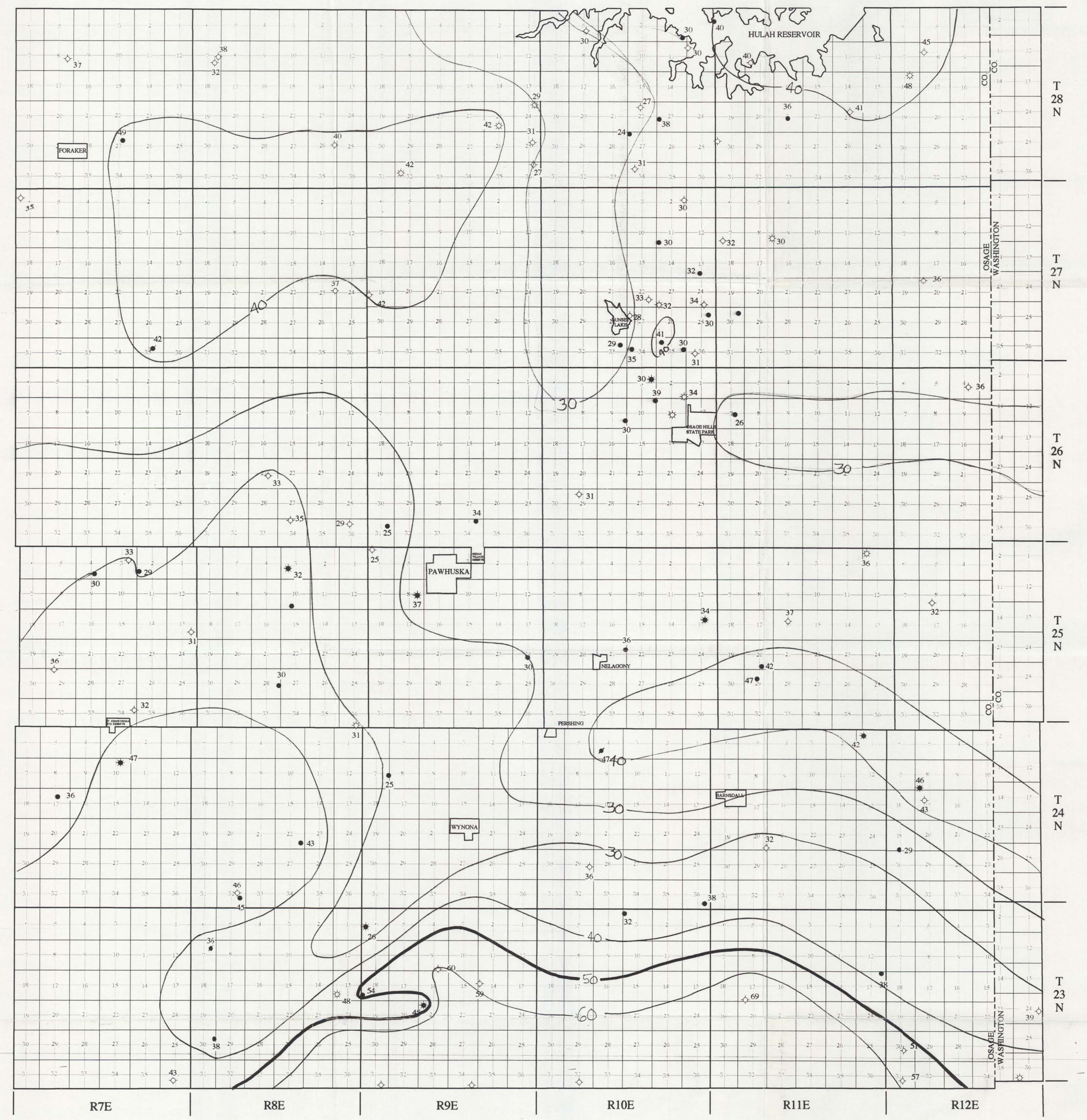
0 1 2 3 4 5 6 7 8 9 10 kilometers

0 1 2 3 4 5 6 miles

Enclosure 13

BANDERA ISOPACH
CONTOUR INTERVAL 5 FT.

Amy B. Leavell
Master's Thesis
May 1997




Well symbols

- Dry, abandoned
- Gas
- Oil and gas
- Oil, abandoned
- Oil

Scale:

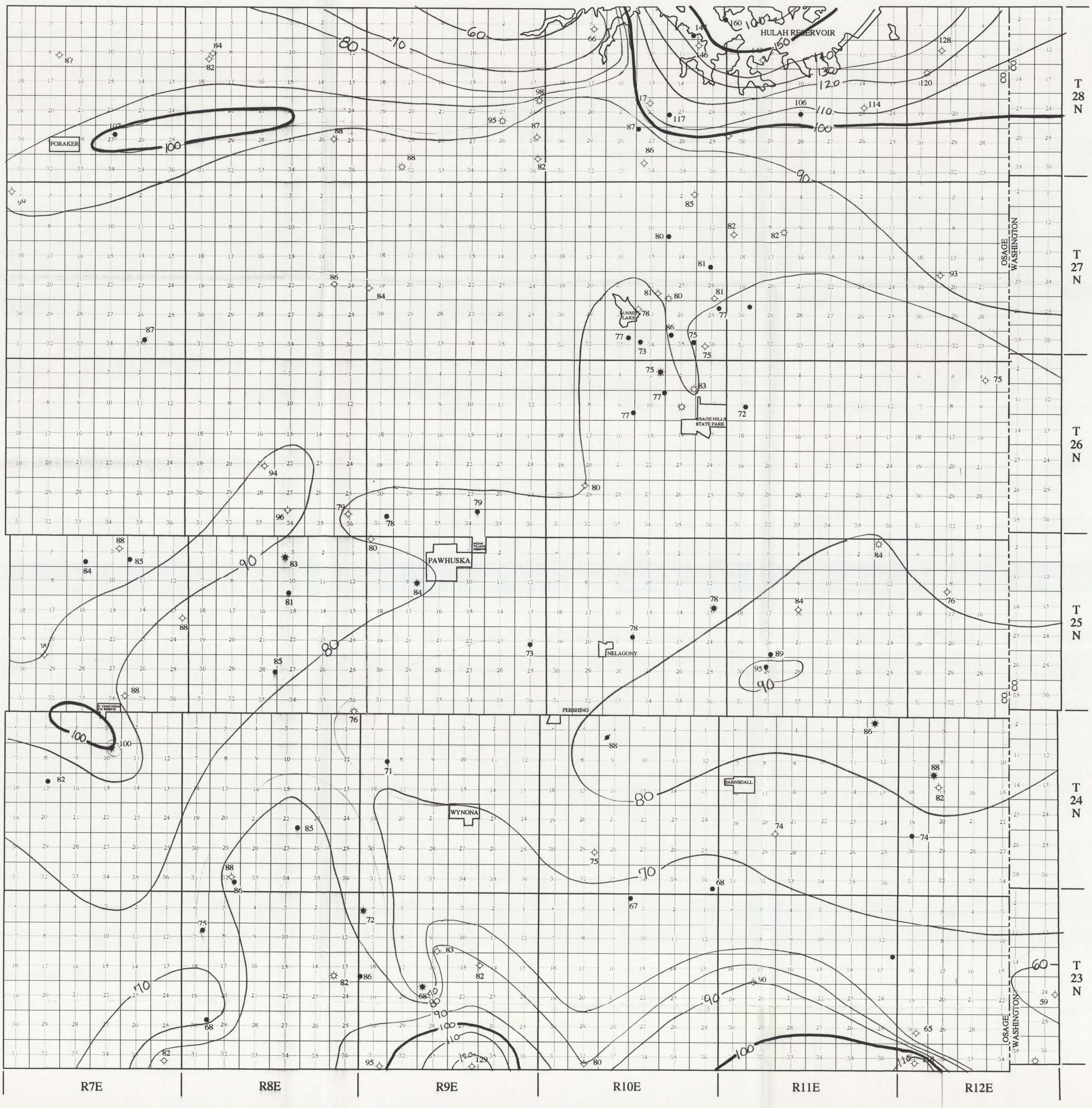
0 1 2 3 4 5 6 7 8 9 10 kilometers

0 1 2 3 4 5 6 miles

## Enclosure 14

## PAWNEE LIMESTONE ISOPACH
## CONTOUR INTERVAL 10 FT.

Amy B. Leavell
Master's Thesis
May 1997




Well symbols

- Dry, abandoned
- Gas
- Oil and gas
- Oil, abandoned
- Oil

Scale:

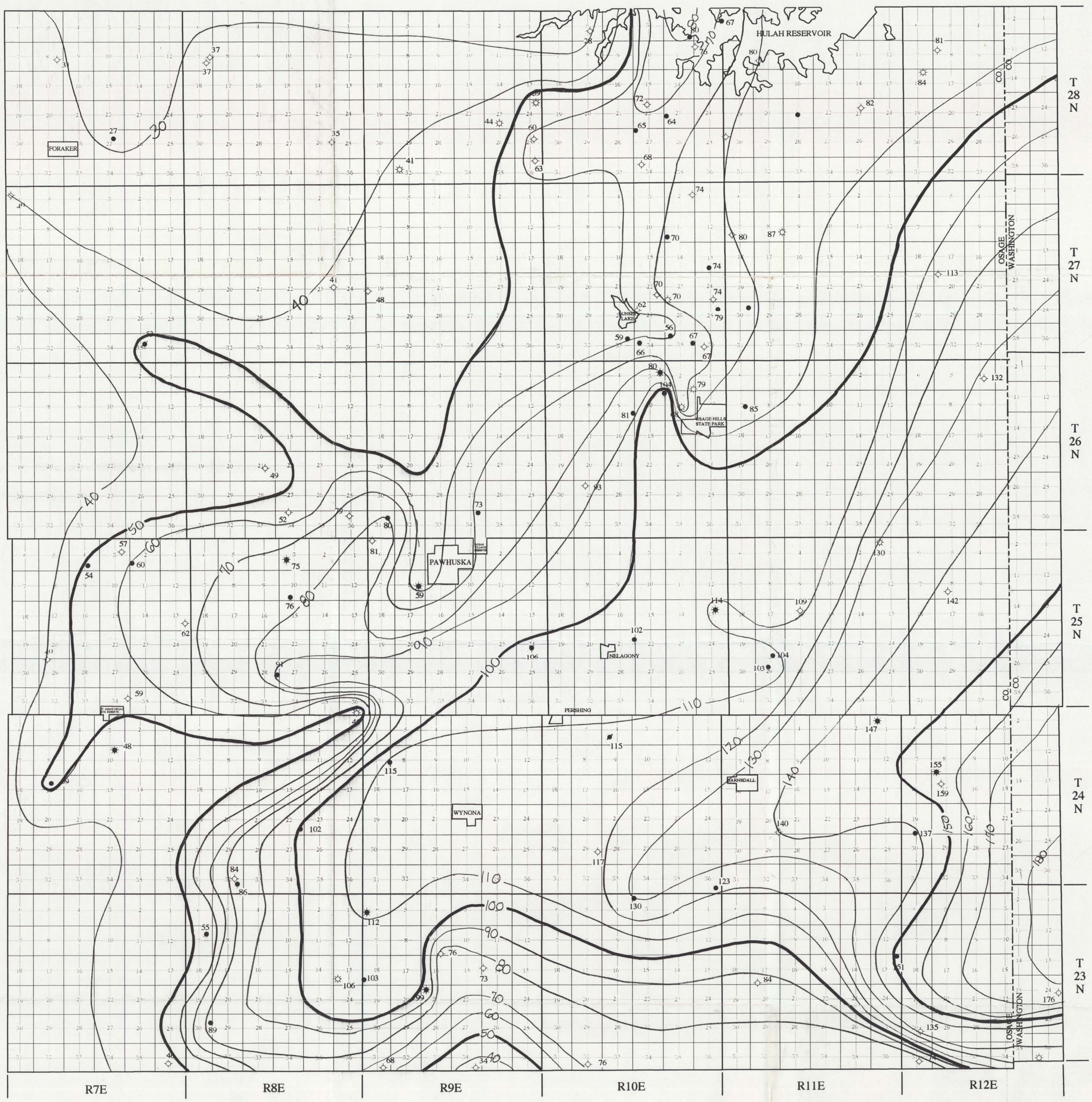
0 1 2 3 4 5 6 7 8 9 10 kilometers

0 1 2 3 4 5 6 miles

Enclosure 15

PAWNEE through ALTAMONT
GROSS INTERVAL ISOPACH MAP
CONTOUR INTERVAL 10 FT.

Amy B. Leavell
Master's Thesis
May 1997




Well symbols

- Dry, abandoned
- Gas
- Oil and gas
- Oil, abandoned
- Oil

Scale:

0 1 2 3 4 5 6 7 8 9 10 kilometers

0 1 2 3 4 5 6 miles

Enclosure 16

LABETTE ISOPACH MAP
CONTOUR INTERVAL 10 FT.

Amy B. Leavell
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May 1997