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STRATIGRAPHIC SIGNIFICANCE OF LIMESTONES OF THE MARMATON GROUP (PENNSYLVANIAN, DESMOINESIAN) IN EASTERN OKLAHOMA

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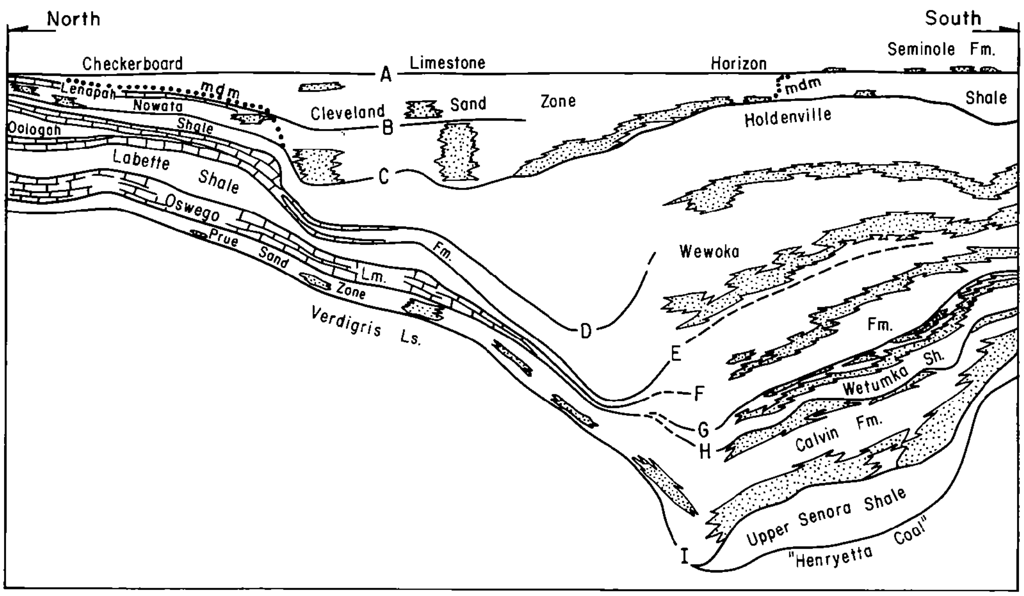

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Title Page Illustration

Stratigraphic profile of interval studied, extending from Northeast Oklahoma Platform, at left, southward across McAlester Basin, at right (see fig. 22).

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STRATIGRAPHIC SIGNIFICANCE OF LIMESTONES OF THE MARMATON GROUP (PENNSYLVANIAN, DESMOINESIAN) IN EASTERN OKLAHOMA

George W. Krumme[1]

Abstract—A 200-foot series of limestone banks composing the Marmaton Group (Middle Pennsylvanian) of the Midcontinent and northern Oklahoma terminates abruptly in the middle part of Oklahoma. Pre-Marmaton rocks on the Northeast Oklahoma Platform had a northern source, whereas post-Marmaton sediments came from the southeast. A study of the patterns of sedimentation shows that the northern source slowly waned in importance, allowing the banks to develop until they were finally buried by clastics from the growing Ouachita mountain chain.

Electric-log correlations show that the Calvin Formation of the McAlester Basin (the western portion of the Arkoma Basin) is equivalent to the Prue sand zone of the platform and not to the "Oswego" limestone as heretofore believed, and that the Checkerboard Limestone horizon extends into the basin sequence below the Seminole Formation, not above it as previously believed. The writer recommends rectifying these errors by shifting the Calvin from the Marmaton to the Cabaniss Group, by enlarging the Holdenville Formation to include the strata directly below the Checkerboard, and by designating the Seminole as a local member of the Coffeyville Formation.

The paleobathymetry of the upper Marmaton strongly influenced the location of the succeeding Cleveland channel sands. The paleogeography determined herein accords well with neighboring depositional patterns, which together suggest that a Middle Pennsylvanian seaway extended from northern Texas to the Appalachians.

INTRODUCTION

Purpose of Investigation

The Pennsylvanian beds of northeastern Oklahoma form a predominantly sand-shale sequence, with one notable exception. In the middle of the Pennsylvanian, across most of northern Oklahoma, a series of limestone banks separated by thin layers of shale occupies an interval of about 200 feet. This limestone province, which constitutes most of the Marmaton Group, extends northward into Kansas, and some of the limestones continue around the Ozark Uplift as far east as Ohio (Moore, 1957, p. 78–79), covering a span of more than 700 miles.

Oil men exploring the Midcontinent fields informally divided the beds into two formations, the "Oswego" limestone below and the "Big Lime" (Oologah Limestone) above, and the two served as the most convenient reference horizons for subsurface correlation and mapping. As exploration continued southward, the wildcatters found that the limestones terminated rather abruptly. The absence of the markers caused a considerable amount of stratigraphic confusion, and a satisfactory correlation into the sand-shale sequence to the south has not previously been published.

In addition, no attempt has been made to fit the Marmaton limestones into the paleoenvironmental history of eastern Oklahoma. Geologists have established in recent decades that the sands and shales directly underlying the Marmaton limestones came from the north (Busch, 1956, p. 27; Oakes, 1963, p. 18; Visher, 1968; Visher and others, 1971, p. 1214) and that the sands and shales above these limestones have a southeastern source (Calvin, 1965, p. 28; Wanless and others, 1970, p. 229; Krumme and Visher, 1972). The stratigraphic significance of the Marmaton banks in this transition remained unexplored.

The first sandstone zone above the Marmaton limestones contains channel sandstones deposited by streams flowing northwestward (Krumme and Visher, 1972). The contrast with the southward flow below the Marmaton suggests the hypothesis that the Marmaton limestones represent a period of stable, shallow marine conditions across the northern Midcontinent that marked the end of one sedimentary era and the beginning of another. The transition began when mud and sand from the craton ceased to reach the southern Midcontinent. Thick limestone banks accumulated in the cleared waters, except during brief re-invasions of terrestrial clastics. Growth of the banks was finally halted, not by the return of sedimentation from the north, but by the northward growth of a distributary system of the ancestral Ouachita moun-

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tains, whose muds and sands overrode the limestone banks, killing and burying the organisms that had built them. (A reversal of dip is not required to explain the source reversal; the volume of sediment supplied by the Ouachitas seems to have been the determining factor.)

The present work is a study of a sequence of strata between the Verdigris Limestone, the first marker bed below the Marmaton, and the Checkerboard Limestone, the first marker bed above. The results of the study fully support the original hypothesis and, in addition, establish new correlations that require adjustments in the previously accepted nomenclature of eastern Oklahoma.

Location

The area covered by this study extends from the outcrop of the Verdigris Limestone and its equivalents in eastern Oklahoma westward to the Nemaha Ridge in central Oklahoma, and from the Kansas state line southward through T. 5 N. In addition, the principal channel of the Cleveland sand was followed 60 miles or so westward from the main study area. The area includes more than 10,000 square miles and more than 300 townships.

Tectonic Setting

The strata under consideration were deposited in three tectonic provinces, the Northeast Oklahoma Platform, the McAlester Basin, and the Seminole Uplift (fig. 1). The platform was a depositional shelf, and the basin a depositional sink during Early and Middle Pennsylvanian time. The Seminole Uplift is a structural saddle separating the Anadarko Basin from the McAlester Basin, which is itself the western portion of the much larger Arkoma Basin.

To the south lies the Arbuckle Uplift, whose folds and faults during the Pennsylvanian brought older Paleozoic rocks to the surface. To the west, the area is bounded by the Nemaha Ridge, a broad rise extending from Oklahoma City north-northeastward across Kansas into Nebraska. The Nemaha Ridge had been gradually onlapped and was finally buried by earlier Pennsylvanian strata, but it subsided more slowly than the sea floor

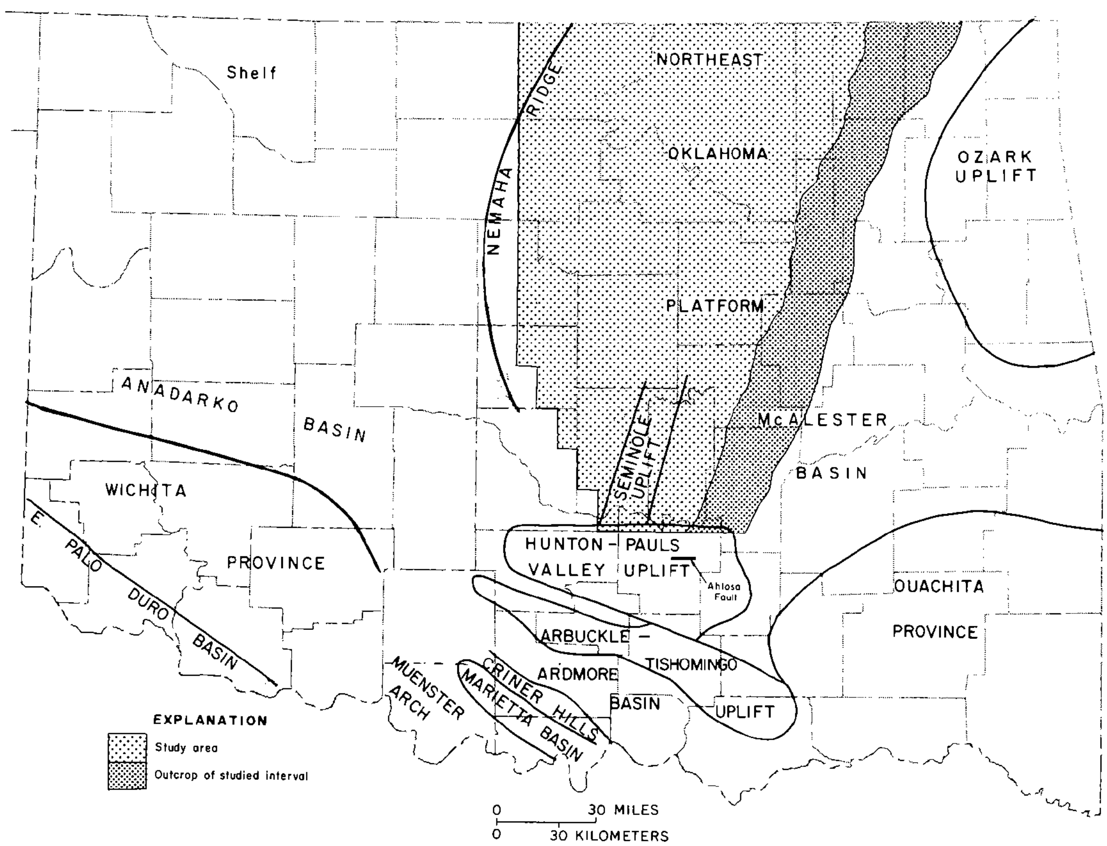

Figure 1. Map showing major structural features and provinces of Oklahoma. Modified from Jordan (1967).

on either side, and its presence is reflected by thinning in most of the strata (Pennsylvanian and Permian) that cover it. The Cherokee Basin to the north is essentially an extension of the Northeast Oklahoma Platform into Kansas.

The study area is limited on the east by the outcrop of the beds investigated. The outcrop commences at the Ahlosa Fault, on the north flank of the Arbuckle system, and strikes northnortheastward, crossing the Kansas state line near Coffeyville before continuing around the Ozark Uplift.

The beds now dip gently westward at about 1°, with little variation (fig. 2), but the present dip is unrelated to the slope on which the beds were originally deposited. The Pennsylvanian section is characterized by thinning northward and westward from the McAlester Basin at every level.

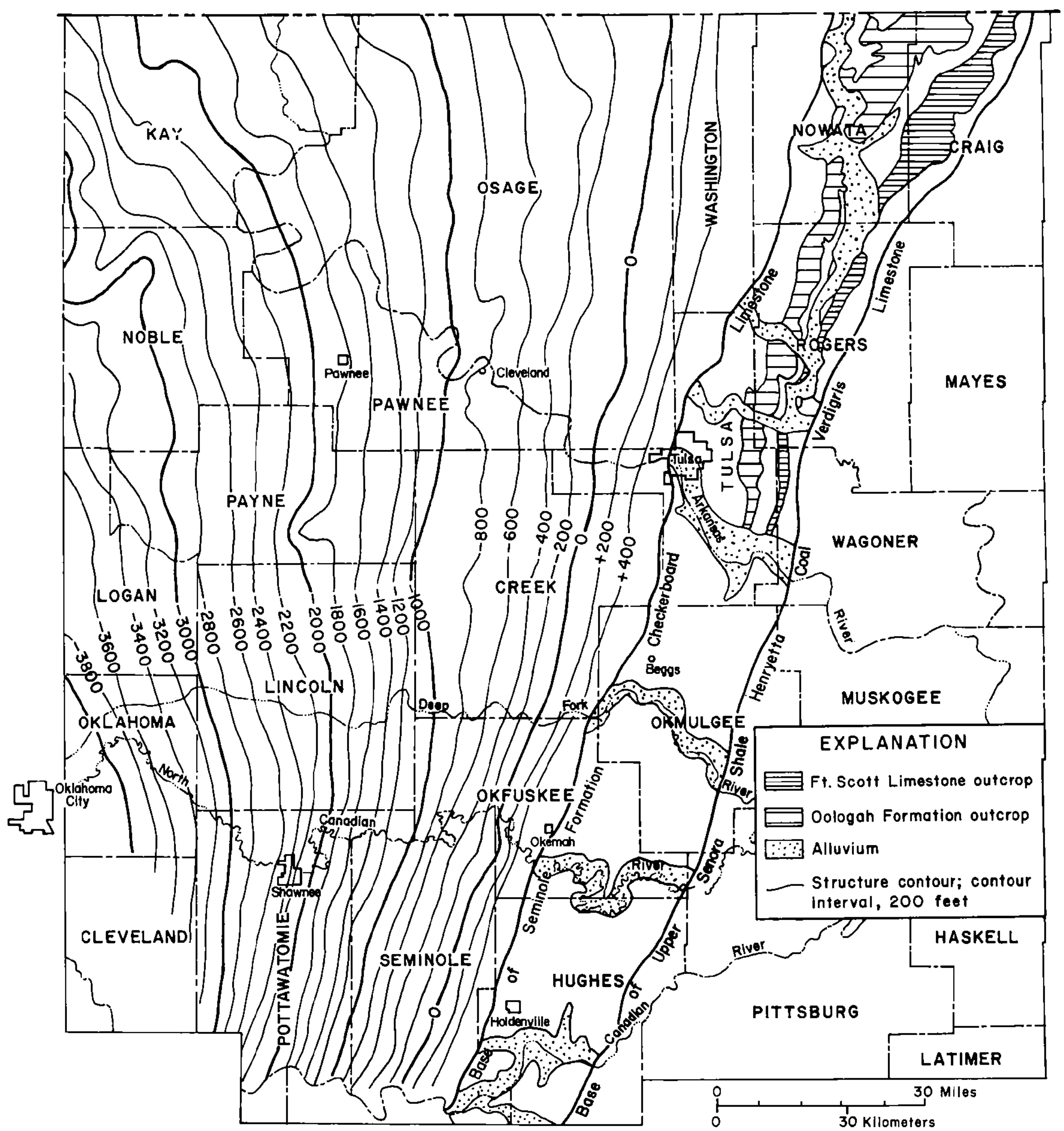

Figure 2. Structure map of Checkerboard Limestone in eastern Oklahoma, showing outcrops of Checkerboard and Verdigris Limestones.

Method of Study

This paper is based on a review of previous investigations, a study of well records and electric logs, and an examination of the surface outcrops.

Thousands of electric logs were examined, mostly from the files of the Oklahoma Well Information Service in Tulsa. Many cross sections were prepared to establish correlations, especially in areas of abrupt facies change and, in a few cases, in faulted areas. In most cases, a spacing of 1 or 2 miles between wells was maintained to ensure accurate correlations.

In order to facilitate comparisons with the correlations published in the works of other geologists, cross sections shown herein include many electric logs that have appeared in previous publications. These logs are identified in the appendix.

In addition to electric logs, strip logs made from cable-tool well records were used in areas of inadequate coverage, principally in the eastern ranges close to the outcrop. Other information from well records and from scout tickets served as an aid in a few cases. Detailed maps were prepared only for the sands directly below and above the Marmaton, since these effectively demonstrated the change in source direction. The examination of the surface beds was directed principally toward those features that indicate the environment of deposition and the direction of transport of the sediments.

STRATIGRAPHY

General Statement

The regression that marked the end of the Mississippian Period restricted the seas in central and northern Oklahoma to the Anadarko–Ardmore and McAlester Basins. The Pennsylvanian strata of eastern Oklahoma are essentially a record of the return of the sea northward, while at the same time rocks of geosynclinal Ouachita facies were being thrust northwestward into the State. The concurrent uplift of the Arbuckles had a limited effect on the sedimentation in eastern Oklahoma.

The post-Mississippian regression and the subsequent transgression represent only two stages of the cyclic tectonic behavior that has affected the entire North American continent from the late Precambrian to the present (Sloss, 1963, p. 102). This "Absarokan" transgression continued into the Permian. Most of the rocks exposed in eastern Oklahoma were deposited during the early part of this transgression.

Until late in the Pennsylvanian, the sediments deposited in the McAlester Basin were significantly different from those on the Northeast Oklahoma Platform, and two geologic columns with complementary names have come into usage (fig. 3).

Attempts to force the two columns into a single classification have illustrated a fundamental stratigraphic dilemma that has become increasingly obvious in the past half-century (Krumbein and Sloss, 1963, p. 22). In practice, stratigraphers cannot force the naturally occurring rock units into a single framework of subdivision and classification because of the lateral facies changes in almost all strata. Beds that are continuous stratigraphic units have been shown by paleontological and stratigraphic evidence to transgress time planes, just as other laterally continuous beds that have been deposited contemporaneously vary radically in composition and thickness over short distances.

The strata can therefore be subdivided according to their position in geologic time or according to their physical characteristics, but the two kinds of classification frameworks generally will not coincide. Stratigraphers have been forced to develop a dual classification system with a distinct separation between the two types of stratigraphic units: (1) objective, traceable, mappable units, called rock units, based on observable physical characteristics; and (2) units subdivided according to their position in geologic time, called time-stratigraphic units (Krumbein and Sloss, 1963, p. 22).

In the first category, strata are formally differentiated into rock units called groups and further subdivided into formations and members (American Commission on Stratigraphic Nomenclature, 1961). In the second category the rocks are divided into systems, series, and stages. Thus the Pennsylvanian System includes the Desmoinesian Series, which could then be subdivided into stages. (The Desmoinesian has generally not been subdivided, although "Marmaton" and "Cherokee" have been designated as stages in some fusulinid studies. Division into time-stratigraphic units normally should be based on paleontological evidence, which is frequently ambiguous, and separation of series into subdivisions is often not attempted.) In practice, the lithology strongly influences the boundaries chosen for the time-stratigraphic framework, and many areally extensive beds, such as bentonites, thin limestones, and thin black shales, are time markers as well as lithologic units.

The present classification of the Pennsylvanian System in Oklahoma is a hybrid, utilizing time-stratigraphic units (series) for the major divisions and rock-stratigraphic units for the subdivisions of each series (Branson, 1962). Thus the Desmoinesian Series is considered to include the Krebs, Cabaniss, and Marmaton Groups, even though the Desmoinesian Series is a subdivision

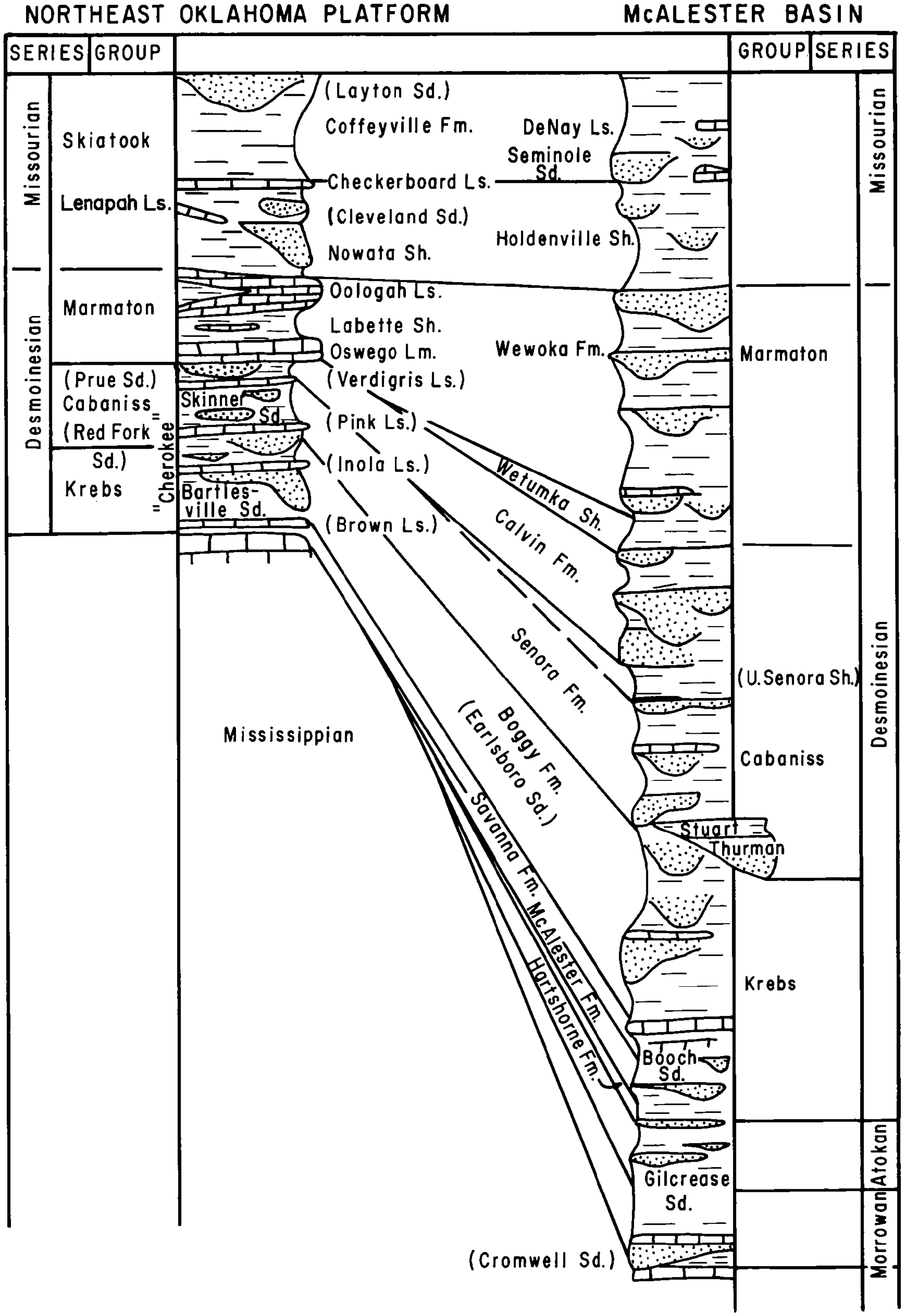

Figure 3. Correlation sections, showing stratigraphic nomenclature of Lower and Middle Pennsylvanian rocks in eastern Oklahoma (Krumme, this report).

in the time-stratigraphic system of classification and the groups belong in the rock-unit system of classification. The horizons chosen to separate the groups were believed to be unconformity surfaces; in this case, then, each group would be a time unit as well as a rock unit.

The Pennsylvanian in eastern Oklahoma is divided into five series, the Morrowan, the Atokan, the Desmoinesian, the Missourian, and the Virgilian. As indicated in figure 3, Morrowan and Atokan rocks were deposited only in the basin and on its flanks. The succeeding Desmoinesian strata progressively onlapped the platform as the advancing waters covered it, reducing the Nemaha Ridge to an archipelago, presumably still attached to the craton somewhere to the north, and finally submerging it completely. The complete burial of the ridge in Oklahoma was finally achieved by middle Desmoinesian (Cabaniss) sediments.

Petroleum exploration in the Midcontinent commenced in Kansas and then moved to the northern part of the platform in Oklahoma. In these areas the lower Desmoinesian strata from the base of the "Oswego" limestone to the base of the Pennsylvanian were named the Cherokee Group because they were first studied at their outcrop in Cherokee County, Kansas (Jordan, 1957, p. 42). The name was abandoned for formal use in Oklahoma because it was felt to be a useless grouping defined from a poorly exposed type area; furthermore, the name Cherokee was preempted by prior use for the Cherokee slates of North Carolina and the Cherokee Limestone of Missouri and Kansas.

About 1950, geologists of the Oklahoma Geological Survey decided that the tracing of the outcrop in eastern Oklahoma was achieved sufficiently to adopt uniform nomenclature for the Pennsylvanian rocks of eastern Oklahoma. Older names from the McAlester Basin were extended northward for formal usage in describing the "Cherokee" rocks of Oklahoma (Branson, 1962).

The basin sequence was divided into two groups by examination of the outcrop. South of the Canadian River, the Thurman Sandstone, which locally contains zones of chert conglomerate, was believed to lie unconformably on Boggy shales. The beds above this contact are markedly coarser than those below. Oakes (1953) created two divisions separated by this "unconformity" and named the lower division the Krebs Group and the upper the Cabaniss Group.

Unfortunately, the Thurman Formation and the overlying Stuart Shale are absent by nondeposition not far to the north and west, and therefore, for the most part, the Cabaniss Group contains only the Senora Formation. Furthermore, on the platform, there is no indication of an unconformity at the horizon of the proposed Cabaniss–Krebs contact. The contact there lies in the zone of the Red Fork sand, where its location in the stratigraphic succession is inexact and genetically meaningless. For these reasons, the terms Krebs Group and Cabaniss Group were impractical for extension beyond the McAlester Basin, and their use on the platform has always been artificial.

Authors of works concerning the stratigraphy of eastern Oklahoma generally acknowledge the separation of the lower Desmoinesian into the Krebs and Cabaniss Groups and shift to more serviceable terminology thereafter. The term Cherokee Group is still used informally on the platform, and the writer believes the term should be returned to formal use. As will be discussed later, the Cherokee beds form a genetic sequence of strata that does not lend itself easily to a subdivision based on the entirely different tectonics and sedimentation of southeastern Oklahoma.

In Kansas, Missouri, Nebraska, and Iowa, the term Cherokee Group is still formally accepted (Branson, 1962, p. 433). The Krebs and Cabaniss Groups of Oklahoma have been designated formations in Kansas (fig. 4) and subgroups in Missouri, but in practice their use suffers the same limitations as on the platform.

In northern Oklahoma, Kansas, Missouri, and Nebraska, the upper Desmoinesian strata are called the Marmaton Group. The Marmaton of the northern Midcontinent is notable for its sequence of limestone banks (principally the "Oswego" and Oologah limestones). Rocks of the same age to the south are of a sand–shale facies.

The Marmaton is succeeded by the Skiatook Group in Oklahoma and by the Pleasanton Group in Kansas. In both areas, the "Oswego" and Oologah limestones were covered by 100 to 200 feet of sand and mud, after which clearer waters returned, allowing the deposition of the Checkerboard Limestone, probably the most extensive thin limestone of the Midcontinent sequence.

Although the strata above the Checkerboard are beyond the scope of this investigation, it should be noted that on the platform they are principally shale and sandstone. In Kansas, on the other hand, the strata contain much limestone; the Kansas City–Lansing carbonate sequence, several hundred feet thick, lies close above the Checkerboard horizon in Kansas.

Verdigris–Checkerboard Interval

The section from the Verdigris Limestone to the Checkerboard Limestone requires a detailed description, since the present study will focus on this interval (fig. 5). The platform sequence will be considered first.

Upper Senora Zone

On the platform, the Verdigris Limestone, generally less than 10 feet thick, is overlain by a

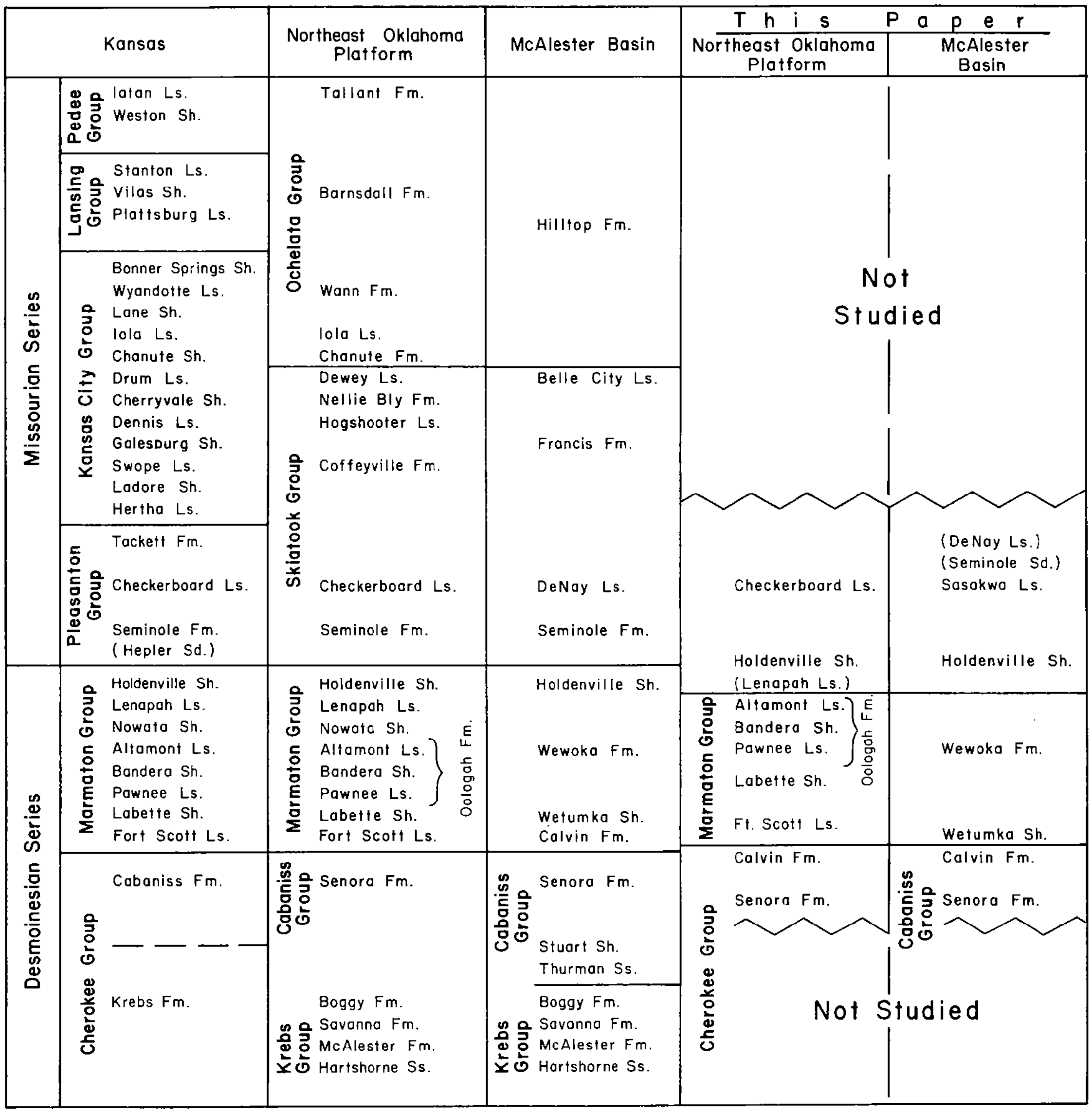

Figure 4. Correlation chart of Kansas and Oklahoma rock units of Middle Pennsylvanian age. Columns to left modified from Branson (1962); columns to right indicate correlations and nomenclature of this report.

shale containing the Prue sand, the subsurface equivalent of the Lagonda Sandstone. This zone is usually 50 to 100 feet thick. Above the shale zone lie, in ascending order, the Iron Post coal, the Kennison Shale, the Breezy Hill Limestone, and the Excello Shale. These four members of the Senora Formation generally occupy an interval jointly of 15 feet or less. The Iron Post coal and the Breezy Hill Limestone do not extend far north of the Kansas line (Wanless and others, 1963).

Marmaton Group

Oswego Limestone.—The lowest formation of the succeeding Marmaton Group is a series of interbedded limestones and shales originally called the "Oswego lime" from exposures at Oswego, Kansas. The name "Oswego" is not acceptable for formal use because of prior usage for a Devonian limestone in New York State. The name Fort Scott was formally applied to the beds, but the name has not become popular, principally owing to the usual

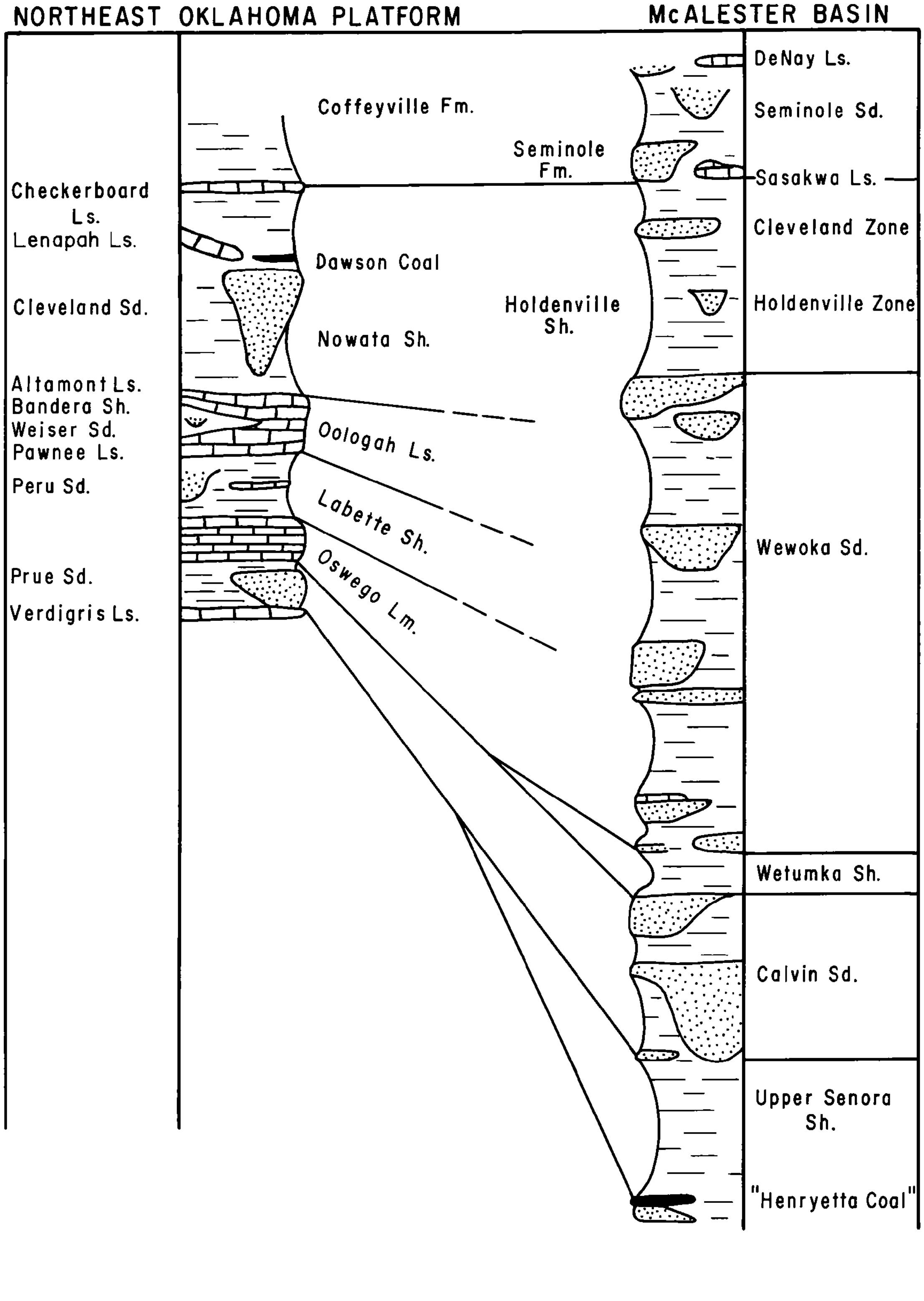

Figure 5. Correlation sections, showing stratigraphic nomenclature of study interval in eastern Oklahoma (Krumme, this report).

resistance to change but also because there is a difference between the two terms.

Subsurface geologists of Oklahoma have always included the Breezy Hill Limestone in the "Oswego lime" (Bennison, 1972b, p. 25), whereas the Fort Scott, as formally defined, excludes the Breezy Hill. Since this paper is mainly concerned with the subsurface, the name Oswego will be used without quotation marks, and the Breezy Hill Limestone will be included in the formation. A considerable simplification of stratigraphic nomenclature would be accomplished by redefining the Fort Scott Formation of Oklahoma to include the Breezy Hill. The writer proposes that this adjustment be made.

At the surface, the Fort Scott is divided, in ascending order, into the Blackjack Creek Limestone Member, the Little Osage Shale, and the Higginsville Limestone Member. The Blackjack Creek Member extends farther south than the Higginsville, but both members are present over most of the platform. Usually, no attempt is made to subdivide the Oswego in the subsurface.

The Oswego thins abruptly at about the latitude of Tulsa; this line of thinning will be referred to as the Oswego front (fig. 6). In the subsurface, the base of the Oswego is considered to be the contact of the Marmaton and the Cherokee Groups.

Labette Shale.—The Labette Shale overlies the Oswego lime. Although the Labette is as thick as 250 feet in Tulsa County, it is much thinner over most of the platform (fig. 7). In the subsurface, a limestone bed appears in the Labette that is continuous across most of the platform and the northern shelf of the Anadarko Basin. Berg (1973, p. 160) mapped the bed as the Labette Limestone Member of the Labette Formation in the west ranges, but Cole (1970, p. 53), in the east ranges, elected to include it as a basal bed of the Oologah Formation. In general, the bed is closer to the Oologah than the Oswego, so the writer has chosen to follow Cole's practice. The presence of this limestone, as much as 40 feet thick in the west ranges, emphasizes the genetic homogeneity of the Marmaton sequence. The term Labette Shale has not been previously applied south of the Oswego front because the Oswego horizon and the Oologah Limestone above it have proved difficult to trace southward both at the surface and in the subsurface. The increased density of electric-log coverage now allows tracing the Labette much farther southward than possible before, well into the margin of the basin (fig. 7).

One noteworthy feature of the Labette Shale is a trough-like thinning in T 22 N. near the outcrop. The trough runs west-south-westward between Sperry and Skiatook. It will be referred to as the Sperry Trough (fig. 7).

In the 20 or so miles nearest the outcrop, where the Sperry Trough is most pronounced, the Labette Shale is generally 150 to 200 feet thick. In the trough it thins to less than 20 feet. The trough, with a flat floor about 4 miles wide, is a pronounced feature for the first 30 miles west of the outcrop, but it loses character westward as the Labette Formation thins. A faint remnant of the trough can be traced into the west ranges. A less pronounced trough trends across a saddle west of Kiefer in T. 17 N., R. 12 E, and joins the Sperry Trough.

The Labette Shale contains the Peru sand (named for Peru, Kansas—Jordan, 1957, p. 155—and not to be confused with the Prue sand directly below the Oswego) in the northeastern part of the platform and in the Cherokee Basin of Kansas. The Peru is equivalent to the Englevale Sandstone of the surface in Kansas. The approximate limits of the Peru are shown in figure 7.

Oologah Formation.—In northernmost Oklahoma the Oologah Formation consists of a lower Pawnee Limestone Member and an upper Altamont Limestone Member, with the Bandera Shale between. The Altamont and Pawnee join southward to form a massive, continuous bed along the southern margin of the Oologah, averaging almost 100 feet in thickness. Like the Oswego, the Oologah thins abruptly across the platform at the approximate latitude of Tulsa; the line of abrupt thinning will be referred to as the Oologah front (fig. 8). The obvious influence of the Sperry Trough in the underlying Labette Shale is shown by the S-curve in the Oologah front north of Tulsa, where the front follows the rim of the trough, probably because, where the Labette was thin, the lime-secreting biota found the deeper waters inhospitable. The Oologah front lies north of the Oswego front. The Oologah is generally much thicker than the Oswego. In the subsurface it is called the "Big Lime."

Several thin, local patches of limestone are associated with the principal Oologah limestones. A limestone is found above the Altamont in some localities, and the Bandera Shale contains a few thin carbonate beds. A limestone in the upper Labette Shale has already been noted.

The Pawnee member of the Oologah is the most persistent of the Marmaton limestones. It extends into the western parts of Oklahoma and Kansas, and it has been traced under other names (Myrick Station, Brereton, Providence) around the Ozarks through Iowa and Illinois and into western Kentucky (Wanless and others, 1963).

The Bandera Shale of the northern platform is generally about 10 feet thick. In the extreme northeastern part of the platform, it begins to thicken and reaches a thickness of 130 feet at one locality in Nowata County. Patches of sand that are present in this northeastern wedge are called the Weiser sand.

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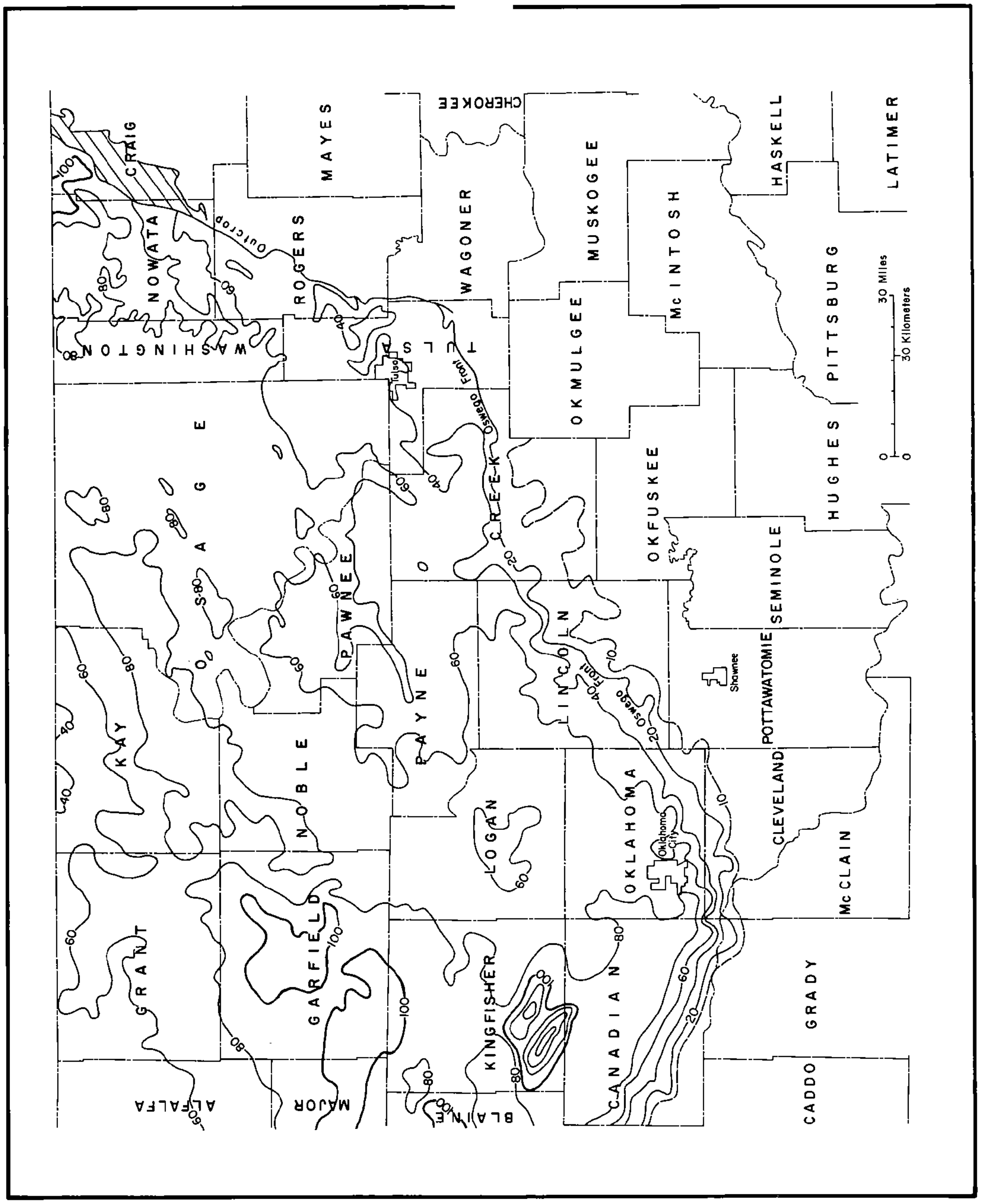


Figure 6. Isopach map of Oswego limestone in eastern Oklahoma; isopach interval, 20 feet. Adapted from Berg (1973) and Cole (1967, 1970).

ticing geologists do not subdivide the formation. Since the Labette cannot be identified easily in most logs of the western platform, some geologists do not distinguish any of the parts of the Oologah–Oswego sequence; they carry the Oologah, Labette, and Oswego as one unit, sometimes referring to the entire sequence as the Big Lime, sometimes as the Oswego, and sometimes as the "Marmaton."

Nowata Shale–Lenapah Limestone.—The next persistent limestone bed above the Oologah–Oswego sequence is the Checkerboard. The intervening sand–shale interval is several hundred feet thick over the southern platform but thins to about 100 feet along the Kansas line. It contains the thicker, but more restricted, Lenapah Limestone, which extends only about 30 miles into Oklahoma from the Cherokee Basin of Kansas.

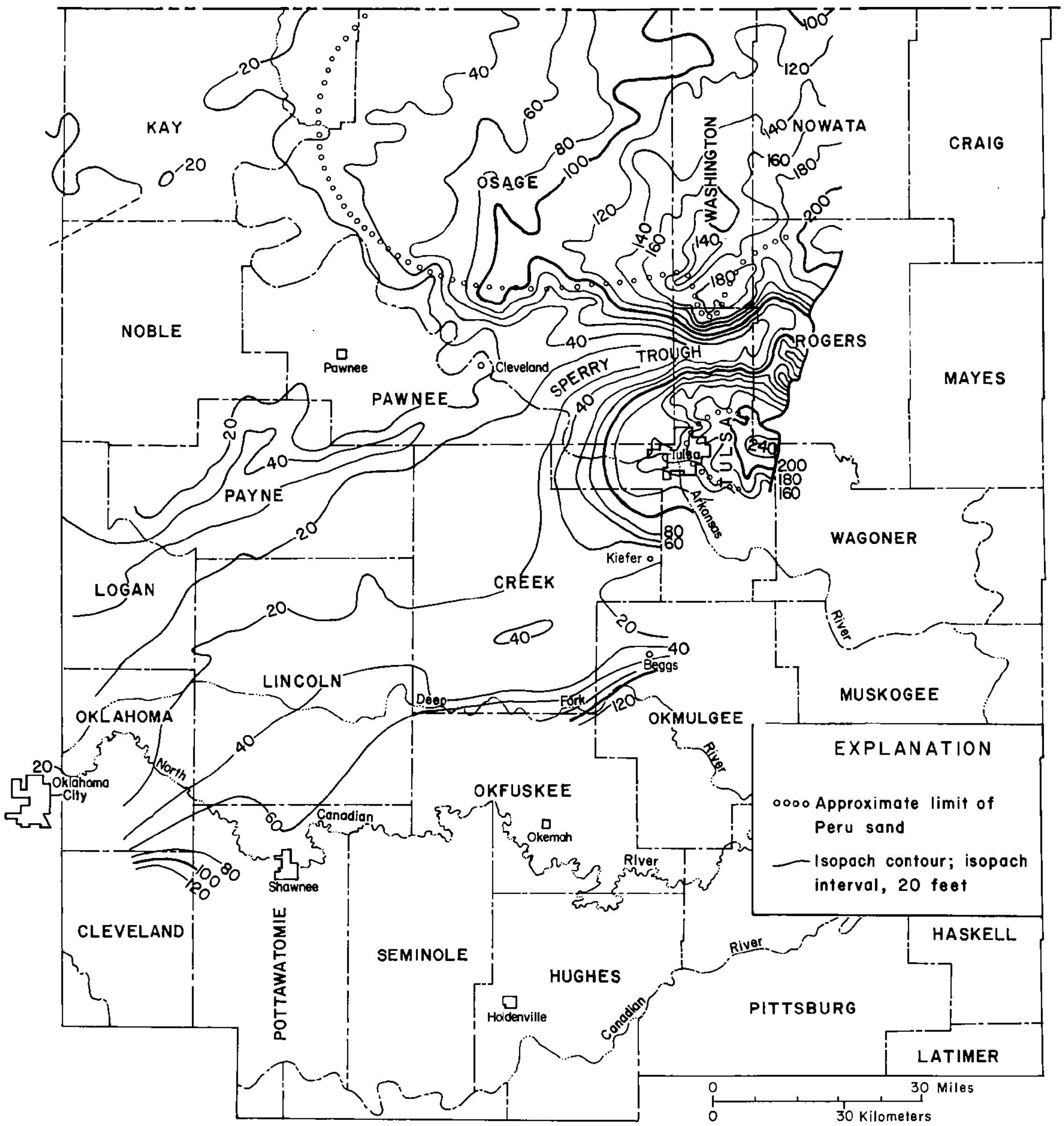


Figure 7. Isopach map of Labette Shale in eastern Oklahoma. Modified from Cole (1967, 1970).

The shale below the Lenapah is called the Nowata Shale.

An outlier of the Lenapah was at one time believed to be present as far south as Tulsa (Oakes, 1952, p. 36), but subsequent surface work (Cole, 1967) and subsurface cross sections show that the Lenapah is not present south of the general line of T. 25 N. The name Nowata Shale is not applicable south of this line. The section between the Lenapah and the Oologah averages almost 100 feet in thickness. It contains patches of sand called Wayside sand in northeastern Oklahoma and called Cleveland sand in north-central Oklahoma.

On the first Geologic Map of Oklahoma, Miser (1926) showed the Nowata as far south as the vicinity of the Arkansas River, using the Dawson coal as the southward stratigraphic equivalent of the Lenapah. Oakes (1952, p. 36–41), however,

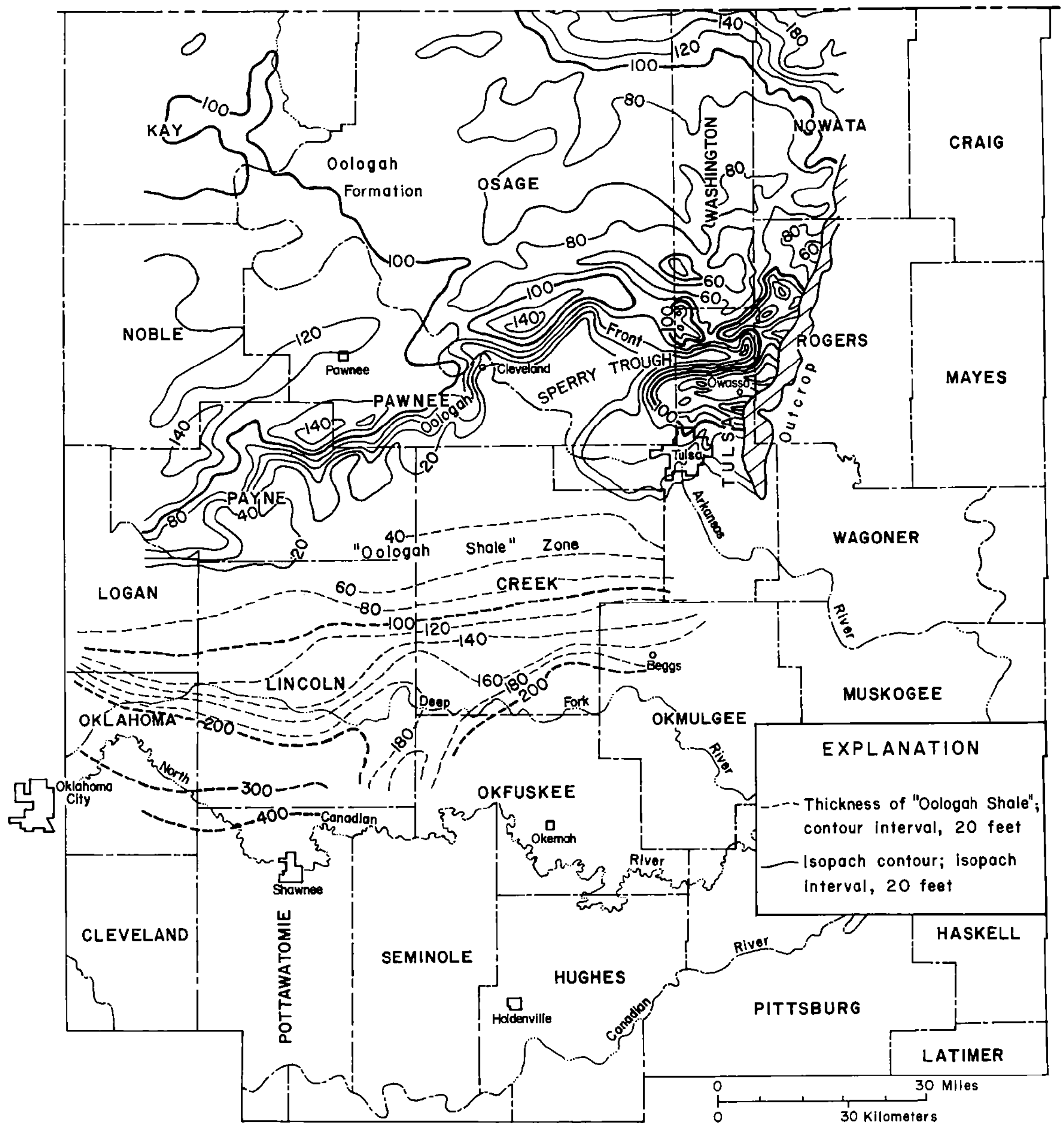


Figure 8. Isopach map of Oologah Formation (solid contours) in eastern Oklahoma. Modified from Cole (1967, 1970).

following Cullen and Dott (Dott, 1941), erroneously believed that a layer of limestone appearing well below the Dawson in central Tulsa County (Eleventh Street Limestone) was a southern representative of the Lenapah, separated from the main body by a Cleveland sand channel north of Owasso, in northern Tulsa County.

Oakes, therefore, limited the Nowata south of Owasso to the interval below the Eleventh Street Limestone. He used the term Holdenville Shale for the zone above the limestone because it is laterally equivalent to the Holdenville Shale of the McAlester Basin stratigraphic column. Oakes stated that patches of Holdenville Shale extend to the Kansas line above the Lenapah, although he acknowledged the difficulty in determining their boundaries.

Cole (1967) found that the Dawson coal does, in fact, lie at the approximate horizon of the true Lenapah. He found that the Eleventh Street

Limestone is only a local occurrence, lying substantially lower in the section than the Lenapah. Cole found little evidence of an unconformity and therefore inferred that the Nowata Shale and the sandstone near Owasso, which lies below the Dawson coal, belong in the same stratigraphic unit. The writer's subsurface correlations support Cole's and Miser's surface correlations.

To return to the older nomenclature and define the Nowata of Tulsa County as that zone between the Oologah and the Dawson coal is not unreasonable, but other relationships must be considered. The Dawson coal probably does not continue very far in the subsurface. In addition, the sandstones below the Dawson coal and other sandstones above the Dawson coal have usually been considered to belong together both in the surface and in the subsurface. These sands are called the Cleveland sands because sizable reserves of oil and gas have been discovered in them at the town of Cleveland about 25 miles northwest of Tulsa.

A wide outcrop of a thick section of Cleveland sandstone occurs north of Owasso, about 10 miles northeast of Tulsa. Another, narrower one appears about 10 miles south of Tulsa, east of Kiefer. These bodies will be called the Owasso and Kiefer Channels, respectively. Both lie below the Dawson coal. At the outcrop, the Owasso Channel lies within 30 feet of the Oologah Limestone (channel scouring, differential settling, and compaction have all acted to thin this interval). The outcrop of the Kiefer Channel lies south of the Oologah front.

The presence of the prominent 200-foot-thick Owasso Channel so close above the Oologah persuaded stratigraphers that it marked a regional unconformity, and the boundary between the Desmoinesian Series and the Missourian Series was placed at the base of this channel (Moore and others, 1937). Oakes (1952, p. 47), believing that the Lenapah and Eleventh Street Limestones had originally been continuous but subsequently were separated by scouring in the formation of the Owasso Channel, stated that the contact is unconformable and that it is marked by a stratigraphic hiatus and faunal change from the Arbuckle area to the Kansas line. Other geologists, including the writer, have not observed the contact to be unconformable.

Although a complete discussion will be delayed until later in the paper, it should be noted that electric-log cross sections indicate that the beds are conformable and that only local channel scouring occurred. The Kiefer Channel lies at the same horizon as the Owasso Channel and both are lateral equivalents of the Holdenville Shale of the type locality. The lower Cleveland sands, and also the upper Cleveland sands near the outcrop, are Holdenville channel sands that were deposited in Holdenville muds. The Dawson coal–Lenapah Limestone zone marks a temporary abandonment of the delta after the Owasso and Kiefer Channels were deposited. Although the sands extend much farther northward and westward than older sands, the deposition was apparently continuous, and no unconformity exists.

With regard to the position of the Lenapah, it should be observed that the Kansas Geological Society electric-log cross sections for southeastern Kansas (Kansas Geological Society, 1956) have used as the Lenapah an upper member of the Oologah, which appears in the section at about the Kansas–Oklahoma line. The true Lenapah can be readily traced to the type locality in northeastern Oklahoma (fig. 9). Although the Lenapah is separated from the Checkerboard by several tens of feet at the outcrop in Oklahoma, the two converge northwestward. Less than 10 feet separates them along the state line in north-central Oklahoma, and in places the limestones are almost in contact.

The KGS subsurface cross sections have thus effectively restricted the Marmaton to the Oologah, Labette, and Oswego Formations, a practice that is also common in northwestern and north-central Oklahoma, where the Lenapah lies so close below the Checkerboard that its presence is not generally acknowledged. Whether or not the Checkerboard and Lenapah have been correctly followed into Kansas at the outcrop is not known to the writer. The shallow subsurface of Kansas, where not many electric logs are available, seems not to have been greatly studied.

Restricting the Marmaton to the Oologah, Labette, and Oswego has definite stratigraphic advantages. Most subsurface geologists already regard the top of the Oologah as the top of the Marmaton. The Lenapah extends only 30 miles or so into Oklahoma, and it lies much closer to the Checkerboard than to the Oologah. Last, to include it in the Marmaton has awkward consequences, because to the south the horizon divides the upper and lower Cleveland zones, which historically and genetically belong together.

The writer proposes that the Nowata Shale and the Lenapah Limestone be excluded from the Marmaton Group.

Holdenville Formation

As already noted, Oakes (1952) stated that the Holdenville Shale extends to the Kansas line above the Eleventh Street Limestone and the Lenapah of the type locality. He believed the Owasso Channel was a post-unconformity sand cut into Holdenville Shale. The Holdenville was extended into Kansas, but, as might be expected in a sand–shale province with no regional unconformities, precise limits to the formation in northern Oklahoma and Kansas proved difficult to establish.

According to presently accepted terminology, the Holdenville is the topmost formation of the

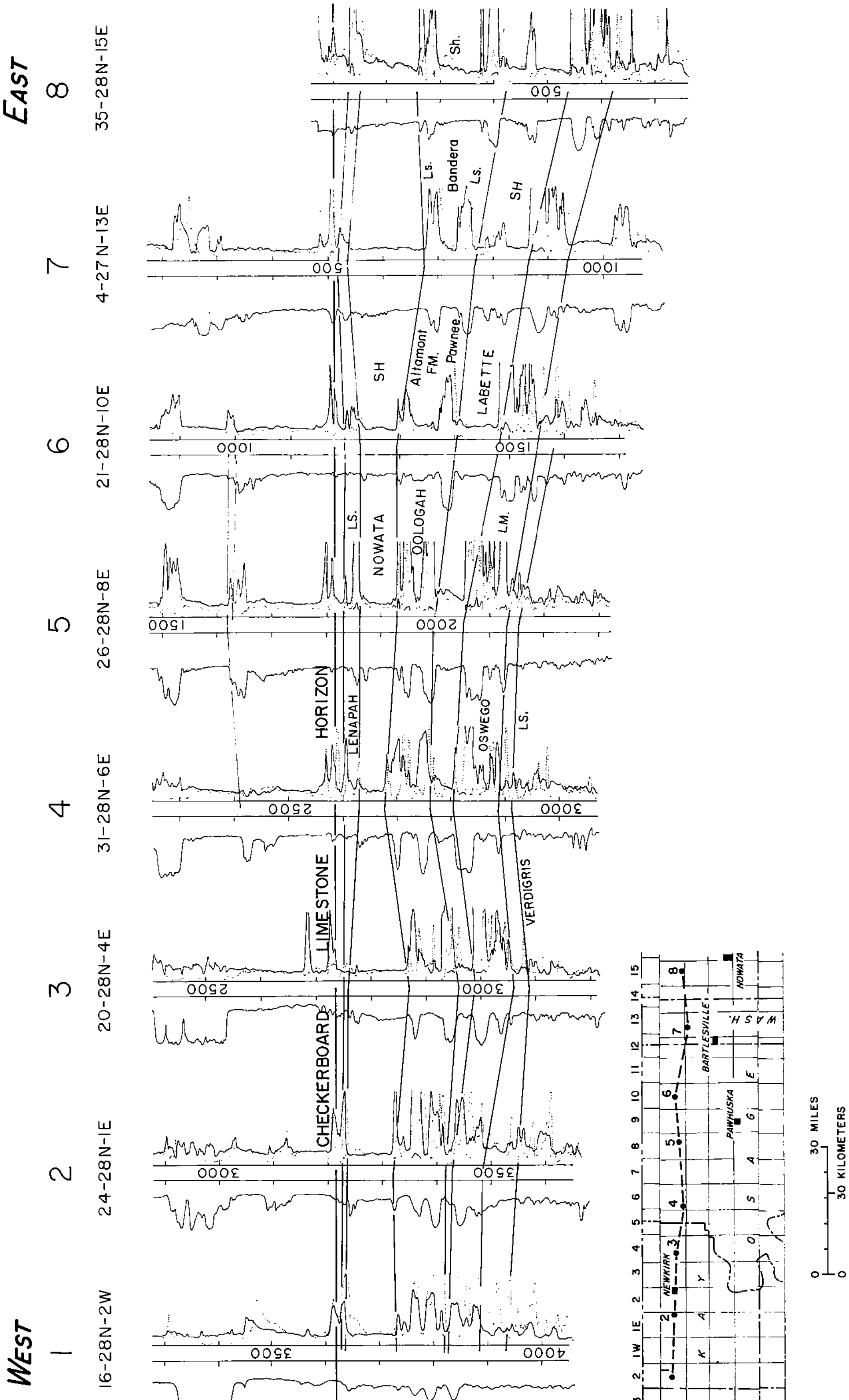


Figure 9. West-east electric-log cross section across northern platform, showing proximity of Checkerboard and Lenapah Limestones.

Marmaton Group, but the writer has proposed that the top of the Marmaton be placed at the top of the Oologah. The Holdenville Shale is now demonstrably equivalent to the Cleveland sands and to most of the shales that cover the Oologah below the Cleveland sands. Stratigraphically, the simplest concept is to consider all beds between the Oologah and the Checkerboard Limestone as units of an expanded Holdenville Formation.

The Eleventh Street Limestone, the Nowata Shale, the Dawson coal, the Lenapah Limestone, and all of the Cleveland sands would then become subdivisions of the Holdenville, with definitions compatible with their original descriptions. This redefined Holdenville Formation could serve nicely as the lowermost unit of the Pleasanton Group of Kansas and of the Skiatook Group of Oklahoma.

The base of the Missourian Series would be lowered slightly by this redefinition. Since there is no unconformity in Oklahoma at this level, any horizon chosen will be somewhat artificial. The Cleveland sands do represent an important surge of coarse clastics into the seaway, and the choice of the base of these sands as the base of the Missourian Series had the merit of recognizing this event. As a practical matter, however, the base of the Holdenville, as redefined, is a much more serviceable horizon to separate the Missourian from the Desmoinesian.

Cleveland Sand Zone

As earlier noted, the Cleveland sand zone first attracted attention when it produced oil and gas at shallow depths (1,600 feet) near the Cleveland townsite in 1905. The sands lie in a thick shale section below the Checkerboard Limestone. The upper Cleveland is locally called the Jones sand, and occasionally the lower Cleveland has been called the Dillard sand. The zone can be traced directly to the outcrop; the Kiefer Channel and the Owasso Channel unquestionably belong to the lower Cleveland zone of the Cleveland Oil Field.

In western Pawnee County, the Cleveland is commonly called the Peru sand, even though it lies above the Oologah and the name Peru correctly applies to a sand below the Oologah. On the other hand, geologists of the U.S. Geological Survey (Bass, 1942, p. 371–372) determined that the Wayside sands, in the Nowata Shale below the Lenapah, and the lower Cleveland sands lie at the same stratigraphic level long before electric logs were available to make the correlation positive. The writer has already proposed placing the Cleveland sands and the Nowata sands together in the Holdenville Formation.

The name Cleveland is generally restricted to the platform. Sandstones at this horizon in the basin do not continue more than 25 miles into the subsurface and do not produce oil or gas.

The most southerly exposure of sandstone generally referred to as Cleveland occurs northeast of Okemah in Okfuskee County. There, the Cleveland sandstone is about 50 feet thick, and it contains beds of conglomerate with chert pebbles as long as 2 inches. The sand extends about 6 or 7 miles along the outcrop, but other Cleveland sands appear a short distance to the north, and sandstones are present sporadically in the outcrop northward into Kansas. The Cleveland zone is thickest along the latitude of Tulsa, reflecting the topographic configuration of the basin into which the sediments prograded. The Cleveland sands have been correlated with the Hepler sand of Kansas and with the Wayside sand of northeastern Oklahoma by the U.S. Geological Survey. The Hepler lies above the Lenapah Limestone, and the Wayside below.

No conglomerate appears in the outcrop to the north of Beggs, in northwestern Okmulgee County, but the sands contain whitish flecks in Tulsa County that have been believed to be the remains of small particles of profoundly weathered chert (Oakes, 1952, p. 51).

In Tulsa County, the Cleveland zone, some 350 feet thick, has been divided into a lower sandy zone and an upper sandy zone separated by a shale containing the Dawson coal. Several very thin coal beds are present at other levels in the Cleveland strata. The Dawson, which reaches a maximum thickness of about 30 inches, is the youngest commercial coal bed in Oklahoma. In outcrop the Dawson is limited essentially to Tulsa and Rogers Counties.

The Dawson coal is a relic of a swamp that formed over the abandoned distributary system of which the Owasso and Kiefer Channels were a part. The presence of the coal and of the Lenapah carbonate bank to the north are compatible; they both record a temporary abandonment of the distributary system.

The principal bodies of sand lie in the lower portion of the Cleveland zone. As noted earlier, the thickest exposures of lower Cleveland sand lie about 5 miles east of Kiefer (more than 150 feet thick), and north of Owasso (about 200 feet thick). The upper sandy zone contains thinner exposures, the most prominent of which is a heavily crossbedded sandstone bluff at 61st Street South on the west side of the Arkansas River in the city of Tulsa. This bluff is the cross section of a channel sandstone with westward flow features. This channel may bifurcate in the shallow subsurface. Two channels, the "Tulsa Channels," which appear in the subsurface, seem to converge toward this outcrop (fig. 32). The Tulsa Channels are smaller and shorter than the channels of the lower Cleveland.

North of Tulsa, beyond the depocenter, the Cleveland zone thins and becomes less sandy. About 30 miles south of the Kansas line, the Lenapah Limestone appears midway between the Oologah and the Checkerboard, at about the level of the Dawson coal. The Lenapah and Checkerboard gradually converge northward, and the Checkerboard has been reported to lie directly on the Lenapah locally (Cole, 1967, p. 97).

At present, the Cleveland sand zone is officially considered to be the northern continuation of the Seminole Formation, which was first described by Taff (1901). Taff defined the lower boundary of the Seminole as the base of a conglomerate cropping out in the northwest corner of the Coalgate Quadrangle (secs. 5 and 8, T. 6 N., R. 8 E.) in the Seminole Indian Nation. He defined no upper limit but stated that the formation is about 150 feet thick. Taff presumed that the conglomerate represented a regional unconformity. Morgan (1924) set the upper limit at the DeNay Limestone, which lies about 150 feet above the base of the conglomerate. Unfortunately, the DeNay disappears by nondeposition immediately north of Taff's type locality.

The Seminole Formation directly overlies the Holdenville Shale. As the Seminole was followed northward in the outcrop, it was believed to trace directly into the Cleveland sand zone, and the Cleveland zone was designated as the northern extension of the Seminole Formation. Subsurface correlation, however, consistently shows that the Seminole Formation lies above the level of the Checkerboard Limestone rather than below it as do the Cleveland sands. As will be shown later, the surface trace of the Checkerboard was misplaced by steps in Okfuskee County, first at the Deep Fork crossing and again at the North Canadian River. The Holdenville Shale is thus the southern equivalent of the Cleveland zone, and the Seminole Formation is the southern equivalent of the lowermost beds of the Coffeyville. The name Seminole should be restricted to the sands in the area where they were originally defined. Further consideration of this new correlation, made possible by the abundance of electric logs now available, will be deferred until later in the paper.

Checkerboard Formation

The Checkerboard Formation is composed of a single bed of limestone, commonly only 2 or 3 feet thick and seldom thicker than 10. It is one of the most persistent and uniform beds of northern Oklahoma. At the type locality at Checkerboard Creek west of Beggs, the bed presents a "checkerboard" appearance, owing to solution channels along two sets of perpendicular joints. According to John F. Harris (personal communication), the east-northeast set aligns with a major fracture trend that exists in most Pennsylvanian rocks of the region. The perpendicular set of joints is a surface phenomenon caused by loss of support owing to creep in the underlying shale. The internal strength of the limestone is not adequate to withstand the resulting stress, and the carbonate "planks" have responded by fracturing at right angles to the major fracture set, forming the checkerboard pattern. There is a third, indistinct set of joints in the bed at an angle of about 60° from the major trend, but the perpendicular set dominates the appearance of the bed at the outcrop.

The shale that overlies the Checkerboard directly contains a persistent layer of phosphate nodules (Oakes, 1952, p. 55). Perhaps because of the presence of these nodules, the shale is more resistant electrically than the adjacent shales. Over much of the platform, the Checkerboard zone can be readily recognized on electric logs by the presence of a resistive shale 20 or 30 feet thick lying on a thin limestone bed (well 13, fig. 10, and well 9, fig. 11). At places this shale is capped with a thin sandstone; in many areas it is capped with a thin limestone.

The Checkerboard extends into western Oklahoma, and the zone can also be traced on electric logs southward in the western end of the basin and along the Seminole Uplift. In these latter regions, the shale above the Checkerboard is characterized by marked positive SP readings (a curvature to the right on a conventional SP trace). The limestone becomes less prominent southeastward from the platform, but the indentation of the SP curve serves to identify the zone at a glance (well 11, fig. 11). South of the latitude of Okfuskee County (T. 12 N.), the section above the Checkerboard becomes more and more sandy, and farther southward it grades into the basal sandstones of the Seminole Formation.

The Checkerboard Limestone marks a period of widespread clear waters of relatively uniform depth over the platform and most of the basin area as well. Only in the extreme southeast of the study area, in Seminole and Hughes Counties principally, were the waters too muddy, or perhaps too deep, for a limestone layer to accumulate. There, the shales directly below the Checkerboard zone contain channels of Holdenville sand. North of Holdenville these channels trend westward, but to the southwest, where they are reddish and conglomeratic, they trend northwestward. They extend only 20 or 30 miles into the subsurface.

Directly above the Checkerboard zone the Seminole sands appear. They extend northwestward about the same distance as the Holdenville channels, and those south of Holdenville are reddish and conglomeratic. The Seminole and Holdenville fingers were separated by no more than a few tens of feet of mud, but this momentary absence of sand probably marked a considerable transgression of the sea. The feather edge of the Checkerboard extends to the very tips of the fingers of sand that lie above and below. Taff's "type Seminole" channel, which marks the return of coarse sediment, cut and foundered into the mud floor until it now lies only slightly above the level of the Checkerboard.

The Checkerboard Limestone zone is the highest stratum of detailed study in this paper.

Henryetta Coal–Seminole Interval of Basin

The sequence in the western end of the basin that is equivalent to the Verdigris–Checkerboard interval is significantly different from that of the platform. A few thin limestones appear in the section, but no thick limestones like those of the Oswego–Oologah banks are present. No limestone bed extends across the entire area. The interval is much thicker, and it contains much more sand. Many of the outcropping sandstones are conglomeratic.

From the time of the earliest studies, geologists experienced great difficulty in correlating the formations of the basin and the platform. The original correlations were necessarily based on surface geology, which is particularly difficult because of two formidable problems.

First, they were studying an outcrop traversed by four important streams with wide river valleys, the Canadian, the North Canadian, the Deep Fork of the North Canadian, and the Arkansas (fig. 2). Many lesser streams, like Little River, Wewoka Creek, and Bird Creek, also cross the outcrop. The alluvium of each of these streams and the associated windblown deposits create gaps in the outcrop of as much as 6 or 8 miles. In the case of the traverse of the Arkansas River, the break in the outcrop is particularly unfortunate because the Arkansas, in choosing the least resistant rocks for its path, has cut its channel in the shales between the Oswego–Oologah sequence and the Wewoka sandstones. Because this critical trace is broken, the correlation southward of the Oswego lime horizon was always a matter of dispute among the surface geologists. This confusion was regrettable, because the Oswego is a standard mapping horizon in northeastern Oklahoma.

Another obstacle is the difference in source for the middle Desmoinesian rocks of the platform and the basin. Even with the present abundance of electric logs, tracing the various horizons from the platform into the basin sequence must be done with care and frequent "loop-and-tie" verifications. Furthermore, since the sources were different, the rocks are different. For both these reasons, names given to the strata in northeastern Oklahoma could not be confidently extended into east-central Oklahoma. In common usage, the names for equivalent beds remain different to this day. The Red Fork–Earlsboro is such a set of complementary names for sandstones of the same age, as are the Skinner–Senora and the Prue–Calvin.

Fortunately, careful work with cross sections of closely spaced electric logs permits reasonably certain correlations from one area to the other. Many papers, theses, and dissertations have taken advantage of the growing number of electric logs to establish relationships across the basin margin, but no comprehensive study of the stratigraphic relationships between the platform sediments and the basin sediments has been published to date.

In practice, the exact correlation of every bed is hardly possible where the sediments have come from different directions, and reasonable amounts of interfingering and mixing occurred. Electric logs, however, are very sensitive to slight variations in properties of the sediments, and faint markers can often be traced for many miles. Many variations in the resistivity curves, which might be only inconclusively identified individually, can be confidently distinguished in conjunction with others above and below.

Slight miscorrelations are inevitable, perhaps to be corrected by other investigators, but enough electrical surveys are now available that serious errors in correlation can be avoided even in areas of complicated or indistinct stratigraphy.

Correlations for this paper were based on a network of cross sections, most of which were made with an average of almost one log per mile. Figures 10 and 11 show the correlations made by the writer from the network described.

Senora Formation–Henryetta Coal

The Henryetta coal is equivalent to the Broken Arrow coal of Tulsa County and the Croweburg coal of northeastern Oklahoma and Kansas. It lies about 20 feet below the level of the Verdigris Limestone in northeastern Oklahoma. The Verdigris does not extend south to the margin of the basin, and in the basin and the Seminole Uplift areas, the Henryetta coal serves as a convenient stratigraphic approximation (fig. 10). Core holes have shown that the coal is still about 3 feet thick some 8 miles west of the outcrop near Henryetta, but how far west and south the coal continues is not known. Fortunately, the horizon can be traced even in the absence of the coal, for it lies at the base of the upper Senora shale, which is continuous across the basin and the Seminole Uplift. A change in the electrical properties appears at the boundary; the shales below are sandier and have higher resistivities. There is also generally a shift in the shale base line at the boundary, the lower beds exhibiting more negative SP readings.

The Henryetta coal zone has been carefully noted in the exploration for petroleum, because the zone directly below it contains the Allen sand, which produces oil and gas in many pools of the area.

By consensus, in the basin the Henryetta coal is used as a marker instead of the Verdigris Limestone, which grades into shale at the south edge of the platform (Jordan, 1959, p. 94). A limestone several tens of feet below the Verdigris, separating the upper and middle Skinner sands, has mistakenly been called the "Henryetta coal" over much of the central platform area. This bed traces into a limestone that underlies the upper Senora (Allen) sand in the basin, where it is generally called the Senora lime, although the name has also been applied locally to other limestones in the Senora Formation.

Upper Senora Shale

The upper Senora shale is about 200 feet thick at the Okfuskee–Hughes County line but becomes thinner in all directions. Northward it thins markedly to about the latitude of T. 11 N., where it disappears into the shales that enclose the Verdigris Limestone. It is less than 100 feet thick at the western margin of the basin, and it loses its identity westward across the Seminole Uplift, where the overlying Calvin sands were not deposited. To the south, it thins and disappears against the faults of the Arbuckle–Tishomingo Uplift. A few sandstones are present in the upper Senora shale, but they are not widespread.

Calvin Sandstone

The Calvin Sandstone, which overlies the upper Senora shale, also reaches its maximum thickness at the outcrop near the Okfuskee–Hughes County line, where it is about 350 feet thick (Weaver, 1954, p. 51). It disappears against the faults of the uplift to the south. The sandstones do not extend west of the Seminole Uplift. To the north, the formation merges with the Prue sand zone. The Calvin can be divided conveniently into a lower and an upper sand zone separated by a stratum of sandy shale averaging perhaps 100 feet in thickness. Although the two sand zones overlap, the upper zone is more prominent in Okfuskee County while the lower sand is the principal sandstone in a much larger area to the south and west.

Oil-well drillers working in the greater Seminole oil district have frequently miscalled the top of the Calvin (Weaver, 1954, p. 92). Where present, the two Calvin sand zones and the four Wewoka sand zones directly above are very similar. Often little or no sand is present in one or more of the zones, and identification of the top of the Calvin can be made only by careful correlation.

In T. 11 N. and T. 12 N., the Calvin merges with the Prue sand along a line marking the trough that lay between the two depositional provinces. This trough extended east-northeastward from the vicinity of Shawnee during the deposition of the Prue–Calvin sands. Its location was a function of the original bathymetry, the rate of subsidence, and the relative rates of deposition. Subsidence was greater along the south slope of the trough, but, during the period under study, the supply of sediments from the south became greater than the trough could accommodate, and the southern sediments prograded up the north slope, gradually pushing the depositional trough northward.

The relationship of the Calvin sands to the Prue is confused by the sudden thinning of the zone at the north edge of this trough, and it is further complicated by the presence of other thick sands in the Senora and Earlsboro sections directly below. The Wilzetta and Keokuk Fault Zones in R. 5 E. and R. 6 E. cross this line of transition obliquely and add to the difficulties of unraveling the stratigraphy of the area.

Without electric logs, it proved difficult to establish the relationship of the Prue sand zone and the Calvin Formation. At the outcrop, the Prue and the Calvin beds are very difficult to trace where they merge in Okmulgee County. Since limestones are usually more continuous than sandstones, the Oswego lime offered greater promise as a marker, and much early work was devoted to following the Oswego southward into the basin.

The Oswego horizon, however, also proved difficult to trace. The Oswego serves as an important marker on the platform, where it is continuous and can generally be identified with confidence. Near the edge of the platform, however, it thins abruptly, with only a few lime stringers continuing southward. The limestone remnants disappear into sandy shales rather quickly at the outcrop.

Although several early writers believed that the Oswego lime would prove to be the equivalent of the Calvin Formation, and bulletins published by the Oklahoma Geological Survey adopted this view, petroleum geologists and others who have actually traced the vestiges of the Oswego southward in the subsurface have been led by the lowest stringer of the Oswego into strata overlying the Calvin, at the Calvin–Wetumka Shale contact.

Furthermore, the Prue sand zone can also be traced directly into the Calvin zone in electric-log cross sections. Near the platform edge, the Prue section of eastern Oklahoma contains a silty zone that characteristically displays a funnel shape on electric logs. This funnel shape is generally considered typical of prodelta sediments, where coarser particles are deposited over finer ones as the delta progrades seaward. This zone can be traced across the platform edge directly into the Calvin sand–shale sequence. Figure 12 shows the merging of this zone with the Calvin beds. The Prue sands and the Calvin sands are stratigraphic equivalents.

Wetumka Shale

The Wetumka Shale lies above the Calvin

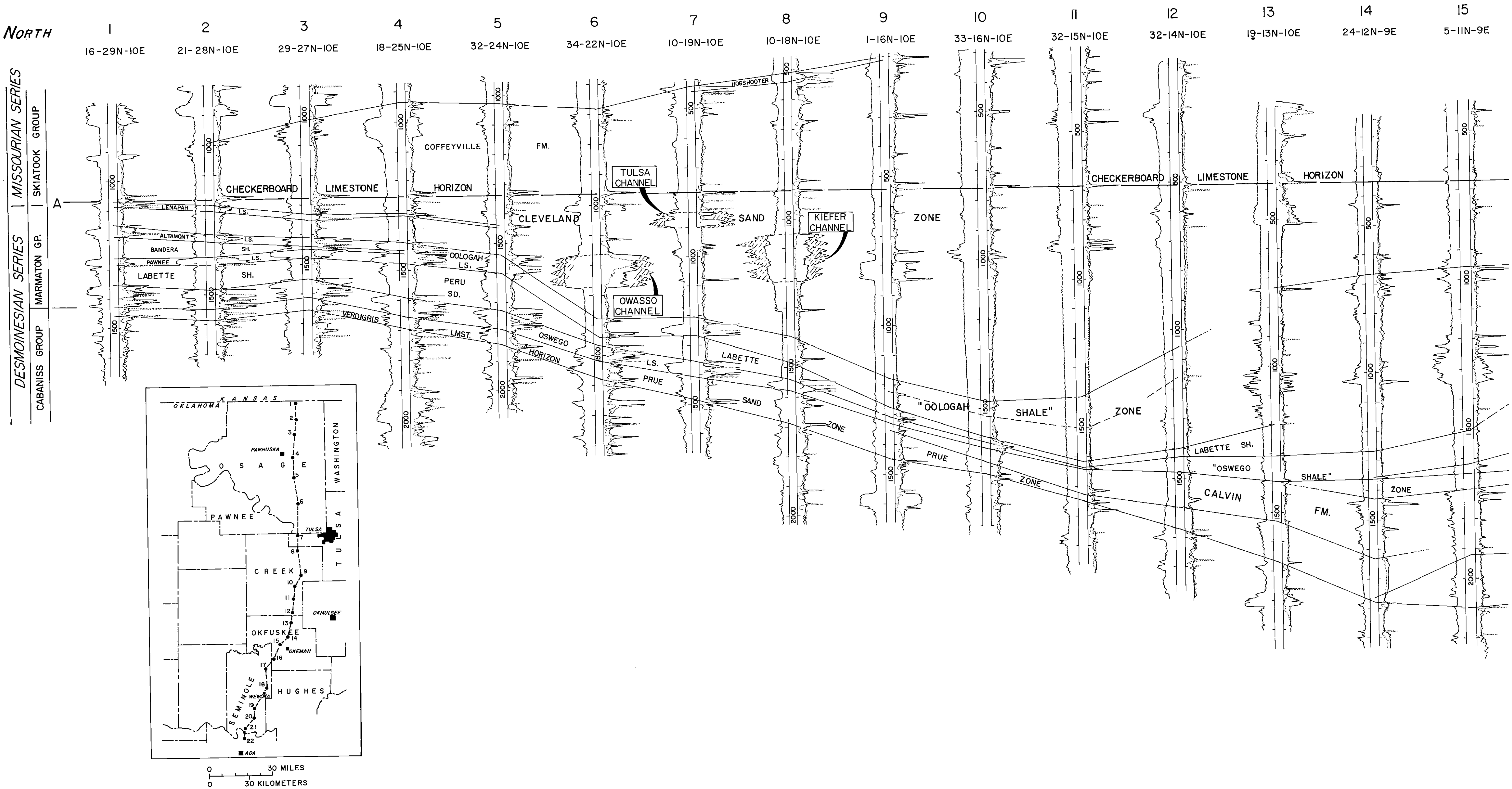
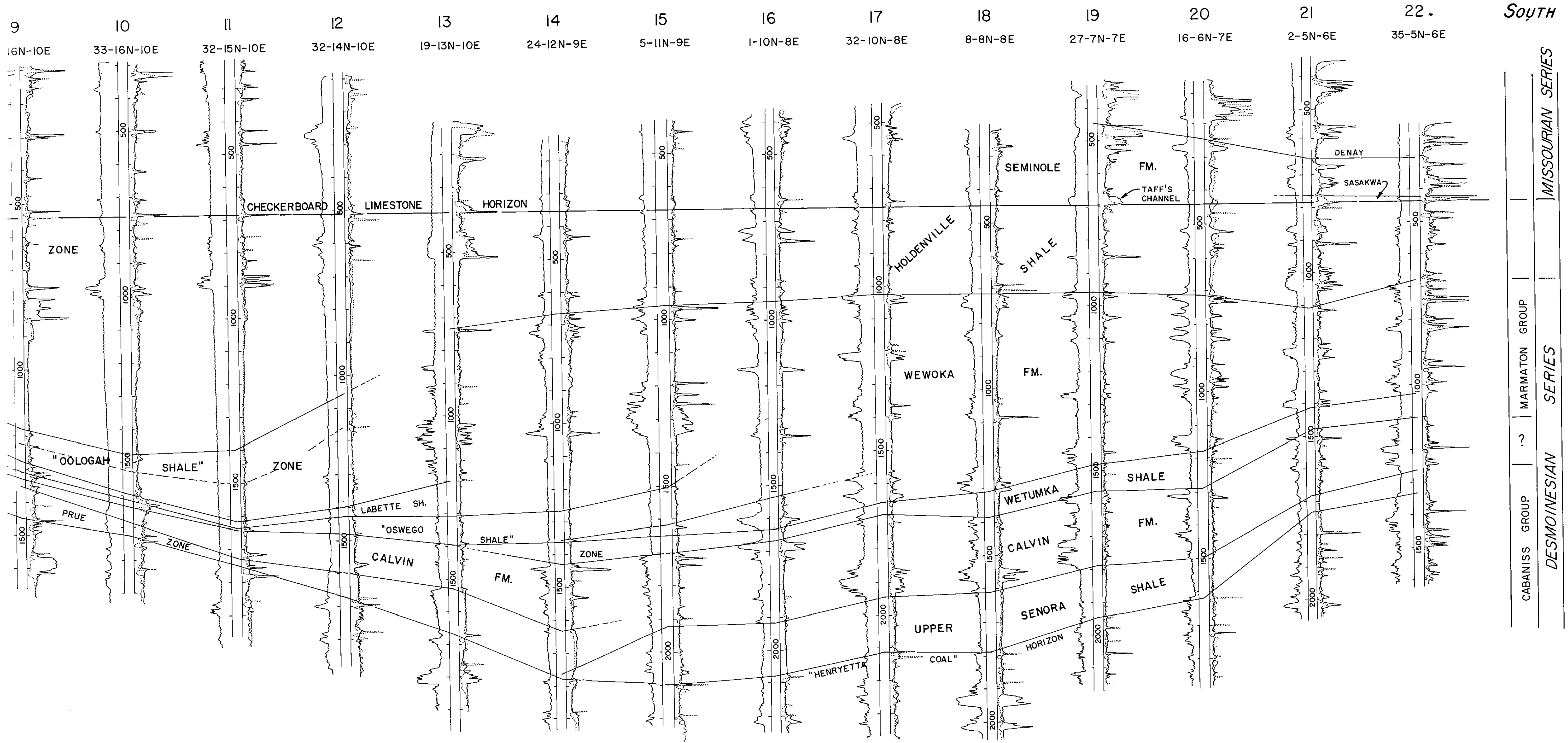


Figure 10. North-south electric-log cross section of study interval from Kansas line to Pontotoc County, Oklahoma.



SOUTH
9
16N-10E
10
33-16N-10E
11
32-15N-10E
12
32-14N-10E
13
19-13N-10E
14
24-12N-9E
15
5-11N-9E
16
1-10N-8E
17
32-10N-8E
18
8-8N-8E
19
27-7N-7E
20
16-6N-7E
21
2-5N-6E
22.
35-5N-6E
MISSOURIAN SERIES
DESMOINESIAN SERIES
MARMATON GROUP
?
CABANISS GROUP
DENAY
SASAKWA
SEMINOLE FM.
TAFF'S CHANNEL
CHECKERBOARD LIMESTONE HORIZON
ZONE
HOLDENVILLE SHALE
WEWOKA FM.
"OOLOGAH SHALE" ZONE
LABETTE SH.
"OSWEGO SHALE" ZONE
PRUE ZONE
CALVIN FM.
WETUMKA SHALE
CALVIN FM.
SENORA SHALE
UPPER "HENRYETTA COAL" HORIZON

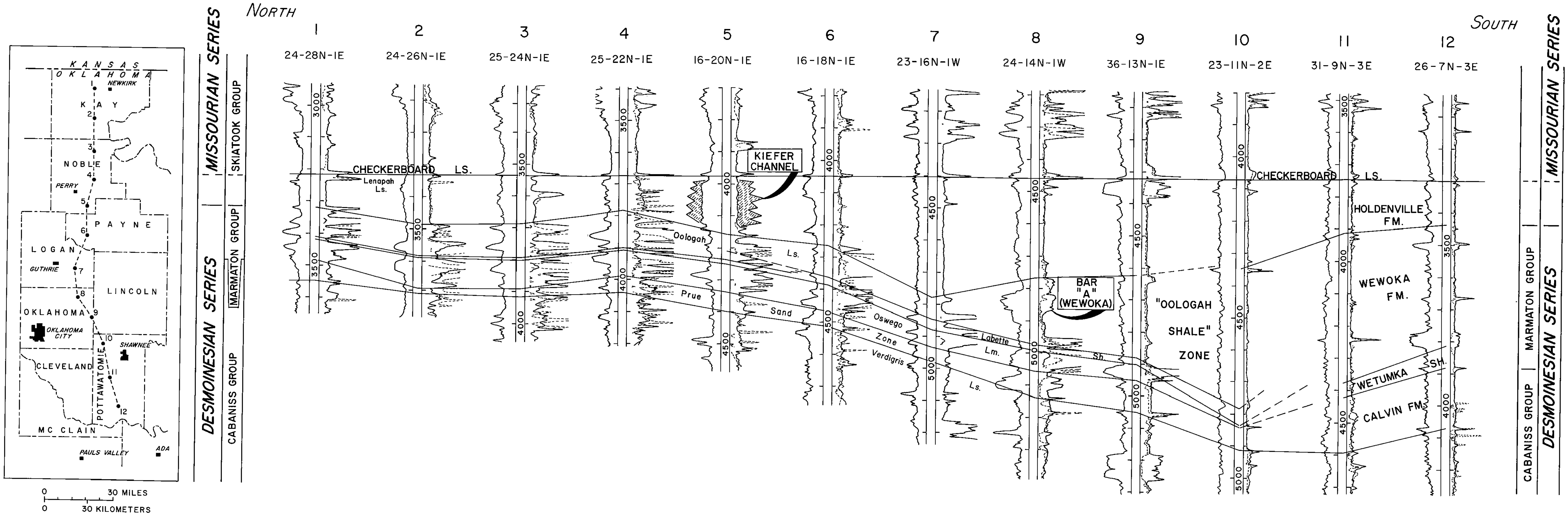


Figure 11. North-south electric-log cross section of study interval from Kay County to Pottawatomie County, Oklahoma.

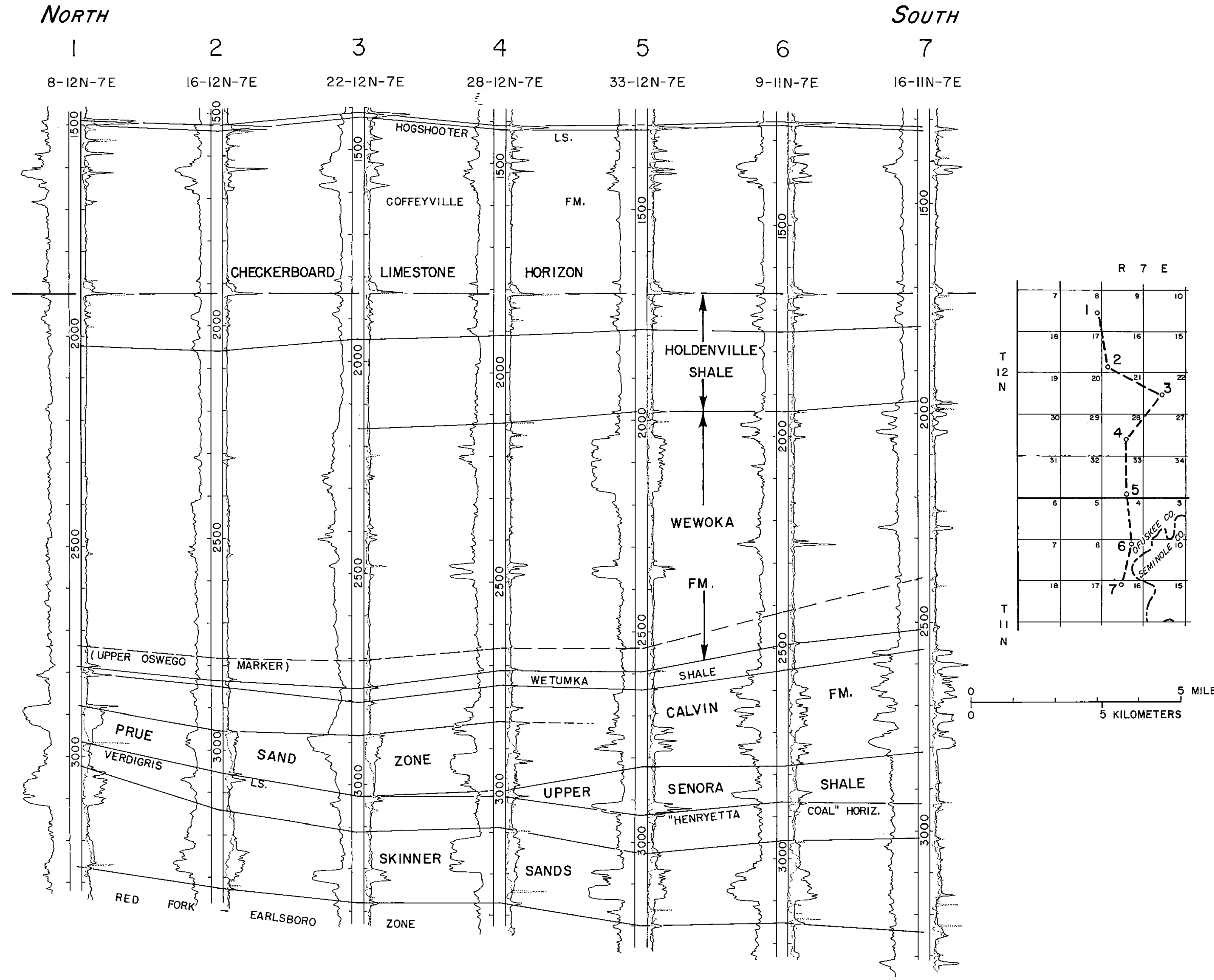


Figure 12. North-south electric-log cross section in western Okfuskee County, east-central Oklahoma, illustrating representative trace of Prue sandstone zone into Calvin Formation.

Sandstone. At its outcrop in Hughes and Okfuskee Counties, the Wetumka is generally about 100 feet thick, but it is less than 20 feet thick in some wells in the northern part of the Seminole Uplift.

The Wetumka is overlain by basal sandstones of the Wewoka Formation. The Wetumka Shale is continuous in the subsurface, but frequently it can be distinguished from the middle shale unit of the Calvin and from the lower shale unit of the Wewoka only by direct correlation. It has been misplaced frequently in the subsurface by oil-well drillers.

It was previously noted that the lowermost vestige of the Oswego carries southward into a limestone lying at the Wetumka–Calvin contact (figs. 10 and 12). The stringer next above, however, is generally more prominent and more persistent. It can be traced at the top of the Wetumka along the basin margin, but southeastward the basal Wewoka sandstone unit appears below the limestone stringer, which soon disappears as the section becomes more sandy. Both the Wetumka Shale and the lowermost Wewoka sand unit, then, are equivalent to the Oswego.

It should be observed that, in general, limestones are more likely to grade into shales than into sandstones. Although it is rather common for thin limestones to cap marine sandstones, the depositional environments represented by the two units are unlikely to occur adjacent to one another contemporaneously.

In Creek and Okfuskee Counties, one more marker from the Oswego section persists into the basin. Directly south of the Oswego front in Creek County, an electric-log marker appears at the top of the Oswego; it can be traced 25 miles southward into central Okfuskee County. The marker, an otherwise insignificant contact characterized by a slight, but sharp, drop in resistivity at increasing depth (figs. 10 and 12), gradually diverges from the lime stringers below until it disappears in the middle Wewoka in T. 11 N. and T. 12 N. The interval from the lowest Oswego lime stringer to the upper Oswego marker increases from slightly more than 40 feet in central Creek County to approximately 260 feet in central Okfuskee County, where it is equivalent to about 40 feet of Wetumka Shale and about 220 feet of the lower Wewoka Formation.

That the basin section equivalent to the Oswego should be much the thicker is not at all surprising. Although carbonate banks can be built rather quickly under favorable conditions, it is reasonable that sand-shale sedimentation from the Ouachitas would progress even more rapidly in the subsiding basin.

The "Oswego shale" zone lying directly south of the Oswego front is thin because it lay on the north side of the platform-basin trough. This trough, which occurred where the foot of the Wewoka delta slope abutted the platform, protected the carbonate bank by trapping the distal prodelta muds of the Wewoka system. The Oologah bank was similarly protected at a later time.

With regard to the surface trace of the Oswego into a zone directly below an uppermost Calvin sand, as reported by Oakes (1952, p. 25), such a circumstance is not impossible or even unlikely. The surface contact of these beds is considerably too far northeast of the area where electric logs are sufficiently numerous to permit reasonably certain correlations, but it would not be unlikely that a last surge of "Calvin" sand, actually of lowermost Wetumka age, could override an early lime stringer extending southward from the Oswego front. The general stratigraphic relationship is clear, however; the Oswego is a younger unit than the Calvin.

Wewoka Formation

The succeeding Wewoka Formation contains four sandstone divisions and three intervening shales in its type locality in Hughes County (fig. 13). It is about 700 feet thick there. The Wewoka thins southwestward along the outcrop, and it disappears at the Ahlosa Fault south of Ada. It thins only slightly northward from the type area until it approaches the Arkansas River, where it begins to thin abruptly before the outcrop disappears under the alluvium. Equivalent beds north of the river belong to the platform facies (Marmaton limestones).

In the subsurface, the Wewoka sands extend westward and northwestward to the margin of the basin (fig. 13). One notable exception is a large isolated sand body of middle Wewoka age located 10 or 15 miles northeast of Oklahoma City. This sand body, marked *A* in figures 11 and 13, lies at the horizon of the Oologah Formation. The lowermost of the Wewoka sand units is the least extensive.

At the outcrop in Hughes County, the basal sandstone and the third sandstone contain conglomeratic streaks with chert pebbles averaging one-quarter inch in diameter (Weaver, 1954, p. 64). Chert conglomerates appear at several levels in the Wewoka Formation in Pontotoc County (Morgan, 1924, p. 103). At outcrops closer to the Arbuckle-Tishomingo Uplift, Morgan also found pebbles of limestone resembling those of the Viola and Hunton Limestones and, in one small area, well-rounded pebbles of igneous rock.

The Wewoka sands are approximately coextensive with the Calvin sands and appear to be similar to the Calvin in other respects. In the subsurface there is no natural break in the sequence from the base of the Calvin to the top of the Wewoka, and the "Wewoka" of the oil fields may contain one sand zone more or one less than the surface Wewoka. Weaver noted that the Calvin of many petroleum geologists contains only the lower Calvin of the surface. In other areas, oil-field workers called the basal Wewoka sand the "upper Calvin," and an upper, middle, and lower Calvin were called, with the shale between the third and fourth Wewoka sands mistakenly designated the Wetumka. This sort of error is easily carried into formal works, as, for example, in the study of the subsurface geology of northern Seminole County by Cutolo-Lozano (1969), where a threefold division of the Calvin sand is accepted without comment. A comparison with Weaver's cross section (1954, pl. 2), which carries the Calvin from the outcrop into northern Seminole County, reveals the discrepancy.

It has long been apparent that the Wewoka is the stratigraphic equivalent of the Marmaton limestone sequence of the platform. The correlation of the Oswego with the Wetumka Shale and the lower Wewoka has already been described. Except near Tulsa, however, the Oologah front is farther removed from the sandstones, and the trace of the Oologah southward is more subtle.

An electric log of the shale section between the carbonate facies and the Wewoka sands shows a set of characterless "wiggly" lines with occasional small surges in the resistivity of the strata, often as little as 1 or 2 ohms. These surges are not random; each apparently marks a stratum of slightly increased carbonate content. Individually, the surges would prove impossible to follow from one log to another. In sets they can be followed in a detailed cross section with reasonable confidence (fig. 14).

It has already been noted that the thickness of the "Oswego" strata increases southward from less than 20 feet in the starved trough bordering the Oswego front to about 260 feet in central Okfuskee County, where it spans the third Wewoka shale, the fourth Wewoka sand, and the Wetumka Shale.

As might be expected, the "Oologah shale" facies similarly thins south of the Oologah front and then thickens basinward. The highest Oologah marker can be traced to the top of the Wewoka in T. 9 N., R. 3 E., southwest of Shawnee, but only into the first Wewoka shale in northern Okfuskee County, the "Oologah" section having thickened from less than 40 feet south of the front to more than 200 feet at the Wewoka margin. As illustrated in figure 13, the Oologah front lies considerably north of the Oswego front, and the upper Wewoka sandstones reach out farther over the basin margin than the basal sand unit (fig. 11).

The trace of the Oologah into the Wewoka beds is not possible continuously along the margin of the Wewoka sands. The Oologah markers fade as the sand fringe is approached. Nevertheless, reasonable extrapolations over the central and western parts of the fringe of the Wewoka sands indicate that the top of the Oologah is approximately at the level of the top of the Wewoka.

Near the outcrop, in northern Okmulgee County, however, sands are present that seem to lie 200 or 300 feet above the highest Oologah marker and yet are lower than the Cleveland sands. These sands do not extend far into the subsurface. They have been mapped as Wewoka at the surface. If indeed these sands do lie so far above the highest Oologah marker, they are younger than the Wewoka sands to the southwest. They apparently mark a northeastward shift of the center of deposition, a shift that culminated in the great wash of Cleveland sands down the trough which lay at the north edge of the Wewoka system.

While the Wewoka sands did not prograde toward the platform quite as far as the Calvin sands, the mid-seaway trough north of the clastic wedge retreated to approximately T. 18 N. (figs. 10, 11, and 34). The Wewoka clastics were unable to fill this trough, and the platform remained protected from Ouachita muds. As noted earlier, the organic bank on the platform was occasionally buried, but these re-invasions of mud must have had a different source. The succeeding Cleveland clastics subsequently filled the trough, overstepping the Wewoka Formation, lapping well onto the platform and forcing the carbonate bank to retreat into Kansas.

Holdenville Shale

The Holdenville Shale, which overlies the Wewoka Formation, is about 250 feet thick at its type locality near Holdenville. In the subsurface it thins westward at about 3 feet per mile until it loses its identity where the Wewoka sandstones disappear over the Seminole Uplift (Tanner, 1956a). The description and thickness of the Holdenville Shale northward is subject to the definition of the formation, which in turn depends on the correct correlation of the Checkerboard Limestone and Cleveland sand zones into the basin.

At the outcrop in southeastern Seminole County, the Holdenville contains a zone of coarse sandstone and chert conglomerate, sometimes in a red matrix, reaching a combined thickness of 33 feet (Tanner, 1956a, p. 46–47).

To the southwest in Pontotoc County, Morgan (1924) likewise found Holdenville sandstones locally developing into massive chert conglomerates. He observed that the Holdenville thins to the west and vanishes, being overlapped by the Seminole Formation.

Near the top of the Holdenville Shale in its southern outcrop, the Sasakwa Limestone appears (fig. 10), reaching a thickness of 29 feet at the Sasakwa quarry (Tanner, 1956a, p. 46). In outcrop, this thick lens of Sasakwa is only a local occurrence, and about a mile south of Sasakwa, the limestone is only a foot or two thick and it continues southwestward at this greatly reduced thickness. Northward, the limestone also thins abruptly. The thin limestone stringer is buried under the alluvium of Little River 2 miles north of Sasakwa, but Tanner noted that a thin limestone that appears north of Little River at about the same stratigraphic position abuts a thick conglomeratic channel and disappears. This conglomeratic sandstone is the exposure chosen by Taff (1901) as the basal bed of the Seminole Formation directly overlying the Holdenville Shale. Taff presumed that the contact marked a regional unconformity.

Electric logs are now available to clarify correlations at the Holdenville–Seminole contact, which are unclear in outcrop because of the valley of Little River. Electric logs show that the basal Seminole conglomeratic channel at Taff's type area is at the same level as the Sasakwa Limestone to the south. Even more unexpectedly, they show that the base of the Seminole also lies approximately at the level of the Checkerboard Limestone to the north (fig. 10).

This relationship was not previously recognized. The first published effort to follow the Checkerboard outcrop southward was that of Ohern (1910), whose map traced the bed as far south as the North Canadian River at Okemah. At the time, he believed this limestone to be the Lenapah, but he corrected the error several years later (Ohern, 1918). Ohern's map was generalized, however, and showed only the approximate location of the outcrop.

The first USGS *Geologic Map of Oklahoma* (Miser, 1926) correctly traces the Checkerboard to the North Canadian River not far from Ohern's approximation of almost two decades earlier. The Checkerboard becomes too faint for ready identification to the south, however, and the Checkerboard is not shown south of the river.

Even so, electric-log cross sections tied to the outcrop show that a serious miscorrelation was made at the river crossing. The 1926 map purports to trace the outcrop of the Seminole Formation northward from its type area to the Tulsa–Okmulgee County line. As will be demonstrated later, north of the North Canadian the "Seminole Formation" shown on the map lies entirely below the Checkerboard, while south of the river the Seminole Formation shown on the map lies at and above the actual level of the Checkerboard. Since the Checkerboard horizon was not mapped south of the river, the miscorrelation of the Seminole with the Cleveland zone was not apparent.

The next published geologic map of the area appears in Ries' study of Okfuskee County (1954). Rather than correcting the miscorrelation at the river, Ries unfortunately chose as the surface "Checkerboard" between the North Canadian and Deep Fork a limy bed that lies about 100 feet above the correct horizon. Furthermore, by a mis-tie, the limestone marked as the "Checkerboard" on his electric-log cross section is even higher in the section than his surface Checkerboard.

Ries believed that the limestone chosen by oil-field geologists as the subsurface Checkerboard is not the same bed as the Checkerboard of the type locality but is instead "the same age as a sandy limestone in the Seminole formation of the surface" (p. 90). There is no doubt, however, that this "subsurface Checkerboard" is the true Checkerboard. The bed is easily traced from the outcrop into the subsurface, and Kirk (1957, p. 9) and Jordan (1959, p. 98), as well as the author, have confirmed that this "subsurface Checkerboard" is actually the Checkerboard of the type locality.

Figure 15 shows the author's trace of the Checkerboard from the type locality into the subsurface of eastern Creek County to well 11 of figure 10. The Checkerboard can there be followed to well 15 (log 12 of Ries' cross section). Figure 16 shows Ries' cross section from log 12 through log 8, with the true Checkerboard horizon marked and a comparison made with the outcrop on Ries' surface geological map. Several points are obvious about the surface-to-subsurface correlation.

First, Ries' surface Checkerboard lies about 100 feet above the true Checkerboard, as noted earlier. Furthermore, the horizon Ries picked as the Checkerboard in his subsurface cross section is about 70 feet higher than his surface Checkerboard. Ries' subsurface choice is, then, about 170 feet above the true Checkerboard.

Ries' surface IPsl-1a, his basal "Seminole" sandstone, lies at the base of the Cleveland sand zone, about 120 feet below the true Checkerboard. This horizon can be traced into the subsurface to well 15 (Ries' log 12), thence southward to well 16 in figure 10, and from there again to the surface on the south side of the North Canadian River in figure 17. Comparison with Ries' surface map shows that, south of the river, this outcrop (called IPsl-1a north of the river) is designated IPhd-3b.

The outcrop of the zone that is the southern equivalent to the true Checkerboard is labeled IPsl-1a south of the river. Therefore, south of the North Canadian River, Ries' subsurface nomenclature remains inconsistent with his surface nomenclature, but in a new way (see fig. 18).

By this combination of miscorrelations, Ries' surface "Checkerboard" was raised 100 feet above the true level and his subsurface "Checkerboard" 170 feet above the true level, beginning at the Deep Fork crossing, and then, at the North Canadian crossing, the base of the Cleveland sand zone was raised to the level of the southern facies of the Checkerboard Limestone. In this manner, the miscorrelation made earlier at the North Canadian on the 1926 USGS geologic map was magnified in the OGS bulletin for Okfuskee County.

Weaver (1954), working in Hughes County to the south, accepted Ries' subsurface designations. His subsurface basal Seminole is actually a con-

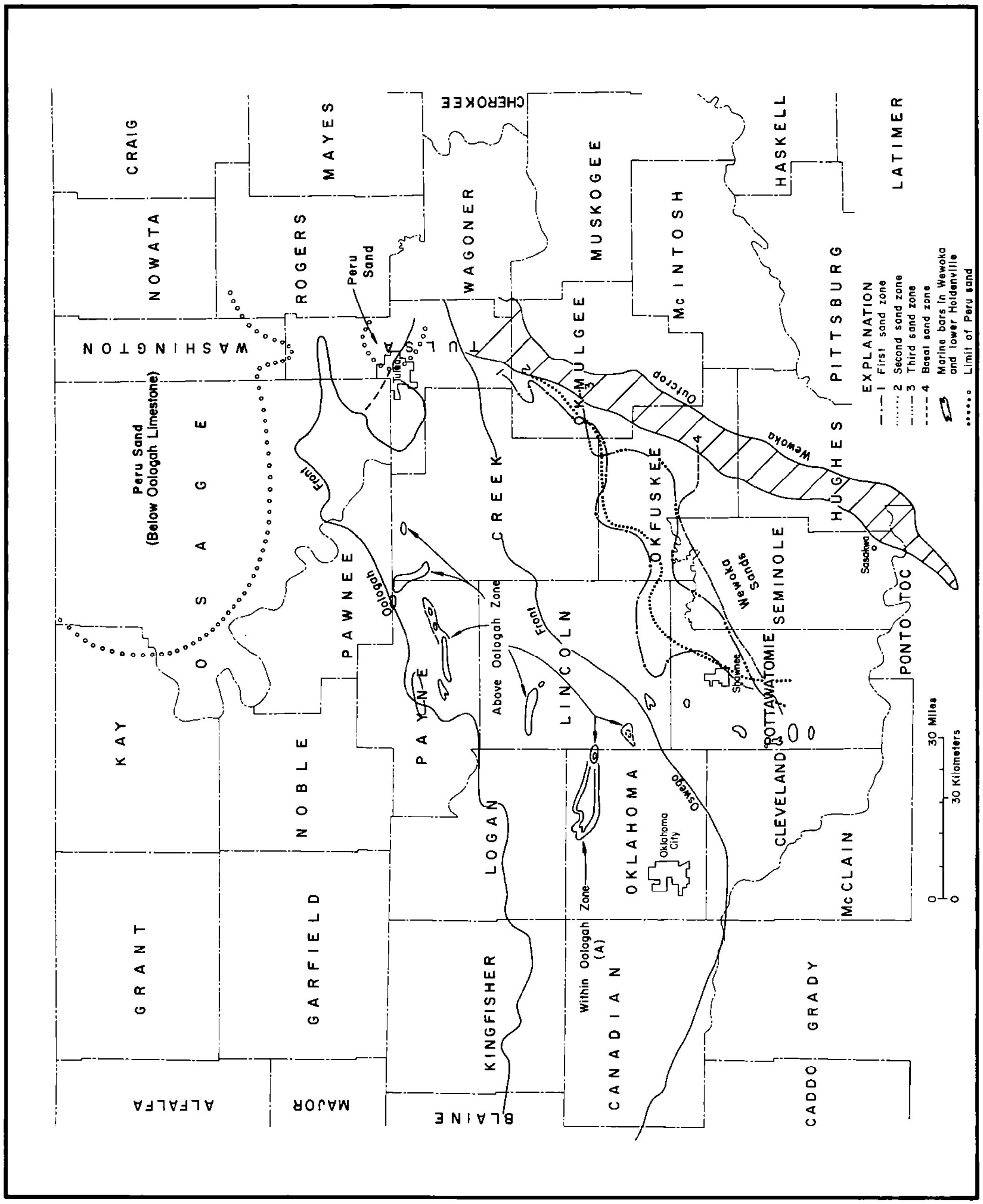


Figure 13. Map of eastern Oklahoma showing approximate limits of four Wewoka sandstone zones and their relationship to Oswego and Oologah fronts.

tinuation of the sandy zone in the surface Holdenville Formation. The relationships can be seen by reference to figure 10 and figure 19. The Checkerboard horizon can be traced southward in figure 10 to well 17 (Weaver's log 11) and then to the surface in figure 19. The true Checkerboard horizon reaches the surface at the base of the Seminole of the geologic map, and the base of the "Seminole" of Weaver's cross section reaches the surface at the level marked IPhd-2c on the geologic map.

Tanner (1956a) carried the same subsurface designations into Seminole County, as can be seen in figure 20, which ties into the cross section of figure 10 at well 18 (log 3 of Tanner's cross section *B–B′*). The surface tie occurs in Hughes County, since the Seminole Formation enters Seminole

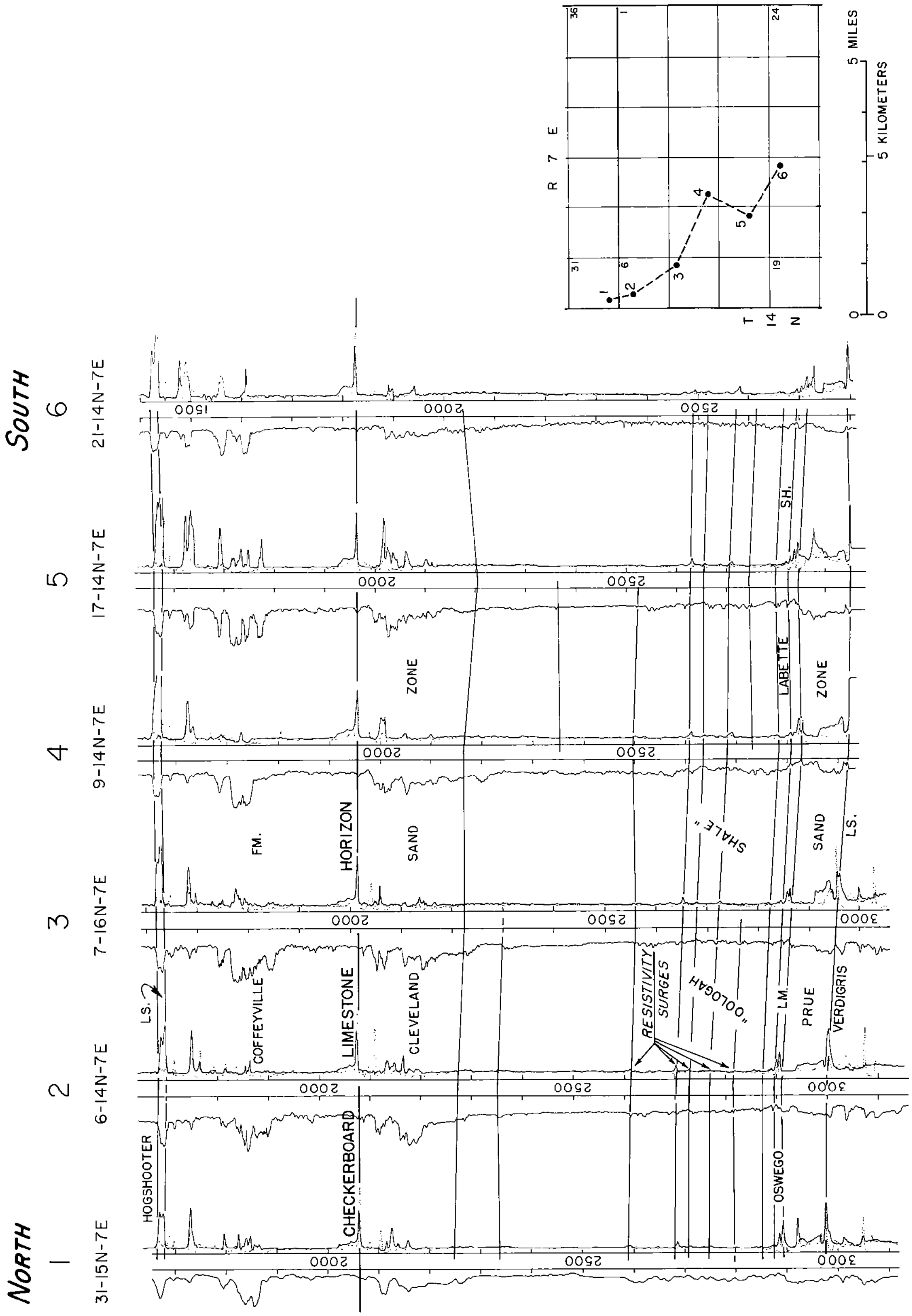


Figure 14. Northwest-southeast electric-log cross section in southwestern Creek County, east-central Oklahoma, showing trace of resistivity surges in "Oologah shale" and superjacent shales.

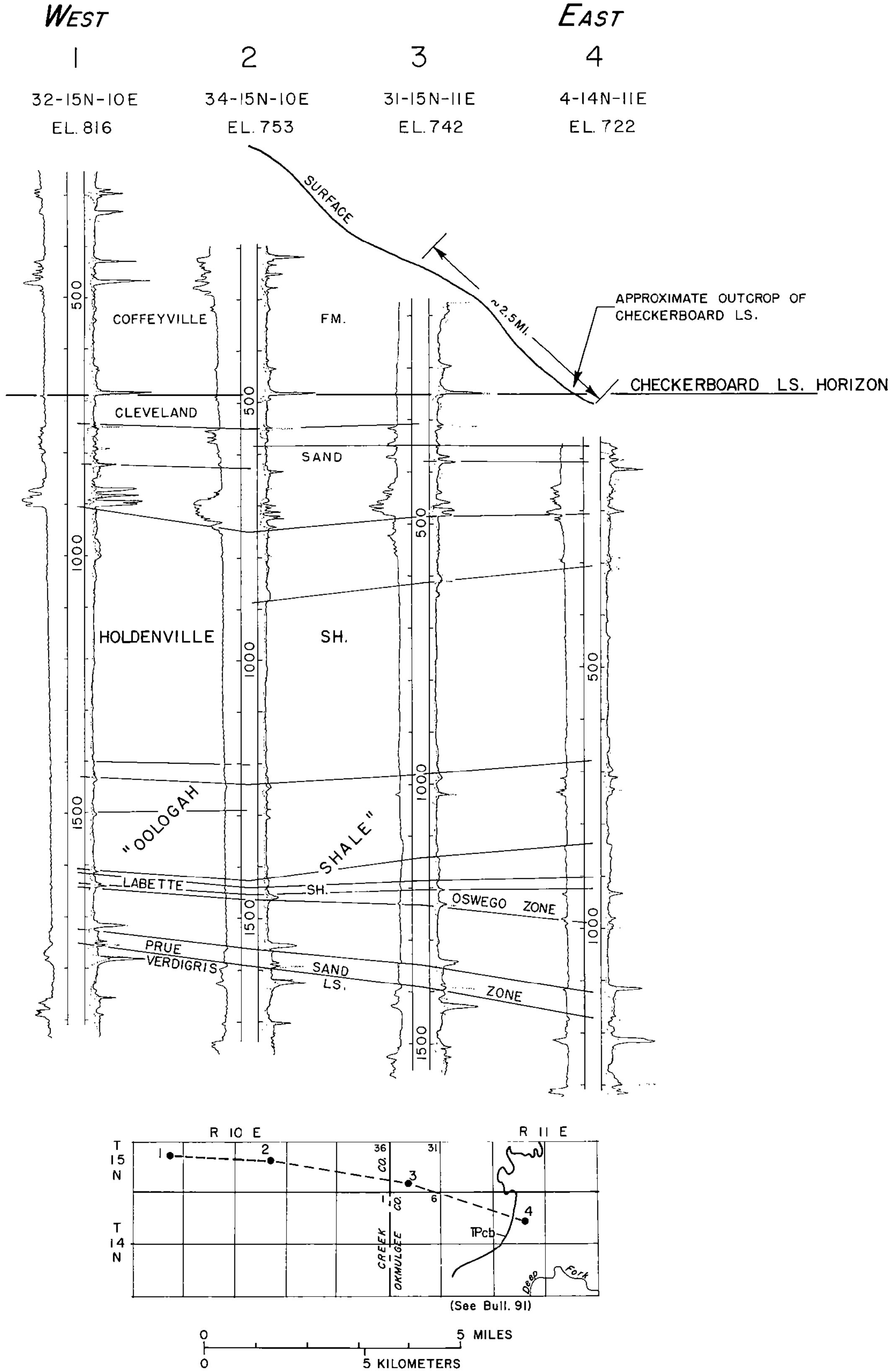


Figure 15. West-east electric-log cross section in Creek and Okmulgee Counties, east-central Oklahoma, showing correlation of Checkerboard Limestone in subsurface with type locality at surface. (Well 1 is well 11 in figure 10.)

County obliquely from the northeast. The Checkerboard horizon traces into the surface at the base of the Seminole Formation of Weaver's geologic map, while Tanner's base of the Seminole traces into the sandy bed marked IPhd-2c on the geologic map.

In southeastern Seminole County, Tanner did not simply accept the previously made subsurface choices but directly tied his cross section *A–A′* to the surface, even though the type locality of the Seminole still lies mostly in Hughes County (fig. 21). The base of the Seminole designated in his well 1, cross section *A–A′*, is at approximately the same level as the surface exposure of the basal Seminole sandstone. Although the initial tie into the subsurface is correctly made, the trace westward in the subsurface was inexact, and in the next few wells to the west the "base of the Seminole" was dropped by steps until it was at the same level (IPhd-2c) as those of the other cross sections just discussed.

Figure 21 shows the tie of Tanner's cross section *A-A′* into the surface at the type locality of the Seminole Formation (Taff, 1901). Comparison with figure 10 confirms that the base of the Seminole Formation lies at the horizon of the Checkerboard Limestone.

Taff's conglomeratic channel at the type locality, although at the stratigraphic level of the Sasakwa and Checkerboard limestones, is probably slightly younger. The currents carrying the conglomeratic sands undoubtedly eroded somewhat into the sea floor, and the greater density of the sands would have caused them to sink even deeper into the mud. These actions need not have been appreciable, however. Several thin sandstone fingers in the shallow subsurface to the west lie close above and below the Checkerboard and Sasakwa, and yet they do not noticeably affect the associated marker beds.

Currents that deposited these thin fingers apparently subsided or retreated after depositing the Holdenville channels, yet carried sufficient mud into central Seminole County to prevent the Checkerboard Limestone from being continuous southward with the Sasakwa bank, which seems to have been contemporaneous. The Sasakwa bank was probably protected by its shallow, nearshore position fringing the carbonate lowland to the south, where Paleozoic limestones were presumably exposed along the Arbuckle–Tishomingo Uplift. It is also possible, of course, that the water was too deep in central Seminole County to allow the growth of lime-secreting organisms. The fact that earlier Holdenville channels and succeeding Seminole channels flowed toward central Seminole County suggests that the area was a local sink. In any case, the areal extent of the Checkerboard signifies that, for an appreciable length of time, clear waters covered middle and northern Oklahoma. The Seminole channels are associated with the return of sand–shale deposition.

To return to consideration of the Holdenville, Oakes (1952, p. 45) carried the Holdenville Shale continuously into Tulsa County and sporadically to the Kansas line. As noted earlier, Oakes considered the depositional sequence to have occurred as follows: (1) deposition of the Nowata Shale and the Lenapah Limestone on the platform contemporaneously with the upper Wewoka in the basin, with the Holdenville Shale then being deposited over both areas; (2) regional uplift and erosion; (3) deposition on the unconformity surface of Cleveland sands on the platform and, at the same time, of Seminole conglomeratic sandstones in the basin.

The proposed sequence was a reasonable solution for the limited evidence visible at the surface, where wide gaps in the outcrop were created by the Arkansas River and by Bird Creek. The relationships shown in figure 10 require a reevaluation of this proposed depositional sequence for several reasons. First, the lower part of the Holdenville Shale and the upper part of the Nowata Shale are stratigraphically equivalent, and the lower Holdenville grades into the Nowata with no determinable break. Second, the Cleveland sand zone has proved not to be equivalent to the Seminole Formation. Furthermore, as will be discussed below, the strata contain no convincing evidence of a regional unconformity.

In its type area, the Holdenville Shale lies between the Wewoka Formation and beds directly correlatable to the Checkerboard Limestone. It has been remarked earlier that some of the easternmost Wewoka sands appear to be younger than the Oologah, but essentially all of the platform strata between the Oologah and the Checkerboard are equivalent to the Holdenville Shale. All of the Cleveland channel sands lie in shales of Holdenville age. The Lenapah Limestone and the Nowata Shale, except for the lowermost strata, perhaps, are Holdenville equivalents.

Most early writers believed that the basal Cleveland sands were deposited on an unconformity surface (Oakes, 1952, p. 47–48; 1959, p. 13; 1963, p. 53). Since a boundary between the Desmoinesian Series and the Missourian Series had been placed somewhere near this level in the northern Midcontinent, and since unconformities were supposed to occur at series boundaries, the contact between the Cleveland sands and the shales below was chosen as the Desmoinesian–Missourian boundary.

Later writers have found no convincing evidence of an unconformity. Tanner (1956a, p. 37, 39) reported that the Desmoinesian–Missourian contact is, to all appearances, conformable in Seminole County and that paleontological evidence is not very helpful. Weaver (1954, p. 73) found no apparent structural discordance along the contact in Hughes County. Ries (1954, p. 46) believed that an unconformity existed but noted that there was no truncation in Okfuskee County and that the burden of proof must rest on paleontological evidence. Jordan (1959, p. 97), in writing about the subsurface geology of Creek County, stated that an unconformity of minor magnitude may exist but that northward thinning is more a result of deposition than erosion. Kirk (1957, p. 5, 6) agreed with Ries that there is little evidence of an unconformity in Okfuskee County, but he believed that the thick channel sands of Osage, Pawnee, and Creek Counties imply prior erosion. This implication, however, applies to channel erosion in general, whether or not at an unconformity surface.

Cole (1967, p. 97), who studied the outcrop and shallow subsurface in Tulsa, Washington, Rogers, and Nowata Counties, maintained that there is no conclusive evidence of a widespread unconformity at the base of the Cleveland sands in these counties. He found that the Lenapah Limestone thinned and vanished southward into strata directly above the lower Cleveland with no indication of truncation. Cole postulated essentially continuous deposition, observing that channeling, where present, represents an influx of coarser clastics into the area with accompanying scour and fill.

In a subsequent work covering most of northeastern Oklahoma, Cole (1970, p. 63) still found no evidence of truncation or onlap by the Cleveland sands and explained the supposed unconformities by channeling in a generally continuous depositional sequence.

The writer likewise found no evidence of an unconformity in the subsurface in the studied interval. No truncation is apparent at any level. All strata appear to be conformable after allowance is made for the normal processes of sedimentation.

Seminole Formation

Consideration of the Seminole Formation, which lies above the Holdenville, is essentially beyond the scope of the present investigation, which found the basal Seminole sand to lie at the level of the Checkerboard Limestone. However, to complete the study, some of the lower sandstones of the Seminole were examined at the outcrop, and their distribution in the subsurface was mapped.

The Seminole was first described by Taff (1901) in his report on the Coalgate Quadrangle. Taff named the formation the Seminole Conglomerate on the strength of an exposure 4 miles northeast of Sasakwa with 40 to 50 feet of conglomeratic sandstone at its base. Taff reported pebbles as large as 3 inches in diameter. While there are several conglomeratic beds in the Seminole, the formation is composed mostly of shale, as are all of the sand–shale sequences of the Midcontinent. The conglomeratic lenses disappear from the outcrop only 6 or 8 miles north of the type locality. The Seminole outcrop thins southwestward, and Morgan (1924), working in Pontotoc County, reported that it is overlapped by the Ada Formation some 10 miles southwest of Ada.

The type exposure appears in the extreme northwest corner of the Coalgate Quadrangle, and Taff rather loosely defined the Seminole as being about 140 or 150 feet thick. Morgan chose the DeNay Limestone, which is about 150 feet above the base of the type Seminole, as its top. Unfortunately, the DeNay disappears in Seminole County only a few miles north of Sasakwa, and the base of the next succeeding sandstone has necessarily been used to define the top of the Seminole.

Several geologists early expressed the expectation that the DeNay would prove to lie at the approximate level of the Checkerboard Limestone of the platform. Surface work done for Bulletin 71 (Okfuskee County) of the Oklahoma Geological Survey seemed to confirm this expectation, for the limestone bed chosen as the Checkerboard in central Okfuskee County does lie at the horizon of the DeNay. A gap of about 30 miles exists between the outcrops of these two limestones.

Unfortunately, as shown earlier, the limestone bed chosen lies more than 100 feet above the true Checkerboard. This upper limestone does not extend far in any direction. The true Checkerboard changes facies across Okfuskee County, and the limestone grades into a zone that can be traced directly into the basal Seminole horizon of Hughes and Seminole Counties (fig. 10). The consequences of this error in correlation have already been discussed.

Correlation of Checkerboard and Seminole–Sasakwa

Correlation of the Checkerboard horizon with the type Seminole channel has been discussed, but the extension of the basal Seminole horizon southward has yet to be considered. The type locality of the Seminole Formation is only 1 mile north of Little River, and the base of the Seminole cannot be directly traced across the river valley.

Before Tanner did his field investigation for Seminole County, no published work questioned the natural presumption that the basal Seminole sandstone south of Little River was at the same stratigraphic level as the basal Seminole sandstone north of Little River. Tanner, however, observed otherwise, noting that the Sasakwa Limestone, after attaining a considerable thickness at the Sasakwa quarry, thins drastically northward and vanishes against a coarse conglomerate in Hughes County. This conglomerate Tanner judged to be a channel fill, probably the member "approximately 50 feet" thick which led Taff to apply the name "conglomerate" to the formation.

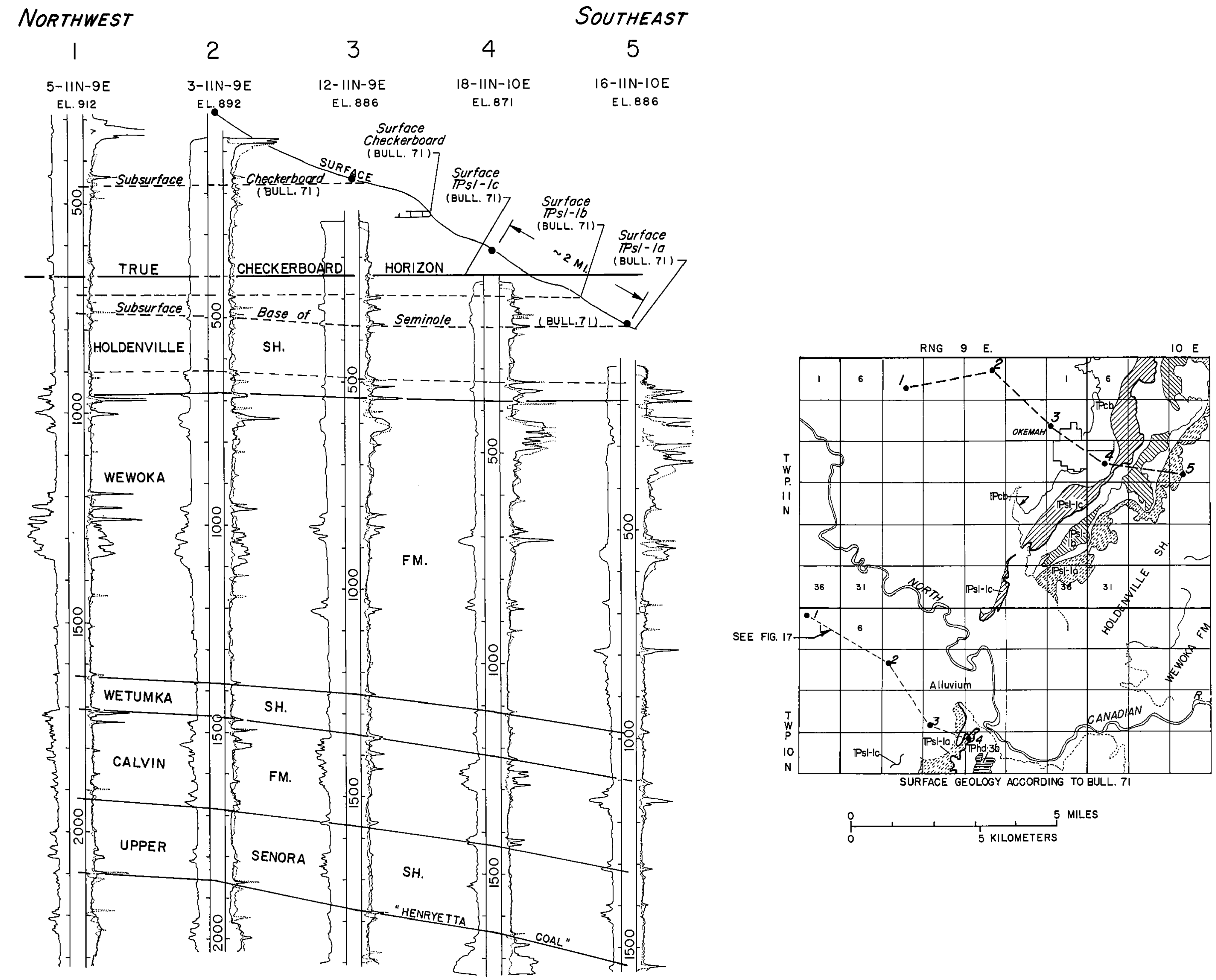


Figure 16. Northwest-southeast electric-log cross section and partial geologic map (Ries, 1954, pl. 1) in Okfuskee County, east-central Oklahoma, tracing Checkerboard Limestone from subsurface to outcrop at Okemah. (Subsurface correlations show that IPsl-1a south of river = IPsl-1c north of river = IPcb of type locality.)

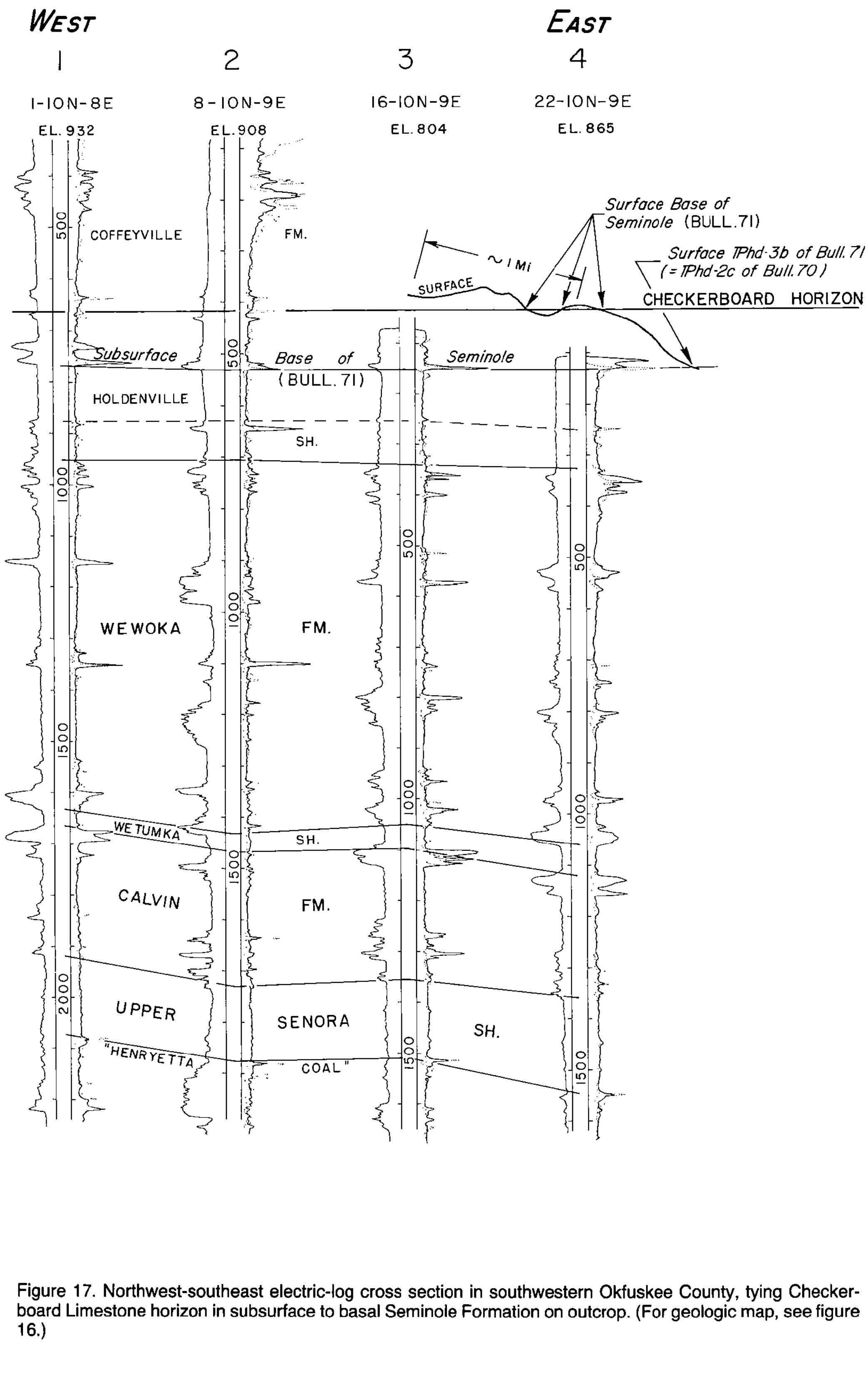


Figure 17. Northwest-southeast electric-log cross section in southwestern Okfuskee County, tying Checkerboard Limestone horizon in subsurface to basal Seminole Formation on outcrop. (For geologic map, see figure 16.)

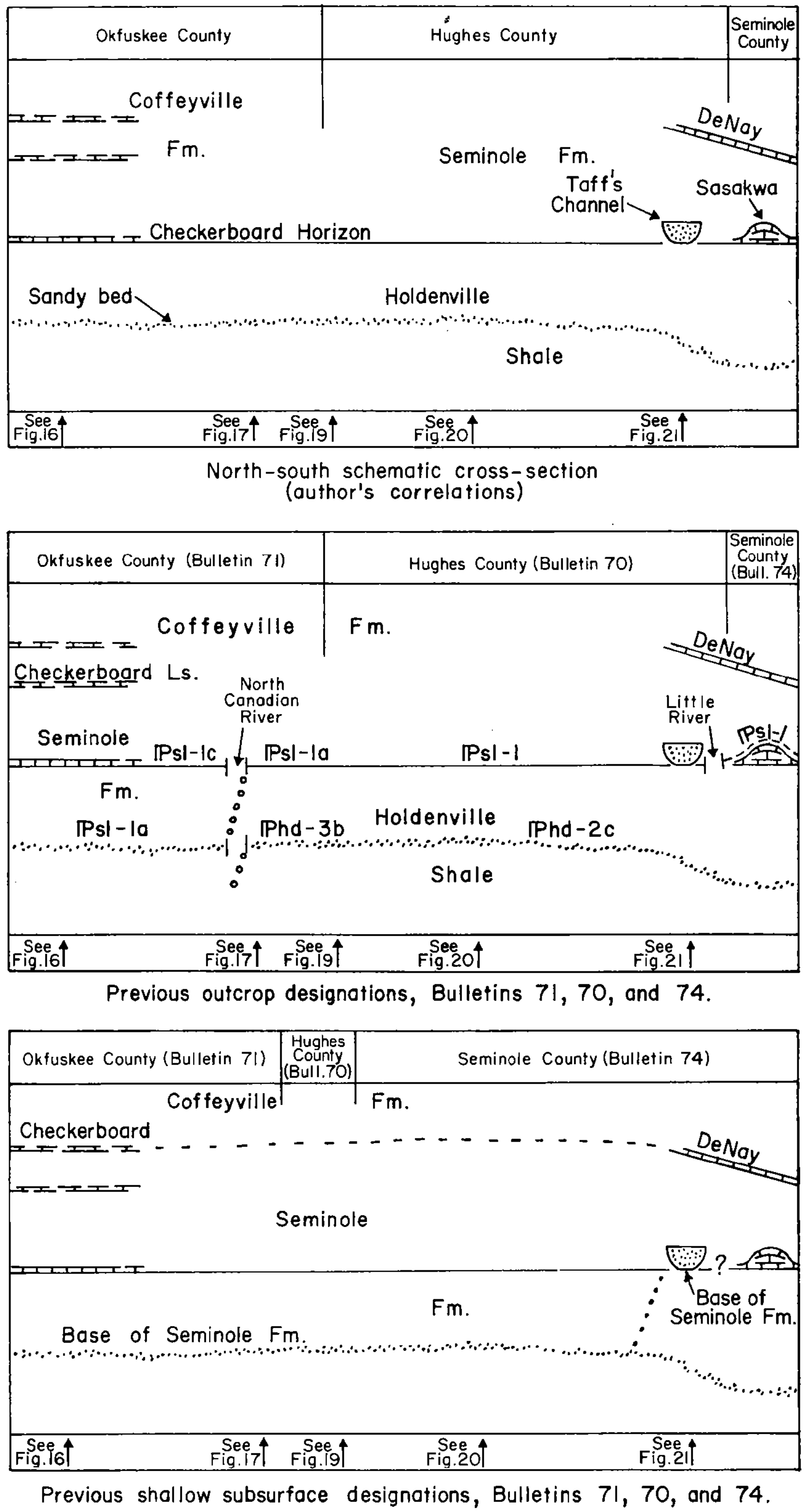
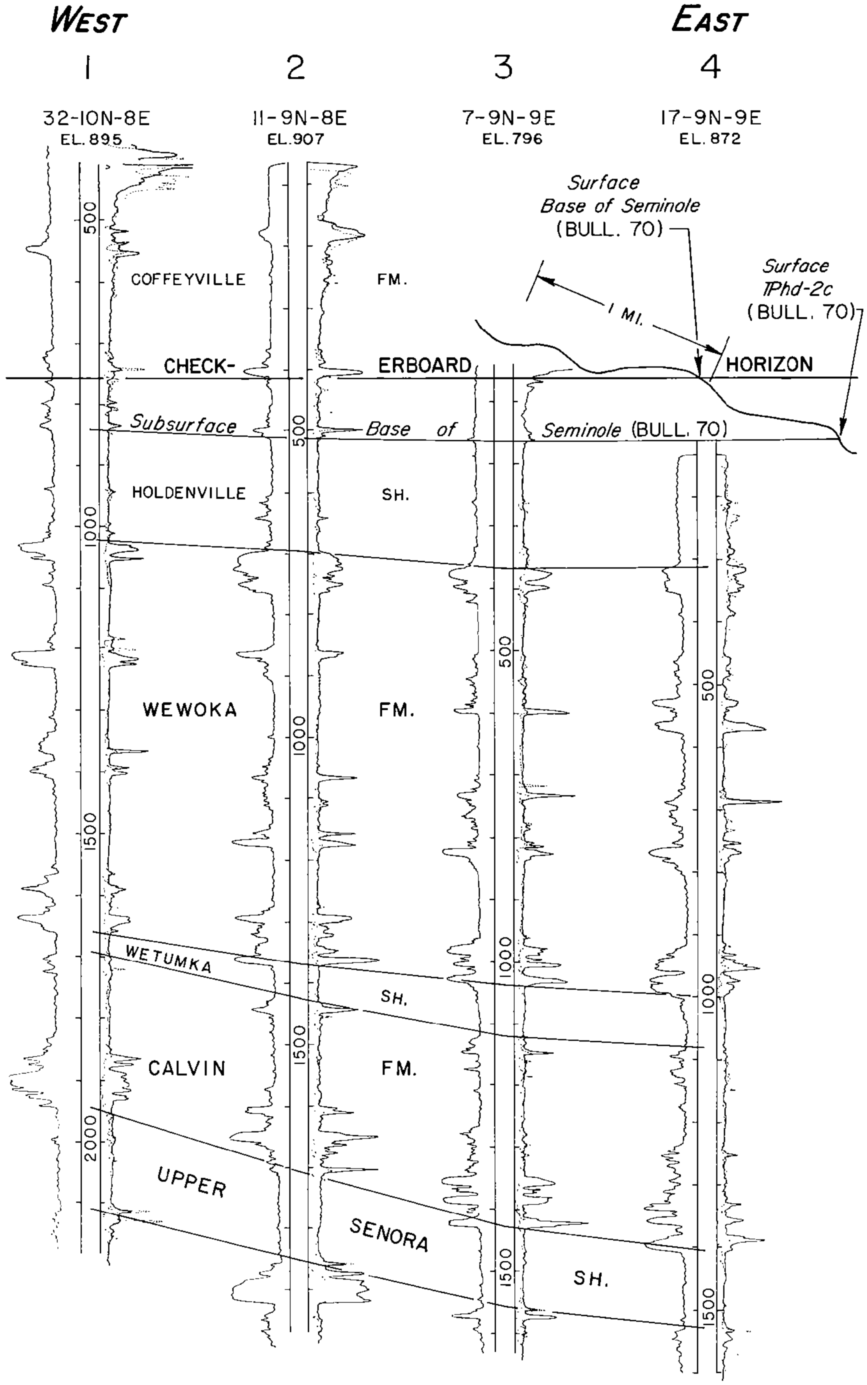


Figure 18. Diagrammatic sections showing comparisons of correlations of Seminole and Holdenville Formations, east-central Oklahoma.



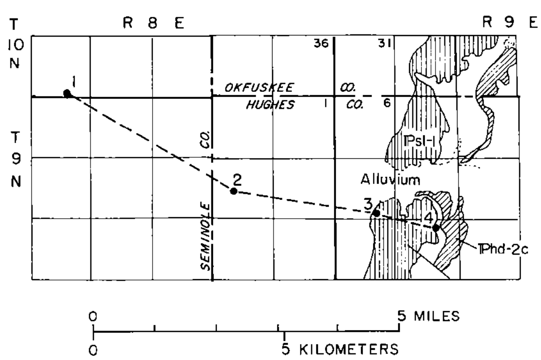


Figure 19. West-east electric-log cross section in Seminole and Hughes Counties, east-central Oklahoma, equating Checkerboard Limestone horizon in subsurface to basal Seminole Formation on outcrop.

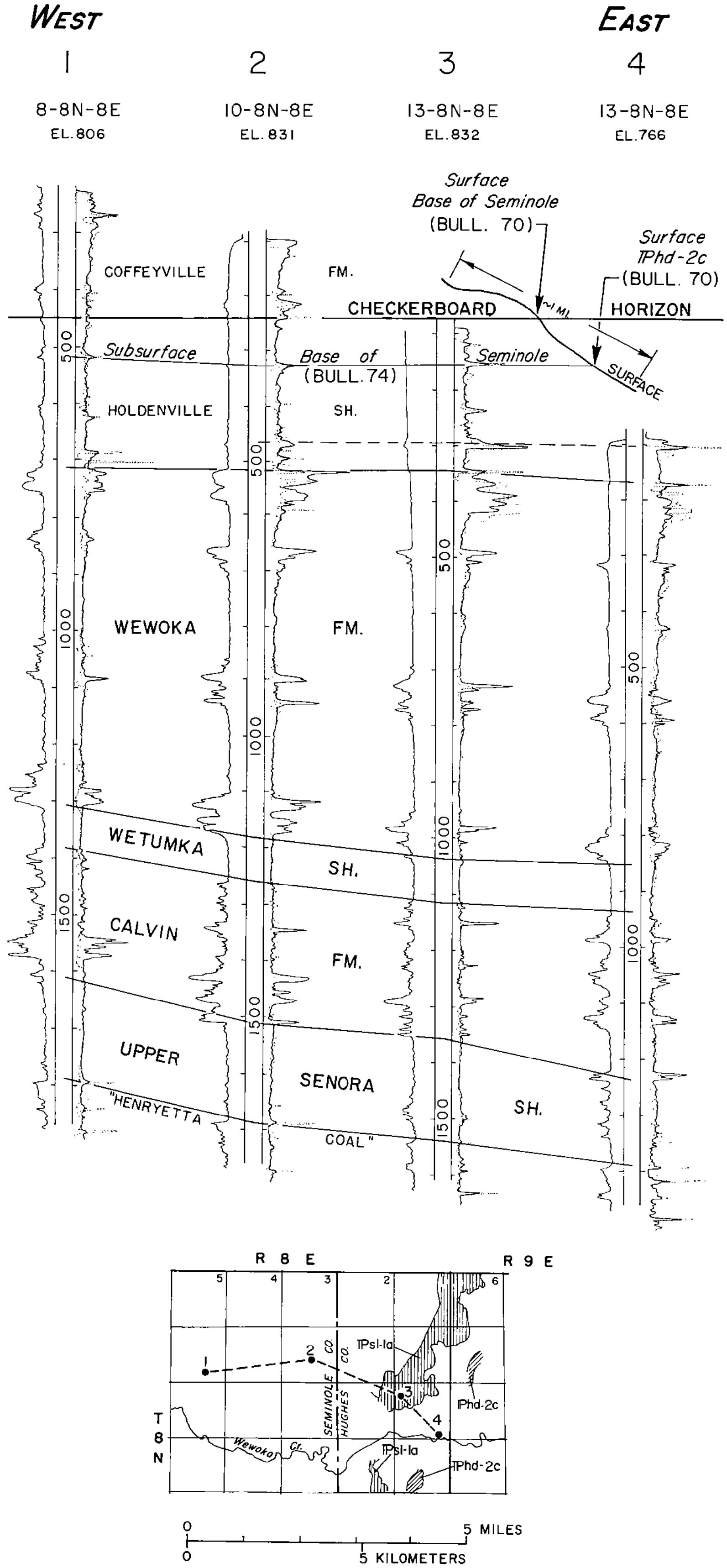
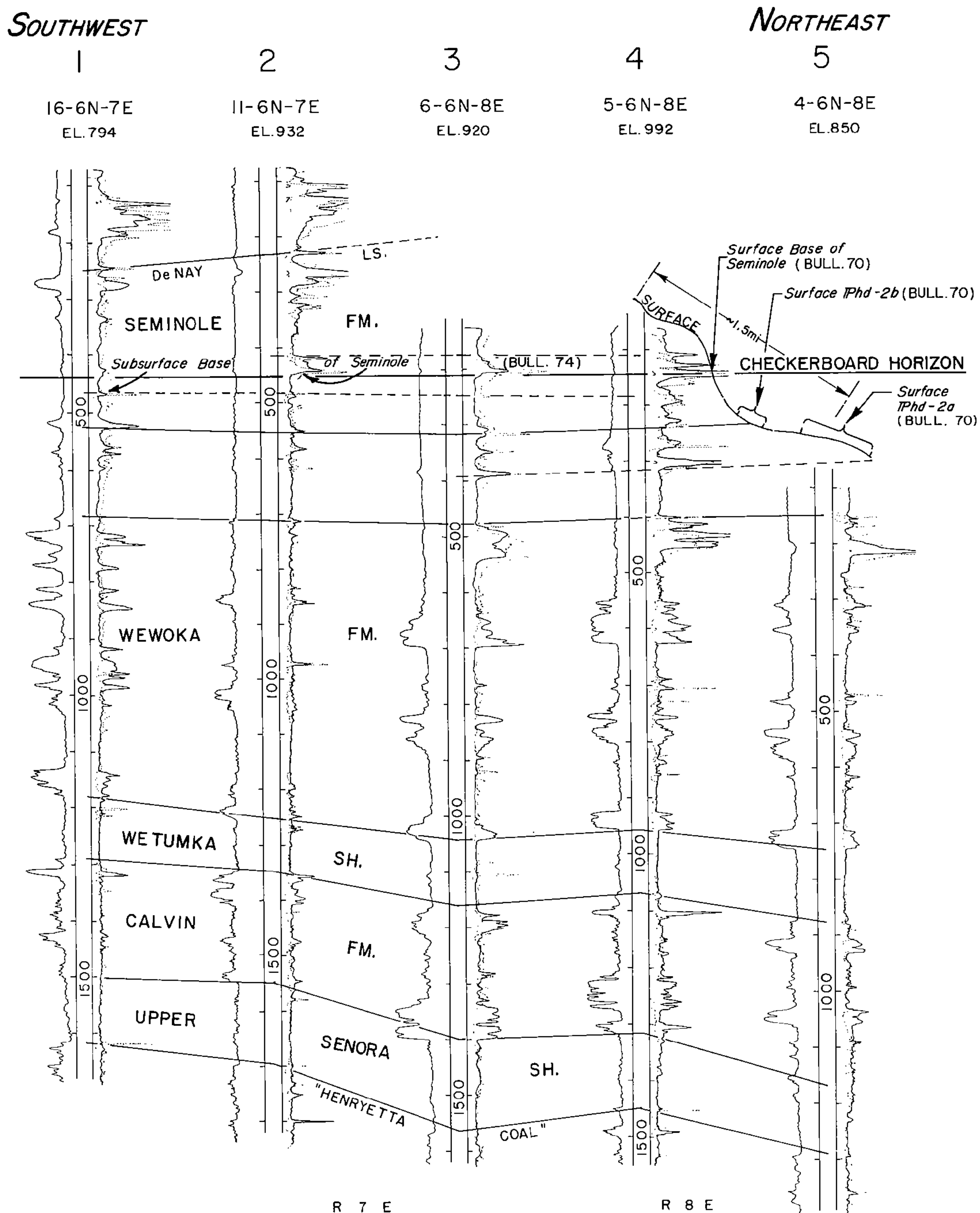


Figure 20. West-east electric-log cross section in Seminole and Hughes Counties, east-central Oklahoma, tying Checkerboard Limestone horizon in subsurface to basal Seminole sandstone on outcrop, as shown by geologic map of Hughes County (Weaver, 1954, pl. 1).



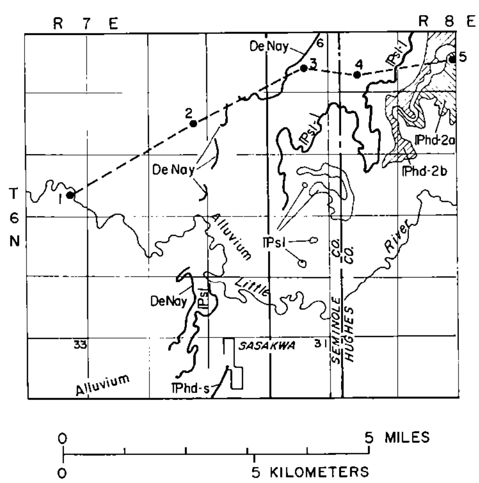


Figure 21. Southwest-northeast electric-log cross section in Seminole and Hughes Counties, east-central Oklahoma, correlating Checkerboard Limestone horizon in subsurface with base of Seminole Formation on outcrop at type locality. (Well 1 is well 20 in figure 10.)

Tanner's observations are verified by electric-log cross sections in the shallow subsurface (fig. 10). The Sasakwa clearly lies at the level of Taff's Seminole conglomerate. Other, younger Seminole conglomeratic sandstones overlie the Sasakwa south of Little River, and conglomeratic sandstones also underlie it in the Holdenville Shale. The Sasakwa represents a temporary period of limestone deposition soon followed by the deposition of a conglomeratic sandstone channel only a few miles to the north. The body of thick limestone lies in a band only a few miles wide extending west-southwest from the Sasakwa townsite. Taff's channel, the earliest in the Seminole, apparently scoured deeply enough that it lies at the level of the Sasakwa carbonate layer.

The upper boundary of the Seminole Formation is the DeNay Limestone, where present. Like the Sasakwa, the DeNay vanishes not far north of Little River. This limit grants the Seminole a thickness of about 150 feet in the type locality. The DeNay, previously considered to be the approximate equivalent of the Checkerboard, actually lies midway in the Coffeyville Formation, which on the platform extends upward from the Checkerboard to the Hogshooter Limestone. It is the Sasakwa Limestone that is the approximate equivalent of the Checkerboard, not the DeNay.

The Seminole, therefore, composes about half the Coffeyville section in Seminole County; the lower Seminole sands extend only about 20 miles into the subsurface, and they contain no conglomeratic lenses north of Holdenville (Weaver, 1954, p. 76). The zone contains appreciably less sand north of Hughes County and is composed mostly of shale over the platform. Although the description of the "Seminole conglomerate" by Taff is one of the oldest designations in the State, predating the first use of the name Coffeyville by several years, the Seminole sands are so localized that they should not affect the well-established terminology of the platform. The writer suggests that the unit be designated the Seminole Member of the Coffeyville Formation.

Redefinitions in Nomenclature

The establishment of corrected correlations makes advisable some redefinitions in stratigraphic nomenclature, if an integrated nomenclature of the basin and the platform is to be achieved. While considerable leeway is allowed by the Stratigraphic Code, the following adjustments are preferred by the writer because of their compatibility with current usage and the other reasons given below.

The Prue sand zone has heretofore been designated as the topmost unit in the Senora Formation of the Cabaniss Group. The Calvin Sandstone has heretofore been considered to be the basal member of the Marmaton Group in the basin. Since they are lateral equivalents, the Prue and the Calvin should be placed in the same group. The definition of the Marmaton is older than that of the Cabaniss, and its established limits should take precedence. The Calvin Sandstone, therefore, should be assigned to the Cabaniss Group.

Similarly, the Prue and the Calvin must either both be part of the Senora Formation or neither be part of it. Since the definition of the Senora (Taff, 1901) is older, the Prue as well as the Calvin should be excluded from the Senora Formation.

The Prue zone and the Calvin are underlain respectively by the Verdigris Limestone and the upper Senora shale. The Henryetta coal horizon lies slightly below the Verdigris level and directly below the shale. The Verdigris and the upper Senora shale then are approximate equivalents. Since the upper Senora shale was early designated to be the topmost member of the Senora Formation (Taff, 1901), the Verdigris should be considered to be the uppermost member of the Senora on the platform.

In the proposed classification, the Calvin–Prue zone is part of the Cabaniss Group but not part of the Senora Formation. The term Calvin was applied to the zone before any other (Taff, 1901), and the name could appropriately be extended to the platform to include the Prue section. The term Calvin Formation should be used because, although there is much sandstone in the interval, it is composed principally of shale and silty shale.

Removal of the Calvin Formation from the Marmaton Group leaves the Cabaniss–Marmaton contact undefined in the basin. The Wetumka Shale correlates with the lower Oswego, and it could quite logically be considered to be the basal formation of the Marmaton in the basin. The limestone that appears to cap the Calvin along the margin of the basin seems to be a basal Oswego stratum and should be included in the Wetumka.

How far south the Breezy Hill Limestone extends is uncertain (electric logs are discontinuous samplings, and the outcrop has a wide gap at the Arkansas). In any case, the stratigraphic column would be much simpler if the Breezy Hill and the few feet of Excello Shale above it were assigned to the Fort Scott Formation. As previously noted, they clearly belong to the Marmaton limestone province genetically. The Breezy Hill has always been included with the Fort Scott strata in the subsurface.

As a bonus, the above redefinition of the Fort Scott would eliminate from every paper dealing with the Oswego the one or two paragraphs that are now required to explain the difference in surface and subsurface usage.

To consider again the Holdenville equivalents on the platform, the correlation of the Seminole with strata above the Checkerboard Limestone alters the possible choices of stratigraphic nomenclature that can be applied to the section between the Oologah and the Checkerboard. As noted earlier, a dual classification system is useful in solving stratigraphic problems. When the character and structural attitude of rock units are important, as in the location of traps for oil and gas, a division into stratigraphic units based on physical criteria is necessary. On the other hand, when solving problems of paleogeography and paleoenvironment, for whatever purpose, the geologist must attempt a time–stratigraphic subdivision.

In stable areas, the two frameworks generally coincide over great distances, and the existence of a dual system can be safely ignored. In the present case, time–stratigraphic considerations have strongly influenced the choice of boundaries for the rock–stratigraphic framework. All of the references to the equivalence of strata in this paper have meant time-equivalence, and, indeed, the table of stratigraphic nomenclature for eastern Oklahoma in use for the last few decades was constructed on what were believed to be time-equivalent horizons. Such a procedure is acceptable both in practice and under the code, provided, of course, that the formations and groups so designated meet the general requirements of these units in the code. The bounding time planes naturally must be correctly traced and readily determinable over most of the area.

Figure 22 shows schematically the stratigraphic profile of figure 10. The formations shown belong in the rock-unit system of classification. On the platform the Marmaton Group has previously been defined, because of a supposed unconformity, to include shales directly above the Lenapah Limestone, because they were believed to represent the Holdenville Shale (Oakes, 1952). When the Marmaton was extended to the basin, the Holdenville became the only formation common to the group in the two provinces. According to the stratigraphic code, the component formations of a group need not everywhere be the same (American Commission on Stratigraphic Nomenclature, 1961), and such an extension would have been quite acceptable if the correlations had been made correctly.

The Marmaton Group was defined in the basin in the belief that the top of the Holdenville Shale was the base of the Cleveland sand zone on the southern platform, as it is the base of the Seminole sand zone in the basin. It was believed that this contact was unconformable and that it marked the top of the Desmoinesian Series and the base of the Missourian Series. The usage of time–stratigraphic units with rock–stratigraphic units is contrary to the code, which requires the term supergroup to be applied to assemblages of groups, but even so this imposition of time–stratigraphic terms on a rock–stratigraphic base would be acceptable if such an unconformity were actually

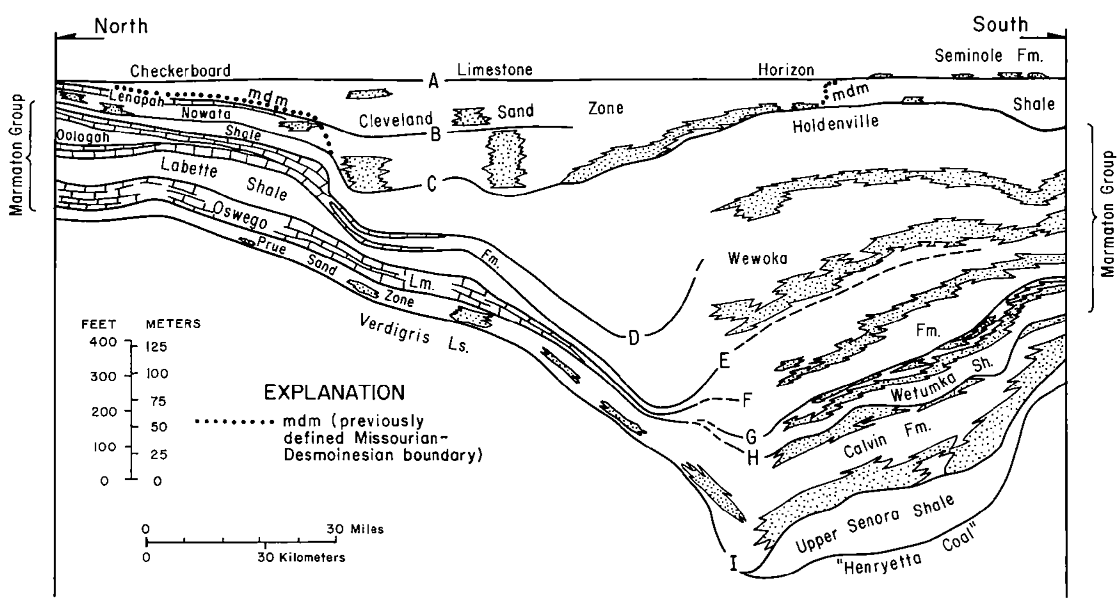


Figure 22. North-south stratigraphic profile based on electric-log cross section shown in figure 10.

present. Since there seems to be no unconformity, the previous stratigraphic division is awkward because it does not fit the actual strata.

Until time markers are traced into Oklahoma from the type areas, the choice of a plane to represent the Desmoinesian–Missourian boundary must rest solely on paleontological evidence. The type area of the Desmoinesian is a little-studied section along the Des Moines River in Iowa (Branson, 1962, p. 439), and the type area of the Missourian is a sequence of strata in northwestern Missouri (Moore, 1949, p. 66). Since no paleontological evidence was gathered in the present study, the writer cannot comment on the merits of any particular plane as the inter-series boundary from the viewpoint of the fossil record. On the other hand, the code acknowledges that "in actual practice, the geographic extension of a time–stratigraphic unit is influenced and generally controlled by stratigraphic features," and many rock–stratigraphic classifications are similarly colored with time considerations because of the natural layering of the strata during deposition.

Several levels that the writer considers to represent approximate time planes are represented by lines on figure 22. The choice of these horizons was based on the writer's interpretation of various sedimentary and paleogeographic criteria. Some of the time lines follow formation boundaries, and some do not. Time line *C*, at or near the base of the Cleveland sands, is only slightly different from the Missourian–Desmoinesian boundary as presently accepted (line *mdm*). The writer recognizes that the base of channel sands lies at lower levels than contemporaneous muds, owing to scouring and settling. The cross section is only schematic, however, and exact positioning of the time line is not intended. Owing to previous miscorrelations, two significant deviations between the lines appear in the cross section. North of the Owasso channel, line *mdm* follows a supposed unconformity above the Lenapah Limestone. South of the North Canadian River (at the outcrop), line *mdm* follows the contact between the Holdenville Shale and the Seminole Formation.

The writer proposes simplifying the nomenclature by assigning to the Holdenville Formation all strata between the Checkerboard and the top of the Oologah and Wewoka Formations. (The Oologah–Wewoka top has already been suggested as the top of the Marmaton Group.) The Holdenville would then contain as members the Cleveland sands, the Nowata Shale, and the Lenapah Limestone.

In the area between the Oologah front and the Wewoka sandstones, the topmost Oologah marker would serve adequately as the top of the Marmaton. The shales south of the Oologah and Oswego could be appropriately assigned to the Wewoka Formation, since they were mostly deposited as Wewoka prodelta muds.

The writer also proposes that the top of the Oologah–Wewoka be designated the top of the Desmoinesian Series. Until paleontologic evidence is more firm, or until the Missourian–Desmoinesian contact is directly traced to Oklahoma, any boundary chosen will be arbitrary. No unconformity is present, and no other potential horizon below the Checkerboard is sufficiently continuous to serve well as the boundary. The top of the Oologah–Wewoka is near the currently accepted boundary, and the top of the Oologah is already generally accepted as the top of the Marmaton in the subsurface in both Oklahoma and Kansas.

At the outcrop in Kansas and northeastern Oklahoma, the base of the Missourian has been previously placed at an admittedly ill-defined horizon in the short interval of shale between the Checkerboard and the Lenapah. The shales above this level have been assigned to the Seminole, and those below to the Holdenville. In Kansas, the Seminole is presently divided into the South Mound Shale Member above and the Hepler Sandstone Member below. Since it is now known that the Seminole lies above the Checkerboard rather than below it, the name Seminole should be dropped from use in northeastern Oklahoma and Kansas. The writer's proposal would mean that all strata between the Oologah and the Checkerboard would belong to the Holdenville Formation and that the Lenapah Limestone and the underlying Nowata Shale would be reduced to member status.

The Holdenville Formation could then become the basal unit of the Pleasanton Group in Kansas. The Holdenville would be composed of beds now attributed to the Seminole Formation and the present Holdenville Formation, only 9.8 feet and 13.7 feet thick, respectively, in the SE¼SW¼ sec. 2, T. 33 S., R. 18 E., Labette County, Kansas (Jewett and others, 1965), plus the Lenapah Limestone and the Nowata Shale, if the suggestions of the writer are followed. (All these beds were, in fact, assigned to the Pleasanton in the KGS cross sections of 1956.)

In passing, it should also be noted that the subsurface designations of the base of the Seminole in the electric-log cross section for Hughes County (Weaver, 1954, pl. 2) and in those for Seminole County (Tanner, 1956a), except for a few logs near the outcrop in cross section *A*-*A*′, should be raised 80 feet or so from the level of the surface IPhd-2c to the true base of the Seminole zone.

In summation, the following important points can be made regarding the Holdenville Shale, the Cleveland zone, and the Checkerboard–Seminole horizon:

1. The "subsurface Checkerboard" of OGS Bulletins 70 (Hughes County, Weaver, 1954), 71 (Okfuskee County, Ries, 1954), and 74 (Semi-

nole County, Tanner, 1956a) is the true Checkerboard of the type locality.

2. The miscorrelation of the surface Checkerboard across Okfuskee County took place in two steps. The first occurred at Deep Fork, where the surface "Checkerboard" chosen actually lies some 100 feet above the true Checkerboard. The true Checkerboard horizon is mapped as IPsl-1c. The bed marked as the Checkerboard on the electric-log cross section is yet another limy layer 170 feet above the true Checkerboard. The surface "Checkerboard" was not mapped south of Okemah, although in fact the true Checkerboard zone does continue southward and is clearly identifiable in the subsurface. A second miscorrelation occurred at the North Canadian River, where the base of the Seminole Formation is correctly designated at the outcrop south of the river but is incorrectly marked as being at the base of the Cleveland zone outcrop north of the river.
3. The Cleveland sands, which lie below the Checkerboard, and the Seminole sands, which lie above the Checkerboard, are not equivalent strata. The Lenapah Limestone is interstratified with beds of the middle Cleveland zone. It does not fit comfortably in the Marmaton Group in Oklahoma. Precise determination of the Desmoinesian–Missourian Series boundary in the sequence cannot be accomplished from evidence available to the writer, but an adjustment to reflect correlations now apparent would yield significant practical advantages. In the absence of an unconformity in the strata, the writer recommends placing the boundary at the top of the Oologah–Wewoka and placing all the strata between this boundary and the Checkerboard in the Holdenville Formation.

ENVIRONMENTS OF DEPOSITION

Review of Previous Investigations

Geologists attempt to infer the environments of deposition of sedimentary rocks not only as a matter of scientific interest but also in the hope that they will be better able to predict the occurrence and extent of some of the beds, generally those containing mineral deposits. The rocks of eastern Oklahoma have attracted much study and speculation because of the deposits of coal and oil and gas found here, particularly in the Pennsylvanian strata. Oakes, in an OGS bulletin for Okmulgee County (1963, p. 17–20), summarized the depositional history of these rocks as accepted by most of the geologists who had studied eastern Oklahoma for the previous half-century.

This region consists of two areas; the northern and western area, usually called the shelf, or platform, area, and the southeastern area, usually called the Ouachita geosynclinal area.

Sedimentary rocks present on the shelf and in the geosynclinal area range in age from Cambrian to Pennsylvanian, inclusive. Limestones are conspicuous among the rocks on the shelf; the clastics are shales, siltstones, and fine-grained sandstones. The many unconformities indicate repeated withdrawal of the sea, erosion, and repeated submergence. Many of the rocks, particularly of the Pennsylvanian, are cyclic.

In contrast, the rocks of the geosynclinal area are mostly clastic; nearly all units thicken remarkably southeastward. The evidence indicates that the source of clastic sediments in the geosynclinal area and of much of the clastic sediments on the shelf was an ancient land mass somewhere to the southeast, now buried beneath Cretaceous and younger rocks. However, some of the clastics on the shelf seem to have come from the east, others from the north, and some even from the west. Many of the sandstones in the geosynclinal area thin out and disappear northward before they reach the shelf area, but some clastic units extend from the geosynclinal area northward over the shelf area with great thinning, convergence of beds, and gradual change of facies; they thus indicate that the shelf area was changing but little with respect to the level of the sea at the time when the geosynclinal area was sinking and being filled continuously or intermittently. It is probable that the geosyncline was so well filled with clastic sediments much of the time that the water was shallower over the geosynclinal area than over the shelf area. Furthermore, coal beds of Pennsylvanian age that extend over part of the shelf area and are still preserved from erosion in the north end of the geosynclinal area indicate that at times swamps extended over parts of both areas.

At the present time, Mississippian rocks crop out around the Ozark dome, except where they are covered by Quaternary sediments, and outliers of Mississippian rocks are so distributed over much of the Ozark dome as to indicate that much of the area of the dome was below sea level in at least part of Mississippian time. Also, outliers of probable Desmoinesian (Pennsylvanian) age are distributed over a considerable part of the Ozark dome, many being preserved in limestone sinkholes into which they have fallen; they indicate that probably as late as Desmoinesian time, and possibly later, the area of the Ozark dome was truly a part of the shelf area.

Rocks of the greater part of the Ouachita geosynclinal area have been much folded, and in Oklahoma they have been much faulted. These folded and faulted rocks now form the Ouachita Mountains, the northern limit of which in Oklahoma is the Choctaw fault. The forces that formed the Ouachita Mountains were compressive, from the south and southeast, and most of the large faults are reverse faults, upthrown on the south side. The rocks in that part of the geosynclinal area north of the Choctaw fault have been squeezed between the Ouachita Mountains rocks and rocks of the more stable shelf area, and now lie in an east-west syncline, formerly called the McAlester coal basin or the Arkansas-Oklahoma coal basin, but now called the Arkoma basin (Branson, 1956, p. 83–86). . . .

The youngest rocks cut by the Choctaw fault are of Atokan age, but earlier uplift of considerable magnitude is indicated by chert pebbles near the base of the Atoka Formation on the southeast side of the Lehigh syncline in Atoka County, west of Stringtown (Taff, 1902, p. 5). It is not possible to date the end of major folding and faulting in the Ouachita Mountains more exactly than post-Atoka pre-Cretaceous. However, from a study of the structure of the rocks north of the mountains, in the Arkoma basin and on the shelf, the author suspects that much of the movement in the Ouachita Mountains and most of that on the Ozark dome were over before the Thurman Sandstone was deposited.

Rocks in the Arkoma basin and on the shelf west of the Ozark dome as young as the Boggy Formation are only less complexly folded and faulted than are rocks in the Ouachita Mountains. The character, distribution, and orientation of these folds and faults indicate that some are related to the compressive forces that made the Ouachita Mountains, and others to the more vertical forces that raised the eastern part of the shelf area to make the present Ozark dome. Some of these structures are discernible in the Thurman Sandstone and younger rocks but in these younger rocks the amplitude is smaller. One exception is the Ahloso fault in Pontotoc County, south of Ada. It cuts the Thurman Sandstone and has a throw of more than 2,000 feet, upthrown on the south side. It is probably associated with movement in the Arbuckle Mountains.

Chert pebbles in the Thurman Sandstone and younger formations seem to have come from the southeast and their presence indicates recurrent uplift in the Ouachita Mountains, but lack of evidence of pronounced movement in the Thurman and younger rocks indicates that these later stresses in the Ouachita Mountains were not transmitted northward across the Choctaw fault with any considerable strength.

The preceding summary follows the judgments of most students of Ouachita geology in placing the Ouachita orogeny at some time in the Middle or Late Pennsylvanian, but not all geologists have agreed.

Melton (1930) noted that a joint pattern affecting rocks in central Oklahoma through Garber time (Permian) seems to radiate as if caused by compressive forces from the southeast. The Ouachita orogeny may therefore have begun in late Permian or post-Permian time. Melton postulated that the chert conglomerates of eastern Oklahoma came from the eastern end of the Arbuckle Uplift, which rose earlier than the western end and is now buried under thrust faults of the Ouachita movements.

Several authors have agreed with Melton. Tanner (1956a) believed that the Ouachitas were uplifted in Permian time and invoked a southern, Arbuckle source for the upper Pennsylvanian rocks of Seminole County. Barrett (1963, p. 28) likewise placed the orogeny in mid-Permian time.

Nevertheless, a Pennsylvanian date continues to be supported by most geologists. In a short article entitled "Chert River," Oakes (1948) reasserted his observation that the chert conglomerates are thickest and the pebbles are largest along a line between Stringtown, north of Atoka, and Tinker Air Force Base, near Oklahoma City. The size of the pebbles becomes smaller to the south as well as to the north of this line, and an Arbuckle source is highly unlikely.

Tomlinson and McBee (1959, p. 40), in a study of the Pennsylvanian of the Ardmore district, proposed a Ouachita source for clastics of the Ardmore Basin as well as for those of the McAlester Basin. They noted that chert pebbles of the Devil's Kitchen conglomeratic sandstone and the Rocky Point conglomerate (both Desmoinesian) diminish in size northward toward the Arbuckle Mountains but increase in size to the southeast in the direction of the Ouachita overthrust. Both the present Arbuckle Mountains and an eastward extension seem to be excluded from consideration as sources.

The case for a Pennsylvanian date for the orogeny is considerably strengthened by studies of the Fort Worth Basin of north-central Texas. Brown (1969), Wermund and Jenkins (1970), and Erxleben (1975) show delta systems in Missourian and Virgilian strata that were built northwestward from the central Texas section of the Ouachita fold belt. As in Oklahoma, the sediments contain beds of chert conglomerate. The chert pebbles, which appear at many levels in the Middle and Upper Pennsylvanian beds of southeastern Oklahoma, must have been derived from some of the Ouachita silicates, perhaps the Bigfork Chert of Ordovician age or the Arkansas Novaculite of the Devonian.

The issue is still not completely resolved, as Jordan acknowledged in one of the latest summaries of the geology of Oklahoma (1967, p. 224):

> The time of folding of the great Ouachita fold belt cannot be precisely determined, but it is believed by some to have taken place in Oklahoma near the end of Atoka time. The Ouachita orogeny intensely compressed the Ouachita geosyncline, raising the Ouachita Mountains into high relief so that great wedges of chert conglomerates, sands, and deltaic sediments extended northwestward into the Ardmore basin. Later pulses possibly extended into Permian time.

As for the platform sediments, a northern source for the Cherokee rocks has been generally presumed. Bass (1936) constructed a neritic model dominated by offshore bars to explain the Cherokee "shoestring" sands of southeastern Kansas. Weirich (1953) observed that Cherokee sediments were also carried across the platform rim into the basin.

Beginning with the publication of a study of the Booch delta (Busch, 1953), the stratigraphic history of eastern Oklahoma has steadily become more clear. Busch's study, probably the first detailed report describing an ancient delta system, showed that the principal Booch sands compose a classic constructional delta with a northern source (fig. 23). The Booch, which is the oldest sandstone of the Cherokee sequence, is confined to the basin and the southeastern part of the platform.

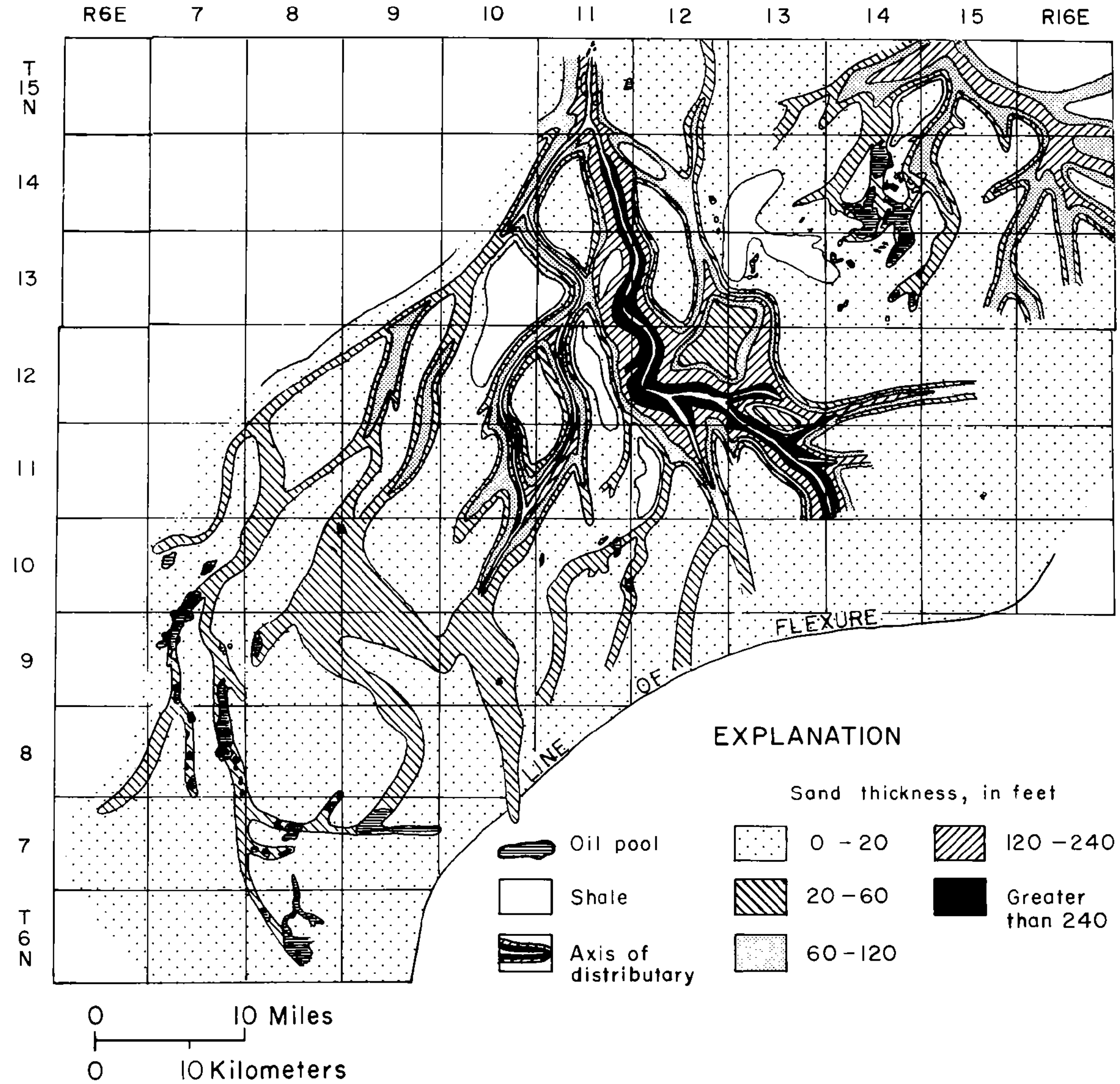


Figure 23. Isopach map of Booch sandstone delta in east-central Oklahoma. From Busch (1961).

The Bluejacket (Bartlesville) sandstones succeed the Booch sediments on the platform. They cover a much larger area, extending from the Cherokee Basin of Kansas across the eastern half of the platform to their outcrop north of the Choctaw Fault. Studies of these sediments by Visher (1968) show that they also compose a large delta system constructed by southward-flowing streams (fig. 24).

While the succeeding beds of the Cherokee sequence have not been studied in such detail, the patterns on sand isolith maps indicate that the basin sediments of later Cherokee age came from the south and southeast, whereas the Red Fork, Skinner, and Prue sands of the platform had a northern source (Dogan, 1970; Visher and others, 1971; Valderrama, 1974). The upper Cherokee sands of the platform are more angular and contain more mica than the lower Cherokee sands, indicating that "by the middle of Pennsylvanian time, the sedimentary cover of the cratonic source area had been removed and the underlying schists

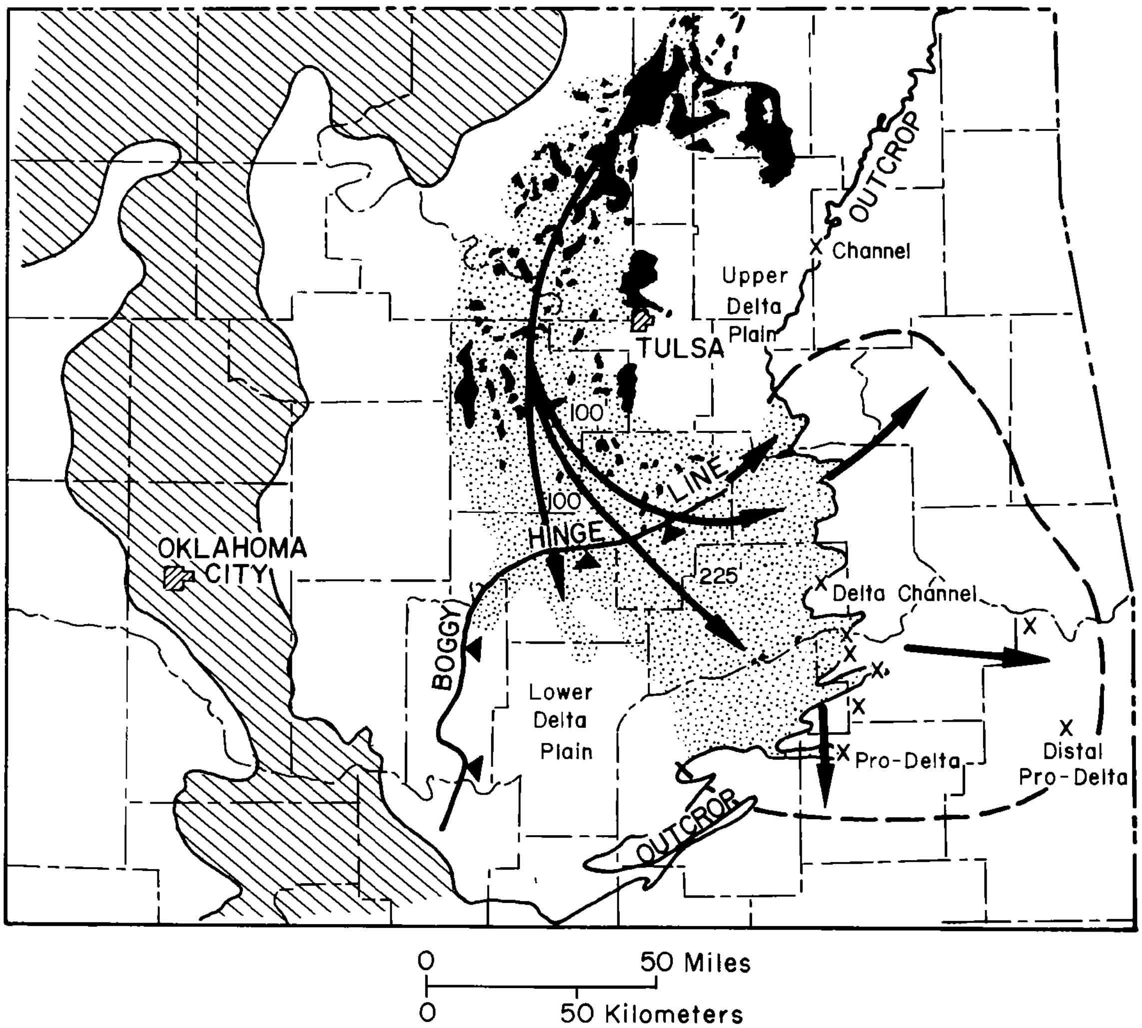


Figure 24. Map showing Bartlesville sandstone distributary system in eastern Oklahoma. Area on west with diagonal lines represents landmass consisting of Mississippian and older units during Bartlesville time. From Visher (1968, fig. 1), adapted from Weirich (1953, fig. 5).

and phyllites became the sources of the sediments" (Wanless, 1957, p. 89).

In studies of younger rocks, however, a southeastern or an eastern source is presupposed by most writers for Upper Pennsylvanian sediments on the platform. Tanner (1956b), Tomlinson and McBee (1959), and Calvin (1965), among others, show essentially northeast-southwest shorelines along the east side of the platform in presenting the paleogeography of the upper Pennsylvanian.

The overall relationships have been slowly developed, and it is now evident that the Marmaton limestones mark the stratigraphic level at which the change in source direction occurred. The Oswego and Oologah limestones could form only when the northern source failed to supply clastics to the platform and before the distributaries draining the Ouachitas washed enough sediments northward to drown the platform in mud.

The Ouachita Uplift dominated platform sedimentation for the rest of the Pennsylvanian and apparently for much of the Permian as well. The encroachment of clastics onto the shelf forced the carbonate province to retreat into Kansas, where the Kansas City–Lansing limestone sequence was deposited contemporaneously with the sand–shale wedge to the south, just as the Marmaton limestones had earlier faced the Wewoka clastic wedge in mid-Oklahoma.

Distribution of Prue and Calvin Sands

The first step in demonstrating the above sequence of events is a study of the sands that immediately preceded the Marmaton, that is, the Prue of the platform and the Calvin of the basin. With this in mind, electric logs covering the east ranges of Oklahoma were examined, and isopach maps of the Prue and the Calvin sands were prepared. The Prue was mapped as one zone, and even though the sands do not all appear at the same levels, no serious confusion resulted, the sediments apparently composing only one genetic increment of strata.

Certain criteria were necessary in preparing the isopach maps. In some of the Prue sand areas particularly, it was necessary to decide rather arbitrarily where the sand content of a zone was great enough that it should be mapped as sand. In most cases, only sand zones having a Self Potential (SP) of 50 millivolts in fresh-water muds were included, and some of these zones were reduced in thickness in rough proportion to their presumed shale content.

On the other hand, in those cases where a microlog was run, and it indicated that the zone possessed permeability, or if a drill-stem test showed fluid recovery, zones of less than 50 millivolts of SP were considered to be sand.

No attempt was made to separate the lower Calvin into separate zones in order to define individual channels, since such a detailed separation was not needed for this study.

The areas near the outcrop were not mapped. Fewer electric logs are available near the outcrop, although thousands of wells were drilled there in the first half of the century. Most of these wells were drilled with cable tools, where electric logs are not run, and many of the wells drilled with rotary tools were completed before electric logging was introduced in the late 1930's. Isopach maps can be prepared from cable-tool well records, but the work is much more tedious and the results more tentative, because the formation records are frequently unreliable.

Even where electric logs are available, they are not always helpful because the uppermost beds are shielded by the surface casing, and, furthermore, fresh or brackish water below the surface casing frequently renders the signal untrustworthy.

Figure 25 is an isopach map of the Prue sand zone and the Calvin Formation. Basin strata are much thicker than platform strata. A band of maximum thickness runs southwestward from central Okfuskee County.

Isopach of Prue and Calvin Sands

The Calvin zone, like most of the basin equivalents, is thicker than the Prue zone. Two distinct sand zones are present in the Calvin, the lower being the thicker and more extensive. The thicknesses of the Prue sand and the lower Calvin sand are shown in figure 26. Along the basin margin northeast of Shawnee, the Calvin and Prue intermingle; individual beds and sand bodies are difficult to distinguish. Precise relationships are uncertain, but the paleoenvironmental pattern seems definitive even so.

Figure 26 shows Prue sand bodies as thick as 100 feet, appearing as two networks of channel sands, each a pronounced constructional delta complex. High SP values indicate that the sand is low in shale content, as would be expected in a high-energy channel environment. Furthermore, the SP and resistivity curves on the electric logs generally show a shape characteristic of channel sands (Visher, 1969). Channel sands are generally cleanest at the base, where fine particles cannot settle because of turbulence. Beach and bar sands are generally cleanest at the top because wave action winnows the fines, which can only come to rest in quieter, deeper water. The electric-log pattern of a beach or bar sand, therefore, is usually funnel-shaped, whereas the pattern for channel sands is usually the reverse, somewhat in the shape of a bell.

The two separate delta systems seem to overlap in the vicinity of Pawnee, although it is possible that they are interrelated and that one feeds into the other. A third delta system probably exists in the Tulsa area, where thick sands are known to be present, but the electric-log network is not sufficiently dense for accurate mapping.

In Creek County, in the eastern parts of Payne and Lincoln Counties, and in northern Okfuskee County, discrete bodies of sand appear that do not resemble the other Prue sands. Their shape and pattern suggest that they are marine bars built of sand swept from the delta to the west. The bars are oriented roughly perpendicular to the delta channels. Their characteristic log shape is funnel-shaped. The top part of each sand body is generally the cleanest, although the sands are notably shaly throughout and contain much mica in the form of flakes parallel to sedimentation laminae. The bars commonly contain oil or gas, commonly with little free water in the reservoir. They generally have low permeability; many wells would not have produced commercially without heavy shots of nitroglycerin or sand-fracture treatments. These properties indicate energy lower than expected in channel or beach environments but appropriate in marine bars. At least two of the bars bifurcate eastward, the West Peck bar, along the south line of T. 14 N., R. 6 E., and the West Arno bar to the east in R. 7 E.

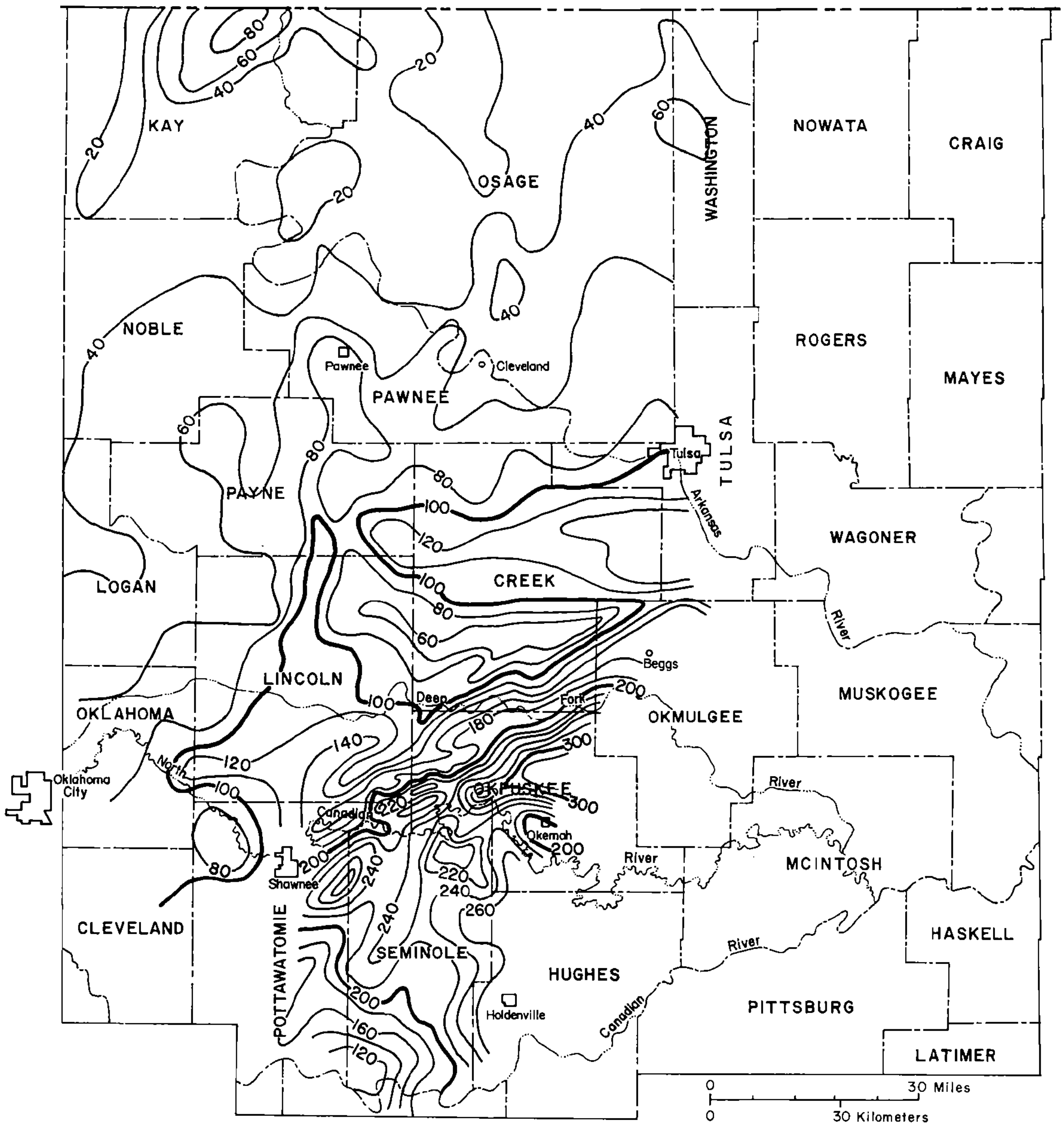


Figure 25. Isopach map of Prue-Calvin zone in eastern Oklahoma; isopach interval, 20 feet.

The origin of the Prue sands in the Oklahoma City area (not mapped) is uncertain. Some Prue sand bodies there are reported to be as thick as 40 feet. It is possible but unlikely that the sands have a source to the southwest. The Nemaha Ridge, completely buried by this time, would have presented no obstacle to sedimentation from either direction. On the other hand, the Anadarko Basin would have protected the area from southern sediments. Sands are present in the Deese Formation of the Pauls Valley area at this approximate horizon, but the writer knows of no suggestion in the literature that they are genetically connected with the Prue sands of the Oklahoma City area. A more likely explanation is that the Oklahoma City sands were deposited by a channel breaking out

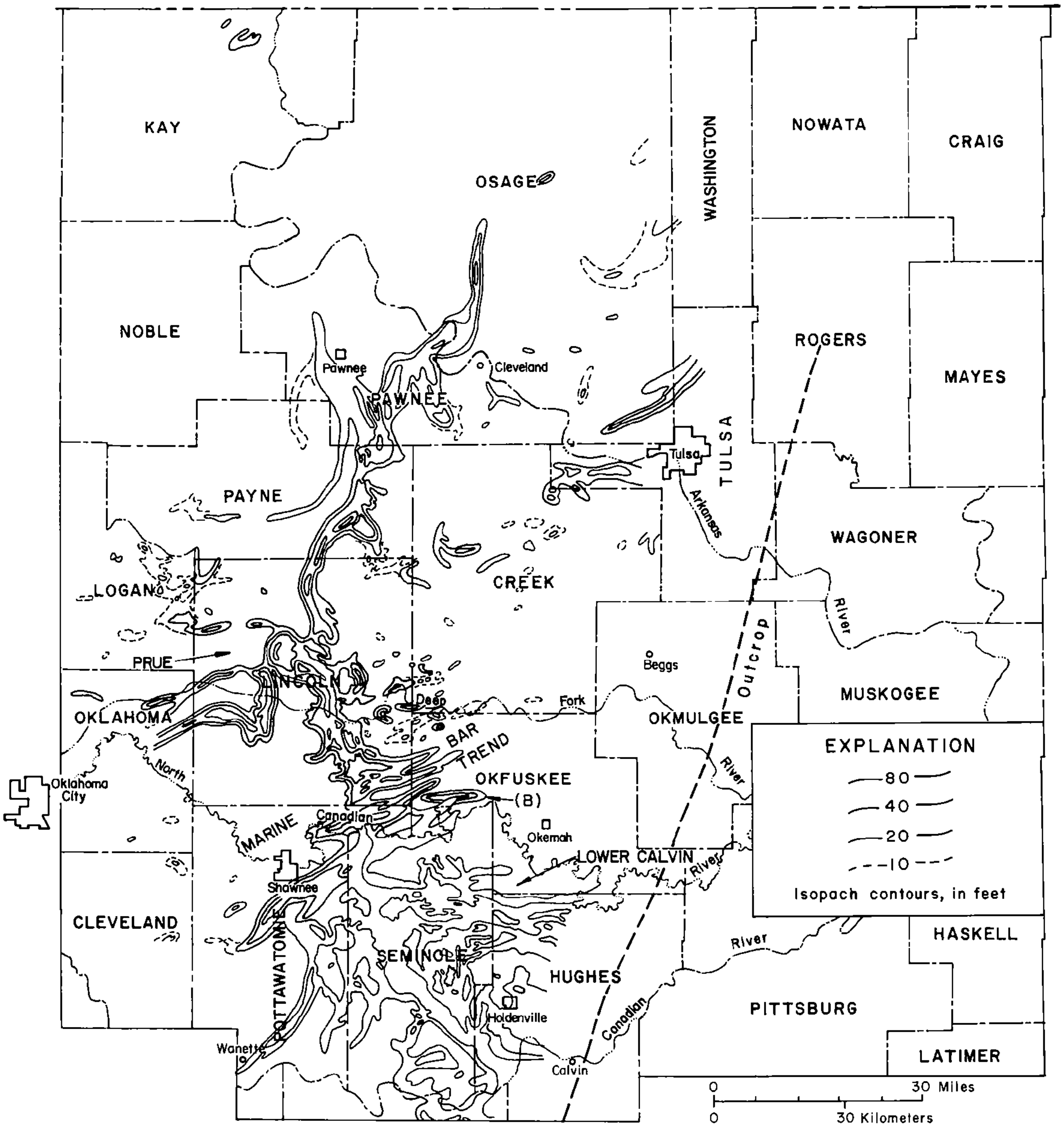


Figure 26. Isopach map of Prue sandstone and lower Calvin sandstone in eastern Oklahoma.

from the main Prue delta toward deeper waters at the eastern end of the Anadarko Basin.

In southeastern Lincoln County, a different sort of marine-bar complex appears. Large sand bodies directly connected to the Prue distributary bodies but almost perpendicular to them appear to have been formed as a distributary-mouth-bar complex at the end of the channels (Coleman and Gagliano, 1965). These bars extend farther eastward than westward, supporting the inference drawn from the bars in Creek County that the longshore currents principally flowed eastward.

One of these presumed marine bars lies at an angle to the rest of the complex. This bar, marked *B* on figure 26, lies at the base of the unit. It is overlain by sands of the main system and must be shown separately. Presumably, it represents the initial discharge of sand into the sea, at which time the current direction was slightly different.

With regard to oil and gas in the Prue, it is noteworthy that most of the hydrocarbons were trapped north of the marine-bar trend of southeastern Lincoln County. The distributary channels contain mostly salt water, but highly productive reservoirs have been found in them, notably the Norfolk, Davenport, and East Sparks Pools. The smaller marine bars of Lincoln, Creek, and Okfuskee Counties possess a higher oil–water ratio, but the sands are less porous and less productive. Of these bars, those nearer the basin generally contain less oil. The large marine bars of the bar trend contain very little oil or gas. Total production from the Prue, which is not one of the major producing sands on the platform, probably approaches 100 million barrels to date.

Calvin Sands

The Calvin sands do not display the classic delta shape. In the lower Calvin there are two broad bands of sand trending northwestward toward the area of the large transverse sand bodies that lie south of the Prue delta. The bands crop out in Hughes County, one east of Wetumka and one at Calvin. The bands do not bifurcate in the classic pattern; rather they merge as they approach the transverse sand bodies. Nevertheless, the lower Calvin has the appearance of two principal distributary networks emptying into a marine-bar trend lying between the Calvin distributaries and the large Prue delta.

The narrow sand body entering the Calvin sand complex from the southwest in southern Pottawatomie County appears to have been deposited by a distributary carrying sand from a source in the Pauls Valley area and beyond, although it could also have been a bar formed by longshore currents flowing southwestward from the main sand mass. The two smaller, narrow sand bodies to the east, 6 and 12 miles respectively, were probably formed in the same manner as the larger one.

In analyzing the pattern of the Calvin sands, it must be remembered that there are many varieties of delta shapes. Deltas can be conveniently divided into constructional, intermediate, and destructional deltas, depending on the balance between constructional factors (strong, heavily laden distributary currents feeding a subsiding shelf) and destructional factors (tidal currents, longshore currents and storms). Constructional deltas are built out into the sea; sands of destructional deltas are generally spread along the shoreline, principally in the direction of the prevailing currents. The interplay of the various factors results in a host of intermediate types (Scott and Fisher, 1969).

Currents in the sea are a crucial factor in delta shape. Even though the Prue–Calvin sea was a relatively narrow body of water, at most a few hundred miles wide, it could have been affected by tidal currents. It was surely open to the Anadarko Basin to the west, and a considerable reach of water was open for the generation of currents. How far east the sea extended is a matter of conjecture. No middle or later Pennsylvanian beds remain to the east or northeast closer than Illinois and Kentucky. Even though the Ozarks traditionally have been considered to have been a positive area since the Mississippian, there is indirect evidence that the Middle Pennsylvanian sea was an elongated, shallow epeiric sea continuous at least from Colorado to the central Appalachians (Oakes, 1963, p. 18; Wanless and others, 1970; Donaldson, 1974).

The marine currents that carried the sands away from the distributary channels flowed mostly eastward. The large bars between the Calvin and Prue distributary systems are parallel to the smaller bars on the shelf to the north.

The upper Calvin sand pattern also suggests a channel system fed from the southeast (fig. 27). The sand bodies are thinner and less extensive than those of the lower Calvin.

Study of Outcrop

Fortunately, both the Prue and the Calvin can be studied in the outcrop. The Prue outcrop in sec. 7, T. 19 N., R. 15 E., south of Catoosa, is a channel sand containing strong planar crossbeds sloping southward (fig. 28). The direction of the channel at Catoosa parallels the trend of the distributary channels of the Prue deltas to the west. The presence of the Iron Post coal only a few feet above the channel suggests that the sands were nearshore deposits. Coal swamps frequently blanket an abandoned delta, because the delta surface serves as a broad, poorly drained, fresh-water platform (Wanless and others, 1963, p. 448).

The lower Calvin outcrop at Wetumka was examined without finding definitive directional features or environmental indicators. The outcrop at Calvin, however, in T. 5 N., R. 10 E., shows crossbedding, festoons, clay chips, traces of wood, and sand-filled channels cut into shale.

The festoons and crossbeds were made by currents flowing west-northwest (fig. 29). The presence of clay chips, which are destroyed by repeated wave action, suggests deposition in a distributary channel (fig. 30). The several channels that are cut into shale west of Calvin are oriented west-northwest. At the base of one appears a sand mold of a log of undetermined species, about 6 inches in diameter and several feet long (fig. 31).

These surface indicators at Calvin strengthen the interpretation made from the isopach map that the lower Calvin sands were deposited by distributary channels flowing northwestward.

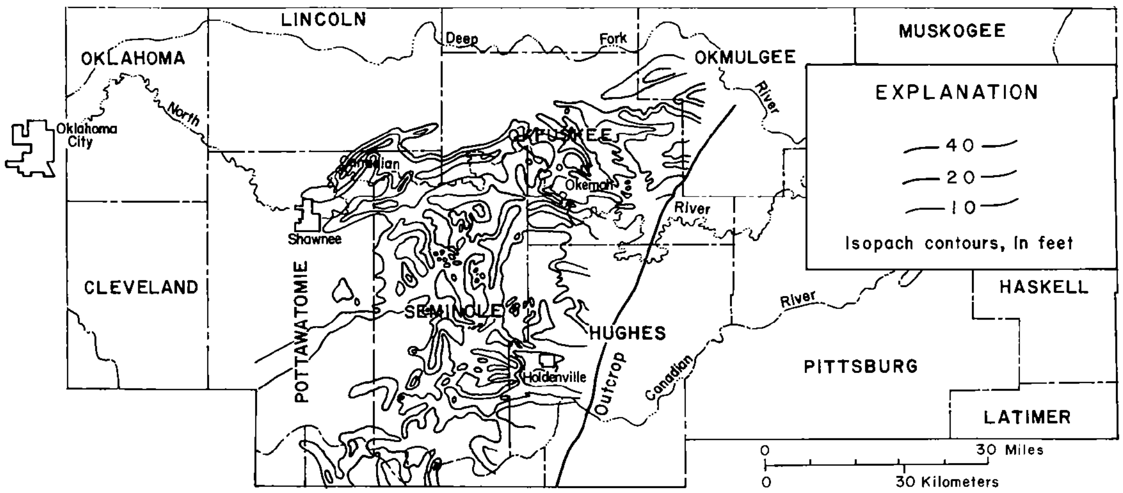


Figure 27. Isopach map of upper Calvin sandstone in east-central Oklahoma.

Figure 28. Crossbedding in Prue sandstone outcrop.

Figure 29. Crossbedding in Calvin sandstone outcrop.

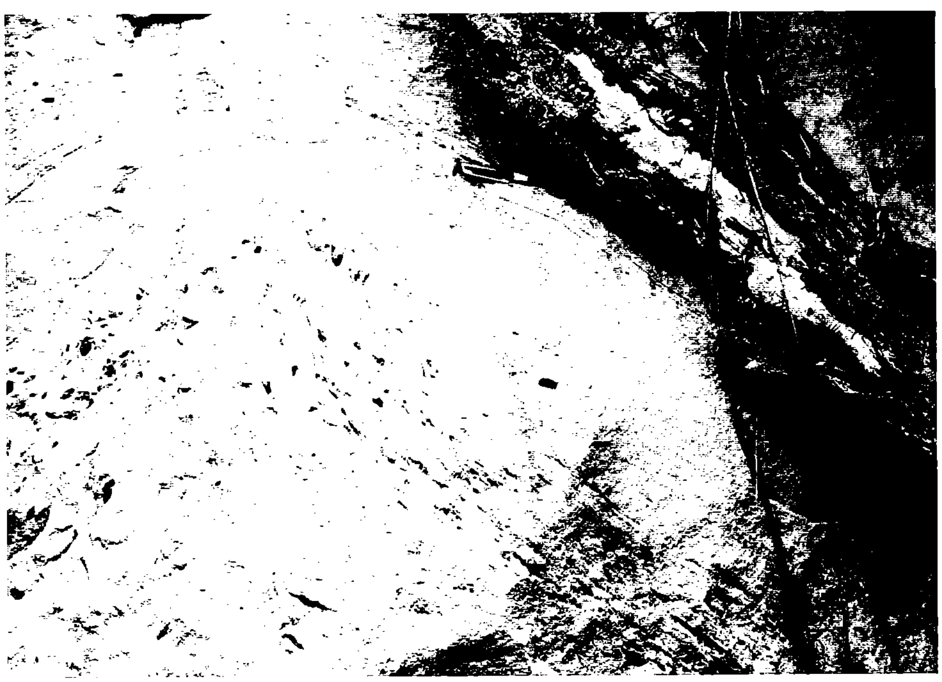


Figure 30. Clay chips in Calvin sandstone outcrop.

Figure 31. Mold of wood at base of channel in Calvin sandstone outcrop.

Distribution of Marmaton Group Formations

Isopach maps of the Oswego, Labette, and Oologah have already been shown in figures 6, 7, and 8. As can be seen by reference to the figures, the Marmaton Group limestones vary considerably in thickness. They are separated by layers of shale, also of varying thickness. The Oswego is notable for the porosity developed along the limestone front where the shelf presumably faced the deeper water of the McAlester Basin and the Anadarko Basin. Oil and gas have been produced from this porosity, particularly in a phylloid-algae section of the Putnam Trend of western Oklahoma, in the Kendrick Pool of Lincoln County, and in the Cushing Field of Creek County, where a well-developed oolitic facies caused the limestone to be called the Wheeler sand.

Cross sections across the fronts in the study area indicate a moderate slope ahead of the Oologah front on the order of a few tens of feet in less than a mile and a somewhat gentler break ahead of the Oswego front. The shales and the lime stringers south of the fronts would be expected to constitute a thinner section, having been starved of clastics and also deprived of a flourishing organic population.

North of the fronts, the Marmaton strata form an alternating sequence of limestone and shale in which the appearance of the Peru sandstone in the Labette Shale and of the Weiser sandstone in the Bandera Shale in the northeastern part of the platform is anomalous. Neither sand has wide distribution in Oklahoma. The source of these sands is uncertain, but it seems unlikely that they are Wewoka sands carried across an intervening province so dominated by carbonate sediments.

The Weiser sand in Oklahoma seems not to have been studied, but Cole (1967, p. 88) found evidences of channels in the Peru, which led him to believe that the Peru had a northern source.

Peru Sand and Sperry Trough

The distribution of the Peru sands seems to confirm Cole's observation that the sands north of the Sperry Trough came from the north (fig. 7). Cole showed only inconsequential patches of sand south of the Sperry Trough. Exposures in new road cuts northwest of Catoosa (secs. 25 and 36, T. 20 N., R. 14 E.) reveal that these sands were deposited by currents flowing west-southwestward.

The sands south of the Sperry Trough are most likely distal sands of a distributary flowing southwestward into Oklahoma from eastern Kansas. The Sperry Trough probably originated as an interdistributary depression between lobes of adjoining systems, one of which reached farther south than the other.

The top of the Labette slopes into the trough at about 100 feet per mile at the point of maximum gradient. Before compaction, the original slope would have been perhaps 2°, well within the range expected along delta margins.

Slumping and sliding would have occurred along a slope of this magnitude before the mud was lithified (Twenhofel, 1932). The sands mentioned above that crop out in sec. 25, T. 20 N., R. 14 E., show pronounced faulting. These sands lie along the south margin of a southeast fork of the Sperry Trough, and the faulting may have been caused by sliding of the uncompacted sediments in the direction of the trough.

Sliding and faulting might not have occurred without the growth of the Oologah around the rim of the trough. The Oologah has been eroded from the locality, but apparently about 140 feet of carbonate debris was deposited above the sandstone.

The slope at the top of the Labette nearby and the locally unequal growth of the bank may have initiated sliding within the Labette below.

Although the trough was probably formed as an interdistributary low, it may have been maintained and deepened by underwater currents from the shelf during the entire time the Oologah bank was being built. While too modest to be considered a submarine canyon, the trough must certainly have served as a conduit for downslope flows, and perhaps also as a natural funnel for submarine flows from the west. Once initiated, the trough could be maintained by currents flowing in either direction.

Most of the Oologah bank lies north of the Sperry Trough and its westward extension. The band of thick limestone buildup along the Oologah front is possibly due to nutrients carried over the rim of the bank by currents from the deeper water to the south. The notches in the front may be remnants of underwater drainage channels from the shelf into the deeper waters.

Distribution of Wewoka Sands

The Wewoka Formation is the major component of the Marmaton Group in the basin. The fact that sandstones are present only in the southeastern part of the study area is an indication that its source is to the southeast. The presence of chert conglomerates in the Wewoka outcrop in Pontotoc and Hughes Counties is strong supporting evidence. No study of directional flow or sand-body-orientation features appears in the literature, and none was made for this paper, but planar crossbedding consistent with northwestward currents was observed in several places. The four sandstone zones of the Wewoka Formation would make an interesting subject for additional study, but it is sufficient for the purposes of this paper to note that the Wewoka is the approximate equivalent of the Oswego lime, the Labette Shale, and the Oologah Limestone of the platform, and that its source lay to the southeast.

The approximate limits of the four Wewoka sand zones have been shown in figure 13. Each succeeding unit slightly overreaches the previous one, but, considering that the formation spans 500 or 600 feet, the sands are surprisingly coextensive. The balance between subsidence in the basin and sediment supply from the Ouachitas must have remained quite steady for a long period of time, a conclusion that is supported by the stability of the limestone shelf in the platform area and the Midcontinent in general during the same period of time. The gradual overreach of each sand unit is reflected in the retreat northward of the carbonate banks. The youngest Wewoka sands appear in northern Okmulgee County and in Tulsa County; these sands were probably a harbinger of the much greater surge of sand soon to enter the area during deposition of the Cleveland sediments.

The pods of sand in central Oklahoma are marine bars appearing at varying levels of the Wewoka Formation and the immediately succeeding shales. Those lying south of the Oswego front are mostly bars of the middle Wewoka, as is the large bar in northeastern Oklahoma County. This latter bar clearly lies between marker beds trailing southward from the bottom and the top of the Oologah front (Bar *A*, fig. 11). The other bars north of the Oswego front lie above the Oologah zone and below the Cleveland channel sands.

Several of the bars bifurcate at their westward ends toward the Anadarko Basin. A slope of the sea floor in that direction seems likely. The Ouachitas lay to the southeast, and the Arbuckles were probably emergent; they were separated from the limestone shelf to the north by an intervening shallow depositional trough that was apparently deeper to the west.

Distribution of Sands in Holdenville Shale

The difficulties of choosing a reasonable horizon for the base of the Holdenville has already been discussed. No continuous marker of any considerable extent lies between the top of the Oologah and the Checkerboard on the platform. For this reason, the base of the Holdenville Shale, traditionally defined as the top of the Wewoka Formation in the basin, has been extended northward and westward at the top of the "Oologah shale" in this paper, and thence at the top of the Oologah Formation to the Kansas state line.

There are several sands in the Holdenville Shale in the basin. Directional features in the outcrop indicate that they are channel sediments deposited by streams flowing westward and northwestward. In Pontotoc County and southern Seminole County, the channel sediments are reddish conglomeratic sandstones. The channels extend only about 20 miles into the subsurface.

According to the proposed adjustments in classification, the Cleveland sands would also be assigned to the Holdenville Formation. Although comparisons are somewhat difficult because of the distance between them, the cross sections indicate that even the lower Cleveland sands are younger than the sands in the Holdenville of Seminole and Pontotoc Counties. The Cleveland sands present an unusual distribution pattern (fig. 32). The principal channels will be referred to by the names indicated in the figure.

Upper Cleveland Channels

The longer channels lie in the lower part of the Cleveland zone. The only two upper Cleveland

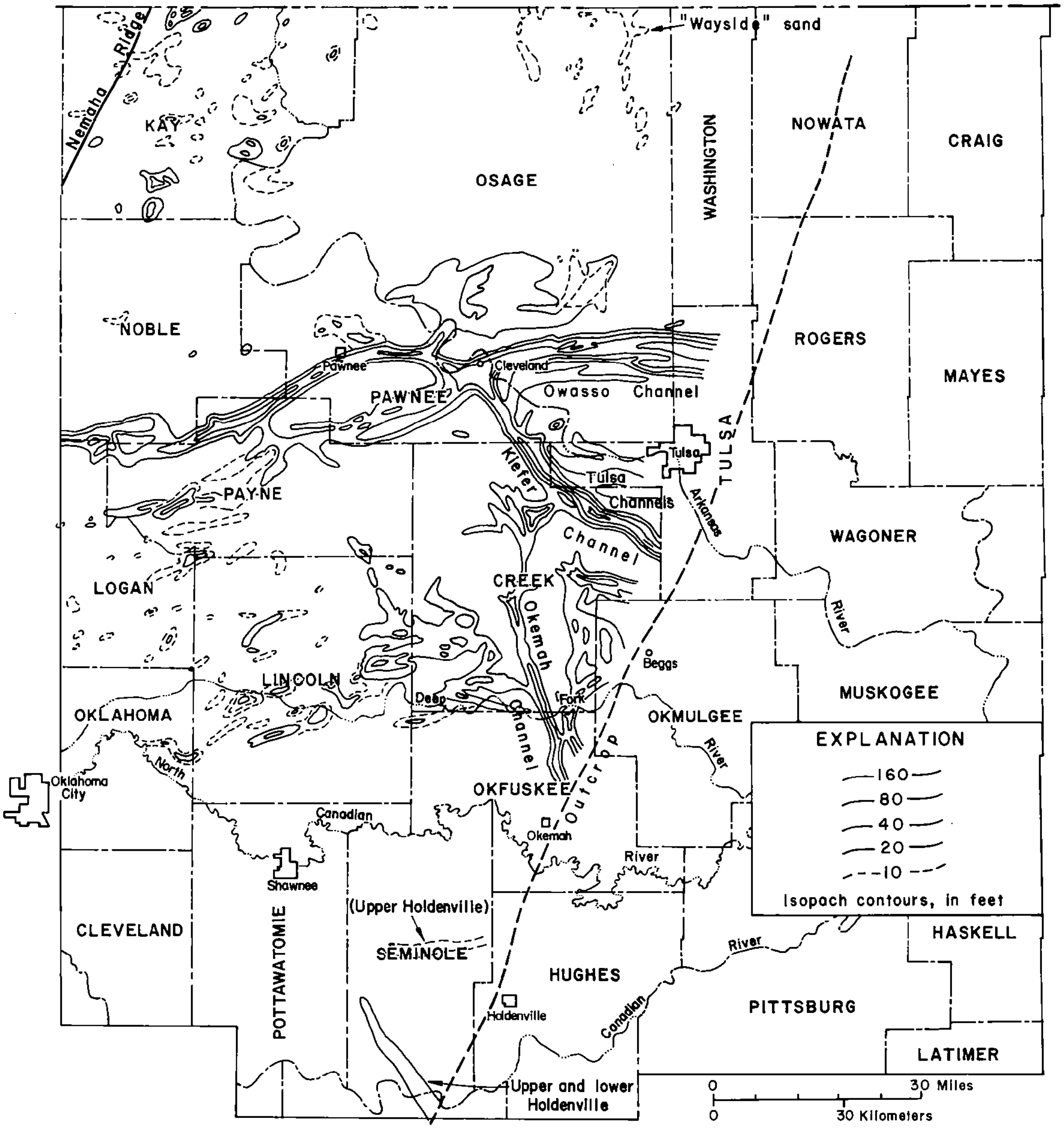


Figure 32. Isopach map of Cleveland sandstones in eastern Oklahoma.

channels, the Tulsa channels, do not extend far into the subsurface, nor are they as thick as the long channels. The stub of one or both of these channels forms the bluff on the west bank of the Arkansas at Turkey Mountain (61st Street South). It is the resistance of the sandstone to erosion that sustains the "mountain" and shapes the local topography.

The outcrop at the bluff contains a long exposure of broad festoons and crossbeds that dip in a generally westward direction.

Lower Cleveland Channels

The major sand bodies lie in the lower Cleveland. At the outcrop, the interval between the base of the channels and the Checkerboard is greater for the two north channels of the lower Cleveland, but the Okemah channels descend in the section northward, and no certain comparison of the relative ages of the channels can be made. The Owasso and Kiefer channels lie at about the same depth below the Checkerboard, and they are at the same approximate level at the townsite of Cleveland, where they meet and apparently cross.

The Cleveland sands can be examined on outcrop, and there is ample evidence to confirm that the principal sand bodies are channel sands. Strong crossbedding in a generally westward direction is evident in several of the outcrops in sec. 15, T. 22 N., R. 14 E. (fig. 33). Clay chips and wood fragments appear in the outcrop, although they are not abundant. Many of the sands are massive, without sedimentary structures visible to the naked eye.

The Kiefer channel and the Okemah channels also contain prominent crossbeds dipping northwestward and northward. Clay blebs and wood fragments appear in the sandstone, and the Okemah channels contain much conglomerate.

The crossing of the Owasso and Kiefer channels at Cleveland at the same level is interesting. The channels could hardly have crossed if they coexisted. It might be maintained that the channels merged and promptly bifurcated, but this condition would require a rather unusual bathymetry. (While the writer presumes that the channels were below sea level at the crossing at Cleveland, the position of the shoreline is uncertain. Marine fossils have been reported in the shales and limestones at the outcrop, but the thin coals and particularly the Dawson coal affirm that marsh conditions prevailed at times.) Furthermore, the northeast-trending "breakout" from the Kiefer channel northwest of Cleveland suggests a crevasse splay. It is rather difficult to visualize a sea floor that would permit a splay at such an obtuse angle to the Owasso channel if the crevasse opened while the Owasso channel was active.

The Owasso channel is considerably wider than the Kiefer channel. The fact that a broad channel continues southwest from Cleveland and a narrower one continues northwest implies an actual crossing. Moreover, the pronounced curvature of the Kiefer channel and the gentler curvature of the Owasso channel indicate that they flowed first northwestward down the face of the clastic wedge and then were drawn westward by a trough leading toward the Anadarko Basin. Only a slight shift in the position of this trough was necessary to accomplish the observed position of the two channels. Each of the "channels" is com-

Figure 33. Crossbedding in Owasso channel.

posed of the several shifting channels of a single stream. The Owasso channel apparently filled a broader "valley" than the Kiefer channel.

Figure 34 is an isochore map from the base of the Oswego to the top of the Oologah–"Oologah shale" section. This map represents a rough approximation of the sea-floor bathymetry at the commencement of deposition of the uppermost Wewoka sands, and it offers an explanation for the subsequent distribution of the Cleveland sands. It does not represent the actual sea-floor bathymetry for several reasons—the base of the Oswego was hardly a horizontal plane even at the beginning of Marmaton time, and tectonic and compaction effects are not considered.

The southeastern Oologah banks were prob-

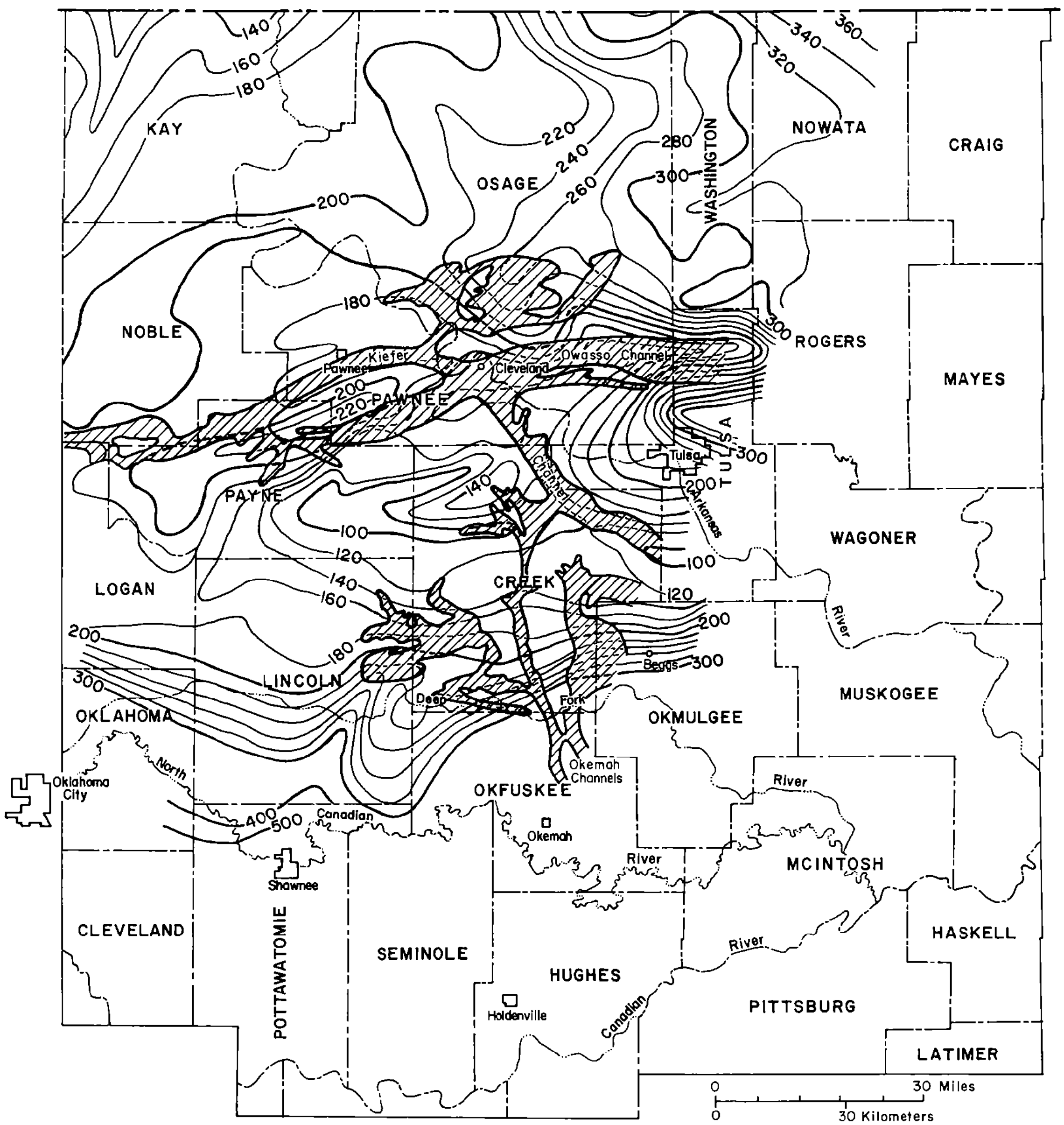


Figure 34. Map of eastern Oklahoma showing lower Cleveland channels superimposed on Marmaton pseudo-bathymetry (in feet).

ably killed and buried by uppermost Wewoka muds when the locus of sedimentation shifted northeastward. This influx of Ouachita clastics to the platform area seems not to have been induced by northward tilting. Apparently the platform continued to tilt slowly southward as the basin subsided. The Ouachitas, however, began to supply more sediment than the basin could accept. The trough ahead of the Marmaton fronts became filled with mud, and the toe of the north-facing slope of the clastic wedge finally surmounted the top of the Oologah bank itself.

The shift of the depocenter northeastward shown by the topmost Wewoka sands continued during deposition of the Holdenville Formation. In the basin, the Holdenville contains mostly shale. The few sand bodies it contains are inconsequential compared to the Calvin and Wewoka complexes. The fact that these southern sandstones are conglomeratic indicates that they were not far from their source. Their limited thickness and extent show that they were not part of important distributary systems. The deflection northeastward of the depocenter may reflect early positive tendencies in the areas of the Arbuckle–Hunton–Seminole Uplifts.

During deposition of the sands of the Owasso channel, the system may have debouched northward from the Ouachitas considerably to the east of the present outcrop. The tectonic causes of such a shift can only be surmised, but such lateral migration of distributary systems is a part of normal sedimentary processes.

Much of the stratigraphic record of these distributary systems has been removed by erosion. The relative ages of the principal Cleveland channels are uncertain, although some speculation is justified. If, as presumed, the encroachment of the Cleveland sands onto the platform resulted simply from the overstepping of successive strata, with no northward tilt, the Kiefer channel must be older than the Owasso channel. (A slow and continued tilt southward is indicated by a general thickening of the sediments basinward at every level.) The Kiefer channel and the Owasso channel cross at Cleveland at about the same level. The Kiefer channel, flowing northwestward, could hardly have crossed a preexisting Owasso channel unless significant northward tilting had occurred. On the other hand, the Owasso channel could have crossed a preexisting Kiefer channel readily if sufficient basin subsidence had occurred in the meantime.

The writer presumes that the two channels were deposited with the same orientation; that is, each had a proximal northwest-trending leg before turning westward, parallel to the Oologah front. The westward turn was caused primarily by the resistance of the platform to subsidence, combined with compaction phenomena and the presence of the Anadarko sink far to the west. The Kiefer channel flowed down the face of the clastic wedge and turned westward near the juncture of the delta slope and the platform. The distributary subsequently broke out far to the east and began to form the Owasso complex, but in the meantime basin settling and compaction of mud ahead of the Oologah front had moved the seaway trough slightly to the south. The Owasso channel flowed through the sands of the Kiefer channel and continued basinward south of the older channel. The northwest-trending proximal leg of the Owasso channel was subsequently removed by Mesozoic and Cenozoic erosion.

The influence of the pattern of previous deposition in the position of the Cleveland channels is striking (fig. 34). The Okemah channels, which may well be the oldest, failed to reach the Oologah front as they flowed generally northward down the south side of the seaway, with one arm flaring westward. The sandstones in this arm appear to be the result of a breakout from the west Okemah channel. The distal portions of this splay are generally tightly cemented, in contrast to the porous, permeable nature of most of the Cleveland sands.

The Kiefer channel was led into the depression between the buried Wewoka sand mass and the Oologah front south of Tulsa. The stream continued northwestward over the barely submerged southern lip of the Oologah, between Cleveland and Pawnee. As it reached the foot of the slope, the distributary turned westward along the elongated depression behind the buildup at the front and flowed through the veneer of mud covering the bank many tens of miles before dispersing in the deeper waters of the Anadarko Basin.

The succeeding (Owasso) distributary, breaking out far to the east, was attracted by the indentation in the Oologah front above the Sperry Trough (figs. 34 and 35). Basin subsidence and settling of the mud south of the Oologah front guided the Owasso channel westward, parallel to the front. The channel, however, did not continue to follow the Sperry Trough, which had mostly been filled with mud. Pushing through the older Kiefer channel, it continued westward, mounting the Oologah front but dissipating far short of the Anadarko deep.

The fact that both channels surmounted the Oologah bank indicates that, not far west of the present outcrop, the Sperry Trough had been completely filled with mud. Both channels intermittently lie directly on the Oologah, testifying that the carbonates were not so deeply buried that channel erosion could not reach them.

Apparently the Kiefer channel broke out into a depression at its left in northern Creek County (T. 18 N., R. 9 E.). Sands of this splay appear to be intermixed with sands from the Okemah channel. The spur that extends northward from the Kiefer channel in T. 21 N., R. 7 E., also seems to be a crevasse splay. Otherwise, the two north channels

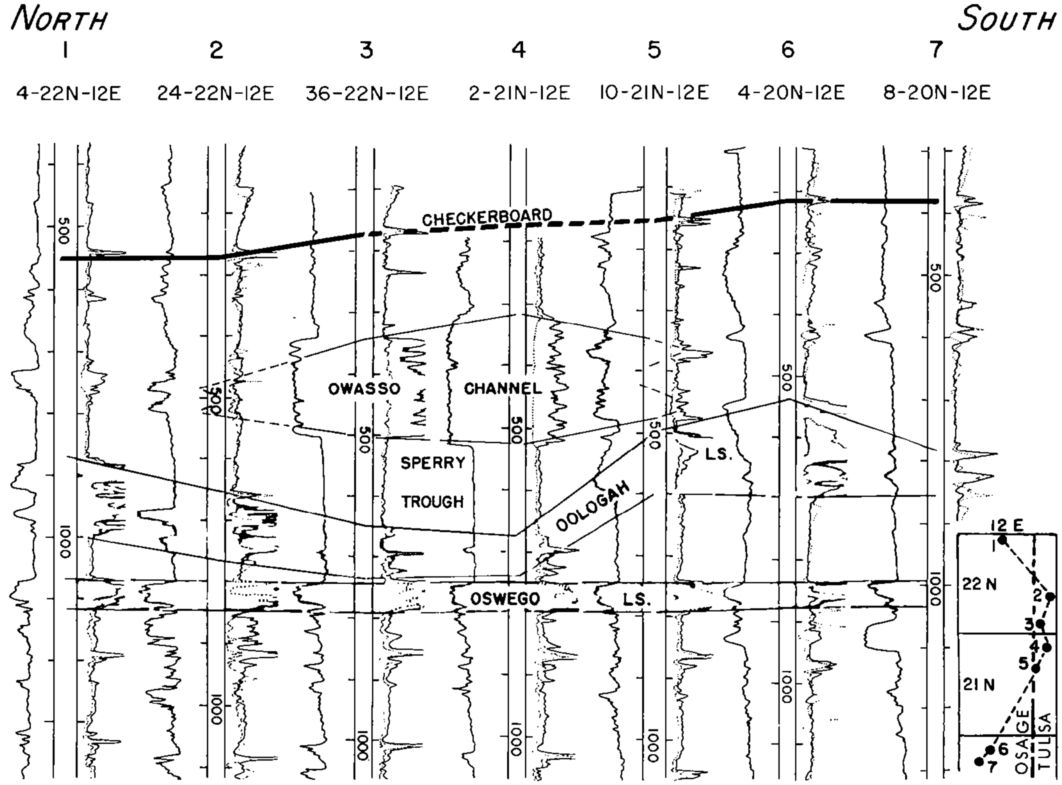


Figure 35. North-south electric-log cross section of Owasso channel above Sperry Trough in Osage and Tulsa Counties, northeastern Oklahoma.

are relatively simple in plan. The Kiefer channel is very long, stretching more than 150 miles from the outcrop into the central region of the Anadarko Basin, and it is apparently the source of the Cleveland sands that are found there ("Cleveland" sands in the Texas Panhandle may be unrelated sands at the same level).

As often happens, the two north distributary channels are blanketed by a coal bed, the Dawson coal. On outcrop, the Dawson coal extends only 6 or 8 miles south of the Kiefer channel, and a like distance north of the Owasso channel. Its extent in the subsurface is not known to the writer.

No coal appears in the outcrops above the Okfuskee County channels, although a coal bed may be present above them in the subsurface. No coals have been reported in the outcrop or the subsurface to the south of Creek County to the writer's knowledge.

The upper Cleveland channels at Tulsa represent a limited resurgence of sedimentation after the Dawson coal was deposited. They do not extend far into the subsurface. Thin layers of coal up to several inches in thickness appear above and below these channels.

The discrete pods of sand that are present in Lincoln and Payne Counties lie mostly in the upper Cleveland, generally less than 50 feet below the Checkerboard Limestone. They appear to be marine bars, although they could also have been formed as shoreline features as the upper Holdenville sea waxed and waned. The Cleveland bars have a different orientation from the earlier bars of the Wewoka Formation (fig. 9), probably owing to a change in direction of the currents along the floor of the sea.

The Wayside sands and the Cleveland sands of north-central Oklahoma seem also to be marine bars. If they are truly Cleveland in age, as seems likely, they belong to the lower Cleveland because they lie below the Lenapah Limestone.

Extent of Checkerboard Limestone

The lower Cleveland sands represent the maximum extent of Cleveland sedimentation. The presence of thin coals in the upper Cleveland outcrop suggests that the cause of the shortened distributaries was more a dearth of sand than a general transgression.

Whether owing to transgression, to a cessation of the supply of clastics, or to a lateral shifting of the locus of sedimentation, eastward in this case, clear waters returned and the whole of the platform and much of the basin was covered by the Checkerboard Limestone (fig. 36). On the southwestern flank of the basin, sands of the basal Seminole concurrently spread out into a small

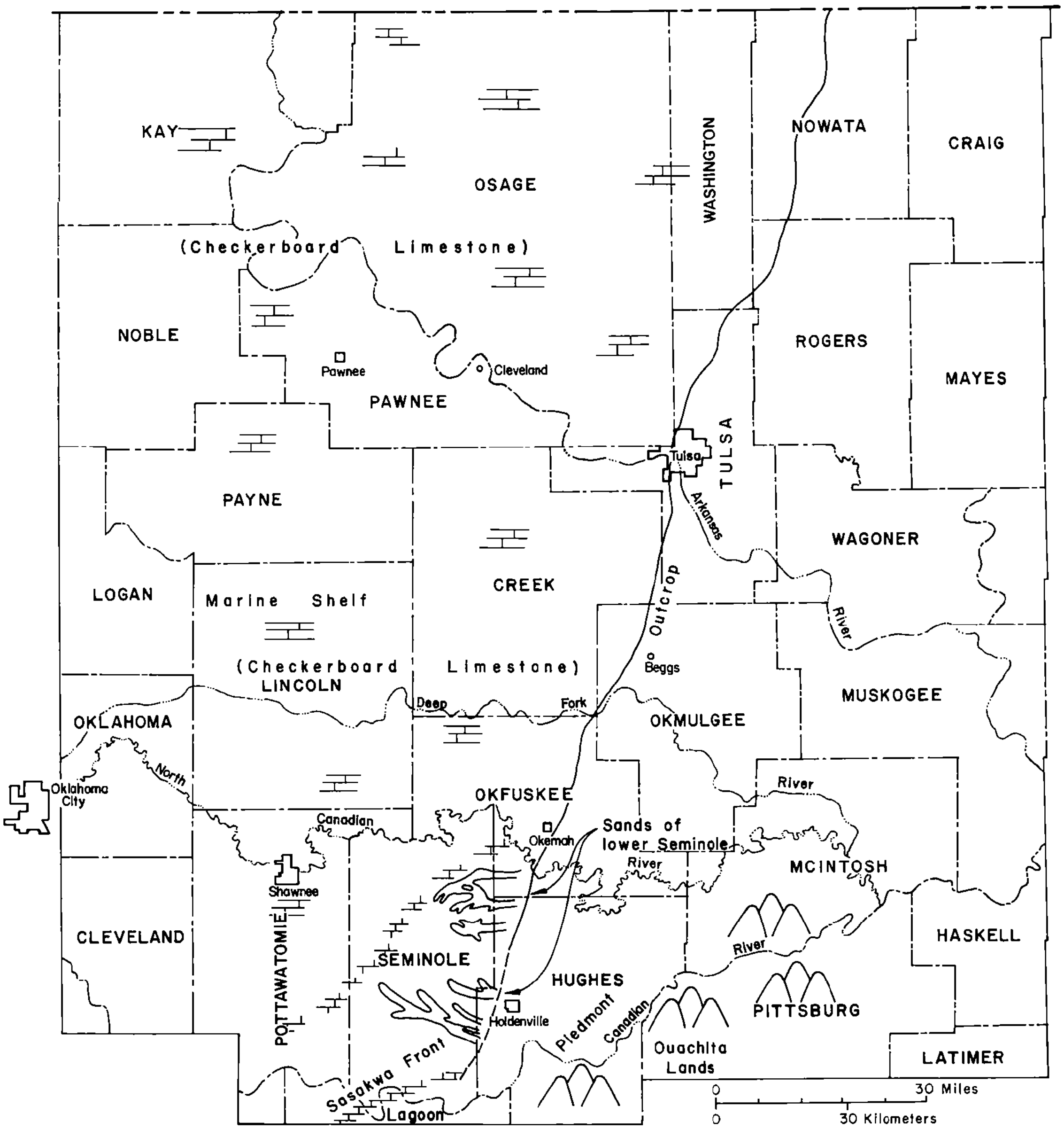


Figure 36. Map of eastern Oklahoma showing paleogeography during Checkerboard time.

area centered in southern Seminole County, although all of those shown in figure 36 are slightly younger than the Checkerboard. Directly south of this area a narrow limestone bank paralleled the Arbuckle peninsula, from which it was separated by a lagoon in which a veneer of organic debris accumulated. Whatever the cause, the platform and most of the western basin were quiescent.

Subsequently, distributary systems again carried coarse clastics from the Ouachitas to central and northern Oklahoma. While little work has been done regarding the depositional environments of the Missourian and Virgilian strata in the basin, studies by graduate students at The University of Tulsa and elsewhere have shown that the centers of deposition of the succeeding distributary systems moved successively northward on the platform. Work by Ekebafe (1973) showed that the Layton sands of the Coffeyville Formation lie slightly north of the Cleveland sands. Lalla (1975) found that sands of the next unit in the series of regressions (the Nellie Bly–Chanute sequence, containing the Cottage Grove sands) lie much farther to the north. In a thesis written at Wichita State University, Calvin (1965) observed that the Cottage Grove sands of the northern platform and southern Kansas lie at the level of the Kansas City–Lansing limestone sequence and that they appear to be distal sands of a distributary system centered in eastern Oklahoma. According to Calvin, the Kansas City–Lansing faced the Cottage Grove clastic wedge much like the Oswego–Oologah had faced the Wewoka wedge some 100 miles to the south earlier in Marmaton time.

It is the writer's opinion that successive Ouachita distributary systems continued to supply sediments northwestward throughout the rest of the Pennsylvanian and into the Permian. Distributaries draining the Arbuckle Uplift and the Wichita Uplift are known to have constructed other systems in southern mid-Oklahoma during this time, but the southern sources were minor with respect to the total volume of sediment supplied. Not only northern Oklahoma but also the north slope of the Anadarko sink and even the deep part of the basin were supplied with sands and muds from the Ouachitas.

Patterns of Sedimentation

A decline of the cratonic provenance and a northwestward progradation of the Ouachita distributary systems are apparent in the successive environmental patterns studied in this paper. While the Calvin shares its depositional basin with the Prue (fig. 37), the Wewoka sediments faced a limestone shelf concurrently forming on the platform during most of Marmaton time (fig. 38). In Cleveland time, Ouachita sediments finally prograded onto the southern margin of the platform (fig. 39).

The results of this study fit well into the patterns of sedimentation revealed by research in adjacent areas. The correlations between depositional basins are subject to some inexactitude, but paleontological evidence supported by direct surface and subsurface connections has gradually established acceptable time correlations between the several depositional provinces.

Figure 40 shows the pattern of sedimentation in mid-Pennsylvanian time from north-central Texas to the Appalachians. The systems shown in northern Texas are mid-Missourian, and the systems shown for southern Oklahoma and the Appalachians are generalizations for an interval of time (Missourian and Middle to Upper Pennsylvanian, respectively). Broad areas are not mapped because of nondeposition or erosion, or because they have not been adequately studied to date.

Nevertheless, the concordance of the various elements is very persuasive that there existed, in mid-Pennsylvanian time, a narrow seaway continuous at least from northern Texas to the central Appalachians.

SUMMARY

Research for this paper was begun with the intention of establishing the significance of the Marmaton Group limestone banks in the paleogeographic history of eastern Oklahoma. Investigations into the accuracy of the previously accepted correlations in eastern Oklahoma led to a recommendation of several adjustments, some long proposed and some new. The correlations between the platform facies and the basin facies, which are set forth in this paper, are reviewed below.

1. Although the correlation of the Verdigris Limestone and the Henryetta coal, as proposed by many investigators, is a practical and useful relationship, the Verdigris actually lies at the horizon of the northward-tapering wedge of upper Senora shale.
2. The Prue zone is correlative with the Calvin Formation.
3. The Oswego lime, comprising the Wetumka Shale, the basal Wewoka sand zone, and the succeeding shale, after an initial thinning, is represented by a somewhat thicker sequence in the basin. The Labette Shale is approximately equivalent to the shale between the second and third Wewoka sands.
4. The Oologah and the upper part of the Wewoka Formation lie at the same horizon; in the east particularly, the upper Wewoka sandstones are younger than the Oologah.

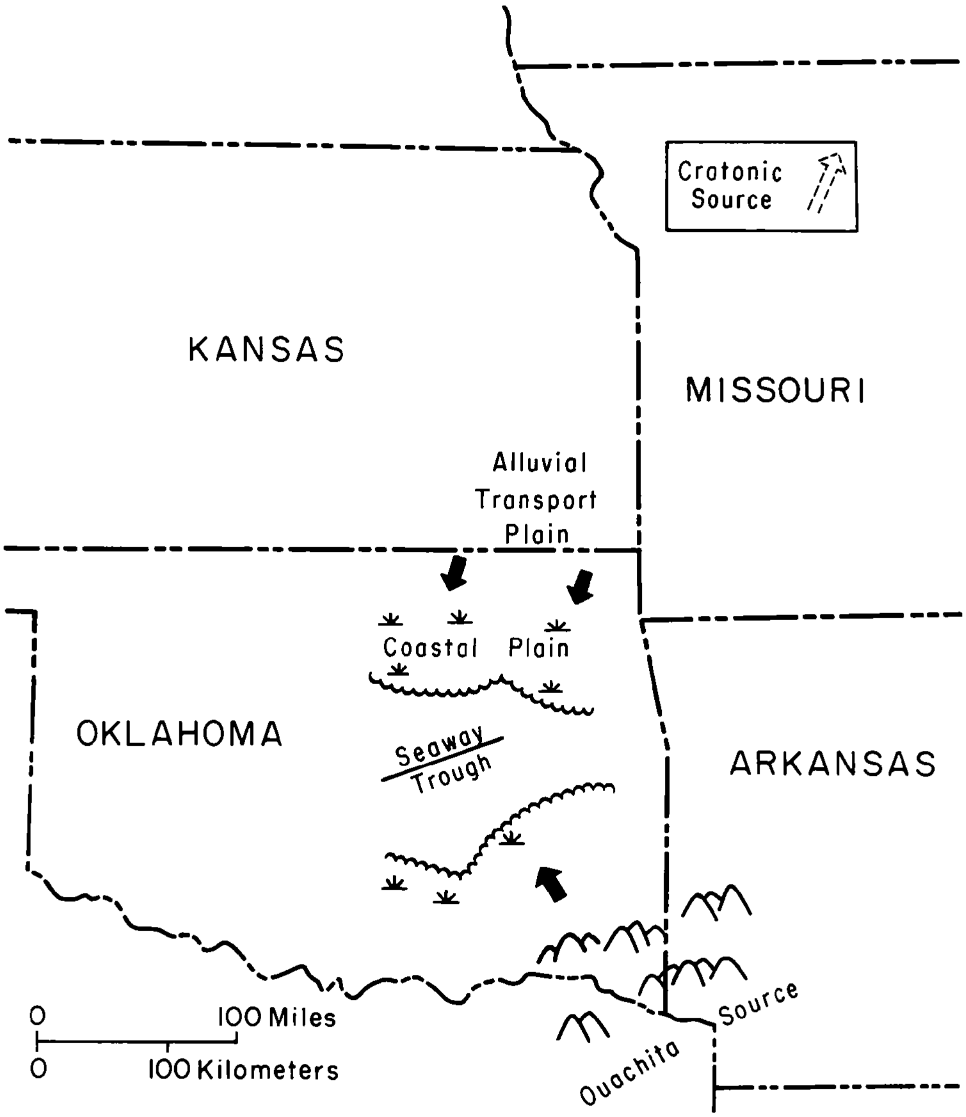


Figure 37. Map of central Midcontinent region showing paleogeography during deposition of Prue and Calvin sandstones.

5. The Cleveland sandstones are equivalent to sands in the upper portion of the Holdenville Shale in the basin and to the Wayside sand of northeastern Oklahoma.
6. The Checkerboard is approximately equivalent to the Sasakwa Limestone. The basal Seminole channel described by Taff lies in a shale interval at about the level of the Checkerboard–Sasakwa.
7. The Seminole sandstones lie above the level of the Checkerboard; the Seminole occupies the lower half of the Coffeyville Formation, and the DeNay Limestone is a middle Coffeyville limestone fringing the Arbuckle Uplift.

The correlations set out above require new definitions of some formation, group, and series

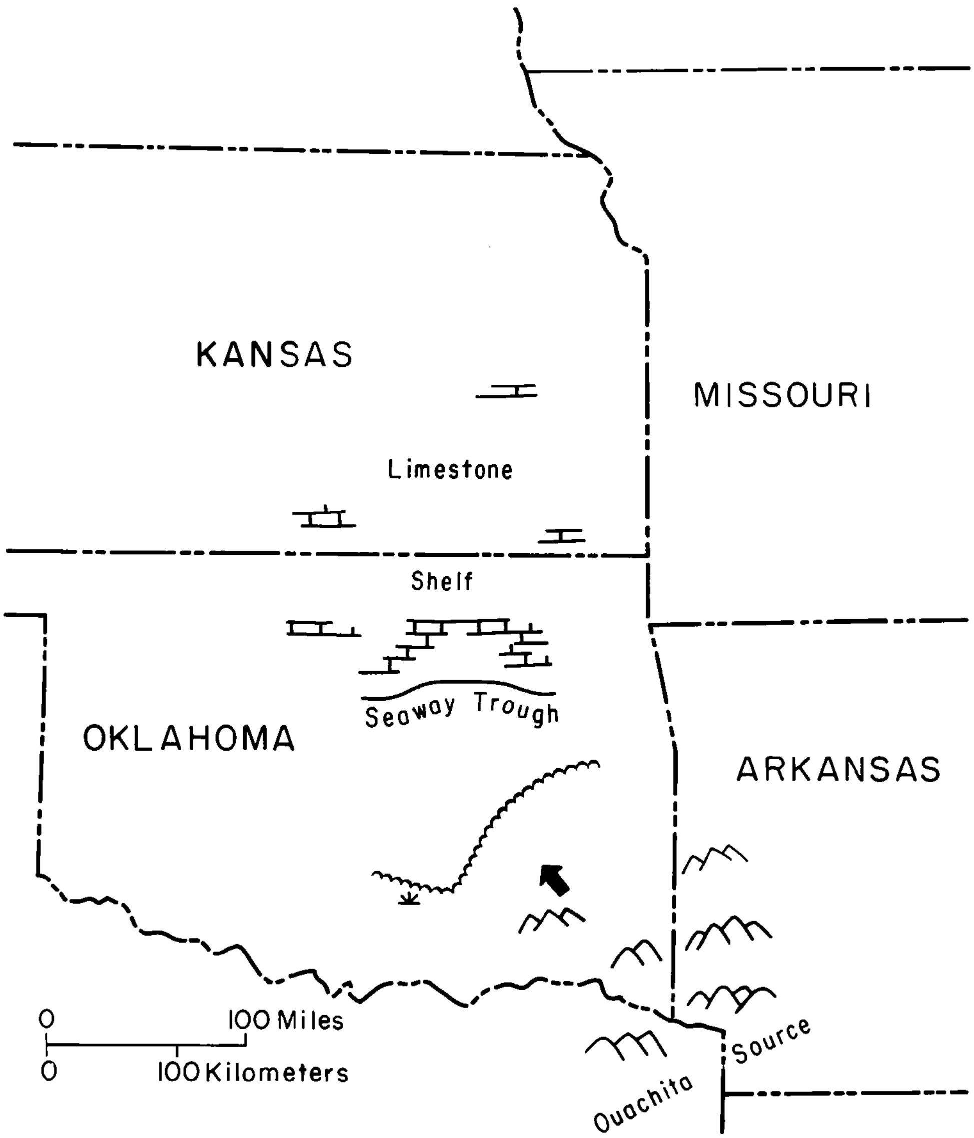


Figure 38. Map of central Midcontinent region showing paleogeography during deposition of Wewoka sandstones and Oologah Limestone.

boundaries, a task that is complicated by the absence of unconformities in the interval. While recognizing that no division will be satisfactory for all needs, the writer proposes the following adjustments:

1. Transfer of the Prue sand zone from the Senora Formation to the Calvin Formation; the Calvin should then be assigned to the Cabaniss Group.
2. Establishment of the base of the Fort Scott Formation at the base of the Breezy Hill Limestone, where present, rather than at the base of the Blackjack Creek Limestone.
3. Establishment of the base of the Marmaton Group at the base of the Fort Scott, as redefined, on the platform and at the base of the Wetumka Shale in the basin.
4. Enlargement of the Holdenville Formation on

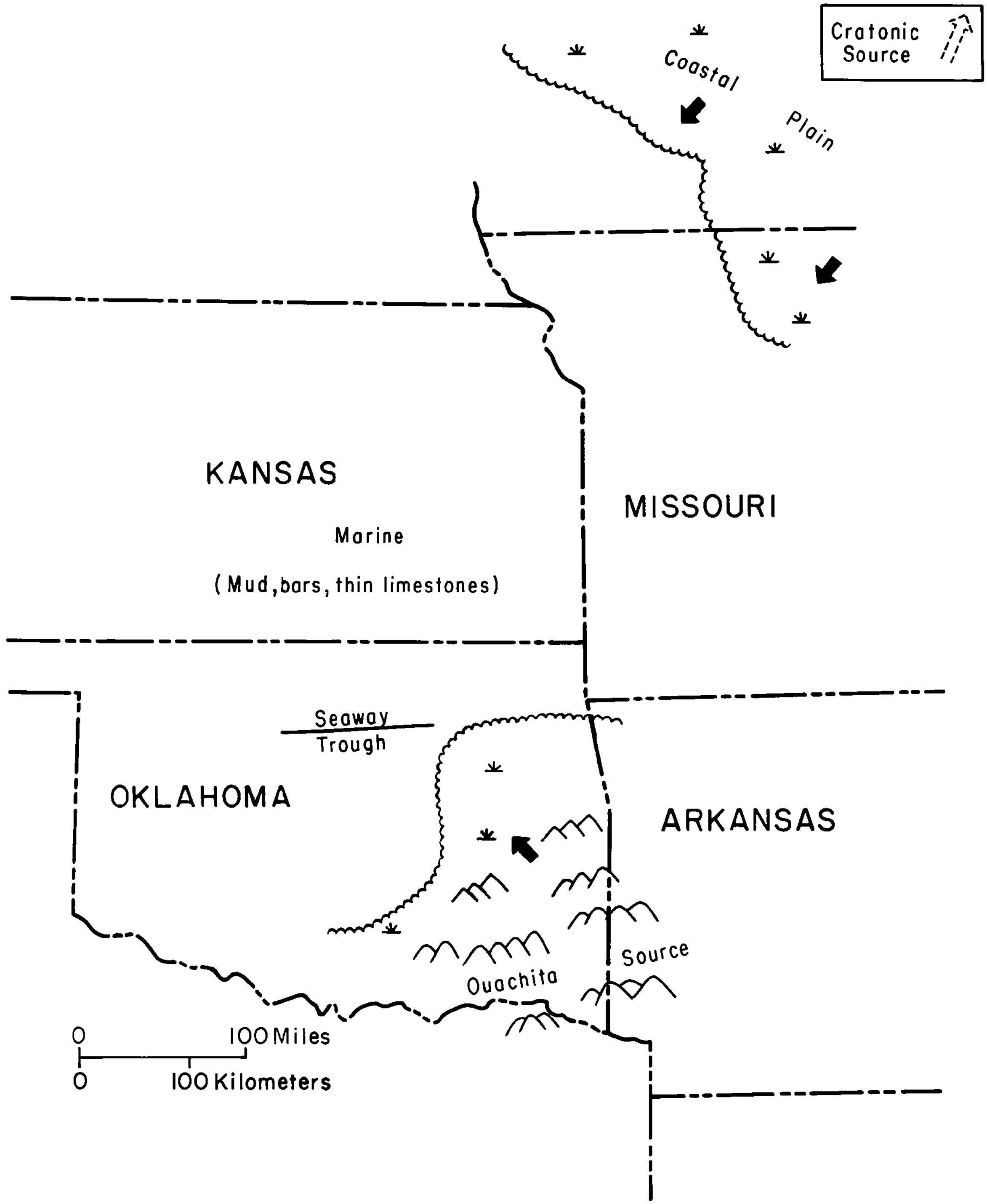


Figure 39. Map of central Midcontinent region showing paleogeography during deposition of Cleveland sandstones.

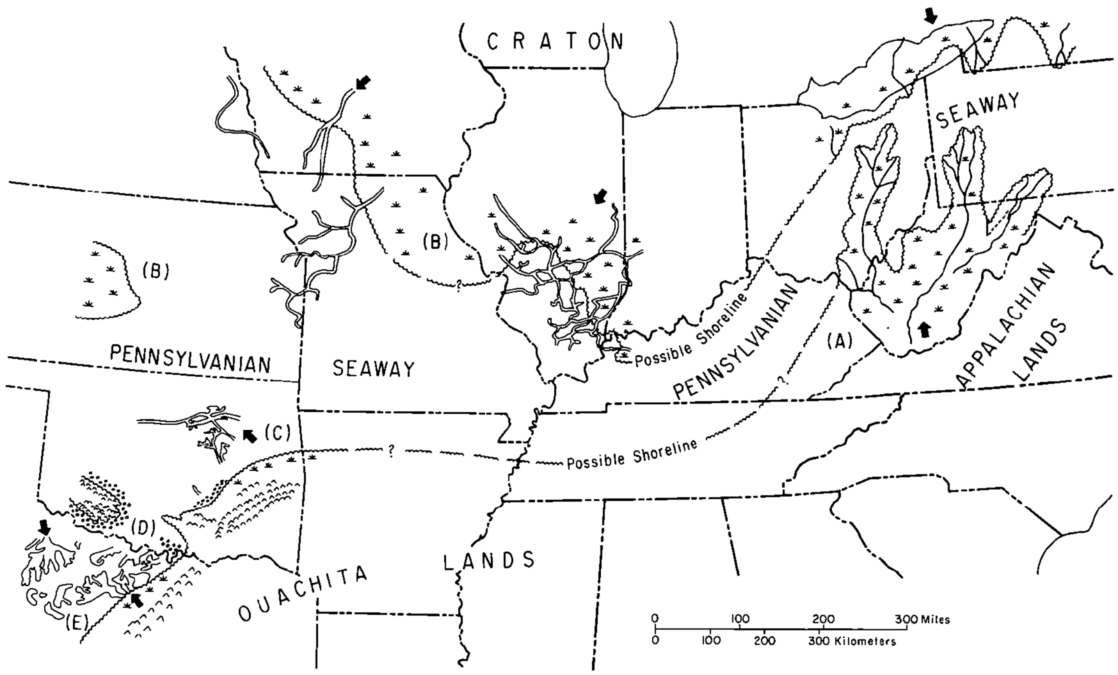


Figure 40. Map showing pattern of sedimentation in mid-Pennsylvanian time from north-central Texas to Appalachians. Reconstruction of Missourian paleogeography based on (A) Donaldson (1974), (B) Wanless (1970), (C) this paper, (D) Tomlinson (1959), and (E) Wermund (1970).

the platform to include all strata between the Checkerboard Limestone and the top of the Oologah Limestone and their lateral equivalents.

5. Designation of the Seminole Sandstone and the DeNay Limestone as local members of the Coffeyville Formation. The name Seminole should be abandoned north of the North Canadian River.

The Pennsylvanian Period in eastern Oklahoma was marked by the northward transgression of a sea that lay between the craton on the north and Ouachita lands to the southeast. Compression from the south forced pre-Pennsylvanian rocks and Early Pennsylvanian rocks to override the northern limb of the old Arkoma depositional basin. The ancient sea floor thus was partly consumed in feeding a shallow trough constantly retreating before it. The process continued until an undetermined date between the middle of the Permian Period and the time of the Cretaceous overlap.

This paper covers an important period in the history of this transgression. The sediments entering the epeiric sea of early Desmoinesian time in this area were first supplied principally by the North American craton. The middle Desmoinesian sediments, however, entered the area from the south as well as from the north, as the Ouachita source gained in strength and importance. The cratonic distributaries progressively retreated northward, and in Marmaton time a limestone shelf formed on the platform between the basin clastic province and the ancestral continent to the north.

Further uplift allowed Ouachita sediments to fill the trough at the platform margin and subsequently to bury the Marmaton limestone banks in mud. Cleveland channel sands were carried northwestward; one of the channels, after overriding the lip of the defunct Oologah bank and turning westward, emptied into the Anadarko Basin many tens of miles to the west.

A period of quiescence followed, during which the thin Checkerboard Limestone was deposited. Ouachita clastics then buried the Checkerboard and forced the limestone-bank province to retreat northward into Kansas.

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APPENDIX—LIST OF WELLS IN CROSS SECTIONS

Fig.–No.	Operator Well name	Location Sec., Twp., Rge.	Work	Cross reference Cross sec.	No.
9–1	Fleet Drilling Co. 1 School Land	SW SE SE 16 28N 2W			
9–2	Edwin C. Bradley 1 Eckert	NE NE SE 24 28N 1E	This paper	11	1
9–3	Marts Oil Co. 1 Elliott	SW SW NW 20 28N 4E			
9–4	Mora Drlg. Co. 1 Floyd Hobbs	SW SW NE 31 28N 6E			
9–5	Appleton Oil Co. 1 Barnard Ranch	NW NW SW 26 28N 8E			
9–6	Globe Oil & Refining 0-2 Osage	NW SW NW 21 28N 10E	Cole (1970) This paper	B-B′ 10	30 2
9-7	Ohio Oil Co. S-1 Stie	E/2 SE NW 4 27N 13E			
9–8	Frankfort 1 Webster	35 28N 15E			
10–1	G. B. Cree 3-A Hurst	SE SE NW 16 29N 10E			
10–2	Globe Oil & Refining 0-2 Osage	NW SW NW 21 28N 10E	Cole (1970) This paper	B-B′ 9	30 6
10–3	Phillips Petr. Corp. 1 Stuart-C	SW NW NW 29 27N 10E			
10–4	Falcon Seaboard 2 Woods	NE NE NE 18 25N 10E			
10–5	National Assoc. Petr. 1 Osage	SW SW SW 32 24N 10E			
10–6	Sunray Oil Corp. W-13 Osage	SE SE NW 34 22N 10E			
10–7	Pete Kime Drlg. 1-A Jefferson	E/2 NE NE 10 19N 10E			
10–8	Great Western O & G 1 Cosar	SW SW NE 10 18N 10E	Kirk (1957)	D-D′	06
10–9	Mid-Continent Petr. 1 Beets	NW NW NE 1 16N 10E	Furlow (1964)	A-A′	1
10–10	Marion Oil Co. 4-A Webb	NW NE NW 33 16N 10E			
10–11	Krumme Oil Co. 1 Fisher	SE SW NE 32 15N 10E	This paper	15	1
10–12	W. N. Price 1 Walker	NE NW NW 32 14N 10E	Jordan (1959)	A-C	22
10–13	Canadian O & G 4 Bras	S/2 NE NW 19 13N 10E			
10–14	British-American Oil 1 Admire	SW NW SW 24 12N 9E	Cole (1970)	A-A	19
10–15	Sands Petr. Co. 1 Mathews	S/2 NW SE 5 11N 9E	Ries (1954)	B-A	12
10–16	S. C. Yingling 1 Landers	SE NW NW 1 10N 8E	This paper	17	1

Fig.–No.	Operator Well name	Location Sec., Twp., Rge.	Work	Cross reference Cross sec.	No.
10–17	Culham Petr. Co. 1 Whitney	SW SW SE 32 10N 8E	Weaver (1954)	B-A	13
10–18	Sinclair-Prairie Oil 1 Jennings	S/2 SW SE 8 8N 8E	Tanner (1956a)	B-B′	3
10–19	Kelso 1-A Whitfield	NW NE NW 27 7N 7E			
10–20	R. P. Traugh 1 Sturgeon	SE NW SE 16 6N 7E	Tanner (1956a)	A-A′	2
10–21	J Marvin Boyd 2-A Boren	SE SE SE 2 5N 6E			
10–22	P. M. Barton 2-B Winters	NW NW SE 35 5N 6E			
11–1	Edwin C. Bradley 1 Eckert	NE NE SE 24 28N 1E	This paper	9	2
11–2	Livingston Oil Co. 1 Wetzel	SW SW SW 24 26N 1E			
11–3	W. T. Fail 1 Wiegel	NW NE NE 25 24N 1E			
11–4	Barnsdall Oil Co. 1 Charles Johnson	SW NE 25 22N 1E			
11–5	Russell Cobb, Jr. 1 Jirious	NE NW SW 16 20N 1E			
11–6	T. T. Eason & Co. 1 School Land	SW SW NW 16 18N 1E			
11–7	D. F. O'Rourke 1 Ferguson Est.	SE SE NW 23 16N 1W			
11–8	Robert M. Jordan 1 Hamey	SE SE SW 24 14N 1W			
11–9	George J. Greer 1 Graff	NE NW SW 36 13N 1E			
11–10	Schafer Oil Corp. 1 Rooker	SE NE SE 23 11N 2E			
11–11	Kingwood Oil Co. 2 Rader	NE SW SE 31 9N 3E	Tanner (1956a)	B-B′	19
11–12	Howard I. Berkey 1 Oldham	NE NW SW 26 7N 3E			
12–1	Southwest Oil Corp. 1 Ingleheart	NE NE SE 8 12N 7E			
12–2	Hubbell-Webb 1 Gragg	SW SW SW 16 12N 7E			
12–3	Clark C. Nye 1 Replogle	SE SE NW 22 12N 7E			
12–4	Evans and Joyes 1 Hessman	NW NW SE 28 12N 7E			
12–5	Watson B. Joyes 1 Patterson	SW SW SE 33 12N 7E			
12–6	Ambassador Oil Corp. 1 McCulla	NE NW NE 9 11N 7E	Cutolo-L. (1969)	B-B′	12
12–7	J. E. Crosbie, Inc. 1 Janeway	NE NE NW 16 11N 7E	Cutolo-L. (1969)	B-B′	11
14–1	Hubbell Drlg. Co. 1 Lindsey	NW SW SW 31 15N 7E			

Fig.–No.	Operator Well name	Location Sec., Twp., Rge.	Work	Cross reference Cross sec.	No.
14–2	Krumme Oil Co. 1 Hubbell	NE SW NW 6 14N 7E			
14–3	Krumme Oil Co. 1 Coser	NE NE NE 7 14N 7E			
14–4	Hubbell & Webb 1 Chapman	SW SW NE 9 14N 7E			
14–5	J. E. Crosbie, Inc. 2 Mullins	NW NE SE 17 14N 7E			
14–6	Murta et al. 1 Chapman	C NE NE 21 14N 7E			
15–1	Krumme Oil Co. 1 Fisher	SE SW NE 32 15N 10E	This paper	10	11
15–2	Krumme Oil Co. 4 Sewell-B	NE SW NE 34 15N 10E			
15–3	Mariko Production Co. 1 McGuire	NW SE SW 31 15N 11E			
15–4	Dobson & Hoxsey 1 Williams	NW NW SE 4 14N 11E			
16–1	Sands Petr. Co. 1 Mathews	W/2 NW SE 5 11N 9E	Ries (1954)	B-A	12
16-2	Phillips-Johnston 1 Ethel Currey	C SW NE 3 11N 9E	Ries (1954)	B-A	11
16–3	British-American Oil A 1 Okemah Com.	SW NW SW 12 11N 9E	Ries (1954)	B-A	10
16–4	Ashland Oil & McBride 1 Palmer	NE NE SW 18 11N 10E	Ries (1954)	B-A	9
16–5	Wilcox Oil Co. 1 Wynne	NW SE SW 16 11N 10E	Ries (1954)	B-A	8
17–1	S. C. Yingling 1 Landers	SE NW NW 1 10N 8E	This paper	10	16
17–2	Kingery Drilling Co. 1 Willie Hawkins	NE SW SW 8 10N 9E			
17–3	Big Chief Drlg. Co. 1 Price	C SW SW 16 10N 9E			
17–4	Anderson and Fillmore 1 Jarman	W/2 NW NW 22 10N 9E			
19–1	Culham Petr. Co. 1 Whitney	SW SW SE 32 10N 8E	Weaver (1954)	B-B′	13
19–2	P. J. McIntyre 1 Allen	NW NE SW 11 9N 8E	Weaver (1954)	B-B′	11
19–3	Earl Evans 1 Oliphant	SE SW SE 7 9N 9E	Weaver (1954)	B-B′	10
19–4	Jones & Shelburne 1 Smith	NW NW NE 17 9N 9E			
20–1	Sinclair Oil 1 Jennings	C SW SE 8 8N 8E	Tanner (1956a)	B-B′	3
20–2	Olsen Drlg. 1 Davis	NW NW SE 10 8N 8E	Tanner (1956a)	B-B′	2
20–3	J. A. Chapman 3 Culler	SW NW NW 13 8N 8E			
20–4	Sam A. King 1 Cordell	SW SW SE 13 8N 8E	Tanner (1956a)	B-B′	1

Fig.–No.	Operator Well name	Location Sec., Twp., Rge.	Work	Cross reference Cross sec.	No.
21–1	R. P. Traugh 1 Sturgeon	SE NW SE 16 6N 7E	Tanner (1956a)	A-A′	2
21–2	Claybrook Drlg. Co. 1 Fleet	NE NW SE 11 6N 7E			
21–3	Deep Rock Oil Corp. 1 Reed	NW NW SE 6 6N 8E			
21–4	Carnation Petr. Co. 1 Harris	SE NE SW 5 6N 8E			
21–5	Brosius and Hall 2 Moore	SE SE NE 5 6N 8E			
35–1	Warren Blufston 10-B Osage	SW NE 4 22N 12E			
35–2	George Pease, Jr. 2 Butler	NE SE NE 24 22N 12E			
35–3	J. M. Allison 3-A Allison	NE SE NW 36 22N 12E			
35–4	White Eagle Oil Co. 1-36 Bird Creek Unit	C S/2 NE 2 21N 12E			
35–5	Sunray D-X Oil Co. 7 Bird Creek	W/2 SW SE 10 21N 12E			
35–6	Sunray Oil Co. 5-1	SW 4 20N 12E			
35–7	Keener Oil Co. A-1 Osage	NE 8 20N 12E			

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