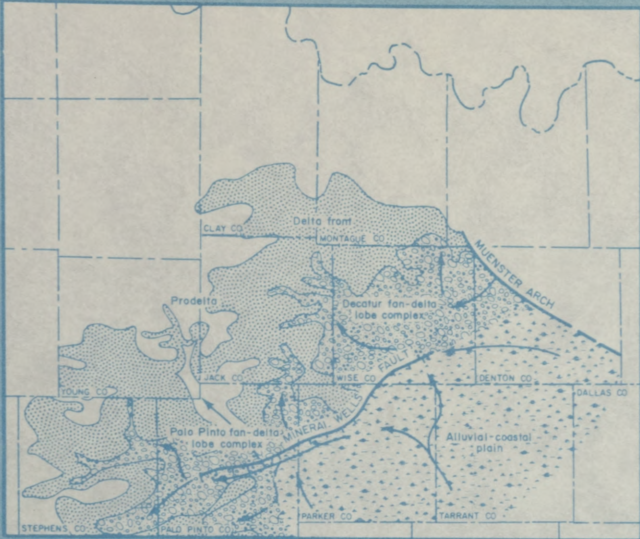
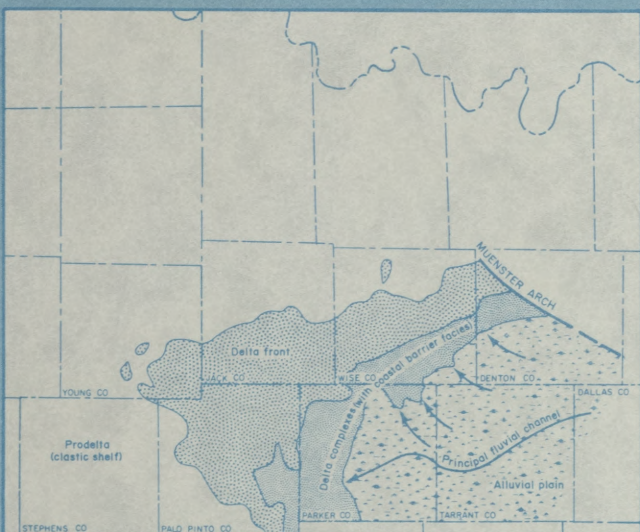
Report of Investigations No. 125

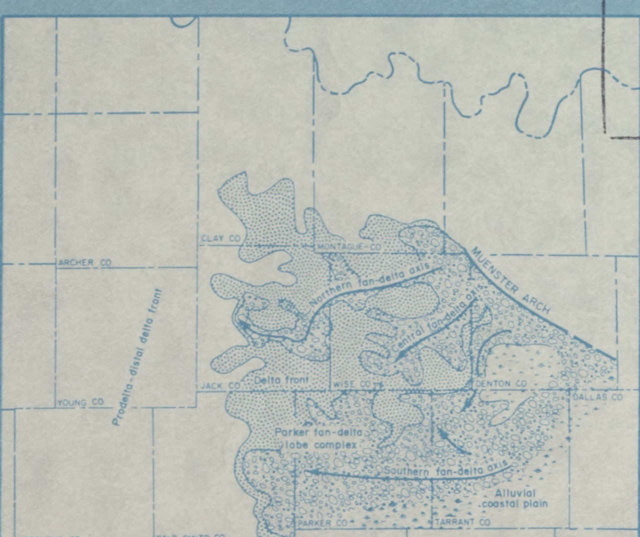


Atoka Group (Lower to Middle Pennsylvanian), Northern Fort Worth Basin, Texas:

Terrigenous Depositional Systems, Diagenesis, and Reservoir Distribution and Quality



Diana Morton Thompson



Bureau of Economic Geology
W. L. Fisher, Director
The University of Texas at Austin
Austin, Texas 78712
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Atoka Group (Lower to Middle Pennsylvanian), Northern Fort Worth Basin, Texas: Terrigenous Depositional Systems, Diagenesis, and Reservoir Distribution and Quality

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·Currently with Chevron U.S.A., Denver, Colorado

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ABSTRACT

The Fort Worth Basin, in North-Central Texas, is a late Paleozoic foreland basin that was downwarped during the Early to Middle Pennsylvanian Period in response to tectonic stresses that also produced the Ouachita Thrust Belt. The Atoka Group was deposited during the initial westward progradation of chert-rich terrigenous clastics derived both from the Ouachita Thrust Belt and locally from the Muenster Arch across the northern part of the basin. At the northern end of the basin, the Atoka Group interfingers with arkosic conglomerates (granite wash) derived from the Red River-Electra Arch. The granite wash is time equivalent but constitutes a separate stratigraphic sequence.

The Atoka Group contains three distinct packages of terrigenous deposits: (1) the lower Atoka lithogenetic unit, interpreted to be a fluvially dominated fan-delta system, (2) the upper Atoka "Davis" lithogenetic subunit, interpreted to be a system of coalesced wave-dominated deltas, and (3) the upper Atoka "post-Davis" lithogenetic subunit, interpreted to be a thin, poorly integrated, fluvially dominated fan-delta system.

Atoka Group sandstones are quartz-rich feldspathic (chert) litharenites. The most significant diagenetic events were silica dissolution and cementation. Net porosities of 10 to 15 percent are the result of the preservation of original porosity in between quartz overgrowths and the creation of secondary porosity by chert grain dissolution. Highest porosities occur in channel-fill and coarse-grained fan-delta plain facies.

The Atoka Group has a cumulative production history of more than 160 million barrels (oil plus gas equivalent). Production and reservoir distribution and quality are facies controlled. Most oil and gas fields coincide with the distribution of lower Atoka fan-delta lobe complexes. Minor production is located along the axes of upper Atoka "post-Davis" fan-delta complexes.

INTRODUCTION

Setting

The Fort Worth Basin is a Paleozoic foreland basin located in North-Central Texas (fig. 1). It is bounded on the east by the Ouachita Thrust Belt, on the north by the Red River-Electra and Muenster Arches, on the west by the Concho Platform and the Bend Flexure, and on the south by the Llano Uplift. The basin is approximately 200 mi (322 km) long, and its width ranges from more than 100 mi (161 km) in the north to less than 10 mi (16 km) in the south. The basin covers about 20,300 mi^2 (57,780 km^2). It is deepest in the east-northeast and shallowest in the west. This study was restricted to approximately 9,500 mi^2 (24,700 km^2), which constituted the northern half of the basin.

Objectives

The study objectives included (1) delineating principal terrigenous depositional systems and component facies of the Atoka Group, (2) determining the diagenetic history of the sandstone hydrocarbon reservoirs, (3) tabulating Atoka hydrocarbon production data, and (4) relating depositional, diagenetic, and production trends to the distribution and quality of Atoka reservoir rock. This study will aid operators in the area to effectively produce from all available horizons in the Atoka Group, and to target areas for additional exploration that had been previously overlooked.

Methods

Because the Atoka Group does not crop out in the Fort Worth Basin, the data base consisted of electric logs, sample logs, and cores (fig. 2). More than 1,000 electric logs were used to define structural and stratigraphic boundaries of the study area (pl. I). Seven hundred and eighty-eight electric logs and 146 sample logs were used in map preparation.

Regional cross sections were correlated, and principal Atoka lithogenetic units were delineated (pls. II-X). From this correlation framework, a structure map of the pre-Atoka surface and isopach maps of the Atoka lithogenetic units were constructed. These maps were rechecked to ensure correct placement of structural features and to refine correlations. Boundaries of structural elements, such as the Red River-Electra and Muenster Arches, were mapped at the site of the most basinward fault that exhibited a displacement of more than 400 ft (122 m). Location of the Ouachita Thrust Belt was based on findings of Flawn and others (1961). Limits of Atoka terrigenous deposition were located where well log response patterns indicated major changes in the physical character of the stratigraphic sequence. The southern limit of the study area was defined by the southern county lines of Tarrant, Parker, Palo Pinto, and Stephens Counties. This generally corresponds to a zone characterized by an abrupt breakup and absence of key rock units and to a change in overall log character. The northern limit of the mapped Atoka Group in Montague, Clay, and Archer Counties was defined by a transition from thin, individual rock units characterized by smooth spontaneous potential (SP) curves to thick, stacked

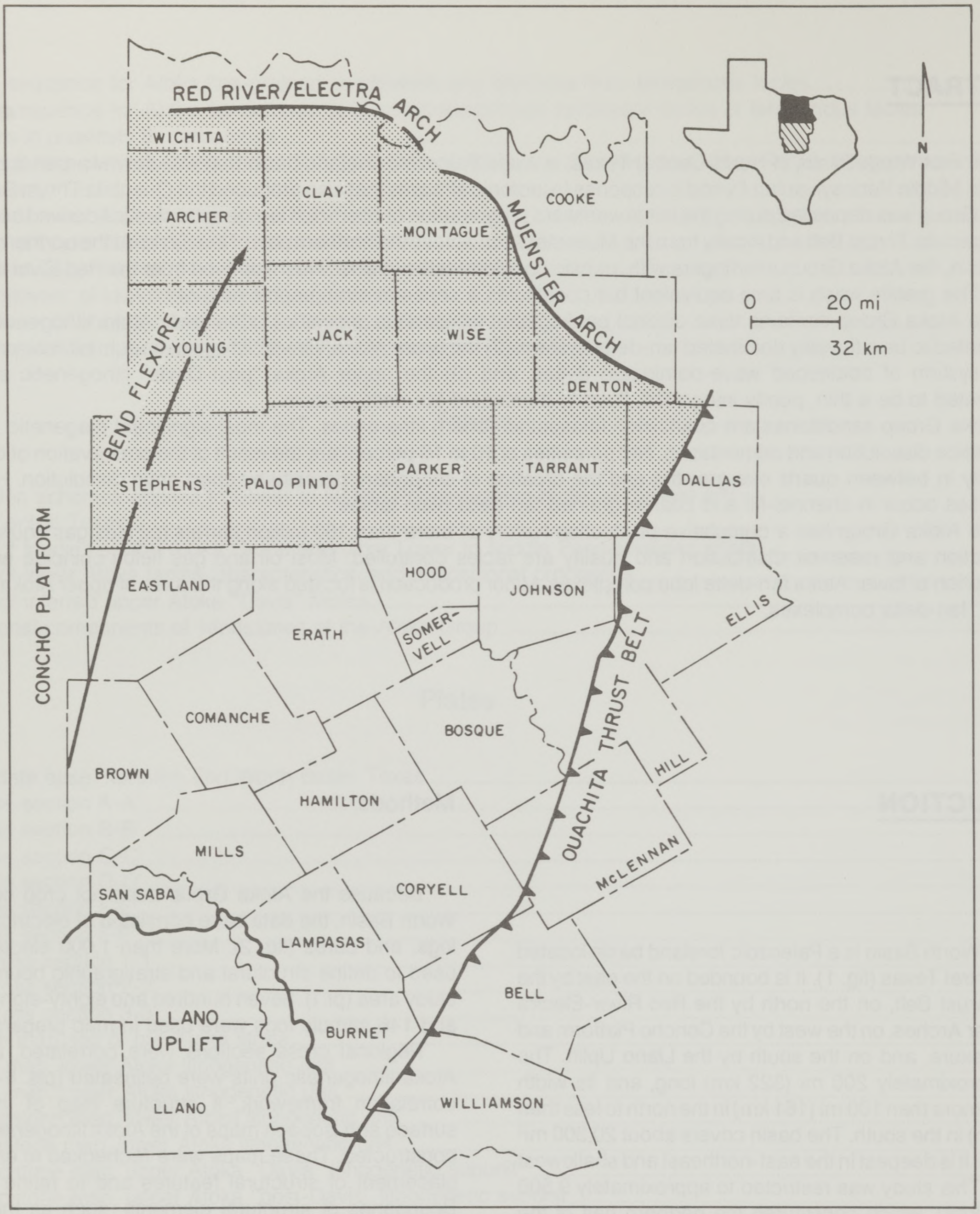

Figure 1. Location of Fort Worth Basin, North-Central Texas. Study area is in gray.

rock units characterized by serrate SP responses. This transition marks a major change in the physical properties and inferred depositional style of the rock units. The western boundary of the study area was selected arbitrarily to coincide with the western county lines of Stephens, Young, Archer, and Wichita Counties. This generally conforms to the axis of the Bend Flexure and to an area characterized by a transition from terrigenous- to carbonate-dominated deposition.

Lithology cannot be determined directly from electric logs, but logs consistently measure physical properties that are, in part, a product of lithic composition. Calibration of well log response patterns with sample logs and descriptions of cuttings and cores plus discussions with geologists familiar with the Fort Worth Basin about well log response to various lithic types in the Atoka Group led to several generalizations. (1) Sandstones and conglomerates are characterized by small, rounded, negative SP deflections and by well-developed resistivity curves; especially high, spikey, positive resistivity deflections characterize conglomerates. (2) Limestones are characterized by flat SP responses and by well-developed resistivity deflections that commonly reach maximum positive values; however, thick limestones tend to produce broad, rounded, negative SP curves.

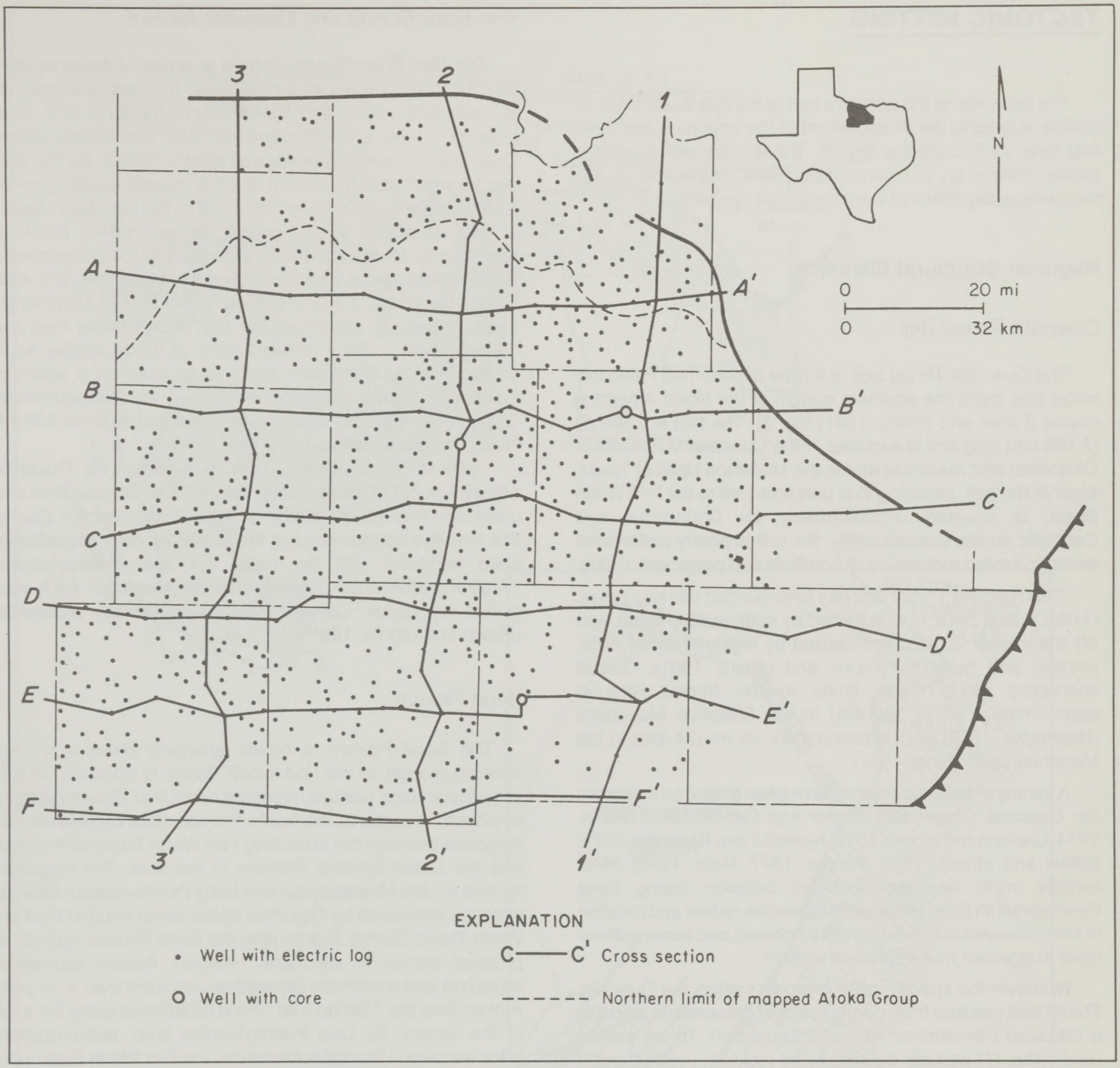

Figure 2. Map of study area, showing well control, cross sections, and core locations. Additional information, including well numbers and major towns, is shown on plate I. Appendix 1 lists names of wells used in cross sections.

Lithic determinations were made for each well log and were checked for lateral consistency by well correlation. Thickness values for sandstones and limestones were determined from the resistivity curve. For consistent results, log deflections were summed only where they extended beyond the shale baseline a quarter of the total distance from the baseline to the highest resistivity deflection. Regional consistency was emphasized rather than anomalous or nondiagnostic curves on individual logs. After net-sandstone and net-limestone values were tabulated for the lithogenetic units, isolith maps were constructed.

Available cores were described in detail and were correlated with the lithogenetic units. On the basis of lithology and sedimentary structures, component facies were delineated, and depositional environments were inferred.

Thin sections of representative samples of the various facies were stained to highlight orthoclase and carbonate minerals. Standard petrographic and scanning electron microscopy (SEM) techniques were used to determine composition, diagenetic sequences, and distribution of porosity. Shale composition was determined by X-ray diffraction of random and oriented samples.

Maps showing the distribution, type, and cumulative production of hydrocarbon from Atoka reservoirs were constructed using data from the International Oil Scouts yearbook (1978) and Railroad Commission of Texas field maps.

TECTONIC SETTING

The evolution of the northern part of the Fort Worth Basin is closely related to the development of the structural elements that form its boundaries (fig. 1). These elements exerted a strong control on the composition and distribution of the terrigenous depositional systems within the basin.

Regional Structural Elements

Ouachita Thrust Belt

The Ouachita Thrust Belt is a zone of deformed Paleozoic rocks that mark the southern margin of the North American craton (Flawn and others, 1961) (fig. 3). The belt is 1,300 mi (2,100 km) long and is exposed in the Ouachita Mountains of Oklahoma and Arkansas and in the Marathon Uplift of Texas. Most of the belt, including that part adjacent to the Fort Worth Basin, is covered unconformably by Cretaceous and Cenozoic strata. Consequently, the belt is poorly understood owing to limited availability of borehole and geophysical data.

The Ouachita Thrust Belt has been divided into two zones: (1) the frontal zone, characterized by sedimentary strata, and (2) the interior zone, characterized by highly sheared slate, phyllite, and quartzite (Flawn and others, 1961). Crustal shortening along major faults in the frontal zone is approximately 50 mi (80 km) in the Ouachita Mountains (Hendricks, 1959) and approximately 15 mi (24 km) in the Marathon Uplift (King, 1937).

A variety of tectonic models have been proposed to explain the Ouachita Thrust Belt (Keller and Cebull, 1973; Morris, 1974; Graham and others, 1975; Nicholas and Rozendal, 1975; Cebull and others, 1976; Walper, 1977; Viele, 1979). Most models imply continent-continent collision during Early Pennsylvanian time. However, the precise nature and location of the collisional suture is currently debated, and some authors have suggested non-collisional models.

Whatever the specific plate-tectonic setting, the Ouachita Thrust Belt resulted from compressional deformation, and it is a classical thin-skinned fold and thrust belt. Thrust sheets were either (1) partially buttressed by residual, positive areas on the craton, such as the Llano and the Belton-Tishomingo Uplifts, or (2) thrust over salients, such as the Oklahoma embayment. Where thrust sheets encountered a buttress, compressive stresses resulted in uplift with normal faults (such as in the Llano Uplift), or uplift with consequent reactivation of old fault systems along high-angle reverse faults. The later mode of deformation is expressed by the extensive series of parallel, fault-bounded uplifts in southern Oklahoma. Where thrust sheets overrode a salient, the older carbonate platform was downwarped to form a foreland basin, such as the Fort Worth Basin.

Along the eastern edge of the Fort Worth Basin, uplifted thrust sheets formed a tectonic highland. This highland shed sediment into the Fort Worth Basin during Early to Middle Pennsylvanian time. During Middle to Late Pennsylvanian time, the basin filled, causing a progressive westward shift of the depocenters.

Red River-Electra and Muenster Arches

The Red River-Electra Arch is a series of discontinuous fault blocks that strike west-northwest. The faults are believed to have been controlled by basement fractures that were initiated in the Late Precambrian and reactivated during Ouachita deformation (Ham and others, 1964). As the fault blocks were uplifted, coarse arkosic conglomerate (granite wash) was shed into the northern end of the Fort Worth Basin.

The Muenster Arch consists of an uplifted block of Cambrian-to Mississippian-age sedimentary rocks that mantle Precambrian igneous and metamorphic basement. The arch strikes northwest along the trend of the Belton-Tishomingo Uplift. It partially separates the Fort Worth Basin from the Marietta Basin. The southwest flank of the Muenster Arch, adjacent to the Fort Worth Basin, is bounded by a series of faults that exhibit displacement down to the southwest. Displacement across these faults is estimated to be 5,000 ft (1,524 m) (Flawn and others, 1961).

Uplift of the Muenster Arch in response to Ouachita compressional stresses began in Late Mississippian time and continued through the Middle to Late Pennsylvanian. During this time the northern end of the Muenster Arch sporadically shed sediment into the basin. By Late Pennsylvanian (Virgilian) time uplift ceased, and the Muenster Arch was buried by Upper Canyon (Missourian Series) sediments (Flawn and others, 1961).

Bend Flexure

The Bend Flexure, a broad structural element on the western margin of the Fort Worth Basin, is observed in the subsurface as a positive, elongate ridge that strikes north to south and plunges to the north. The structure represents the hingeline between the subsiding Fort Worth Basin to the east and the stable Concho Platform to the west. The hingeline formed in Late Mississippian and Early Pennsylvanian time as stresses generated by Ouachita deformation created the Fort Worth Basin. During Atokan time the Bend Flexure was not a physical barrier to sediment transport. Atokan sediments onlapped and eventually prograded westward over it. In Late Atokan time the "Caddo reef" trend developed along the axis of the flexure. By Late Pennsylvanian time, sedimentation rates exceeded basinal subsidence, the Fort Worth Basin was filled, and the Bend Flexure was blanketed by terrigenous sediment. During Late Pennsylvanian and Permian time, North-Central Texas was tilted westward, giving the Bend Flexure its present structural configuration (Brown and others, 1973).

Local Structure

As the Fort Worth Basin subsided, intrabasinal faults developed in response to extensional deformation (pl. XI). In the central part of the study area, the faults strike northeast, subparallel to the western edge of the Ouachita Thrust Belt, and coincide with trends of major faults in the Llano Uplift. These faults are inferred to exhibit normal displacement. Faults are typically downthrown to the southeast. However, they also form an en echelon series of horsts and grabens.

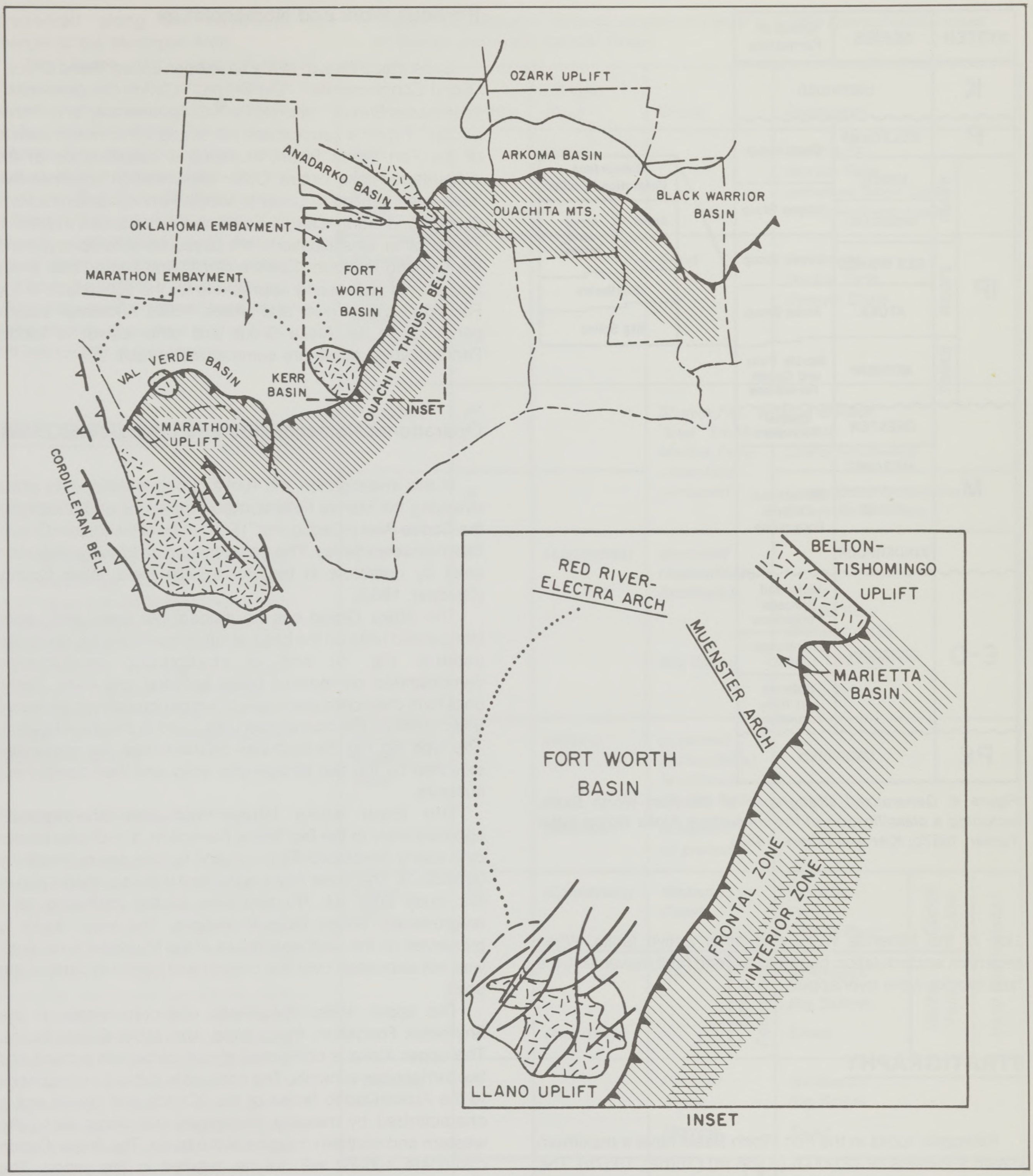

Figure 3. Ouachita Thrust Belt and associated structural elements (after King, 1975).

Near the northern margin of the basin the faults become subparallel to the Electra and Muenster Arches. These faults are also inferred to be normal, and they are downthrown toward the center of the basin.

During Early Atokan time, faulting and sedimentation were contemporaneous; consequently, major faults controlled sediment distribution. The most active and significant fault in the study area is the Mineral Wells fault (pl. XI). This fault, informally named for the Texas town of Mineral Wells that it directly underlies, exhibits approximately 300 ft (91 m) of displacement. Terrigenous sediment derived from the Ouachita tectonic highlands accumulated on the downthrown

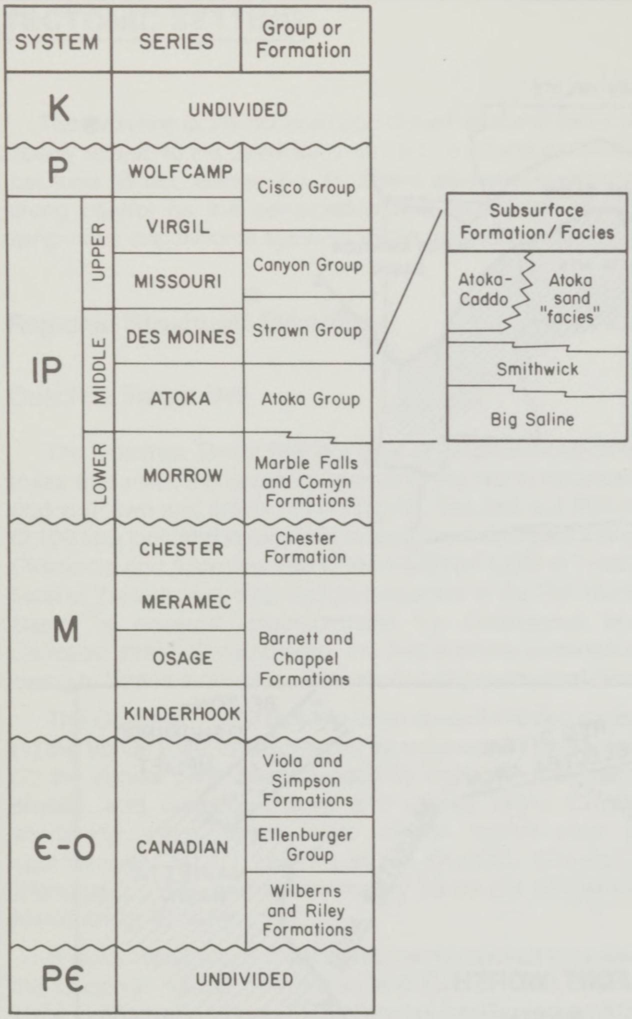

Figure 4. Generalized stratigraphy of the Fort Worth Basin, including a classification of the subsurface Atoka Group (after Turner, 1957b; Kier and others, 1980).

side of the Minerals Wells and other active faults. When sediment accumulation began to exceed fault movement, the fault blocks were overlapped.

STRATIGRAPHY

Paleozoic rocks in the Fort Worth Basin have a maximum known thickness of 12,000 ft (3,658 m) (Turner, 1957b). The Atoka Group, which composes half to three-fourths of the Paleozoic section, is time equivalent to the Dornick Hills Formation in the Ardmore Basin (Moore and others, 1944) and the Atoka Formation in the Ouachita Mountains of Oklahoma (Harlton, 1934). This group is partially time equivalent to the upper Marble Falls and Smithwick Formations near the Llano Uplift (Kier and others, 1980) and gradational with part of the subjacent upper Marble Falls Formation in the Fort Worth Basin.

Previous Work and Nomenclature

Subsurface Atokan strata have been called "Bend Group," "Bend Conglomerate," "Big Saline," "Caddo Conglomerate," "Lampasas Series," "Marble Falls Conglomerate," and "Atoka Group." Figure 4 summarizes the stratigraphic nomenclature of the Fort Worth Basin, including a classification of the subsurface Atoka Group. Other classification schemes that have been applied to Lower to Middle Pennsylvanian rocks of Central and North-Central Texas are summarized in table 1. These other classifications are based on outcrop studies of the Concho Platform (Eastern Shelf) and Llano Uplift areas and are not necessarily appropriate for the subsurface of the Fort Worth Basin (Kier and others, 1980). Additional studies pertaining to the Atoka Group and other Lower to Middle Pennsylvanian strata are summarized in table 2.

Operational Nomenclature and Lithogenetic Units

In this investigation, the Atoka Group is defined as strata overlying the Marble Falls or older formations and underlying the Caddo Pool ("Caddo reef") Formation of the Strawn Group, Desmoinesian Series. This nomenclature follows the definition used by operators in the Boonesville Field, Wise County (Gardner, 1960).

The Atoka Group can be divided into lower and upper lithogenetic units on the basis of differing electric log response patterns (fig. 5) and of stratigraphic relationships demonstrated on regional cross sections (pls. II-X). These units form distinctive packages of terrigenous clastic sediment and constitute the operational units used in this investigation. The type log (fig. 5) illustrates characteristic log responses exhibited by the two lithogenetic units and their component subunits.

The lower Atoka lithogenetic unit corresponds approximately to the Big Saline Formation. It is characterized by a poorly developed SP curve and by thin, spikey resistivity deflections. The lower Atoka is thickest in the southeast part of the study area (pl. XII) and thins to the northwest as it progressively onlaps older formations. The lower Atoka is preserved on the southeast flanks of the Muenster Arch, but it was not deposited over the central and northern parts of the uplift.

The upper Atoka lithogenetic unit corresponds to the Smithwick Formation, Atoka sand, and Atoka-Caddo facies. The upper Atoka is composed of one carbonate subunit and two terrigenous subunits. The carbonate subunit corresponds to the Atoka-Caddo facies of the "Caddo reef" trend and is characterized by massive limestones that occur along the western and northern margins of the basin. The Atoka-Caddo carbonate subunit will not be detailed in this report. The terrigenous upper Atoka subunits are (1) the upper Atoka "Davis," also known as the "pregnant shale," characterized by a weak SP curve and a resistivity curve that exhibits an upward-increasing deflection, and (2) the upper Atoka "post-Davis," characterized by spikey electric log patterns similar to those of the lower Atoka lithogenetic unit. The upper Atoka unit is thickest in the southeast part of the study area along the front of the Ouachita Thrust Belt (pl. XIII) and thins to the northwest as it overlaps the Bend Flexure. The upper Atoka is also preserved along the southeast margin of the Muenster Arch.

The lower and upper Atoka lithogenetic units interfinger with an arkosic conglomerate in the northern end of the Fort Worth Basin. These alluvial fans and fan deltas composed of granite wash were derived from the Red River-Electra Arches. Although they are Atokan age, their source, composition, and depositional geometry are distinctly different from the rest of the Atoka Group. Thus, they are considered a separate stratigraphic sequence and will not be addressed in this report.

DEPOSITIONAL SYSTEMS

Lower Atoka Lithogenetic Unit

The lower Atoka lithogenetic unit is interpreted to be a fluvially dominated fan-delta system in which contemporaneous faulting influenced facies distribution. The lower Atoka is characterized by highly digitate sandstone geometry, extensively interfingered terrigenous and carbonate units, and progradational facies sequences.

Sandstone Distribution

The net-sandstone map of the lower Atoka (pl. XIV) indicates a terrigenous depositional system with a short transport distance from source to basin. Net-sandstone geometry is highly digitate and elongate. Individual sandstone units are thicker in the east and characterized by blocky electric log patterns that imply aggradation. To the west the sandstone units progressively break up into a series of thin, discontinuous beds averaging 10 ft (3 m) thick, and are commonly intercalated with thin limestones.

The primary source of lower Atoka sediment was the Ouachita Thrust Belt; depocenters were located in central Denton County, and in Parker and Tarrant Counties. A secondary source of sediment was the Muenster Arch, which supplied a depocenter in northwest Denton County.

Table 1. Classification schemes applied to Lower to Middle Pennsylvanian rocks of Central and North-Central Texas.

Author	System	(Series) Stage	Group	Formation
Girty, 1919; Moore, 1919.	IP	(Bend)		Smithwick Marble Falls unnamed black shale or Lower Bend Shale
Plummer and Moore, 1921; Moore and Plummer, 1922.	IP		Bend	Smithwick Marble Falls Barnett Shale
Goldman, 1921.	IP		Strawn Fm. "Millsap division" "true" Smithwick Shale Marble Falls Limestone	Lower Smithwick
	M		unnamed	Lower Bend Limestone Lower Bend Shale
Cheney, 1940.	IP	(Lampasas)	unnamed (subsurface) Smithwick Big Saline	Parks Caddo Pool Eastland Lake Sipe Springs DeLeon
Spivey and Roberts, 1946.	IP	(Atoka) (Morrow)	unnamed (subsurface) Smithwick Marble Falls unnamed (if present)	
Cheney, 1947.	IP	(Lampasas)	Kickapoo Creek	Rayville Parks Caddo Pool (Caddo Lime; Bend (subsurface))
		(Morrow)	Bend (Atoka Equivalent)	Smithwick Big Saline Sloan (Marble Falls; Bend (subsurface))
Plummer, 1947.	IP		Bend or Atoka Morrow	Smithwick Big Saline Sloan
Cheney and Goss, 1952.	IP	(Lampasas) Kickapoo Creek (Lampasas) Atoka (Morrow)	Caddo Lime Bend (outcrop)	Rayville Parks Caddo Pool Smithwick Big Saline Upper Marble Falls Comyn (subsurface) Lower Marble Falls

Table 2. Summary of studies on the Atoka Group and other Lower to Middle Pennsylvanian strata.

Author	Study
Cummins, 1889; Tarr, 1889; Drake, 1892.	Described rock sequences in North-Central Texas and designated stratigraphic groups on the basis of lithologic variations.
Harlton, 1934.	Discussed lithologic and microfaunal characteristics of Bendian age rocks in the Ouachita Mountains and applied those characteristics to Texas strata.
Cheney and others, 1945; Moore and Thompson, 1948.	Classified Pennsylvanian strata in the USA with regional divisions on the basis of paleontological features.
Thompson, 1947.	Used fusulinids to date pre-Desmoinesian rocks in the Llano Uplift area.
Barnes, 1948.	Described the occurrence of Ouachita type "facies" in the Austin, Texas, area.
Weaver, 1956.	Discussed the distribution of Middle Pennsylvanian strata in the Fort Worth Basin.
Bradfield, 1957a; 1957b.	Reviewed the general stratigraphy and structural history of Cooke and Grayson Counties, north Texas. Includes cross sections and a description of Atokan age strata.
Turner, 1957a.	Suggested that the term "Lampasas Series" was incorrectly applied to rocks in North-Central Texas.
Tikrity, 1964.	Described the general subsurface characteristics of middle Atokan age rocks in the southwest quarter of Wise County, Texas (Boonesville Bend gas field area). Isopachs of various intervals included.
Turner, 1970; Watson, 1980.	Reviewed Paleozoic stratigraphy of the Llano Uplift area with emphasis on the Mississippian and Pennsylvanian Periods.
Matos, 1971; Solis, 1972.	Described the subsurface structure and stratigraphy of the central Fort Worth Basin.
Gee, 1976.	Described regional characteristics of the base of Pennsylvanian-age rocks in the Fort Worth Basin.
Ng, 1979.	Described subsurface lithologic characteristics of the Atoka Group in parts of Jack, Palo Pinto, Parker, and Wise Counties, Texas. Sandstone/shale ratios given.
Kier, 1980.	Described relation of the Marble Falls Formation in the Llano Uplift area to terrigenous strata of equivalent or similar age.

From geometries exhibited by net-sandstone and isopach maps (pls. XII and XIV), it may be inferred that faulting and lower Atoka sedimentation were contemporaneous. Initially, fault movement exceeded sediment supply, and sand deposition was confined to the downthrown side of active faults, such as the Mineral Wells fault. This caused the sand bodies to become superposed. When sediment supply exceeded fault movement, fan-deltas continued prograding westward across the basin.

Two principal fan-delta lobe complexes are located on the northwest side of the Mineral Wells fault. The older complex, the Palo Pinto fan-delta lobe complex, is centered in Palo Pinto County (pl. XIV). This complex reflects progradation by terrigenous clastics derived from the Ouachita Thrust Belt. With continuous sedimentation, stream avulsion caused deposition to shift to the north, and a second fan-delta lobe complex developed. The younger complex, the Decatur fan-delta lobe complex, is centered in Wise County (pl. XIV). It reflects the progradation of sediment shed from both the Ouachita Thrust Belt and the Muenster Arch.

Limestone Distribution

Comparison of the net-limestone map (pl. XV) and net-sandstone map (pl. XIV) for the lower Atoka lithogenetic unit indicates that widespread carbonate deposition was contemporaneous with and influenced by terrigenous deposition. Individual limestone units average 10 ft (3 m) thick or less. They occur both independent of and in proximity to sandstones. When associated with sandstone, the limestone units either may form an encrusting cap on top of the sandstones or may be conformably overlain by sandstone sequences.

Limestone deposits are thickest in a broad zone that trends northeast through Stephens, Palo Pinto, Parker, and southern Wise Counties, and that generally parallels the Mineral Wells fault. The number of individual limestone units is greater on the southeast side of the Mineral Wells fault because of (1) the initial transition from a carbonate to a terrigenous-dominated environment when Ouachita-derived sediment was first deposited and (2) the abandonment of incipient fan-delta sand lobes and subsequent colonization by marine organisms. Upon subsidence these areas of intermittent sand deposition provided a firm, slightly elevated substrate conducive to the growth of extensive marine biotic communities. Northwest of the Mineral Wells fault, distribution of limestone was controlled (1) by the distribution of fan-delta sand-lobe complexes, and (2) by the relief on the pre-Atoka erosional surface.

Facies

Three facies assemblages exist in the lower Atoka: (1) terrigenous clastic facies, (2) mixed terrigenous-carbonate facies, and (3) carbonate facies assemblages. The characteristics and inferred depositional processes recorded by facies of each assemblage are summarized in table 3. Figure 6 illustrates the lithologic and sedimentary structures characterized by a few of these facies.

The lower Atoka facies tract is characterized by an overall coarsening-upward sequence of terrigenous clastics (fig. 7). This idealized sequence (carbonate shelf - prodelta - distal delta front - proximal delta front - fan-delta lobe) is diagnostic of the progradation of terrigenous clastics into a marine setting; consequently, the sequence reflects a transition from carbonate-dominated environments to terrigenous-dominated environments. Variations of the progradational facies sequence are due to the addition of facies that reflect random events, such as storm deposits and various post-depositional modifications of fan-delta lobes. These variations can be seen in core (figs. 8 and 9). Storm deposits occur in the Gulf Oil Company #2 Button Crowley core (5,350 to 5,352 ft) and in the Mitchell Energy Company #6-4 Deaver core (5,667 to 5,668, 5,673 to 5,674, 5,746 to 5,746.5, and 5,755 to 5,756 ft). Post-depositional modifications include (1) fining-upward sequences caused by gradual abandonment and subsidence of delta lobes (#2 Button Crowley core, 5,303.5 to 5,331.25 ft), (2) coarsening-upward and fining-upward sequences resulting from the deposition of delta lobes followed by rapid subsidence and colonization by an encrusting veneer of marine organisms (#6-4 Deaver core, 5,737 to 5,739 and 5,748 to 5,748.5 ft), (3) coarsening-upward sequences that fine at the top produced by the reworking of abandoned delta lobes by marine processes (#2 Button Crowley core, 5,331.25 to 5,340.5 ft), and (4) blocky, aggradational sequences composed of composite fining-upward, blocky, and coarsening-upward sub-sequences resulting from aggradation by delta channel and delta-plain facies above earlier fan-delta lobes (#2 Button Crowley core, 5,294 to 5,331.25 ft).

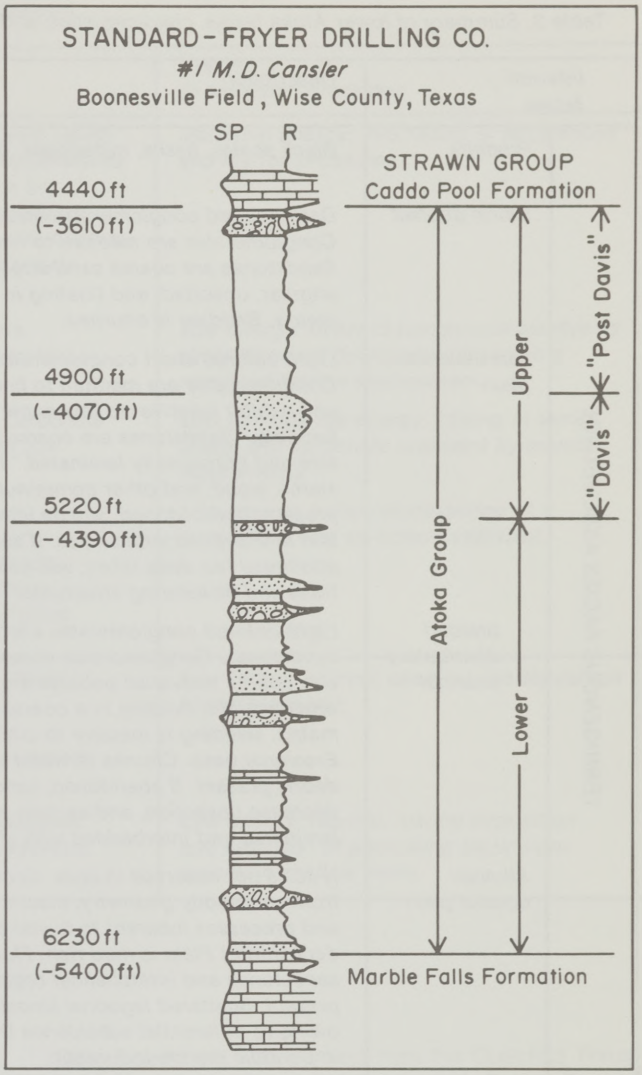

Figure 5. Type log for the Atoka Group, Fort Worth Basin. Log illustrates lithogenetic units and component subunits used in this study. Log is located in the central part of the study area. In other parts of the basin the Atoka Group may overlie the Chappel Limestone, Comyn Limestone, or Barnett Shale. It may be overlain by Strawn sandstones or truncated by the base of the Cretaceous sequence (1 ft≈0.3048 m).

Interpretive Model

The lower Atoka lithogenetic unit is interpreted to be a fluvially dominated fan-delta system because it exhibits characteristics of both a fan-delta and a high-constructive, elongate delta system.

Fan deltas are alluvial fans that prograde into a standing body of water (Holmes, 1965; McGowen, 1970). They are characterized by braided distributary channels, flashy discharge with sediment deposited abruptly during periods of flood, sheet flow, angular and coarse-grained sediment, and extensive interfingering of coexisting terrigenous and carbonate facies. Fan deltas commonly occur adjacent to tectonically active sources, and the short transport distance from source to basin results in poorly developed alluvial-coastal plain facies.

Like other deltas, fan deltas exhibit a geometry that is a result of the interaction of fluvial, wave, and tidal processes. The interaction and balance of these processes combined with other factors, such as water depth, amount and type of sediment, and structure of the depositional basin, affect subsidence rates and determine regional sandstone distribution patterns (Fisher and others, 1969; Galloway, 1975).

Fan-delta analogs for the lower Atoka unit include both modern and ancient examples. Modern fan deltas, where wave energy is the most significant process, are the Liguanea gravel fan near Kingston, Jamaica (Goreau and Burke, 1966), the Gum Hollow fan delta, Nueces Bay, Texas (McGowen, 1970), and the Yallahs fan delta, southeast Jamaica (Wescott and Ethridge, 1980). A fan delta where wave and tidal processes are equally significant is the Copper River fan delta, Alaska (Galloway, 1976). An ancient wave-dominated fan-

Table 3. Summary of lower Atoka facies, characteristics, and depositional processes on the basis of core. (See figures 8 and 9.)

	Inferred facies	Description	Inferred depositional processes
TERRIGENOUS FACIES ASSEMBLAGE	Prodelta	Black shales, fissile, micaceous, organic rich.	Low energy. Subaqueous deposition from suspension.
	Storm deposit	Dark-colored conglomerates and sandstones. Conglomerates are medium to fine granule size. Sandstones are coarse sand size. Grains are angular, unsorted, and floating in a clay-rich matrix. Bedding is churned.	High energy. Rapid, sporadic deposition by fluvial and debris-flow processes.
	Fan-delta-lobe plain	Light-colored chert conglomerates and sandstones. Conglomerates are medium to fine granule size and exhibit massive- to low-angle cross bedding.* Sandstones are coarse to fine sand size and horizontally laminated.* Plant leaves, stems, wood, and other comminuted organics present. If abandoned, will be interlaminated and interbedded with shales. If superposed by additional fan delta lobes, will exhibit contortions and dewatering structures.*	Low to high energy. Rapid, episodic deposition by fluvial, sheet-flow and debris-flow processes followed by a waning of transport energy.
	braided distributary channel	Light-colored conglomerates and conglomeratic sandstones. Conglomerates composed of pebble-size chert.* Individual pebbles are angular, unsorted, and floating in a coarse-grained sand matrix. Bedding is massive to cross bedded. Erosional base. Chunks of wood and other organic debris present. If abandoned, sand size will decrease upsection, and section will be interlaminated and interbedded with shale.	High energy. Rapid deposition by fluvial processes.
	Alluvial/ coastal plain	(Facies not observed in core. Occurrence inferred from sand-body geometry, electric-log responses, and processes inherent to fluvial-deltaic deposition.) Plain is mud rich. Fluvial-channel sandstones and interchannel organic-rich shales present. Scattered lagoonal limestones present owing to differential subsidence that resulted in periodic marine induration.	Low to moderate energy. Deposition by fluvial processes with crevasse splays, overbank flooding and avulsion resulting in aggradation.

delta system is the Pliocene Intra-Apenninic Basin system in Italy (Lucchi and others, 1981). Ancient wave-dominated to fluvially dominated fan-delta systems occur in subsurface Pennsylvanian and Permian strata of the Palo Duro Basin (Dutton, 1980) and in Missourian strata of the Anadarko Basin (Becker, 1977; Dutton, 1982). Ancient, fluvially dominated fan-delta systems occur in the Pennsylvanian Canyon Group of North-Central Texas (Erxleben, 1975) and in the Devonian strata of the Hornelen Basin, Norway (Gloppen and Steel, 1980).

In high-constructive, elongate deltas, fluvial processes dominate marine processes (Fisher and others, 1969). These deltas are characterized by a highly digitate and a dip-elongate sand-body geometry and a coarsening-upward or progradational facies sequence. The sediment load in high-constructive, elongate delta systems is mixed. Sand-rich delta-front facies typically prograde over a relatively thick prodelta mud sequence. Upon abandonment, delta lobes subside rapidly and are covered by mud, and consequently their depositional geometry is preserved (Fisher and others, 1969). Modern high-constructive, elongate deltas include the Mississippi Delta system (Frazier, 1967) and the Colorado River Delta in Matagorda Bay, Texas (Kanes, 1970). Ancient high-constructive, elongate deltas include the Perrin Delta (Pennsylvanian, Canyon Group) of North-Central Texas described by Erxleben (1975), and the Rockdale Delta system (Eocene, Lower Wilcox Group) of the Texas Gulf Coast described by Fisher and McGowen (1967).

A fluvially dominated fan-delta model can provide an explanation for the net-sandstone geometry exhibited by the lower Atoka lithogenetic unit (fig. 10). At the end of lower Atoka deposition, the Mississippian carbonate platform had been downwarped and was being onlapped by granite wash that was shed from the Red River-Electra Arch to the north and chert conglomerates that were shed by the Ouachita Thrust Belt and locally from the Muenster Arch to the east and northeast. In the southeast part of the study area a lower Atoka alluvial/coastal plain formed by the progressive superposing and coalescence of early fan deltas on the downthrown side of the Mineral Wells fault. Northwest of the Mineral Wells fault, fan-delta lobes prograded approximately 30 mi (48 km) into the basin, and prodelta and delta-front facies extended another 20 mi (32 km) onto the marine shelf. Both the alluvial/coastal plain and the fan-delta lobes are interpreted to have had low relief and were periodically subject to marine induration because of differential basin subsidence.

Table 3 (continued)

Inferred facies		Description	Inferred depositional processes
MIXED TERRIGENOUS - CARBONATE FACIES ASSEMBLAGE	Proximal delta front	Sandstones and conglomeratic sandstones. Sandstones are fine to coarse sand size. Conglomerates are fine granule size. Terrigenous grains are dominantly quartz and chert. Carbonate grains include crinoid, brachiopod, bryozoan, echinoderm, and algal fragments. All grains are moderately to poorly sorted.	Moderate energy. Interfacing of terrigenous and marine processes.
	embayment	Grains in black, organic, clay-rich matrix. Carbonate skeletal grains are large, unbroken, with micrite rims and algal borings.	Low energy. Influx of terrigenous clastics by sheet-flow and fluvial processes into a restricted marine environment.
	shoreface	Light color. Low-angle cross bedding. Carbonate skeletal grains are large, sharply broken but not abraded.	Low to moderate energy. Mixing of terrigenous and carbonate sediment by marine wave energy.
	Distal delta front	Silty wackestones and interbedded black shales.* Interbeds thin, wavy to lenticular. Carbonate skeletal grains include fusulinids, bryozoan, gastropod, and crinoid fragments. Ripples, ripple-load casts, burrows, and plant leaves and stems common.	Low energy. Initial interfingering of terrigenous and carbonate sediment.
CARBONATE FACIES ASSEMBLAGE	Shallow marine shelf	Dark gray to black micritic limestones. Wavy bedding. Few unbroken coral, crinoid, brachiopod, trilobite, and mollusk shells. Burrowed. May be silty and contain thin imbedded black shales.	Low energy. Normal, open-marine deposition in shallow water.
	Buildup (banks, molds, and encrustations)	Dark gray to black phylloid algal boundstones.* Sand-sized mollusk and echinoderm fragments.	Low energy. Normal, marine deposition and evolution of encrusting biotic community in shallow water.

*See figure 6.

Upper Atoka "Davis" Lithogenetic Subunit

The upper Atoka "Davis" lithogenetic subunit is interpreted as a system of coalesced wave-dominated deltas. The "Davis" is characterized by a thick, strike-oriented sandstone geometry and by electric log patterns that suggest concurrent progradation and aggradation.

Sandstone Distribution

The net-sandstone map of the upper Atoka "Davis" (pl. XVI) indicates a strike-oriented framework of terrigenous facies. Net-sandstone geometry is tabular, and the locations of maximum thickness trends are concentrated in a narrow, strike-oriented zone. In the southeast part of the study area, individual sandstone units average 30 ft (9 m) thick and are separated by thick shale sequences. The units merge to the northwest and form a single sandstone package locally known as the "Davis sand," which averages 400 ft (122 m) thick. This sandstone package is characterized by a distinctive, upward-increasing resistivity curve, suggesting progradation, and a superposed blocky to serrate pattern, suggesting aggradation. To the north and northwest, this package thins to less than 20 ft (6 m), but maintains its progradational log character.

"Davis" sediment was derived from the Ouachita Thrust Belt; a major depocenter existed in western Parker County. Subsidiary depocenters developed irregularly along the strike of the thick sandstone zone.

Limestone Distribution

Carbonate strata are not extensive in the upper Atoka "Davis" lithogenetic subunit. A few thin limestone units occur southeast of the major sand depocenters. The units have a composite thickness of less than 20 ft (6 m), are geographically isolated, and occur randomly within the "Davis" subunit. These limestone units are interpreted to be delta-plain or alluvial-plain lacustrine deposits. They do not constitute a significant carbonate depositional system, and consequently are mapped with "post-Davis" limestones (pl. XVIII). The presence of "Davis" limestones is reflected by the scattered, anomalously thick net-limestone areas in Parker County.

Facies

Because cores of the "Davis" subunit were unavailable, detailed facies descriptions could not be made. However,

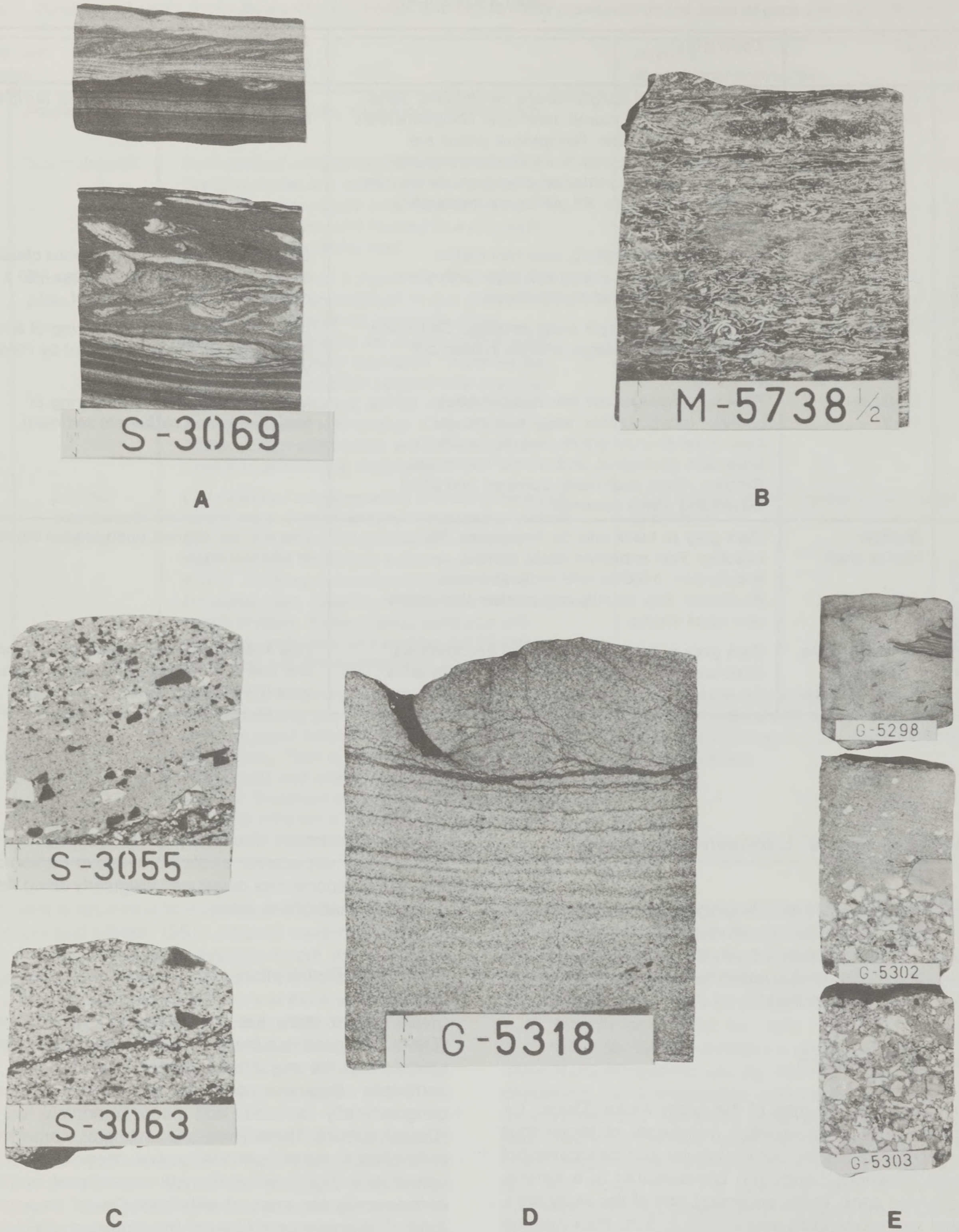

Figure 6. Core illustrating lithology and sedimentary structures characteristic of fluvially dominated fan-delta facies, Atoka Group, North-Central Texas. Number is drilled depth in feet. Label is 0.5 inch (1.25 cm) wide. G: Gulf Oil Company #2 Button Crowley core; M: Mitchell Energy Company #6-4 Deaver; S: Shell Oil Company #1 J. H. Doss. (A) S-3069, distal delta-front facies; (B) M-5738, algal boundstone, shallow marine buildup/encrustation facies; (C) S-3055 and S-3063, fan-delta braided distributary channel facies; (D) G-5318, fan-delta-plain facies; (E) G-5298½, G-5302, and G-5303, channel-fill facies.

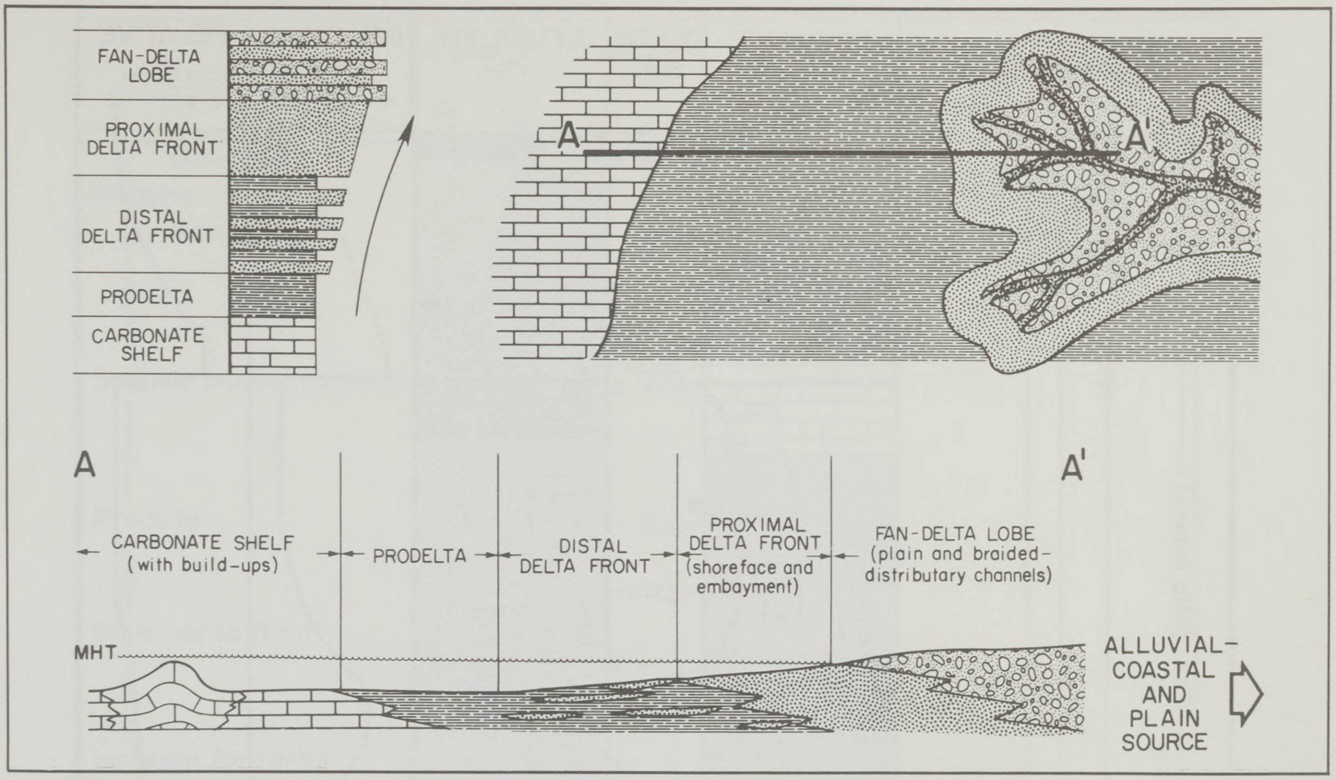

Figure 7. Lower Atoka facies tract. Idealized coarsening-upward sequence that reflects the progradation of terrigenous clastics into a marine setting.

terrigenous depositional systems displaying a similar sand-body geometry, such as the Rhône Delta system of southern France (Oomkens, 1967, 1970), imply the presence of a prodelta-clastic shelf, a delta front, a delta complex, and an alluvial-plain facies. Characteristics and dominant depositional processes of the inferred facies are summarized in table 4. An idealized facies tract for a "Davis" type system is shown in figure 11. This sequence (prodelta [clastic shelf] - delta front - delta complex [composed principally of coastal barrier facies] - alluvial plain) is diagnostic of concurrent progradation and aggradation of terrigenous clastics.

Interpretive Model

The upper Atoka "Davis" lithogenetic subunit is interpreted to be a wave-dominated system composed of coalesced chevron to arcuate deltas composed principally of coastal barrier facies. Coastal barriers are beach ridges or sand-rich strandplains characterized by linear sand ridges that accrete parallel to the shoreline. They are the major framework facies of wave-dominated deltas. In such deltas, wave reworking dominates fluvial processes and net sediment input. Moderate progradation of the coastline results in marine wave processes redistributing substantial amounts of sand to the margins of depocenters. Wave-dominated deltas are characterized by a chevron to arcuate sand-body geometry, strike-oriented sand distribution, and meandering to locally braided distributary channels (Fisher and others, 1969).

Wave-dominated delta analogs for the upper Atoka "Davis" subunit include both modern and ancient examples. Modern wave-dominated delta systems are the Rhône Delta, southern France (Oomkens, 1967, 1970), the Po Delta, western Gulf of Venice (Fisher and others, 1969), the Danube Delta, Black Sea (Zenkovich, 1967), and the Surinam coast, South America (Brower, 1953; Price, 1955). Ancient wave-dominated delta systems include the upper Wilcox system (Eocene) of the Texas Gulf Coast, described by Fisher and McGowen (1967), and the middle Vicksburg system (Oligocene), Texas Gulf Coast, described by Gregory (1966).

A wave-dominated delta model can provide an explanation for the net-sandstone geometry exhibited by the upper Atoka "Davis" lithogenetic subunit (fig. 12). At the end of "Davis" deposition, the upper Atoka "Davis" alluvial plain had superposed the lower Atoka alluvial plain. A wave-dominated system of delta complexes had been established, striking along the same trend as the Mineral Wells fault. Although there is no clear evidence of movement on the Mineral Wells fault during "Davis" deposition, differential subsidence rates may have caused this zone to act as a hingeline. Subsidence rates appear to have been greater on the southeast side of the fault and may have enhanced the accumulation of sand within the delta complex coastal barrier facies.

Comparison of upper Atoka "Davis" facies distribution with lower Atoka facies distribution suggests that the transition from lower Atoka to upper Atoka "Davis" deposition was marked by (1) a period of regional basinal subsidence that resulted in complete foundering of lower Atoka fan-delta complexes northwest of the Mineral Wells fault and in the establishment of new terrigenous depositional patterns, and (2) a transition from a fluvially dominated depositional system to a wave-dominated depositional system. This transition does

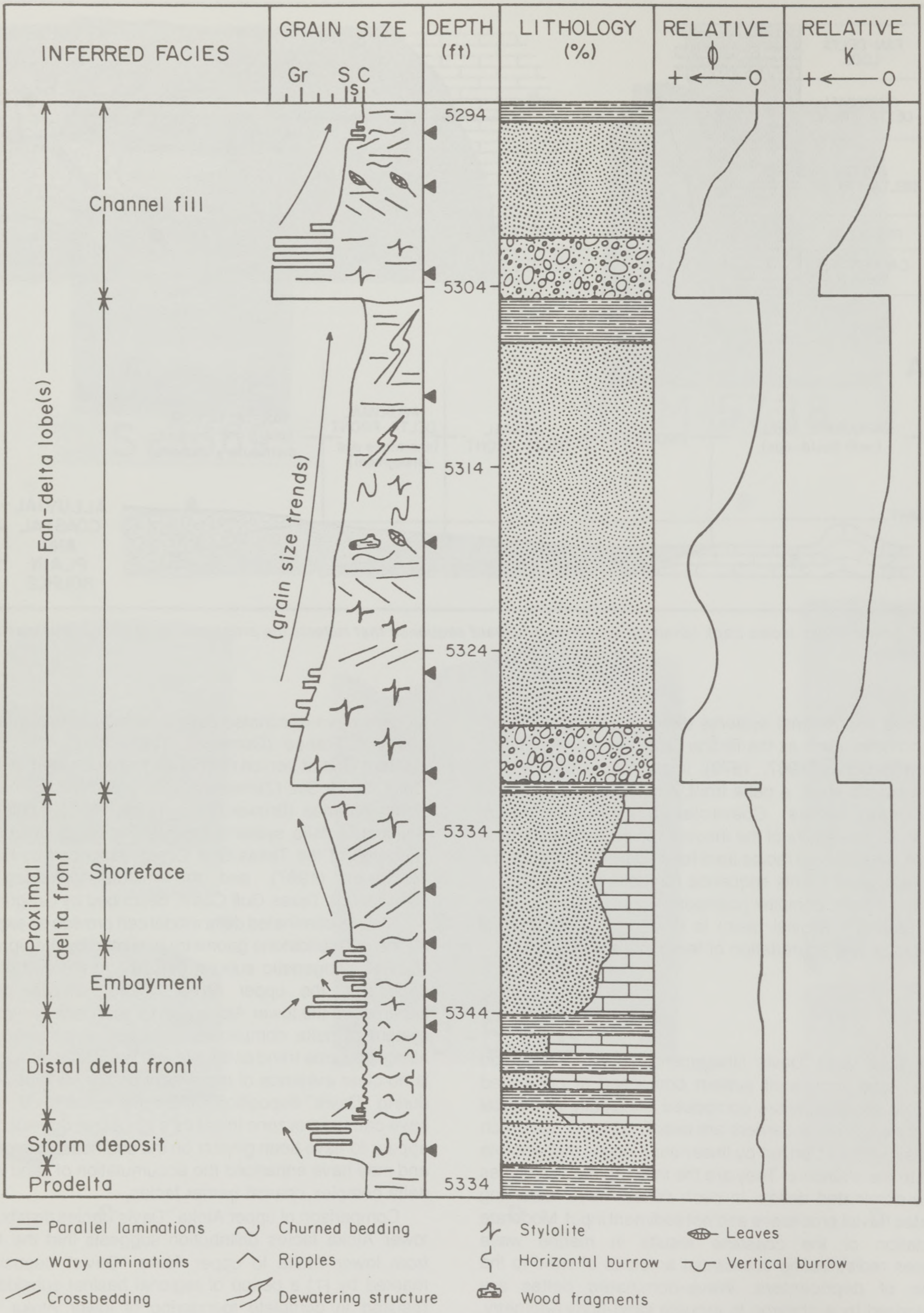

Figure 8. Descriptive log of lower Atoka core, Gulf Oil Company #2 Button Crowley, Jack County. Core shows variations on idealized coarsening-upward progradational sequence (1 ft≈0.3048 m). (Gr = granule, S = sand, s = silt, C = clay)

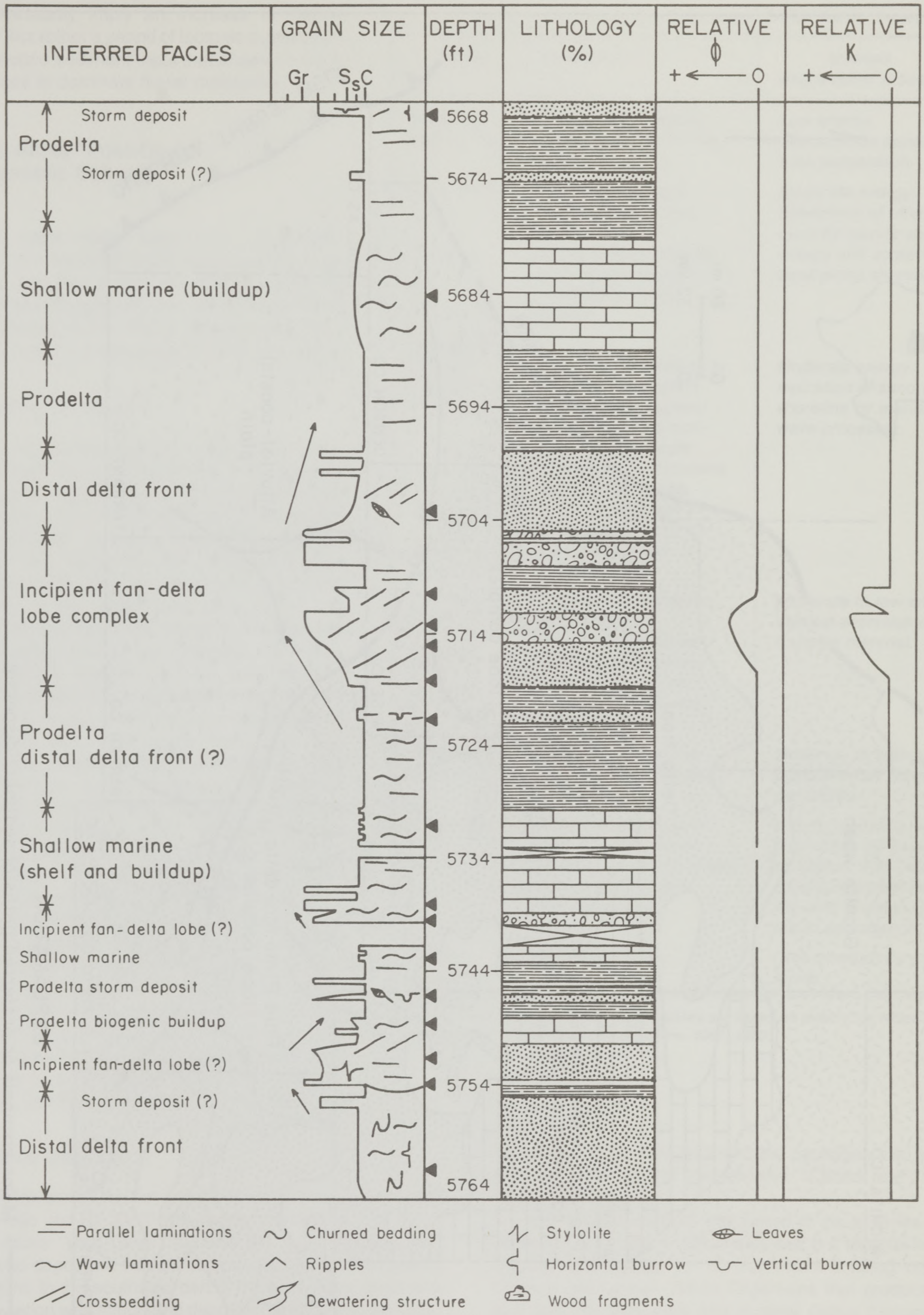

Figure 9. Descriptive log of lower Atoka core, Mitchell Energy #6-4 Deaver, Wise County. Core shows variations on idealized coarsening-upward, progradational sequence (core above 5,730 ft unslabbed) (1 ft≈0.3048 m). (Gr = granule, S = sand, s = silt, C = clay)

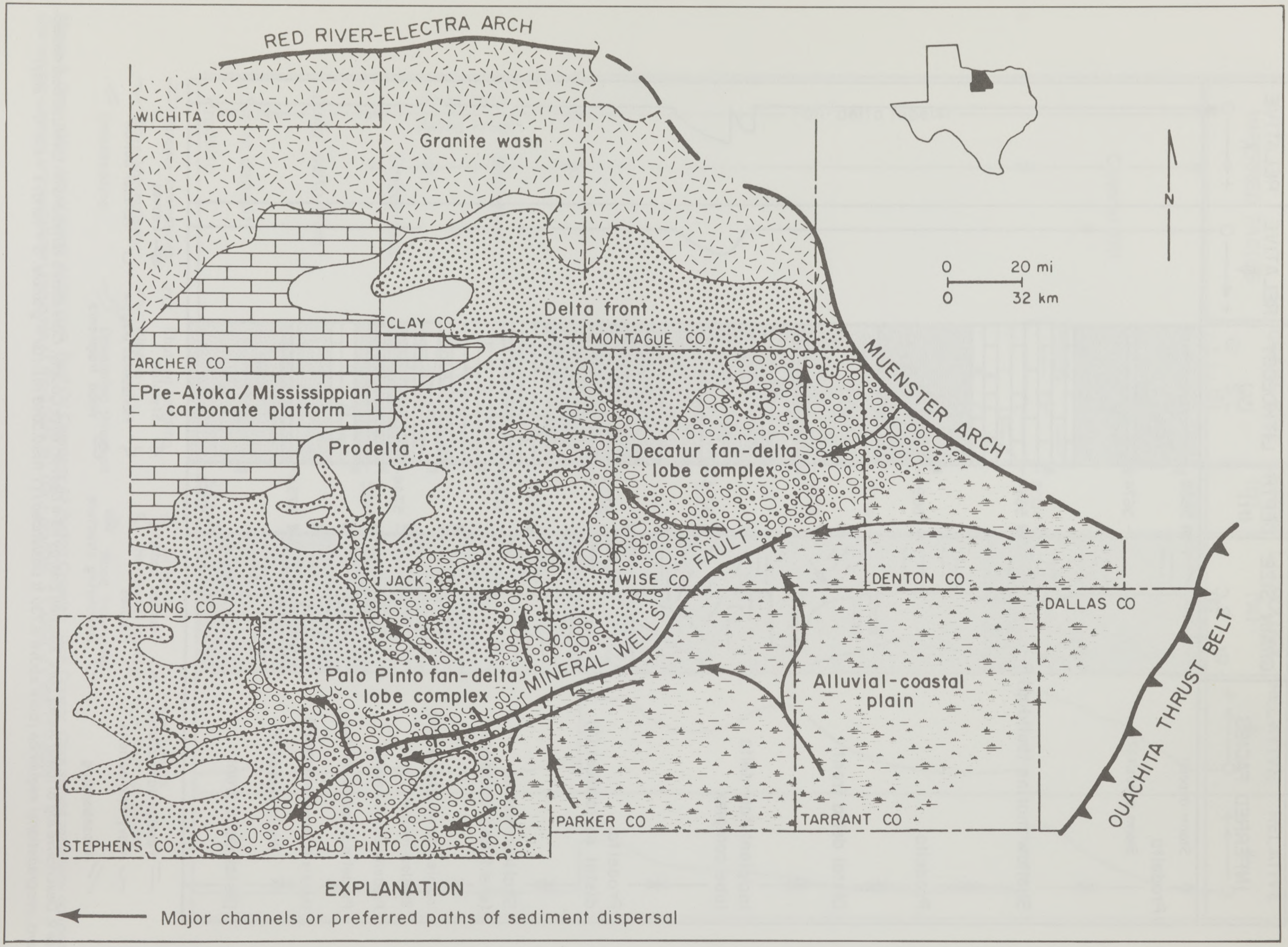

Figure 10. Distribution of lower Atoka facies. Fluvially dominated fan-delta morphology is based on net-sandstone map geometry.

not necessarily imply an increase in marine energy, but rather a period of tectonic quiescence and reduced sediment input that allowed marine processes to dominate fluvial processes.

Upper Atoka "Post-Davis" Lithogenetic Subunit

The upper Atoka "post-Davis" lithogenetic subunit is interpreted to be a poorly integrated, fluvially dominated fan-delta system. Like the lower Atoka lithogenetic unit, the "post-Davis" is characterized by a highly digitate sandstone geometry and a progradational facies sequence.

Sandstone Distribution

The net-sandstone map of the upper Atoka "post-Davis" (pl. XVII) indicates a terrigenous depositional system in which the framework sandstone units are thin and poorly integrated. Net-sandstone geometry is highly digitate, narrow, and elongate. The distribution and character of individual sandstone units are similar to those in the lower Atoka lithogenetic unit. Sandstone packages are thicker in the east and progressively break up westward into thin, discontinuous stringers. In the west (Archer, Young, and Stephens Counties), sandstone units average 5 ft (1.5 m) thick and are difficult to distinguish from hard shale streaks or silty limestones. These units are recognized and mapped as sandstone because of log response (pl. XVII). However, their irregular distribution suggests that they may be siltstones or calcareous shales.

Delta-lobe complexes in the "post-Davis" subunit prograded into the basin along three major depositional axes (pl. XVII). The northern axis of deposition in Wise and Jack Counties and the central axis of deposition in Denton and Wise Counties were supplied with sediment from the Muenster Arch. The southern axis of deposition in Parker County contains sediment derived from the Muenster Arch and the Ouachita Thrust Belt; it is the site of the best developed fan-delta complex, the Parker fan-delta lobe complex.

*Table 4. Summary of inferred upper Atoka "Davis" facies.**

Facies	*Description*	*Inferred depositional processes*
Prodelta (clastic shelf)	*Shales, fossiliferous, well-burrowed, can be silty.*	*Low energy. Subaqueous deposition from suspension.*
Delta front	*(Similar to coastal barrier facies.) Overall thickness of facies thinner, may be interlaminated and interbedded with shales.*	*Moderate energy. Reworking of offshore sand by marine wave energy and accretion of sand along shoreline.*
Delta complex		
coastal barrier	*Sandstones, medium to fine sand size, grain size increases upsection. Bedding is horizontal to low-angle cross bedded. Contains shells from marine, brackish, and freshwater fauna, plant detritus, and minor shale breaks.*	*Moderate energy. Accretion of sand along shoreline by marine wave processes.*
delta plain	*Sandstones, siltstones, and shales. Horizontally bedded. Contains shells from brackish to marine fauna, plant detritus, and rootlets.*	*Moderate to low energy. Vertical accretion of fluviatile material.*
distributary channel	*Sandstones, festoon cross bedded, channel lag.*	*Moderate to high energy. Deposition by fluvial processes.*
Alluvial plain	*Fluvial channel sandstones, interchannel marsh and swamp shales, and lacustrine limestones present.*	*Low to moderate energy. Deposition by fluvial processes with crevasse splays, overbank flooding, and avulsion resulting in aggradation.*
fluvial channel	*(See distributary channel facies.)*	*(See distributary channel facies.)*

**Characteristics and depositional processes are based on analogous facies in the Rhone Delta, southern France (Oomkens, 1967, 1970).*

Limestone Distribution

Comparison of the net-limestone map of the upper Atoka lithogenetic unit (pl. XVIII) with the net-sandstone map of the upper Atoka "post-Davis" subunit (pl. XVII) indicates that carbonate deposition was contemporaneous with terrigenous deposition. In the southeast part of the study area, limestone accumulation was minor, and depositional style was similar to that of the lower Atoka lithogenetic unit. Extensive limestone deposits are confined to the western and northern margins of the basin, outside the areas of terrigenous influence. Thickest limestone sequences coincide with the axis of the Bend Flexure, where individual limestone packages also are thick and constitute part of the massive "Caddo reef" trend or Atoka-Caddo facies.

The "Caddo reef" is interpreted to be a series of algal banks and mounds. A carbonate bank is a skeletal limestone deposit constructed by nonframework-building organisms (Nelson and others, 1962). Organisms that produce, baffle, and trap the lime mud and skeletal debris composing the banks include phylloid algae, bryozoans, and crinoids. Carbonate banks and mounds exhibit depositional relief with respect to the sea floor and are characteristic of low-energy, shallow, marine shelves.

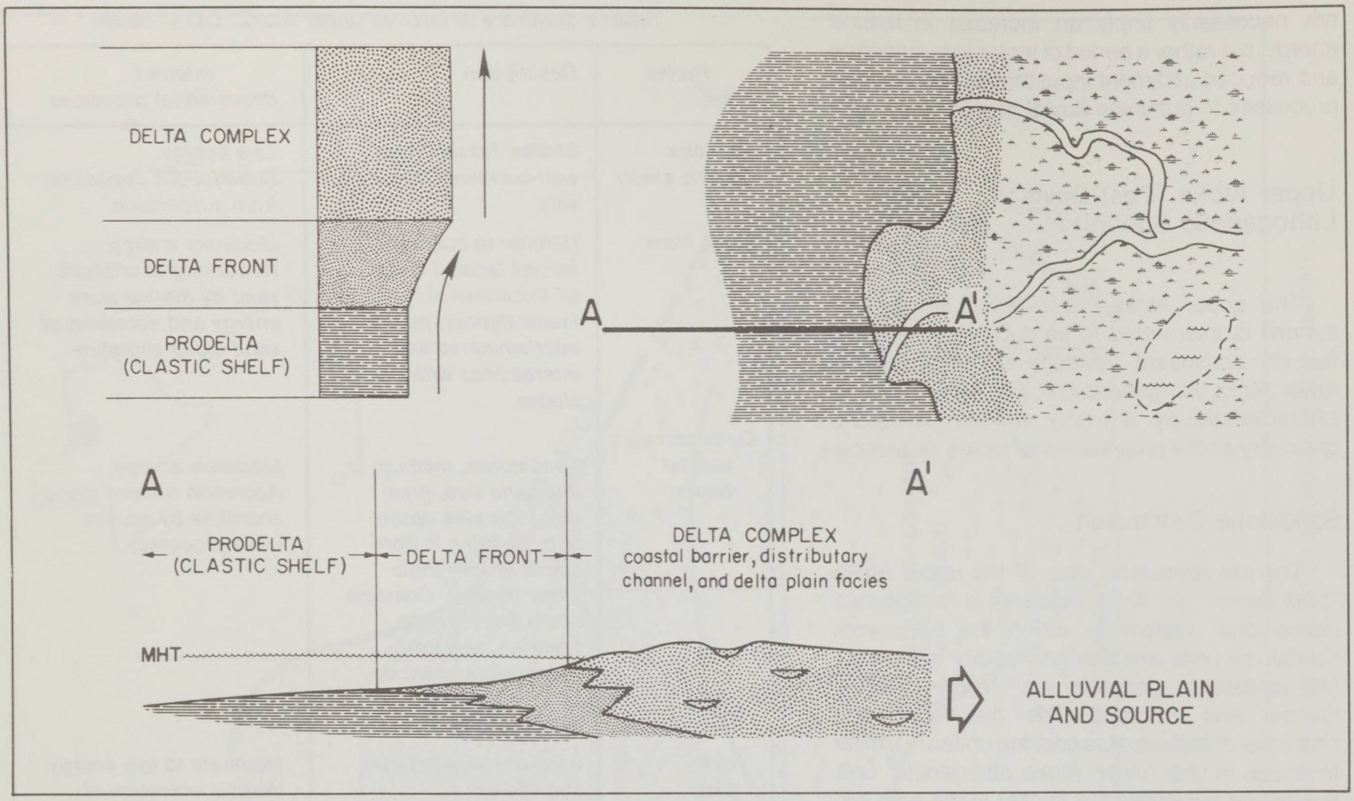

Figure 11. Upper Atoka "Davis" facies tract. Idealized sequence is based on studies of the Rhône Delta (Oomkens, 1967, 1970), and reflects the concurrent progradation and aggradation of terrigenous clastics.

Facies present in Pennsylvanian carbonate banks in North-Central Texas were discussed in detail by Wermund (1975). Depositional and geometric aspects of Pennsylvanian algal mounds and banks were studied by Erxleben (1975), Wilson (1975), Becker (1977), and Dutton (1982).

Facies

Physical characteristics and sequences displayed by "post-Davis" terrigenous facies are similar to those in the lower Atoka unit. A comparison of lower Atoka cores (figs. 8 and 9) with "post-Davis" core (fig. 13) indicates that both lithogenetic units are characterized by (1) a progradational facies tract composed of a prodelta to delta front to fan-delta lobe sequence, (2) vertical sequences of sedimentary structures that reflect fluvial deposition (scour base to cross stratification to horizontal laminations to asymmetric ripples), and (3) coarse, angular, unsorted, chert conglomerates. However, because the sandstone framework of the "post-Davis" lithogenetic subunit is thinner than that of the lower Atoka unit, minor variations do occur. Delta-front facies are thin, and the sediment is finer grained. Mixed terrigenous-carbonate facies are absent, indicating that during "post-Davis" deposition, terrigenous and carbonate systems interfingered less extensively than they did during deposition of the lower Atoka and tended to be restricted to distinct geographical areas.

Interpretive Model

The upper Atoka "post-Davis" lithogenetic subunit is interpreted to be a poorly integrated, fluvially dominated fan-delta system and is similar to the lower Atoka fan-delta system. The upper Atoka subunit is characterized by braided distributary channels, flashy discharge, sheet flow, highly digitate and elongate sandstone geometry, and coarsening-upward progradational facies sequences. Angular and coarse-grained sediment indicate a tectonically active source and a short transport distance from source to basin, resulting in a poorly developed alluvial/coastal-plain facies.

A fluvially dominated fan-delta model explains the net-sandstone geometry exhibited by the "post-Davis" lithogenetic subunit (fig. 14). At the end of upper Atoka "post-Davis" deposition, three thin, poorly developed fan-delta complexes had prograded into the basin along east-west axes. The southern axis followed the same trend as the principal fluvial channel in the "Davis" lithogenetic subunit, indicating a preferential zone of ongoing sediment transport. Along this axis a discontinuous alluvial/coastal-plain environment developed. Along the northern and central axes, deposition was sporadic and no alluvial/coastal plain developed.

Comparison of upper Atoka "post-Davis" facies distribution with upper Atoka "Davis" facies distribution suggests that the transition from "Davis" to "post-Davis" deposition was marked by (1) a period of regional basinal

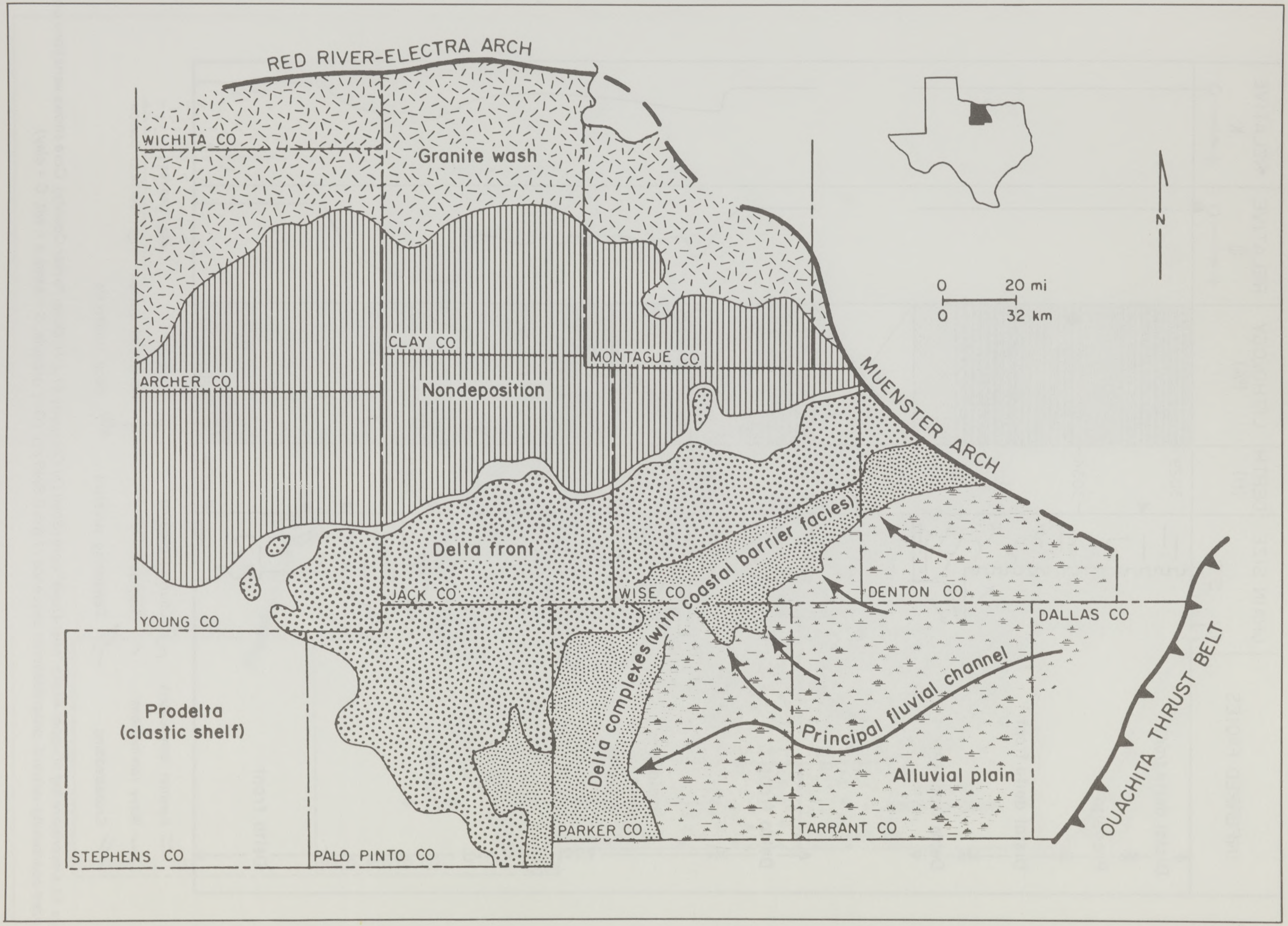

Figure 12. Distribution of upper Atoka "Davis" facies. Wave-dominated delta morphology is based on net-sandstone map geometry.

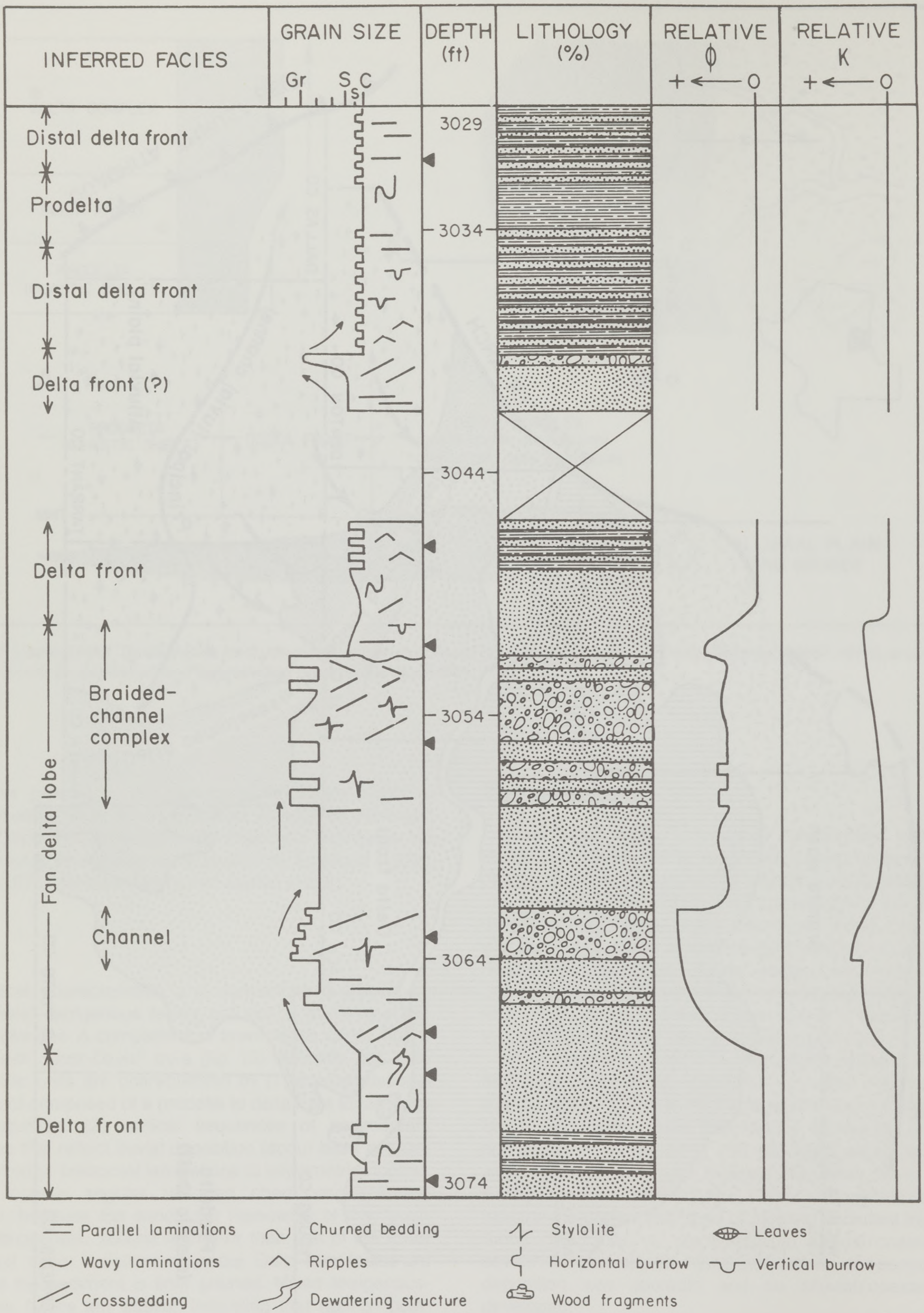

Figure 13. Descriptive log of upper Atoka "post-Davis" core (Shell Oil Company #1 J. H. Doss, Parker County). Core shows variations on idealized coarsening-upward, progradational sequence (1 ft≈0.3048 m). (Gr = granule, S = sand, s = silt, C = clay)

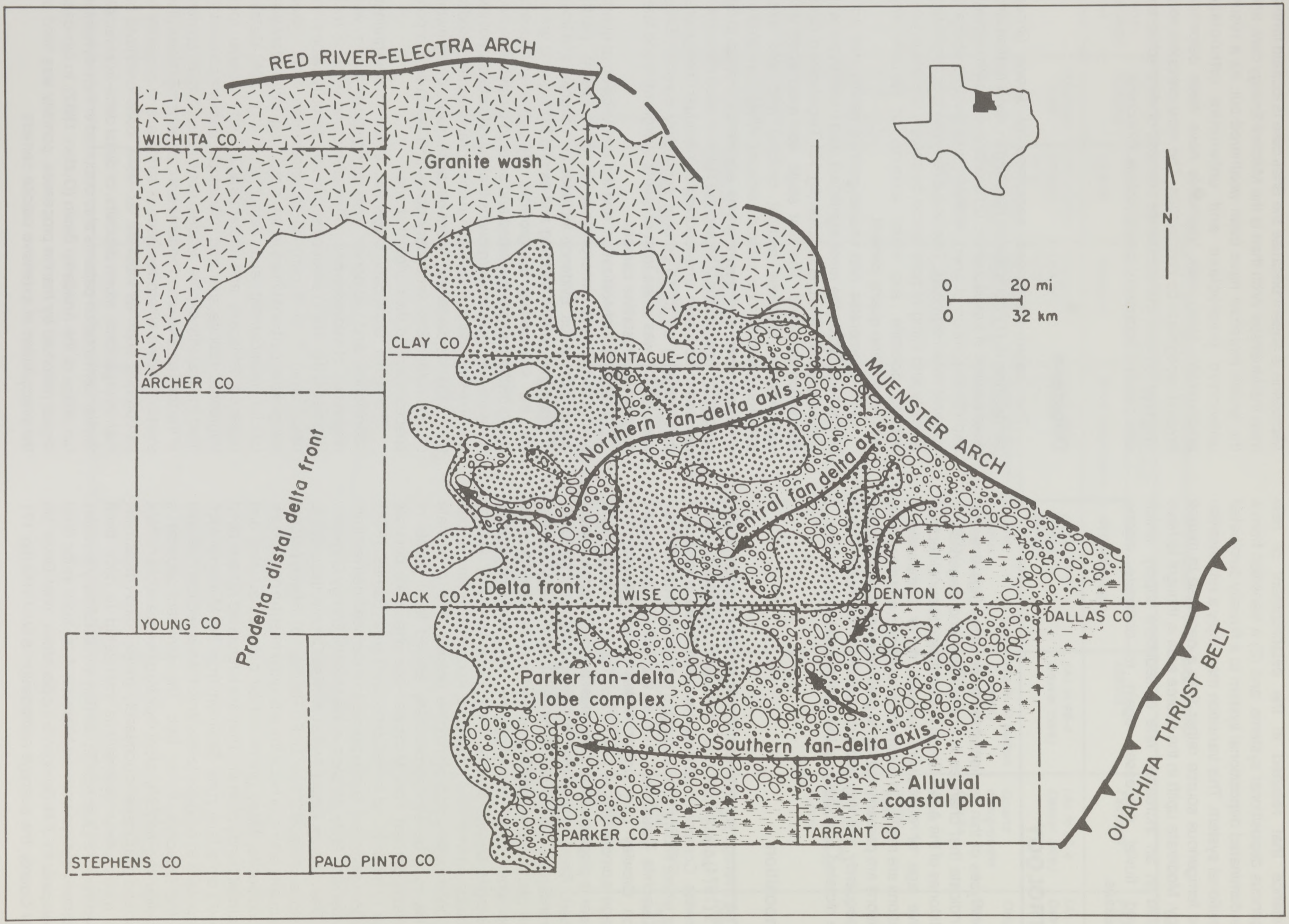

Figure 14. Distribution of upper Atoka "post-Davis" facies. Fluvially dominated fan-delta morphology is based on net-sandstone map geometry.

subsidence that resulted in the establishment of new terrigenous depositional systems, and (2) a transition from a wave-dominated depositional system to a fluvially dominated depositional system. This transition may imply a rejuvenation of the terrigenous source rather than a decrease in marine energy. Moderate uplift in the source area is thought to have resulted in an increased rate of sediment supply, which allowed fluvial processes again to dominate marine processes.

PETROLOGY

Analyses of thin sections from three cores (figs. 8, 9, and 13) indicate that changes in composition and diagenesis of sandstones of the Atoka Group are unrelated to burial depth or relative age of deposition. Instead, minor compositional variations are related to sediment provenance, and diagenetic variations are primarily related to grain size and type of facies. Consequently, porosity and permeability in the Atoka Group were dictated principally by the depositional environment.

Composition

The average sandstone in the Atoka Group, according to Folk's (1974) classification, is a quartz-rich, feldspathic (chert) litharenite. Compositional data are summarized in table 5. In areas where sediment is interpreted to have been derived from the Ouachita Thrust Belt, such as the Gulf Oil Company #2 Button Crowley core (lower Atoka) in Jack County, the average composition is Q_{69} F_9 R_{22} (fig. 15). The dominant feldspar is plagioclase, and the most prevalent rock fragment is chert. Chert grains may be microcrystalline, spiculitic, foraminiferous, oolitic, or exhibit relict algal-mat structures. These grains were probably derived from several Paleozoic stratigraphic units, including the Arkansas Novaculite, Ellenburger Group, Marble Falls Formation, and various Mississippian limestone formations. Accessory grains include glauconite pellets and phosphate pelloids. The phosphate pelloids may be syndepositionally altered fecal pellets or intraclasts derived from Morrowan-age phosphate deposits similar to those found in the Llano Uplift area (Barnes, 1954).

Where sediment is interpreted to have been derived from the Muenster Arch, as seen in the Mitchell Energy Company #6-4 Deaver core (lower Atoka) in Wise County, the average sandstone composition is Q_{55} F_{23} R_{22} (fig. 16). Fifteen percent of the quartz grains, or twice the amount present in other cores, are composite. Many grains exhibit complex suturing and nonparallel bands of strain. They are interpreted to have been derived from a fault zone. Sediment from the Muenster Arch also appears to be more feldspathic than is sediment derived from the Ouachita Thrust Belt. The dominant feldspar is microcline; the most prevalent rock fragments are chert, mica schist, and quartzite, and accessory grains include muscovite.

In areas where sediment is interpreted to have been derived from the Ouachita Thrust Belt with subsidiary amounts of sediment derived from the Muenster Arch, such as the Shell Oil Company #1 J. H. Doss core (upper Atoka "post-Davis") in Parker County, the average composition is Q_{71} F_4 R_{25} (fig. 17). Microcline is absent because the Shell core is located farther from the Muenster Arch than is the Mitchell Energy core, and the grains therefore have been weathered out. As a result, untwinned plagioclase and untwinned orthoclase predominate. Many rock fragments have been deformed beyond recognition by compaction. The most prevalent rock fragment is chert, but substantial amounts of mica schist are also present; accessory grains include muscovite.

Diagenesis

The basic diagenetic sequence of Atoka Group sandstones is (1) compaction resulting in stylolitization and development of pseudomatrix, (2) quartz overgrowth cement, and (3) dissolution of chert, feldspar, and metamorphic and volcanic rock fragments. This sequence results in secondary porosity and filling of pore space by calcite, late-stage iron-bearing dolomite, and minor amounts of kaolinite and microcrystalline quartz cement.

In conglomerates and coarse-grained sandstones from terrigenous facies, the most significant diagenetic event was silica dissolution and precipitation (fig. 18). Two stages of silica dissolution occurred. The first stage was associated with stylolitization. Stylolites parallel bedding and also exist between grains to form sutured contacts. When truncated by stylolites, chert and quartz grains apparently lost up to 50 percent of their volume. The second stage of silica dissolution resulted in corrosion and leaching of individual chert grains, thus creating up to 15-percent secondary porosity. Silica precipitation was in the form of quartz overgrowths and late-stage microcrystalline cement.

Compaction, stylolitization, and the precipitation of quartz overgrowths are interpreted to have been partly contemporaneous. Evidence includes (1) vacuoles and lines of strain that parallel bedding and extend from quartz grains into the surrounding overgrowths, (2) grains with quartz overgrowths that are truncated and sutured by stylolites, and (3) grains with quartz overgrowths that superimpose stylolites. Second-stage silica dissolution in chert grains is interpreted to be a separate diagenetic event because quartz overgrowths do not extend into secondary pores and because the pore spaces maintain their original shape.

The most significant diagenetic event in fine-grained sandstones and siltstones from terrigenous facies was dissolution of feldspars and metamorphic and volcanic rock fragments (fig. 19) to produce secondary porosity values that range from 2 to 6 percent. In sandstones from mixed terrigenous-carbonate facies, the major diagenetic event was calcite replacement and cementation (fig. 20). Calcite replaced feldspars and metamorphic and volcanic rock fragments. Calcite spar and poikilotopic cement completely filled the majority of pore spaces, constituting 5 to 25 percent of the total rock volume. Predominant calcite cementation also exists in facies where terrigenous strata are in proximity to carbonates, such as incipient fan-delta lobes colonized by marine organisms, storm deposits, or distal delta-front facies. Similar cementation patterns also occurred in Pennsylvanian fan deltas of the Anadarko Basin (Dutton, 1982). In fan-delta facies reworked by marine processes, porosity was filled by the precipitation of extensive calcite cement.

Table 5. *Compositional components of sandstones of the Atoka Group.*

<table>
<tr><th colspan="2" rowspan="2">Litho-genetic unit</th><th rowspan="2">Source</th><th colspan="4">FRAMEWORK</th><th rowspan="2">Matrix</th><th rowspan="2">Cement</th><th rowspan="2">Porosity</th></tr>
<tr><th>Quartz</th><th>Feldspar</th><th>Rock fragments</th><th>Miscellaneous</th></tr>
<tr><td rowspan="3">UPPER ATOKA</td><td rowspan="2">"POST-DAVIS"</td><td>Muenster Arch</td><td>(As in #6-4 Deaver core)</td><td>(As in #6-4 Deaver core)</td><td>(As in #6-4 Deaver core)</td><td>(As in #6-4 Deaver core)</td><td>(As in #6-4 Deaver core)</td><td>(As in #6-4 Deaver core)</td><td>(As in #6-4 Deaver core)</td></tr>
<tr><td>OUACHITA THRUST BELT
(Muenster Arch)
(Shell Oil Company #1 J. H. Doss core)</td><td rowspan="2">Common
Vacuolized

Composite
Rare</td><td rowspan="2">Plagioclase
Albite twinned
Untwinned

Orthoclase
Untwinned</td><td rowspan="2">(As in #2 Button Crowley core)
Fewer varieties of chert</td><td rowspan="2">Rare:
Biotite
Tourmaline
(Pyrite)</td><td rowspan="2">(As in #2 Button Crowley)
No mixed facies observed</td><td rowspan="2">Quartz overgrowths

Calcite

Rare:
Microcrys-talline quartz,
kaolinite,
clay rims (associated with pseudo-matrix</td><td rowspan="2">Original

Secondary</td></tr>
<tr><td>"Davis"</td><td>Ouachita Thrust Belt</td></tr>
<tr><td colspan="2" rowspan="2">LOWER ATOKA</td><td>OUACHITA THRUST BELT
(Gulf Oil Company #2 Button Crowley core)</td><td>Common
Vacuolized
Rutilated

Composite</td><td>Plagioclase
Albite twinned

Orthoclase
Microcline
untwinned</td><td>Chert
Microcrystalline to coarse-grained.
Contains:
Spicules
Foraminifers
Oolites
Echinoderms
Algal fibers

MRF
Mica Schist
Quartzite

VRF
Dark, fine-grained;
may contain Plagioclase with Carlsbad twins

SRF
Siltstone
Claystone(?)</td><td>Glauconite pellets
Phosphate pelloids
Magnetite
Biotite

Mixed facies:
Phylloid algae
Echinoderms
Mollusks
Brachiopods
Bryozoans
Trilobites
Foraminifers
Corals
Worm tubes
Ostracods
Crinoids</td><td>Epimatrix
Illite
Plate debris

Pseudomatrix
Due to compaction of rock fragments

Mixed facies:
Calcareous
Micritic</td><td>Quartz overgrowths

Iron dolomite (some dolomite)

Calcite
Spar
Poikilotopic

Rare:
Chlorite
Kaolinite
Clay rims (associated with pseudo-matrix)

Mixed facies:
Micrite</td><td>Original

Secondary

Tertiary (minor)</td></tr>
<tr><td>MUENSTER ARCH
(Mitchell Energy Company #6-4 Deaver core)</td><td>Common
Vacuolized

Composite
Strained with extensive sutures</td><td>(As above)</td><td>(As above)
Only micro-Crystalline & coarse-grained chert present

IRF
Very rare granite</td><td>Biotite
Rare:
Glauconite
Phosphate
Hematite
(Pyrite)

Mixed facies:
(as above)
No corals, worm tubes, or ostracods</td><td>(As above)
Extensive</td><td>Calcite
Spar
Poikilotopic
Iron-rich

Iron dolomite
Kaolinite
Chlorite

Rare:
Quartz overgrowths,
clay rims (associated with pseudo-matrix)</td><td>Original (minor)</td></tr>
</table>

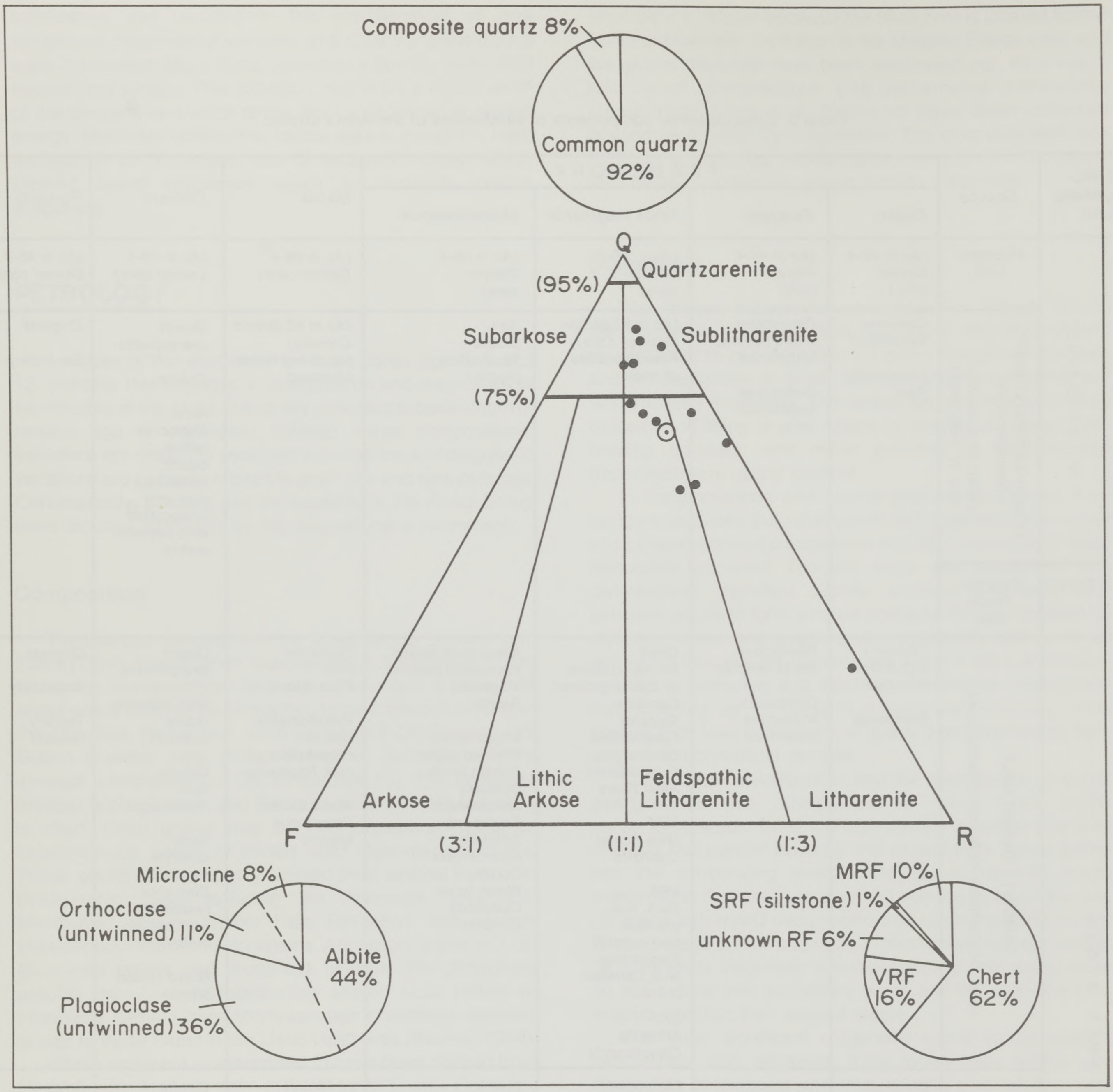

Figure 15. Composition of sandstones interpreted to have been derived from the Ouachita Thrust Belt. Samples are taken from Gulf Oil Company #2 Button Crowley core (fig. 8), lower Atoka lithogenetic unit. Classification is according to Folk (1974). Open circle is average composition.

Porosity and Permeability

Development of porosity and permeability in sandstones of the Atoka Group was controlled by the depositional environment. Highest average porosity and permeability occur in coarse-grained chert conglomerates deposited under high-energy conditions, such as in channel or coarse-grained, fan-delta-plain environments. In these facies, the depositional matrix is negligible, and permeability measured relative to air by Core Lab, Inc., averages between 2,000 and 3,000 md. Porosity includes original porosity remaining between quartz overgrowths and secondary porosity produced by dissolution of chert grains (fig. 21). Pore spaces are angular, clear, moderately interconnected, and range from 0.04 mm up to 2 mm wide, with an average width of 0.8 mm. Secondary leached pore spaces are irregularly shaped. They may be clear, slightly cloudy due to incomplete chert dissolution, or have thin clay rims due to infiltration of pseudomatrix. The pores are slightly interconnected and range from 0.6 mm to 3 mm wide, with an average width of 1 mm.

Moderate porosity and permeability values occur in medium- to fine-grained quartz-rich sandstones that were also

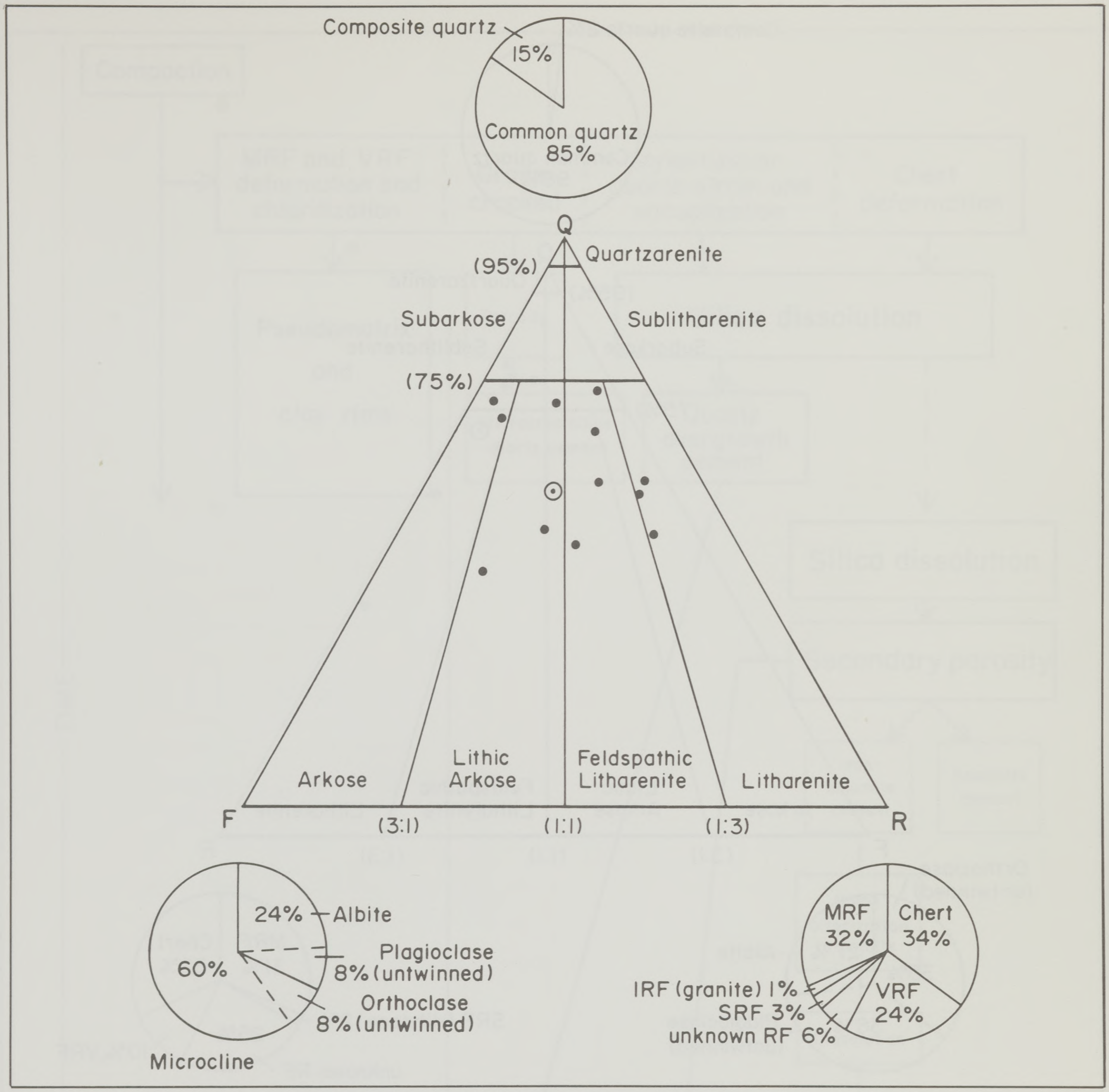

Figure 16. Composition of sandstones interpreted to have been derived from the Muenster Arch. Samples are taken from Mitchell Energy Company #6-4 Deaver core (fig. 9), lower Atoka lithogenetic unit. Classification is according to Folk (1974). Open circle is average composition.

deposited under high-energy conditions, such as in channel or fan-delta-plain environments. In these facies the depositional matrix is less than 3 percent; however, permeability is typically less than 1 md. A porosity range between 8 and 12 percent is due primarily to the preservation of original porosity between quartz overgrowths and to the creation of minor secondary porosity by dissolution of feldspars and metamorphic and volcanic rock fragments. Secondary pore spaces are irregularly shaped, very cloudy due to incomplete dissolution, isolated, and 0.04 mm to 0.24 mm wide.

Porosity and permeability are absent in sandstones deposited in environments characterized by low energy and proximity to marine influences owing to calcite cementation (fig. 21).

A study of sandstone diagenesis in the overlying Strawn Group (Peterson, 1977) indicates that a similar relation exists between depositional environments and porosity. In Strawn sediments the best porosity is associated with sandstones displaying a large mean grain size that were deposited in high-energy environments and that were not in proximity to shales.

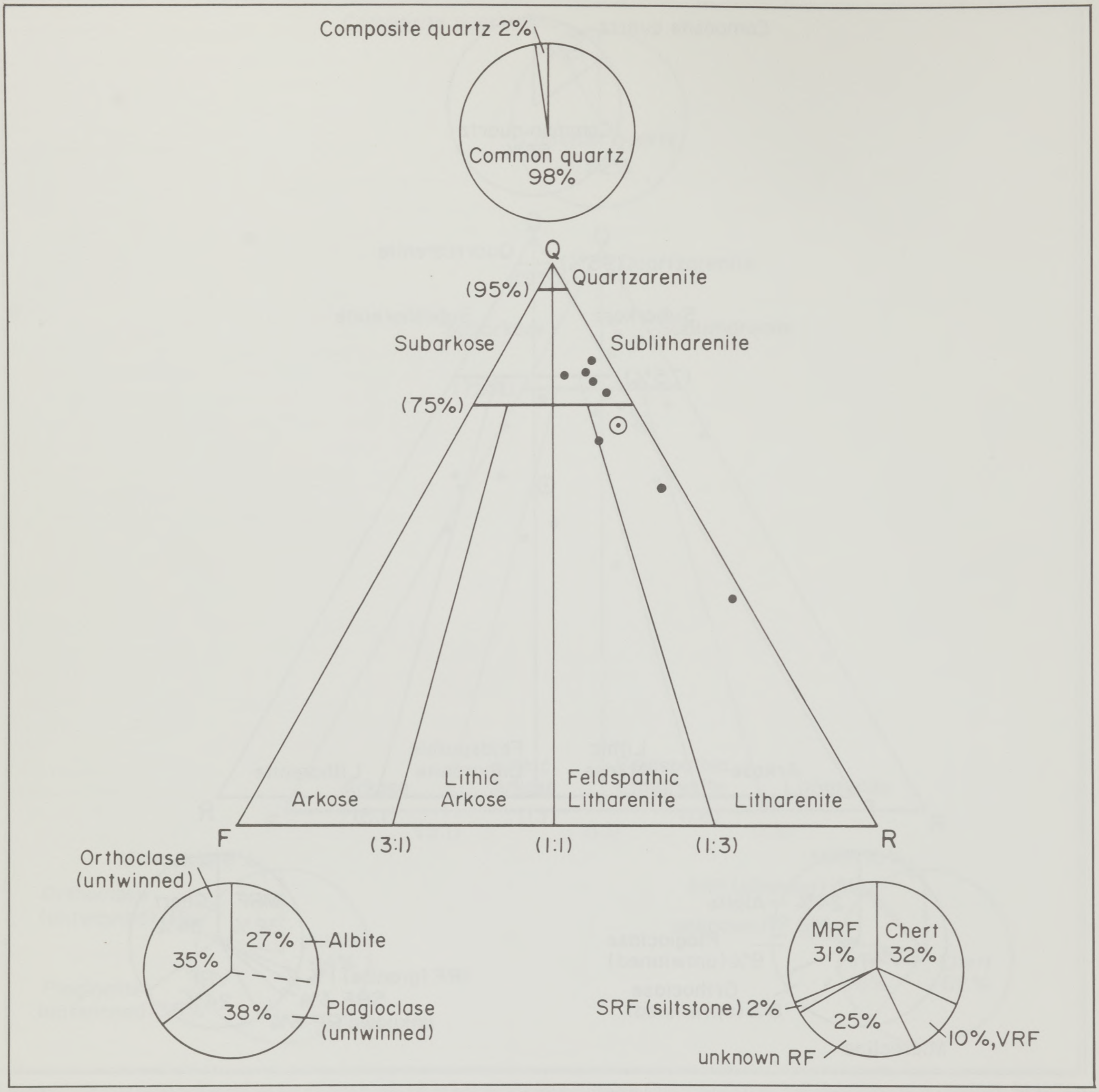

Figure 17. Composition of sandstones interpreted to have been derived principally from the Ouachita Thrust Belt with subsidiary amounts from the Muenster Arch. Samples are taken from Shell Oil Company #1 J. H. Doss core (fig. 13), upper Atoka "post-Davis" lithogenetic subunit. Classification is according to Folk (1974). Open circle is average composition.

HYDROCARBON PRODUCTION

In the northern Fort Worth Basin, the Atoka Group is usually known solely for its tight, gas-producing sandstones and conglomerates. By 1977 the Atoka Group had cumulative production of more than 160 million barrels of oil plus gas equivalent, or more than 408 billion ft^3 (11.5 billion m^3) of gas and 94 million barrels of oil. Most of this production is from a broad zone that trends northeast-southwest through Jack, Wise, and Palo Pinto Counties, Texas (pl. XIX).

Historical Development

Gas was first recognized in the Atoka Group, northern Fort Worth Basin, during the early 1920's from shows in dry holes drilled by cable tool. However, because of poor market conditions, gas and oil were not produced until the 1950's. In

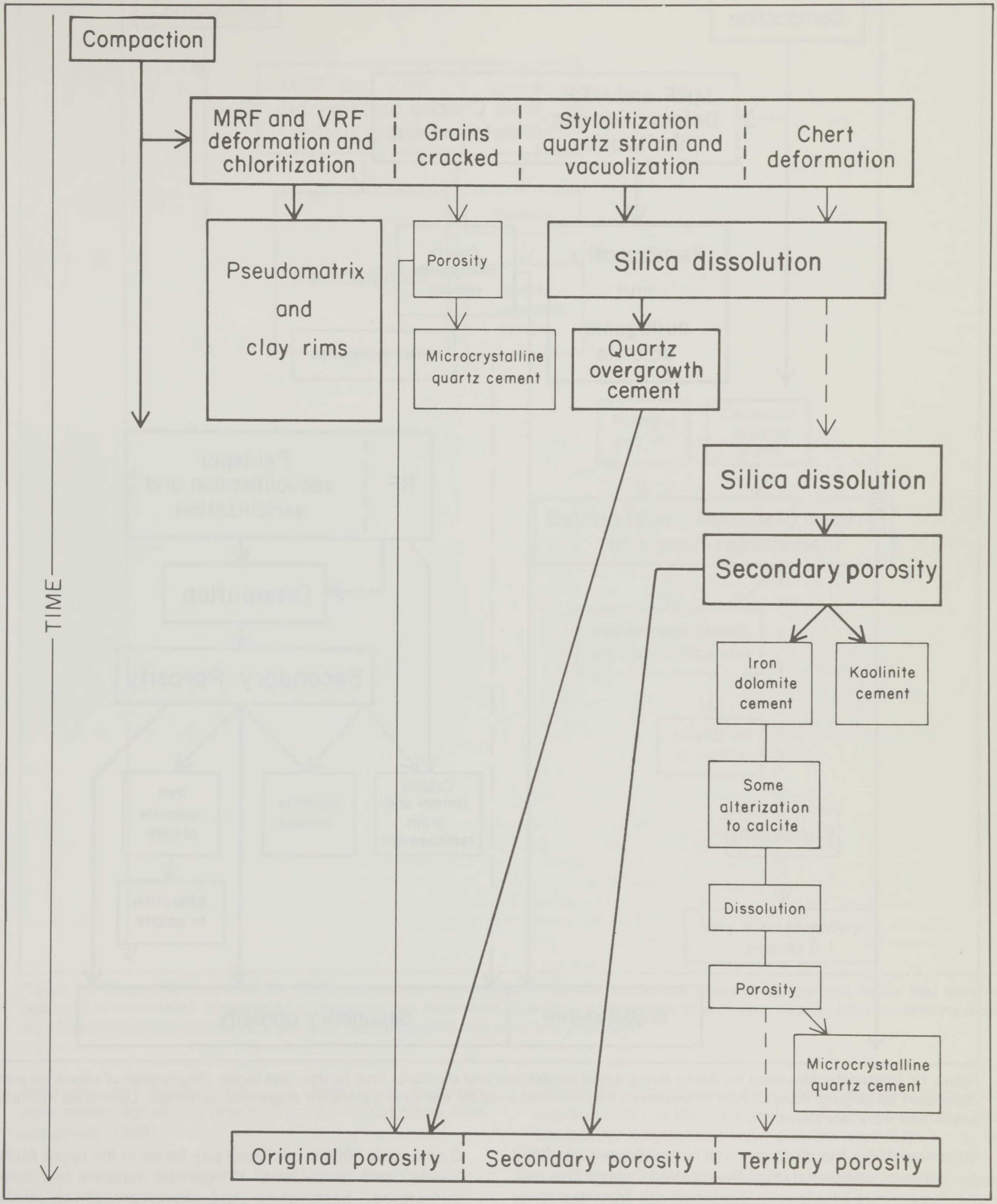

Figure 18. Diagenetic sequence for Atoka conglomerates and coarse-grained sandstones from terrigenous facies. Progression of sequence was dependent on original composition of sediment. Heavier lines indicate the most significant diagenetic pathways. Light lines indicate events that were less prevalent.

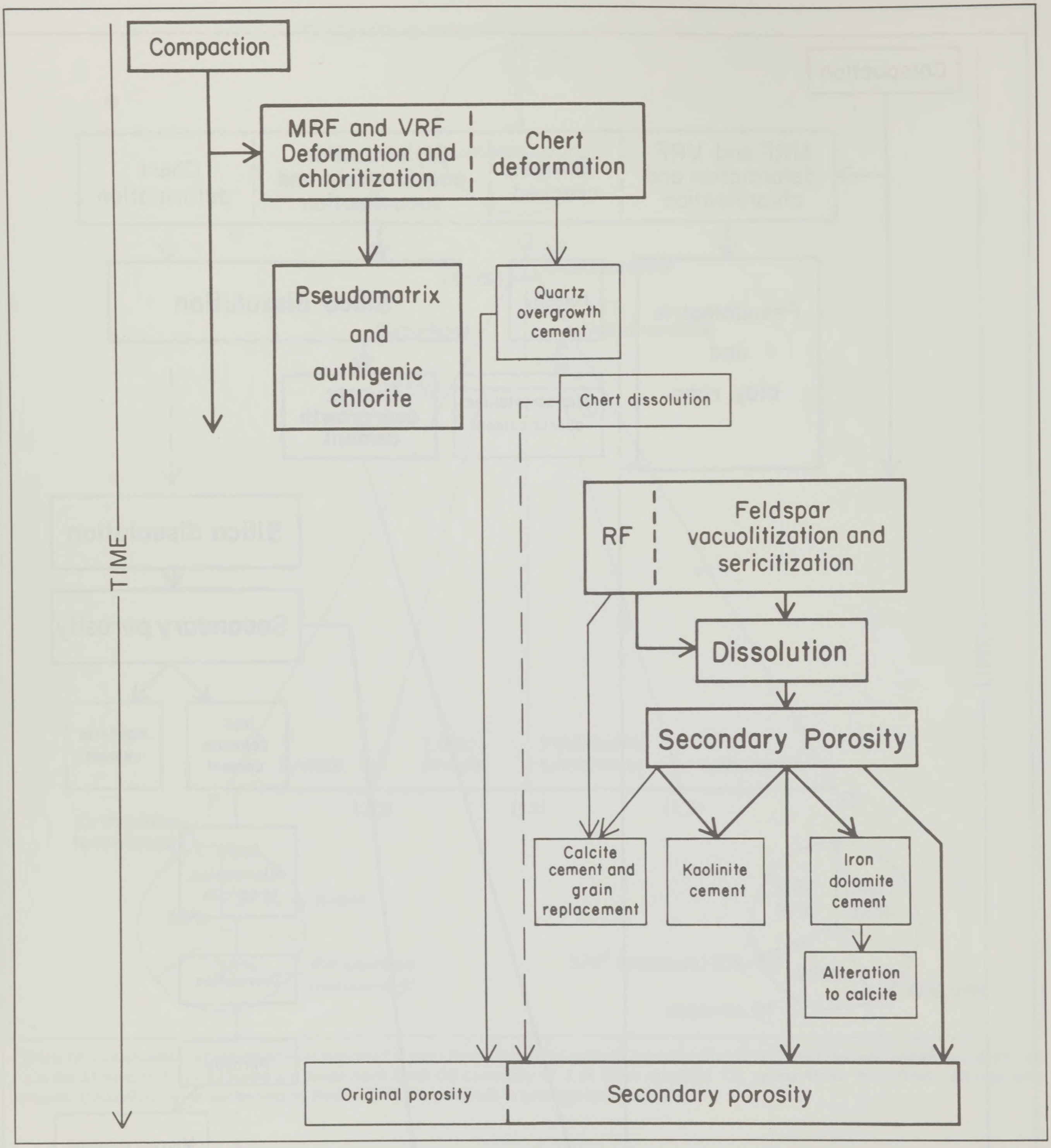

Figure 19. Diagenetic sequence for Atoka fine-grained sandstones and siltstones from terrigenous facies. Progression of sequence was dependent on original composition of sediment. Heavier lines indicate the most significant diagenetic pathways. Light lines indicate events that were less prevalent.

November 1950, the discovery well for the Boonesville Bend gas field was completed in southwest Wise County. This well, the Continental #1 Flowers, produced gas from the lower Atoka lithogenetic unit. Rapid development occurred in the surrounding area, and by 1957, fields covering approximately 450 mi^2 (1,170 km^2) in Wise, Jack, and Parker Counties produced gas and small amounts of oil from lower Atoka strata.

By the early 1960's, additional pay zones in the upper Atoka "Davis" and "post-Davis" lithogenetic subunits had been completed. Exploration and development of Atoka hydrocarbons declined from the mid-1960's to the early 1970's. In the mid-1970's, increased gas prices brought renewed interest in the Atoka Group, resulting in the drilling of infill and step-out wells to expand existing lower Atoka fields.

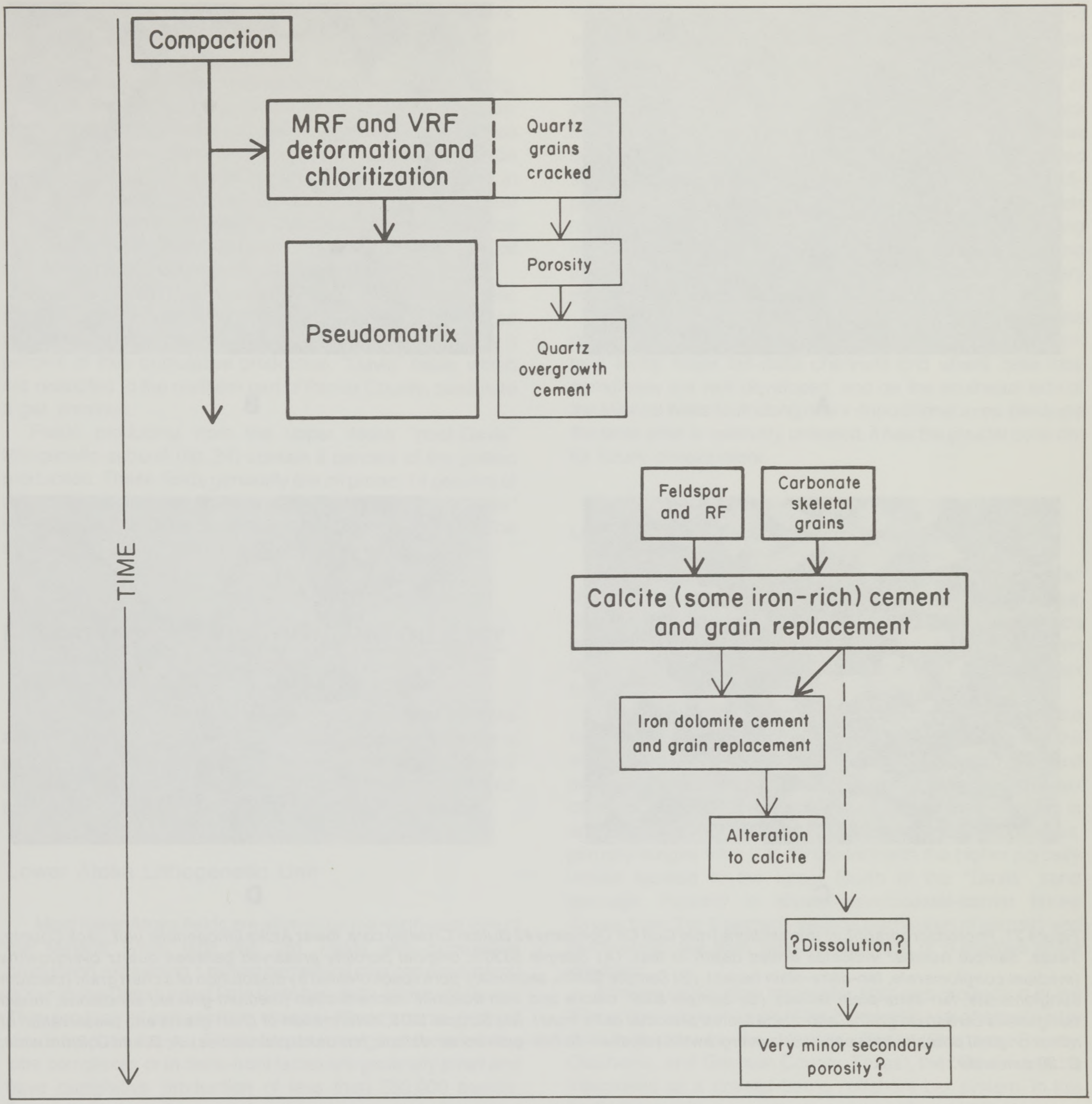

Figure 20. Diagenetic sequence for Atoka sandstones from mixed terrigenous-carbonate facies or terrigenous facies that were in proximity to carbonates. Progression of sequence was dependent on original composition of sediment. Heavier lines indicate the most significant diagenetic pathways. Light lines indicate events that were less prevalent.

Although upper Atoka "Davis" and "post-Davis" reservoirs were tested, actual production remained limited (Blanchard and others, 1959).

Production Characteristics

Because the upper Atoka "Davis" and "post-Davis" lithogenetic subunits are less favorable exploration targets, studies of their reservoir characteristics are currently unavailable. The following discussion is limited to production characteristics of the lower Atoka unit, but because of facies similarities, conclusions may also be applicable to "post-Davis" production.

Characteristics of lower Atoka hydrocarbon fields are best illustrated by the Boonesville Bend gas field in Wise County and the Rickels field in Stephens County. In both fields, production is controlled stratigraphically. Wells produce oil and gas from multiple, stacked, conglomerate lenses. The number of productive zones varies. Individual pay zones

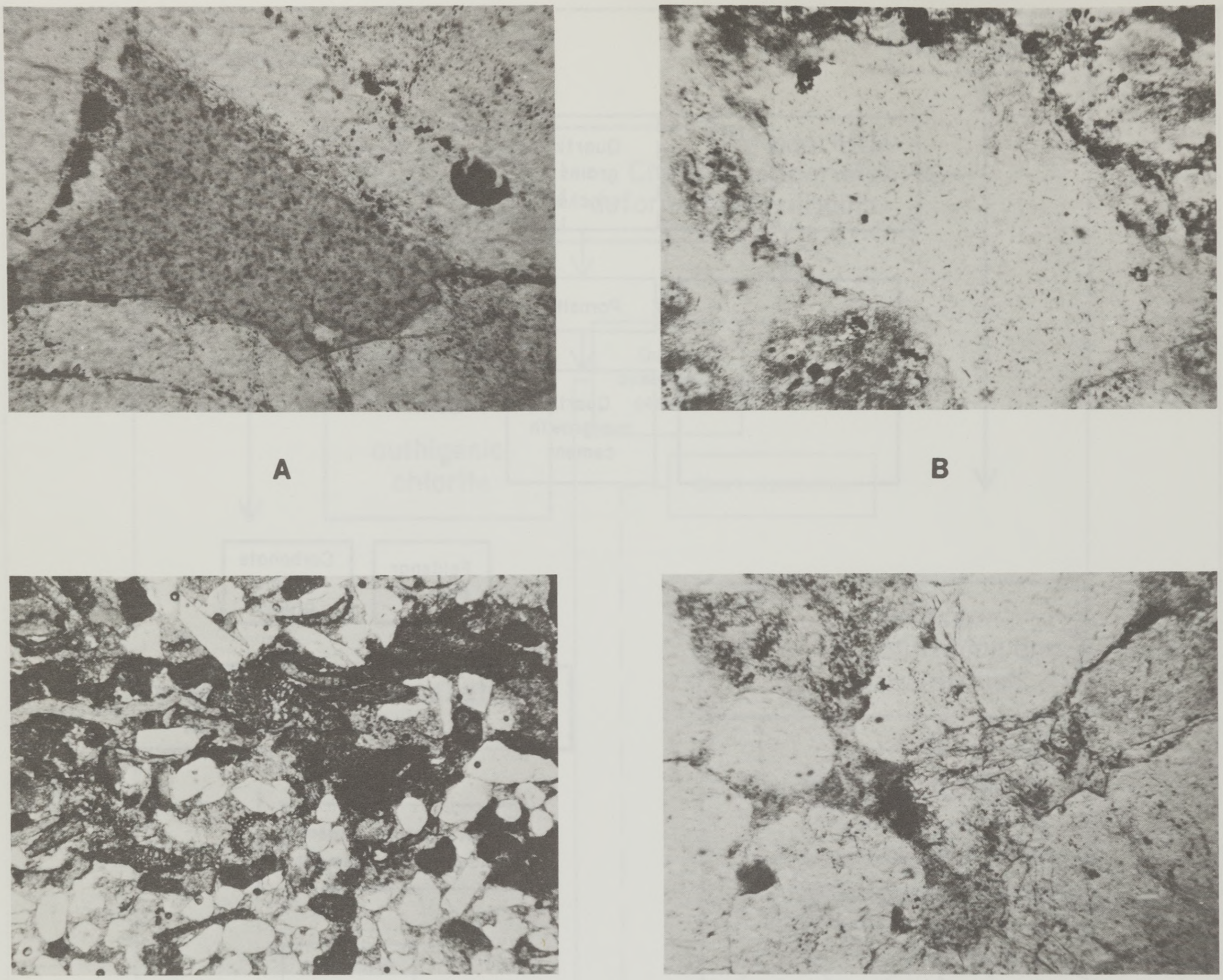

Figure 21. Photomicrographs of thin sections from Gulf Oil Company #2 Button Crowley core, lower Atoka lithogenetic unit, Jack County, Texas. Sample number indicates drilled depth in feet. (A) Sample 5330$\frac{1}{2}$, original porosity preserved between quartz overgrowths (medium conglomerate, fan-delta-plain facies). (B) Sample 5330$\frac{1}{4}$, secondary pore space created by dissolution of a chert grain (medium conglomerate, fan-delta-plain facies). (C) Sample 5337, calcite and iron dolomite concentration (medium-grained sandstone, mixed terrigenous carbonate grains, shoreface facies/proximal delta front). (D) Sample 5318, deformation of chert grains and preservation of minor original porosity between quartz overgrowths (medium- to fine-grained sandstone, fan-delta-plain facies). A, B, and D: 8 mm wide; C: 30 mm wide.

average 10 ft (3 m) thick. Net effective pay ranges up to 100 ft (30 m) but averages 20 to 25 ft (6 to 7.5 m) thick. Porosity distribution is erratic. In productive zones porosity ranges from 5 to 20 percent. Permeability generally is less than 1 md. In nearly all instances zones were fractured by sand injection to obtain commercial production. Lower Atoka fields exhibit gas expulsion drive; reservoir pressures range from 200 to 2,000 psi (14 to 140.5 kg/cm^2), with considerable variation among zones. Reservoir pressures tend to fall rapidly after initial production and then stabilize. This indicates that individual pay zones act as distinct reservoirs that have little intercommunication between zones. Reserves in the Boonesville field have been estimated at 330,000 ft^3 (9,345 m^3) of gas per acre-ft (1,233 m^3) with 1.51 million ft^3 (42,758 m^3) of gas per day open-flow potential (Blanchard and others, 1959; Gardner, 1960; Kingston, 1960).

Volume and Distribution

Plate XIX illustrates volumes and distribution of cumulative hydrocarbon production for the Atoka Group. Fields having a cumulative production of less than 100,000 barrels of oil plus gas equivalent were deleted from this map. Plotted fields reflect 90.5 percent of the total cumulative production, or more than 140 million barrels. The most significant fields are those with a cumulative production greater than 1 million barrels, from which 73 percent of the total Atoka production, or 81 percent of the plotted production, is derived.

Fields producing from the lower Atoka lithogenetic unit (fig. 22) contain more than 90 percent of the plotted production. Although gas is volumetrically greater, barrels of oil versus gas equivalent are approximately equal. Lower Atoka fields can be divided into four provinces: (1) an oil province centered in Montague County, (2) an oil province centered in southern Young and northern Stephens Counties, (3) a gas province centered in Parker and Palo Pinto Counties, and (4) a mixed oil and gas province centered in Jack and Wise Counties.

Fields producing from the upper Atoka "Davis" lithogenetic subunit (fig. 23) contain slightly over 1 percent of the plotted production. These fields are gas prone; oil represents only 3 percent of their cumulative production. "Davis" fields, which are restricted to the northern part of Parker County, constitute a gas province.

Fields producing from the upper Atoka "post-Davis" lithogenetic subunit (fig. 24) contain 8 percent of the plotted production. These fields generally are oil prone; 14 percent of their cumulative production is gas equivalent. "Post-Davis" fields located in Jack and Wise Counties produce oil. The single "post-Davis" field in Parker County produces gas.

RESERVOIR DISTRIBUTION AND QUALITY

By integrating interpretations of the depositional systems and diagenetic history with hydrocarbon production data, it is possible to explain regional trends in reservoir distribution and quality and to identify areas of interest that were overlooked previously because of unfavorable economic conditions.

Lower Atoka Lithogenetic Unit

Most lower Atoka fields are aligned on the northwest side of the Mineral Wells fault (fig. 25). Fields with cumulative production exceeding 1 million barrels (oil plus gas equivalent) occur in the Decatur and Palo Pinto fan-delta-lobe complexes. They produce oil and gas from channel-fill and coarse-grained fan-delta-plain facies. Fields located marginal to fan-delta-lobe complexes or in delta-front facies are generally small and have cumulative production of less than 250,000 barrels. Because of the influence of proximal marine source beds, these fields are oil prone.

Fields located on the southeast side of the Mineral Wells fault are aligned with major channel axes or preferred paths of sediment dispersal. They are overlain by alluvial/coastal-plain facies but produce from subjacent fan-delta channel-fill facies. Because of the abundance of plant matter associated with these facies, production is gas prone (Tissot and Welte, 1978).

Reservoir quality in the lower Atoka lithogenetic unit is good, particularly northwest of the Mineral Wells fault where abundant chert conglomerates were deposited in high-energy environments. Overall reservoir quality is interpreted to decrease southeast of the Mineral Wells fault because of (1) an increase in mud associated with alluvial coastal-plain facies, (2) an increase in the amount of metamorphic and volcanic rock fragments nearer the source, and (3) a greater compaction of sediments on the downthrown side of the fault. This resulted in reduction of pore space by infiltration of depositional matrix and by severe deformation of rock fragments to form pseudomatrix. Exceptions to these conditions occur along major fan-delta channels. Scattered sonic and density logs along channels indicate up to 15-percent porosity, a percentage comparable to porosity in fields northwest of the fault. Therefore, I inferred that sediment along major depositional axes was sufficiently coarse-grained and permeable to facilitate the flow of diagenetic fluids. Secondary dissolution porosity developed as a result.

Primary hydrocarbon exploration targets in the lower Atoka unit lie in two areas: on the northwest side of the Mineral Wells fault along major fan-delta channels and where delta-lobe complexes are well developed, and on the southeast side of the Mineral Wells fault along major depositional axes. Because the latter area is relatively untested, it has the greater potential for future development.

Upper Atoka "Davis" Lithogenetic Subunit

Reservoir distribution in the upper Atoka "Davis" lithogenetic subunit is generally unknown. In the study area, only two fields produce from this subunit (fig. 26). These fields produce gas from the transitional area between alluvial-plain facies and coastal-barrier facies, and from delta-complex facies.

Reservoir quality in the "Davis" is unknown because of the lack of data. Scattered sonic and density logs indicate that the vertical and lateral distribution of porosity is irregular. The best porosity appears to be in fluvial channel-fill facies and in delta-complex facies. In fluvial channel-fill sandstones, porosity is approximately 10 percent. In delta-complex sandstones, porosity ranges from 0 to 15 percent with the higher porosity values located in the upper fourth of the "Davis" sand package. Porosity in alluvial-plain/coastal-barrier facies ranges from 3 to 6 percent. Vertical distribution of porosity and permeability are both irregular because of numerous shale interbeds.

Primary exploration targets for tight gas production in the "Davis" are along the axis of the principal fluvial channel and in deltaic facies. In the Marietta Basin (Sherman County, Oklahoma, and Grayson County, Texas), the "Davis" sand is interpreted as a coastal-barrier/offshore-bar system. In this basin, the sand is a proven oil producer (Gee, 1976). However, the oil-producing tendency of the "Davis" sand probably does not extend into the Fort Worth Basin.

Upper Atoka "Post-Davis" Lithogenetic Subunit

The distribution of upper Atoka "post-Davis" fields corresponds to that of the fan-delta depositional axes (fig. 27). Most fields are aligned east-west along the northern and central depositional axes. These fields produce from fan-delta channel-fill facies. The only field associated with the southern axis is located in the Parker fan-delta-lobe complex and produces from fan-delta channel-fill and coarse-grained fan-delta-plain facies.

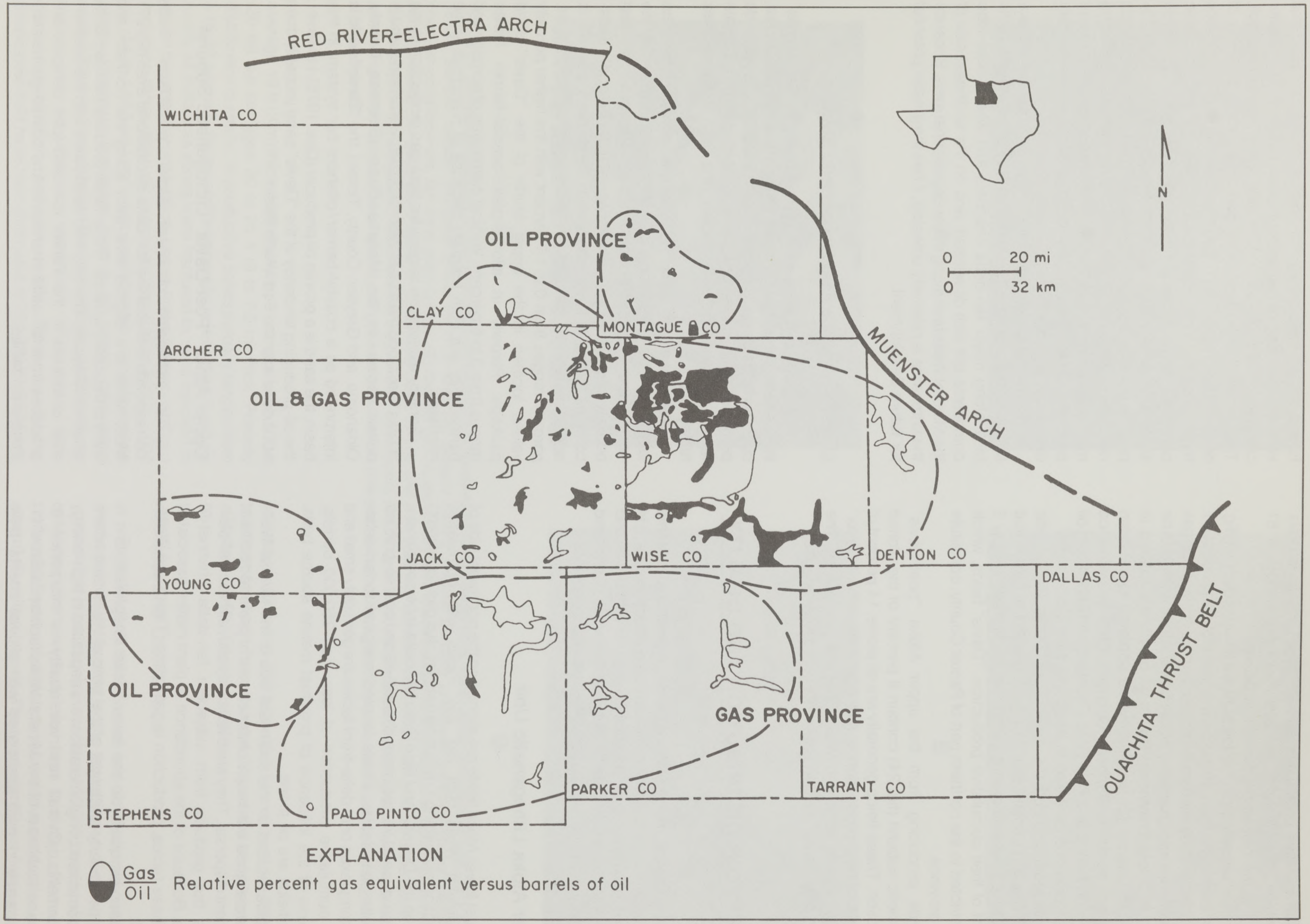

Figure 22. Distribution of lower Atoka hydrocarbon fields. Field outlines shown are prior to consolidation of Boonesville Bend gas field. Irregular field outlines reflect "county regular" designation.

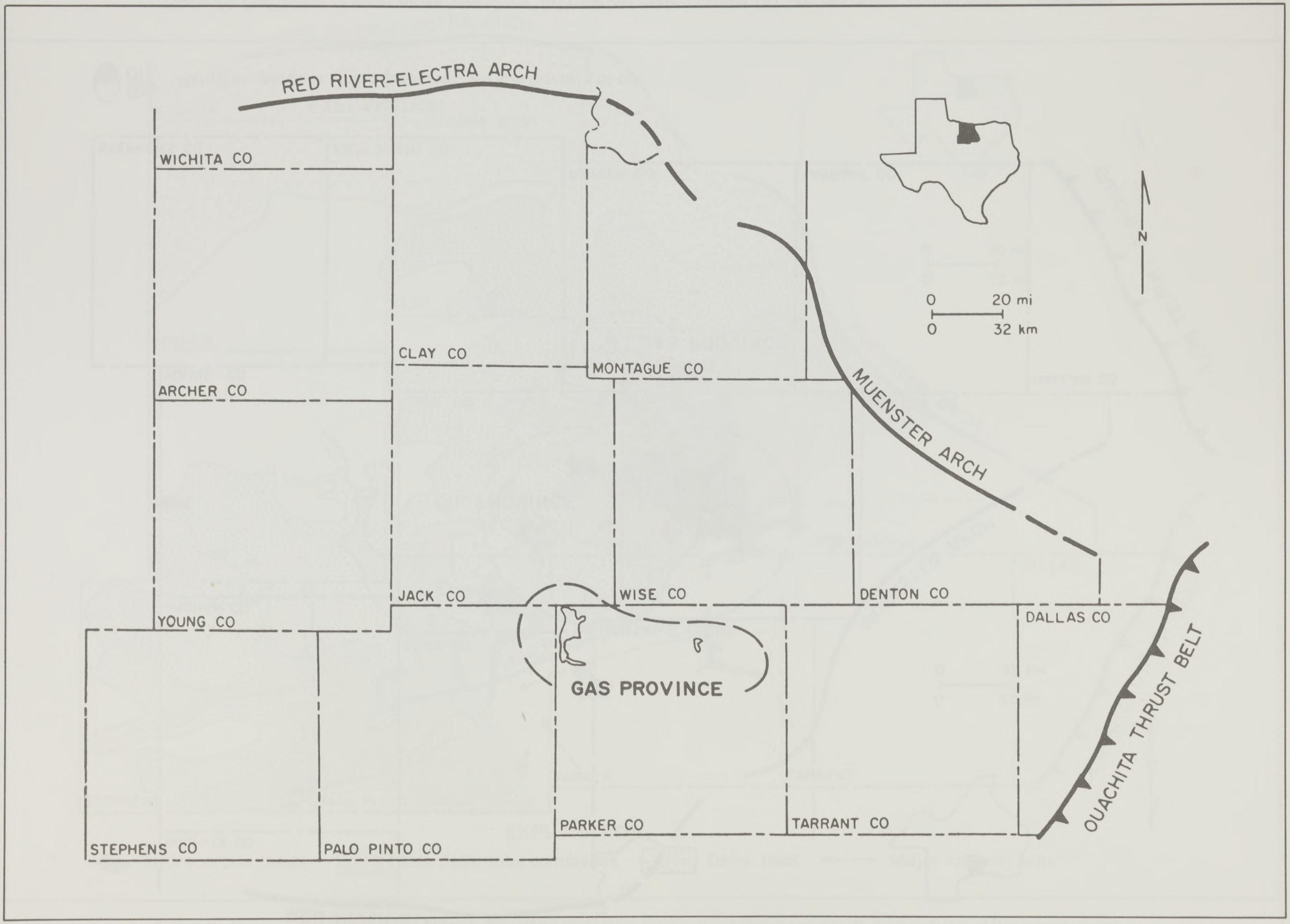

Figure 23. Distribution of upper Atoka "Davis" hydrocarbon fields. Irregular field outlines reflect "county regular" designation.

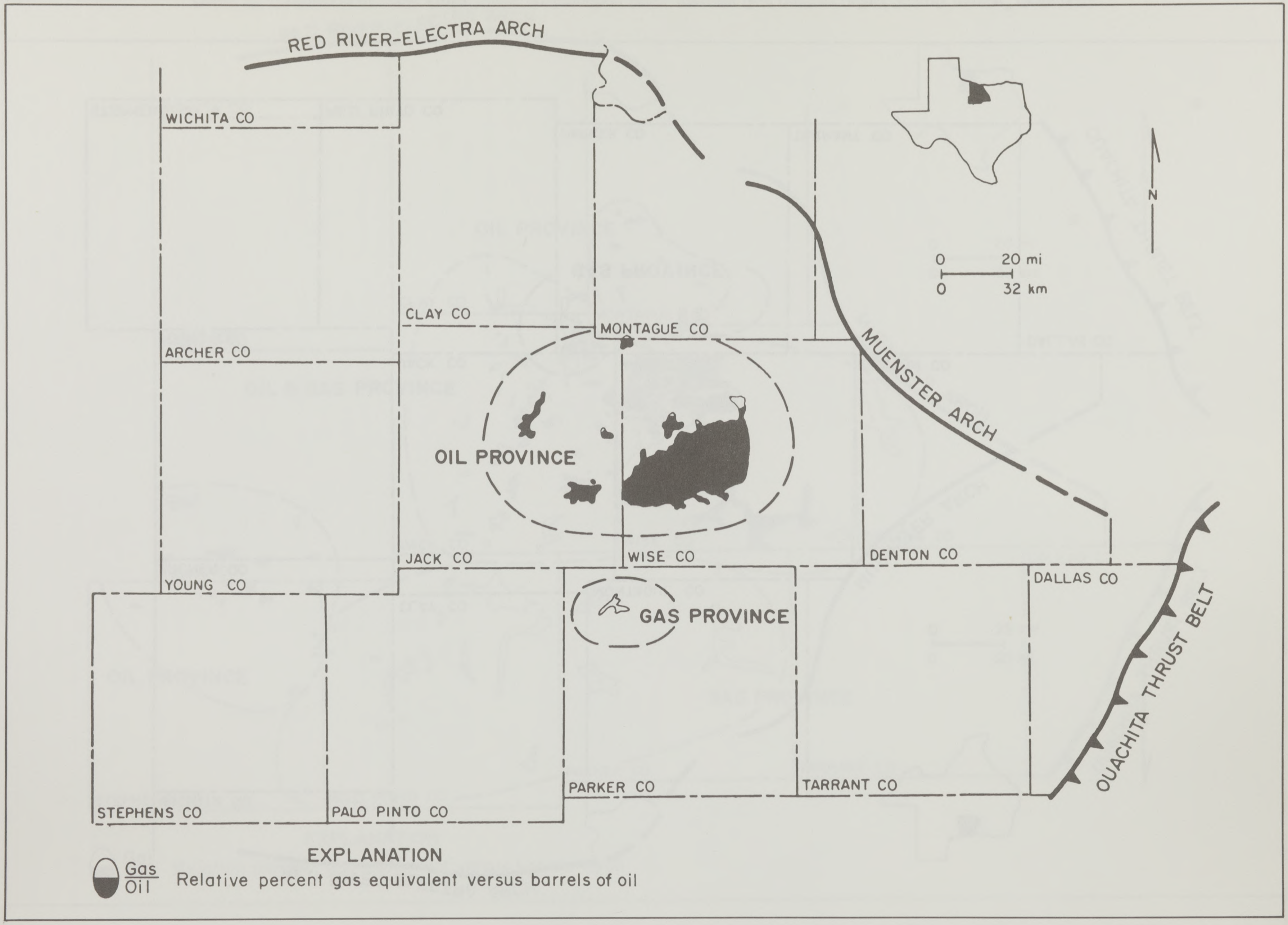

Figure 24. Distribution of upper Atoka "post-Davis" hydrocarbon fields. Irregular field outlines reflect "county regular" designation.

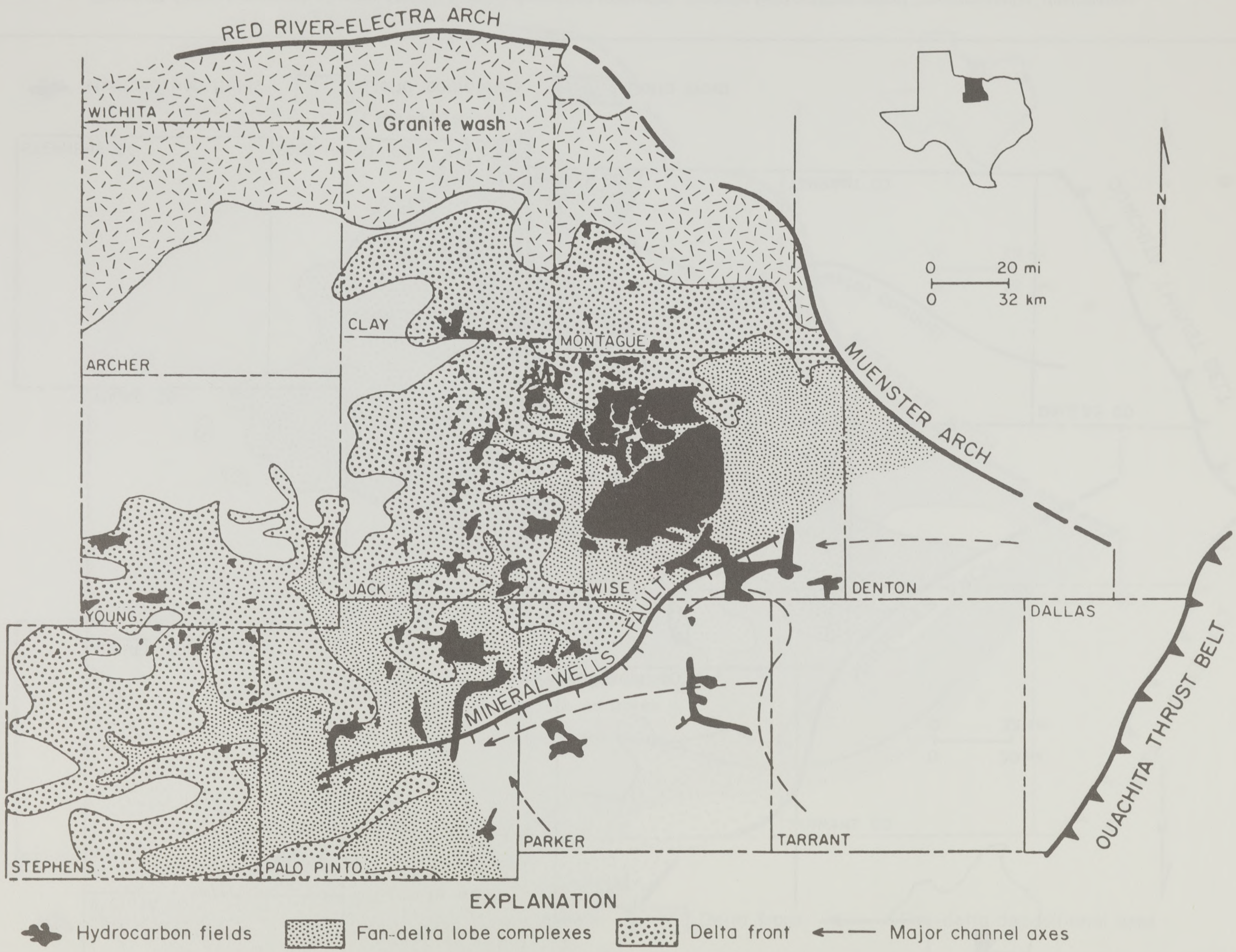

Figure 25. Facies framework of lower Atoka hydrocarbon reservoirs. Field outlines shown are prior to consolidation of Boonesville Bend gas field. Irregular field outlines reflect "county regular" designation.

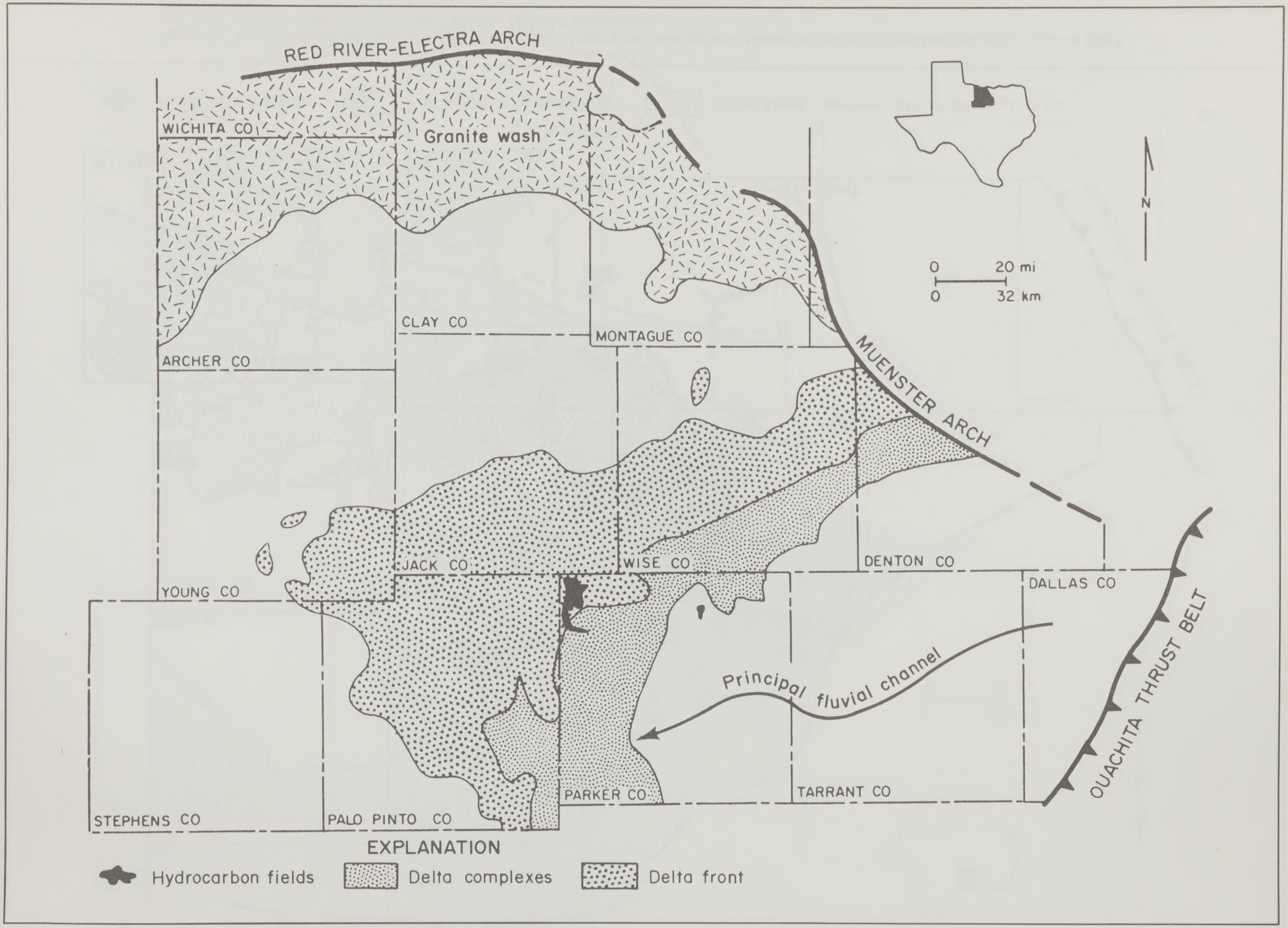

Figure 26. Facies framework of upper Atoka "Davis" hydrocarbon reservoirs. Irregular field outlines reflect "county regular" designation.

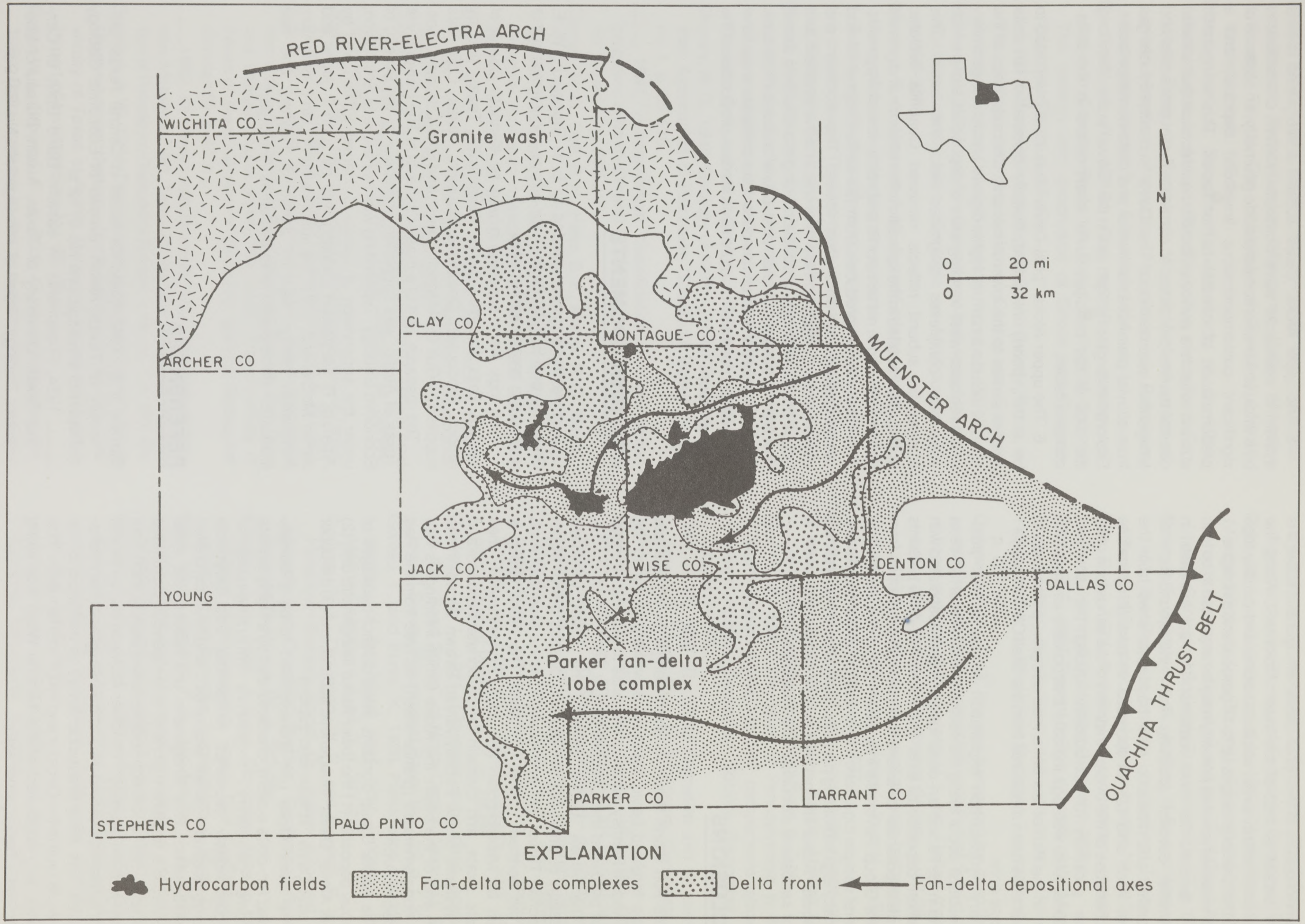

Figure 27. Facies framework of upper Atoka "post-Davis" hydrocarbon reservoirs. Irregular field outlines reflect "county regular" designation.

Reservoir quality in the "post-Davis" lithogenetic subunit is probably similar to that of the lower Atoka unit. Along the northern and central axes, scattered sonic and density logs indicate that porosity ranges up to 16 percent and averages 11 percent. However, overall porosity may be expected to be less than 11 percent for two reasons: (1) an increase in pseudomatrix content resulting from the abundance of metamorphic and volcanic rock fragments shed from the Muenster Arch and (2) an increase in pore-filling calcite cement because of the overall thinness of the sandstone units and the proximity of carbonates. Along the southern depositional axis, well logs indicate that porosity averages 10 percent. In the Parker fan-delta lobe complex, porosity up to 14 percent has been measured from the Shell Oil Company #1 J. H. Doss core.

Primary hydrocarbon exploration targets in the "post-Davis" subunit occur along the northern and central fan-delta axes and in the Parker fan-delta lobe complex associated with the southern depositional axis. The Parker fan-delta presents the greatest potential for future hydrocarbon production from the Atoka Group. Favorable indications for production include (1) several sample logs denoting oil stains, (2) scattered sonic and density logs indicating porosity, and (3) core that is similar to the lower Atoka lithogenetic unit (a proven producer) in terms of sandstone petrology and depositional style.

CONCLUSIONS

1. The Fort Worth Basin, in North-Central Texas, is a late Paleozoic foreland basin that was downwarped during the Early to Middle Pennsylvanian in response to tectonic stresses that also produced the Ouachita Thrust Belt.

2. The Atoka Group reflects the initial westward progradation of chert-rich terrigenous clastics derived from the Ouachita Thrust Belt and locally from the Muenster Arch across the northern part of the basin. The Atoka Group is underlain by Mississippian and Early Pennsylvanian shelf carbonate strata, and overlain by carbonate buildups and deltaic systems of the Pennsylvanian Strawn Group. In the northern end of the basin, the Atoka Group interfingers with arkosic conglomerates (granite wash) derived from the Red River-Electra Arch.

3. The Atoka Group contains three distinct packages of terrigenous deposits: (1) the lower Atoka lithogenetic unit, (2) the upper Atoka "Davis" lithogenetic subunit, and (3) the upper Atoka "post-Davis" lithogenetic subunit.

4. The lower Atoka unit is interpreted to be a fluvially dominated fan-delta system, characterized by a highly digitate sandstone geometry, extensive interfingering of contemporaneously deposited terrigenous and carbonate strata, progradational facies sequences, and fault-controlled facies distribution. This lithogenetic unit reflects the initial transition from a shallow marine to a terrigenous-dominated environment when chert-rich sediment was rapidly shed from tectonically active sources. The lower Atoka produces oil and gas from fan-delta channel-fill and coarse-grained fan-delta-plain facies. The most productive areas lie northwest of the Mineral Wells fault in the Decatur and Palo Pinto fan-delta lobe complexes, and southwest of the Mineral Wells fault along major fan-delta depositional axes.

5. The upper Atoka "Davis" subunit is interpreted to be a system of coalesced wave-dominated deltas, characterized by a thick, strike-oriented sandstone geometry, an absence of significant contemporaneous limestone deposits, and a predominance of coastal-barrier facies. This lithogenetic subunit reflects a period of tectonic quiescence that allowed coastal marine processes to dominate fluvial processes and terrigenous sediment input. The "Davis" subunit produces gas from alluvial-plain/coastal-barrier and delta-complex facies. Exploration targets for tight gas in the "Davis" subunit lie along the axis of the principal fluvial channel and in the delta-complex facies.

6. The upper Atoka "post-Davis" subunit is interpreted to be a thin, poorly integrated, fluvially dominated fan-delta system similar to the lower Atoka unit. Characteristics of the subunit include a narrow, highly digitate sandstone geometry and three east-west-trending axes of deposition, along which delta-lobe complexes prograded into the basin. This lithogenetic subunit reflects renewed Ouachita tectonic activity that resulted in the sporadic influx of sands and gravels rich in chert and in metamorphic and volcanic rock fragments. The "post-Davis" produces from fan-delta channel-fill and coarse-grained fan-delta-plain facies. The northern and central axes of deposition are oil prone, and the southern axis is gas prone. Although production along the southern axis is now limited, the upper Atoka "post-Davis" subunit in this area, particularly in the Parker fan-delta lobe complex, may have the greatest potential for future hydrocarbon production of the Atoka Group.

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APPENDIX 1

Well logs used in cross sections.

County	Map Number	Operator	Well Name
Archer	9	McAllister Fuel	#A-1 C. L. Abercrombie
	25	G. E. Kadane & Sons	#1 Wilson Heirs-Ohio
	26	Novi Equipment	#1 John Purcell
	38	Anderson Petroleum	#1 H. Morbitzer
	46	Phillips Petroleum	#1 Crory
Clay	25	Continental Oil	#1 Crockett
	26	Burnes Estate	#1 Patterson
	31	Consolidated Oil	#1 Scaling
	32	Wilcox & Confidential	#1 Sealing
	43	Shell Oil	#A-1 Hapgood
	48	Phillips Petroleum	#1 Hapgood
	59	Omohundro	#1 Lenabel Courtney
	63	Sinclair Oil & Gas	#A-1 Southhill
Dallas	1	Magnolia Petroleum	#1 Trigg Estate
Denton	10	Standard Oil of Kansas	#1 E. D. Hart
	12	Trentman Jr.	#1 R. M. King
	14	George Engle	#1 Mrs. A. Martin
	21	Carter Oil	#1 Allen
Jack	7	Hanlon-Boyle	#2 Bertha Moore
	15	Mid-Continent	#1 B. Zuber
	22	Davon Oil	#1 Dees
	30	Longhorn Production	#3 Ella May Craft
	51	Jack Grace	#1 Lindley
	53	Continental Oil	#1 R. Cherryholmes "B"
	65	Warren Oil	#1 McClure "B"
	67	Hanlon-Buchanan	#2 Matlock
	70	Warren Oil	#1 George Evett "B"
	73	Continental Oil	#1 Copeland
	90	Gulf Energy	#2 Button Crowley
Montague	2	J. Grace	#1 Skinner-Jackson
	4	Nu-Enamel	#1 W. L. Admire
	66	Sinclair Prairie	#1 Collier
	82	Continental Oil	#1 Richardson
Palo Pinto	1	Continental Oil	#1 W. H. Green
	8	Trans-Texas Energy	#1 Gragg
	14	Pan American	#1 Helen Watson
	17	Petroleum Resources	#1 Padgett Ranch
	18	Kadane & Sons	#1 Chaney
	34	Kadane	#1 J. E. Bankhead
	42	Deaton & Sons	#1 Deaton
	43	Deep Rock	#1-A Gafford-Branson
	45	Rhodes Drilling	#2 Barton
	48	Ashland Oil	#1 Halskill
	84	Mid-Tex Petroleum	#1 Marie Cardi Eubank
	111	R. H. Wininger	#1 Swenson
Parker	7	Manahan Drilling	#1 Anne Doss, et al.
	8	Shell Oil	#1 J. H. Doss
	9	Cities Service	#1 W. H. Glenn
	11	Toto Gas	#1 Carr "L"
	15	Toto Gas	#1 Ruby Sears
	16	Devonian Oil	#1 R. Buck
	17	Continental Oil	#1 C. P. Woody
	24	Nunley & Hale	#1 Lindsey
	26	Diamond Shamrock	#1 Dunlap
	29	Toto Gas	#1 Suggett
	48	Cayman Exploration	#1 Bigg "B," Inc.
	54	Cottonwood Petroleum	#1 L. F. Grimes
	69	J. P. Dunigan Inc.	#1 Wallis
Stephens	1	Woodley & Dangiger	#1 Joe Sickie
	9	Texas Pacific	#1 Robertson
	12	Texas Company	#1 A. V. Jones
	15	Escargot & Dunigan	#1 Brown
	26	Texas Pacific	#1 Hill
	35	Warren Oil	#1 George Glasscock
	53	Delta Oil of Delaware	Bernie McCrea
	54	Woodley & Premier	#1 Thorpe "B"
	68	Kirk Johnson	#1 West
	69	American Manufacturing	#1 Echols
	87	Sinclair Oil & Gas	#1 Alice Walker
	92	McNallen & Griggin	#3 J. W. Crowley
	109	Walter Exploration	#1 Foster
	113	Terrell Petroleum	#1 Gardenhire Heirs
Tarrant	3	C. Andrade III	#1 Sharpless
	5	Bruce Sullivan	#1 Putnam
	8	Mitchell Energy	#1 Wilkinson
Wise	1	Signal Oil	#1 Jack Daly
	4	Miles & Christi, Mitchell & Mitchell	#1 L. D. Florida
	9	W. B. Omohundro	#1 Bryan
	12	Phillips Petroleum	#2 Municipal
	16	Phillips Petroleum	#1 Hired Hand
	17	Toklan Petroleum	#1 Bun Johnson
	18	Standard Fryer Drilling	#1 M. D. Canster
	19	Champlin Refrigerating	#1 Stanfield
	20	Cities Service	#1 Manning
	27	Mitchell Energy	#6-4 Deaver
	28	Sunray DX Oil	#1 E. F. McGaughey
	30	Mitchell & Associates	#1 East Texas Co. Trust
Young	13	British American	#B-2 C. H. Roach
	17	J. J. Lynn	#1 Benson Estate
	18	Superior Oil	#1 A. C. Deats, et al.
	19	A. R. Dillard	#1-B S. R. Jeffery
	30	Perkin Brothers	City of Leverman
	34	Humphrey	#1 Williamson
	70	Standard of Texas & Buchanan	#1 Donnell
	74	Warren Petroleum	#1 Inez King
	89	Dillard	#2-A Stovall "C"
	105	John C. Orgain	#1 S. A. Easterly

APPENDIX 2

Fields with a cumulative hydrocarbon production of 100,000 bbl. or more (oil plus gas equivalent). Plotted on plate XIX.

County	Field Number	Field Name
Clay	1	Dillard SE.
	2	Dillard SW.
	3	Joy S.
Denton	1	Gas Finders
Jack	1	Avis Bend
	2	Avis N.
	3	Bartons Chapel E.
	4	Blueberry Hill
	5	Boling-Crum
	6	CHK
	7	Campsey
	8	Cap Yates
	9	Cary-Mag
	10	Catlin
	11	Catlin SW.
	12	Cundiff N.
	13	Deweber
	14	Dunes
	15	Dunham W.
	16	Gage
	17	Gilley
	18	Gilley W.
	19	Hallwood
	20	Jacksboro
	21	Jacksboro E.
	22	Jacksboro S.
	23	Jerrye-Jan
	24	Jupiter
	25	Ken-Rich
	26	Kinder
	27	Kramberger
	28	Lytle
	29	Marina-Mag
	30	Marietta
	31	Morris
	32	Newport S.
	33	Newport SE.
	34	Newport W.
	35	Perrin N.
	36	Perrin Ranch
	37	Post Oak
	38	Riggs
	39	Rusmag
	40	Rusmag N.
	41	Steed
	42	Stoneman Bend
	43	Wasoff
	44	Wes-Mor
	45	Wizard Wells
Montague	1	Aries
	2	Boedecker
	3	Bowie NE.
	4	Bowie SE.
	5	Eanes
	6	Queen Peak
	7	Stoneberg S.
	8	Sunset
Palo Pinto	1	Belding Bend
	2	Costello
	3	Costello NW.
	4	Emory
	5	Graford
	6	Harken
	7	Johnston Gap
	8	Mineral Wells
	9	Mineral Wells N.
	10	P. K. Park
	11	Palo Pinto
	12	Rife
	13	Seaman
	14	Strawn N.
Parker	1	Bethesda
	2	Dicey
	3	Meeker
	4	Millsap E.
	5	Poolville SW.
	6	Springtown W.
	7	Toto Bend
Stephens	1	Bill Ray Atoka
	2	Blackburn
	3	Breckie
	4	Delong
	5	Donnell
	6	Eloise Kay
	7	Gourley
	8	Haymore
	9	Hill
	10	Iles Conglomerate
	11	Jill
	12	Jill N.
	13	Jim Kern
	14	Richels
	15	William & Jack
Wise	1	Alvord
	2	Alvord S.
	3	Ashe Ranch
	4	Becknall
	5	Bogy
	6	Boonesville
	7	Boonesville S.
	8	Bridgeport
	9	Caughlin
	10	Chico W.
	11	Crim Conglomerate
	12	Leftwick
	13	Miles Jackson
	14	Morris
	15	Nall S.
	16	Paradise
	17	Park Springs
	18	Park Springs S.
	19	Rhome
	20	Risch E.
	21	Sancree S.
	22	Thetford
	23	Tidwell
	24	Younger W.
Young	1	Beth
	2	Bunger SW.
	3	Jim-Ferd
	4	Kendall
	5	South Bend
	6	Sweeney

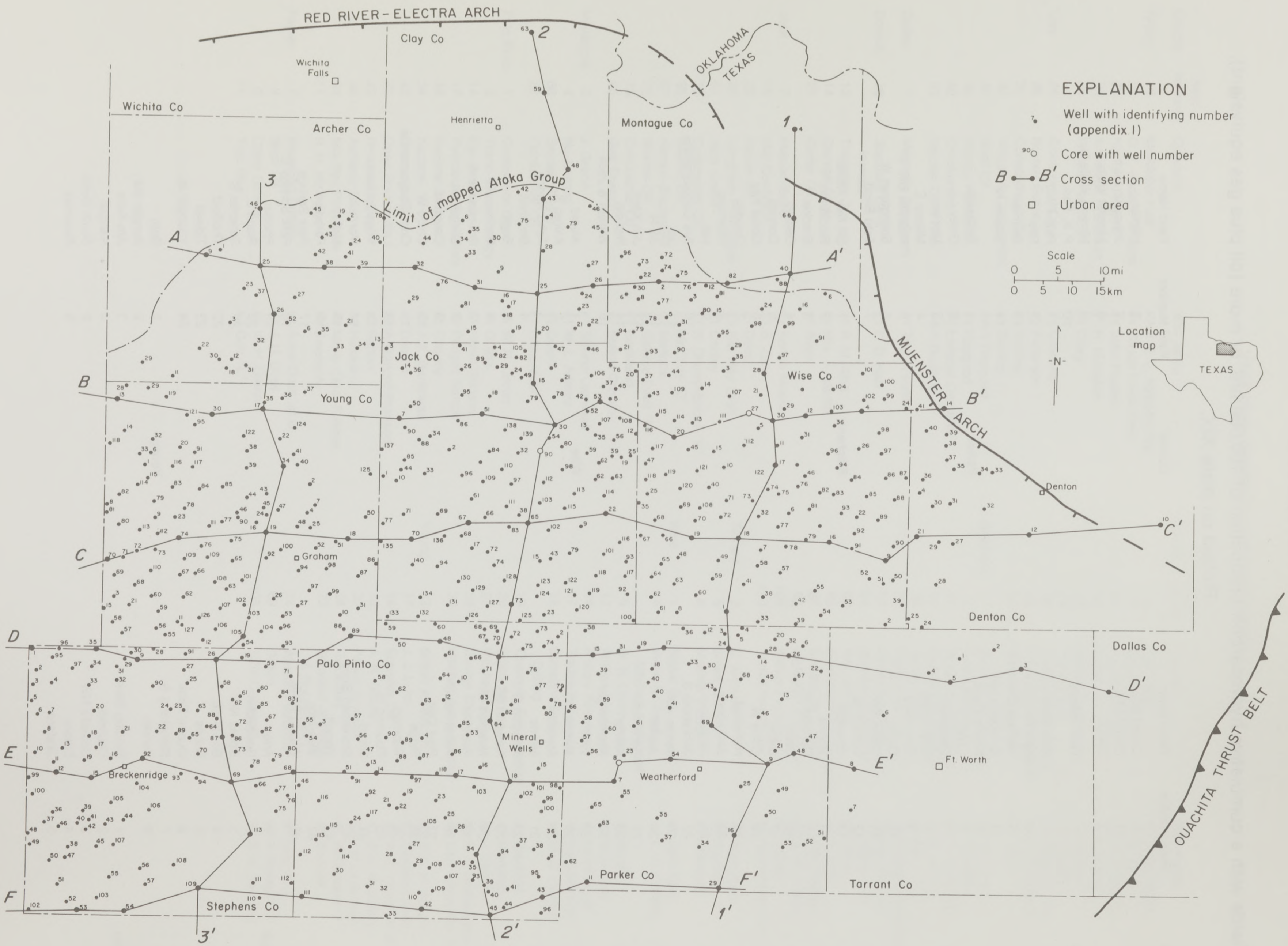

Plate I. Map of data base, northern Fort Worth Basin, Texas.

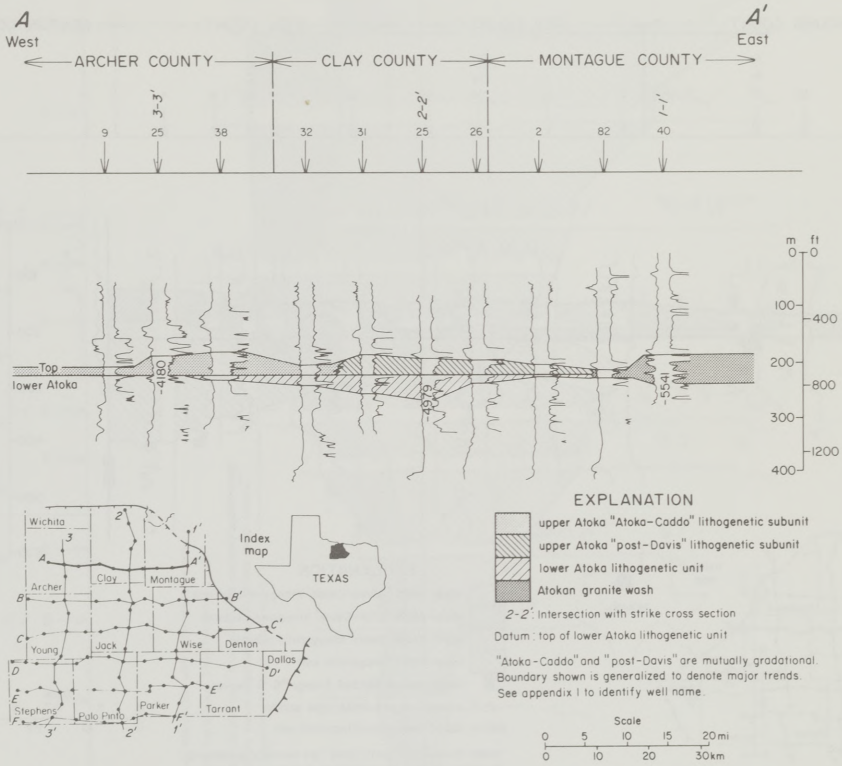

Plate II. Dip cross section A-A'.

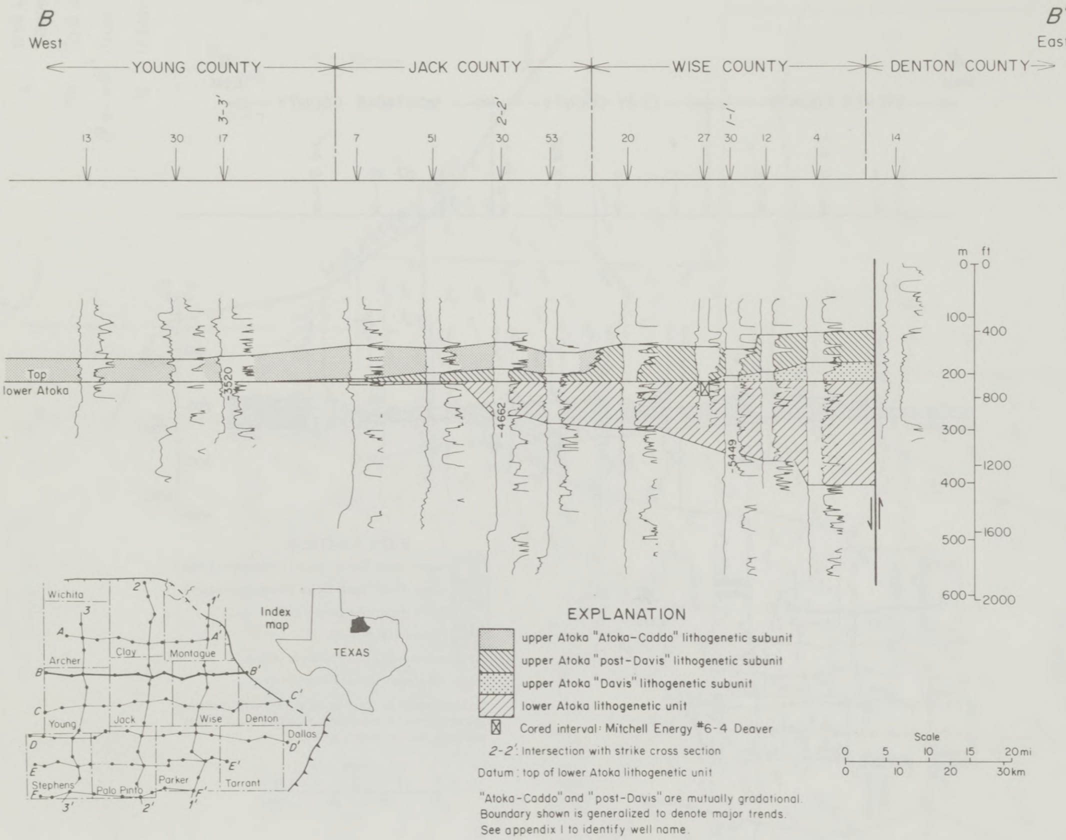

Plate III. Dip cross section B-B′.

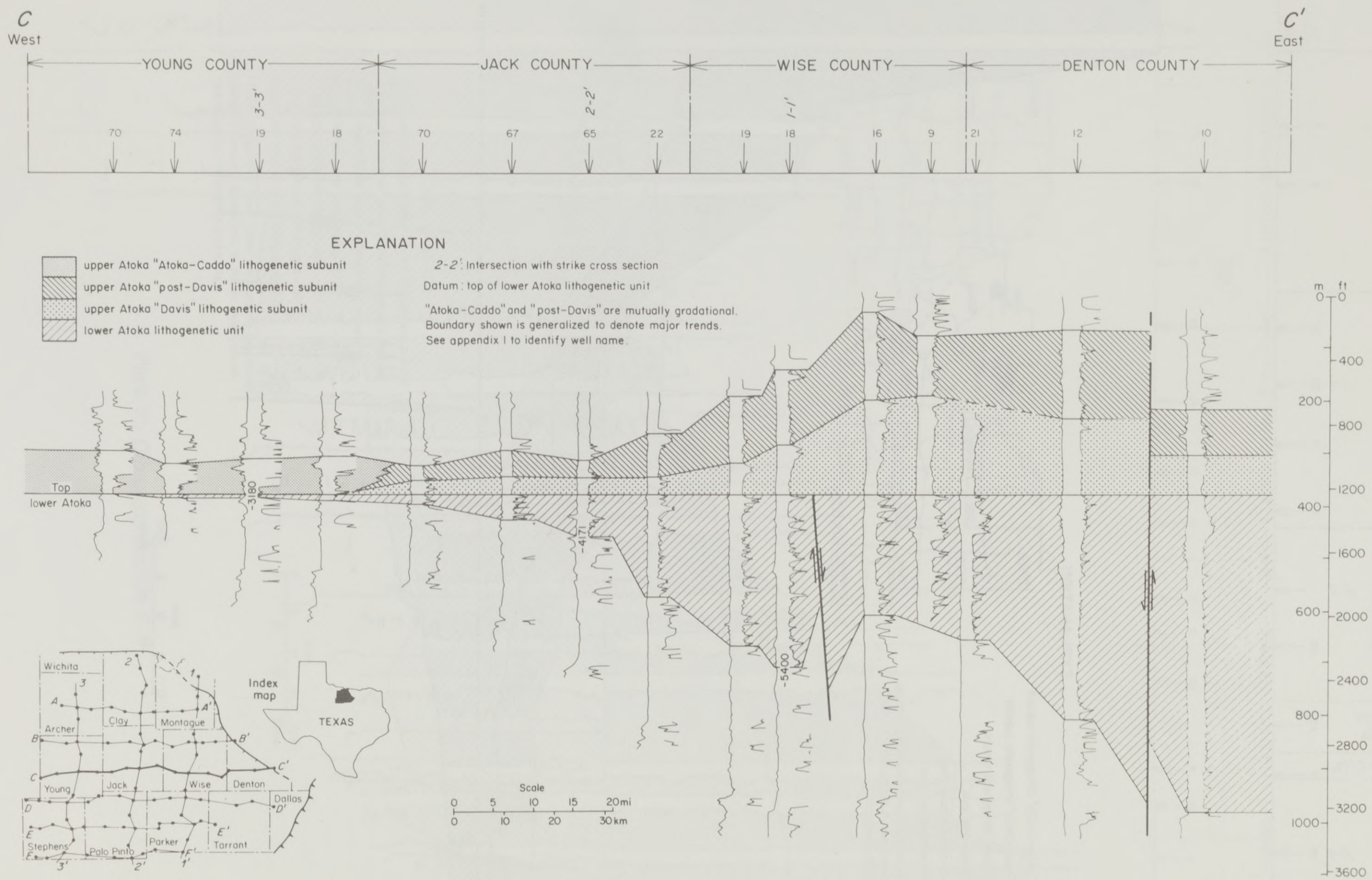

Plate IV. Dip cross section C-C'.

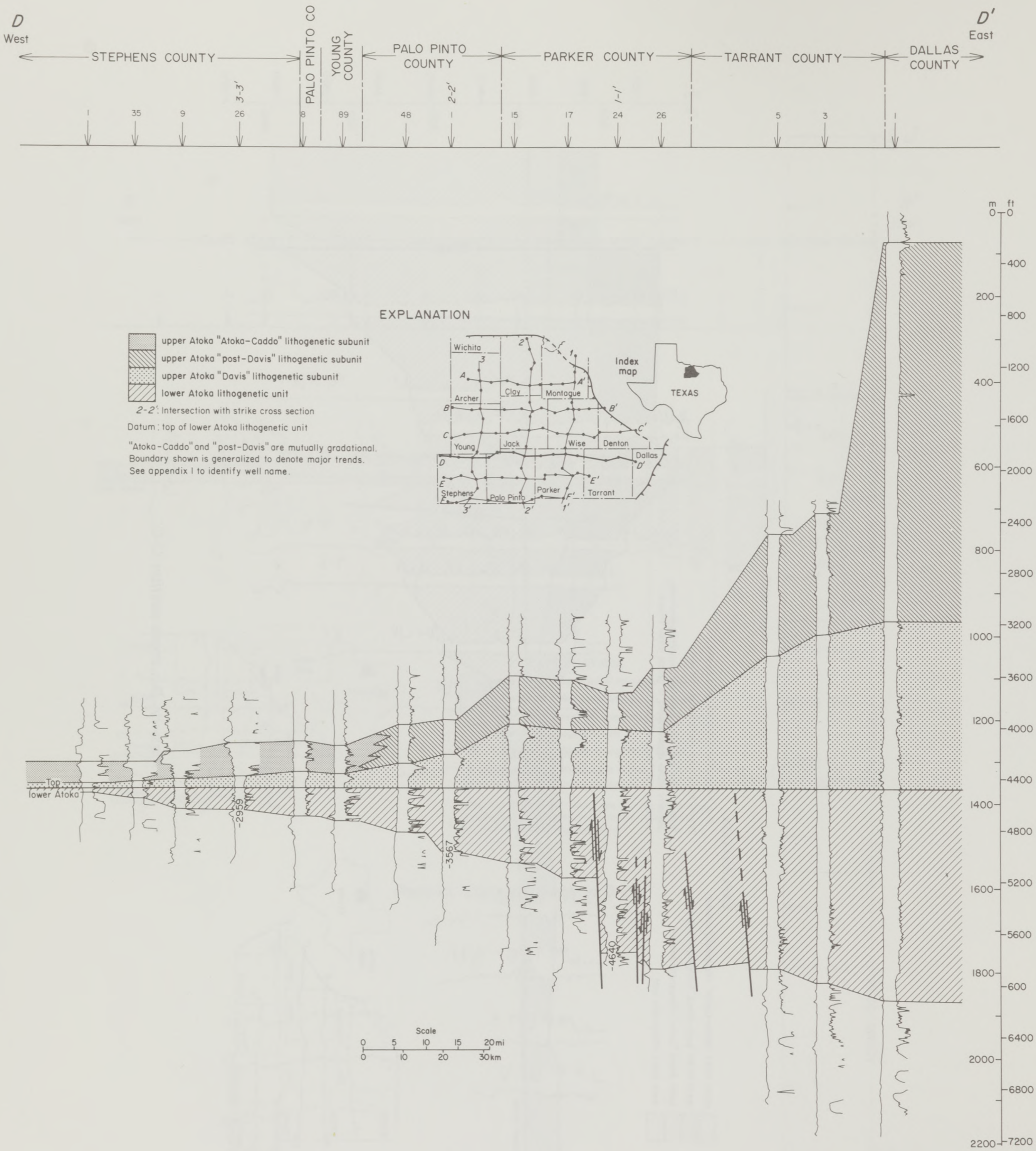

Plate V. Dip cross section D-D'.

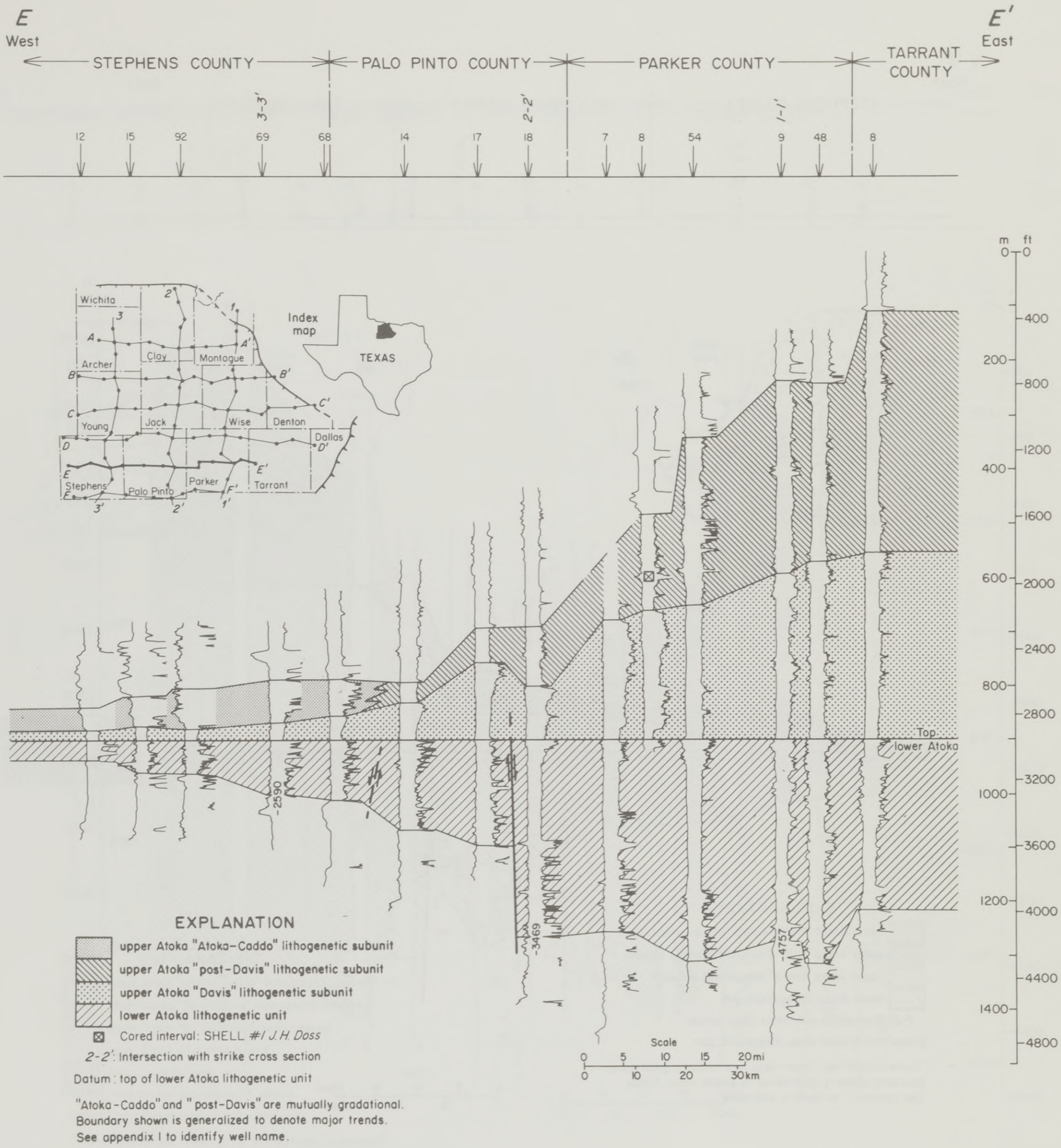

Plate VI. Dip cross section E-E'.

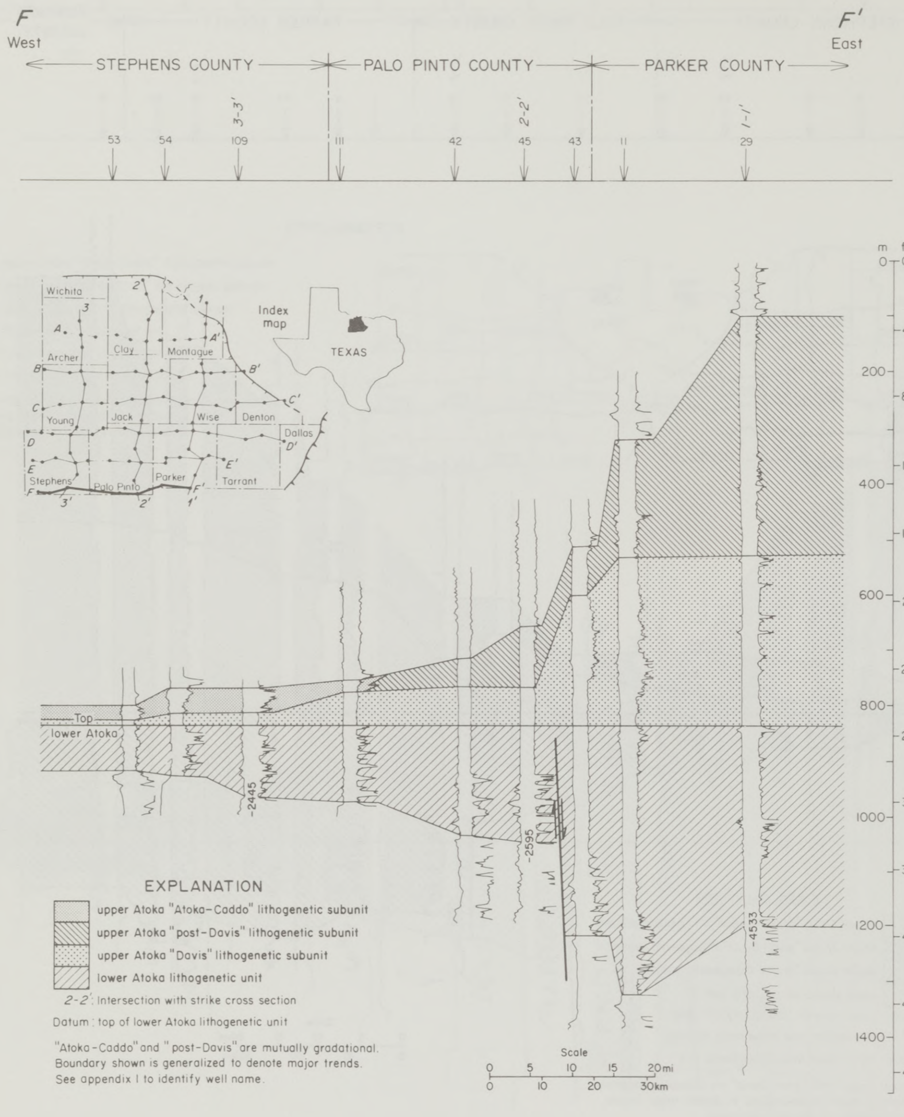

Plate VII. Dip cross section F-F'.

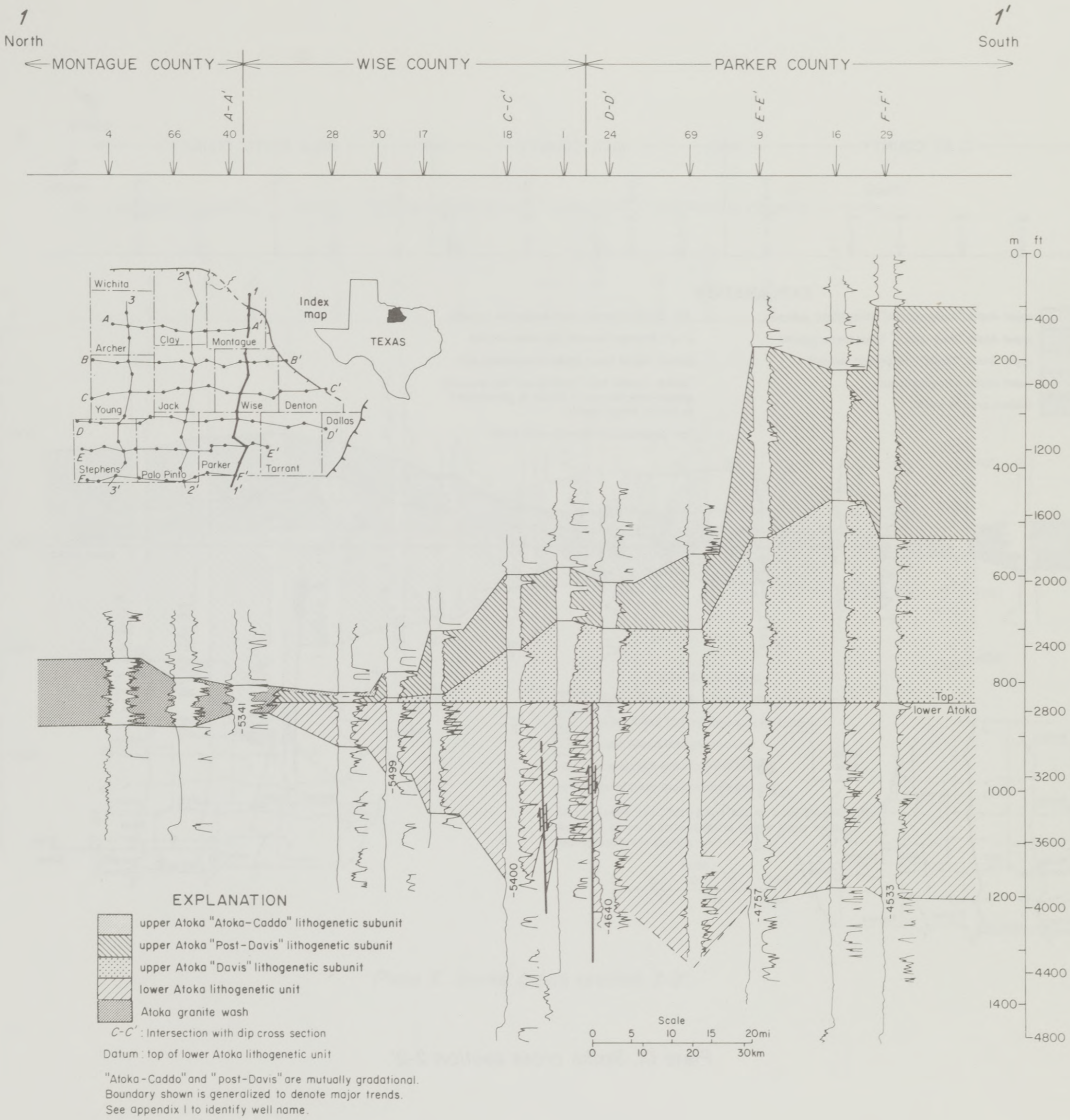

Plate VIII. Strike cross section 1-1′.

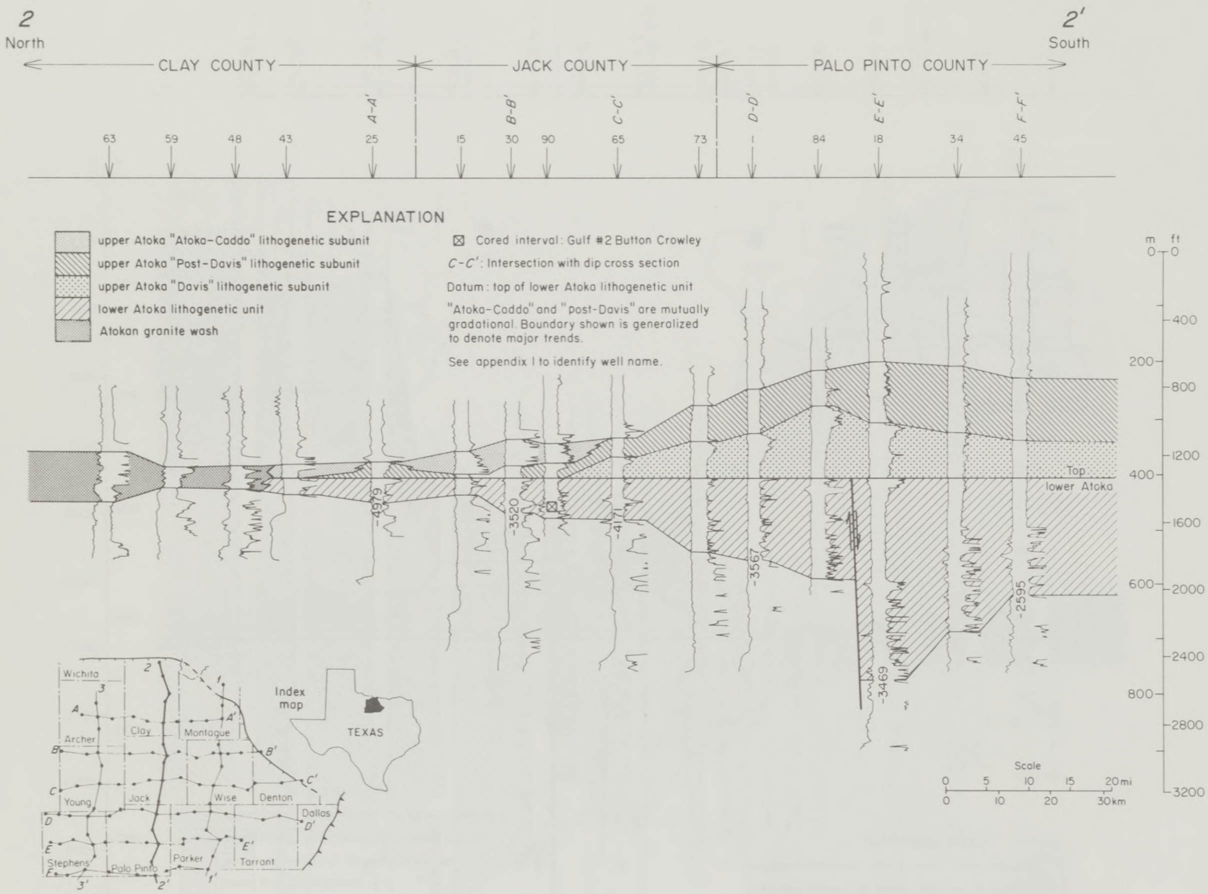

Plate IX. Strike cross section 2-2′.

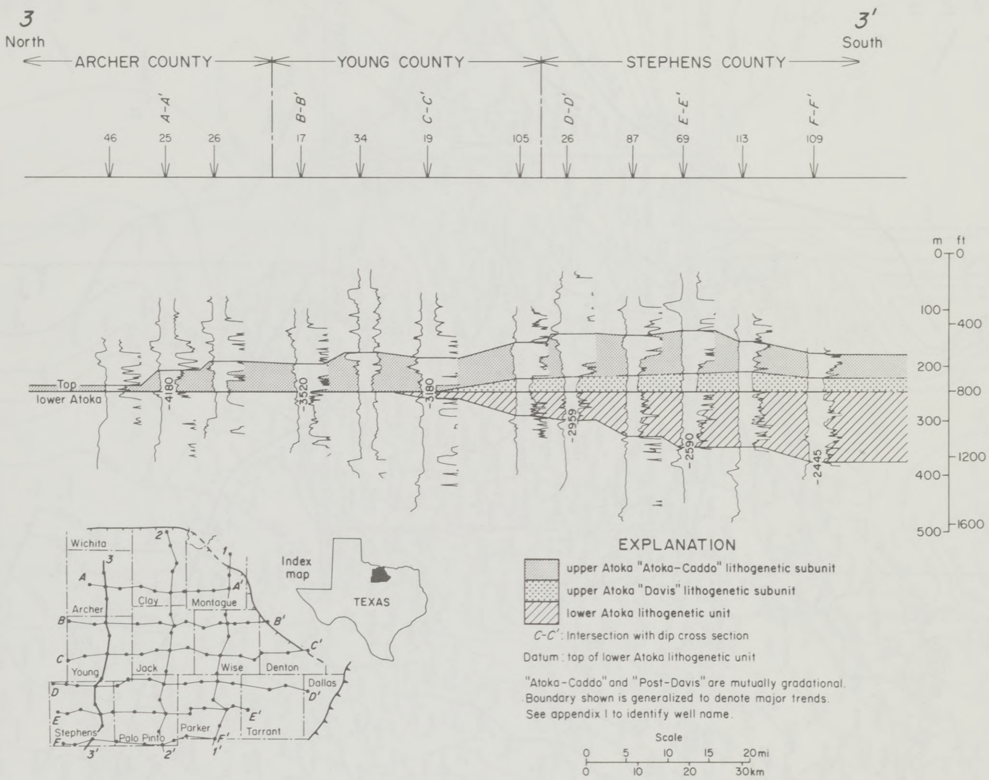

Plate X. Strike cross section 3-3′.

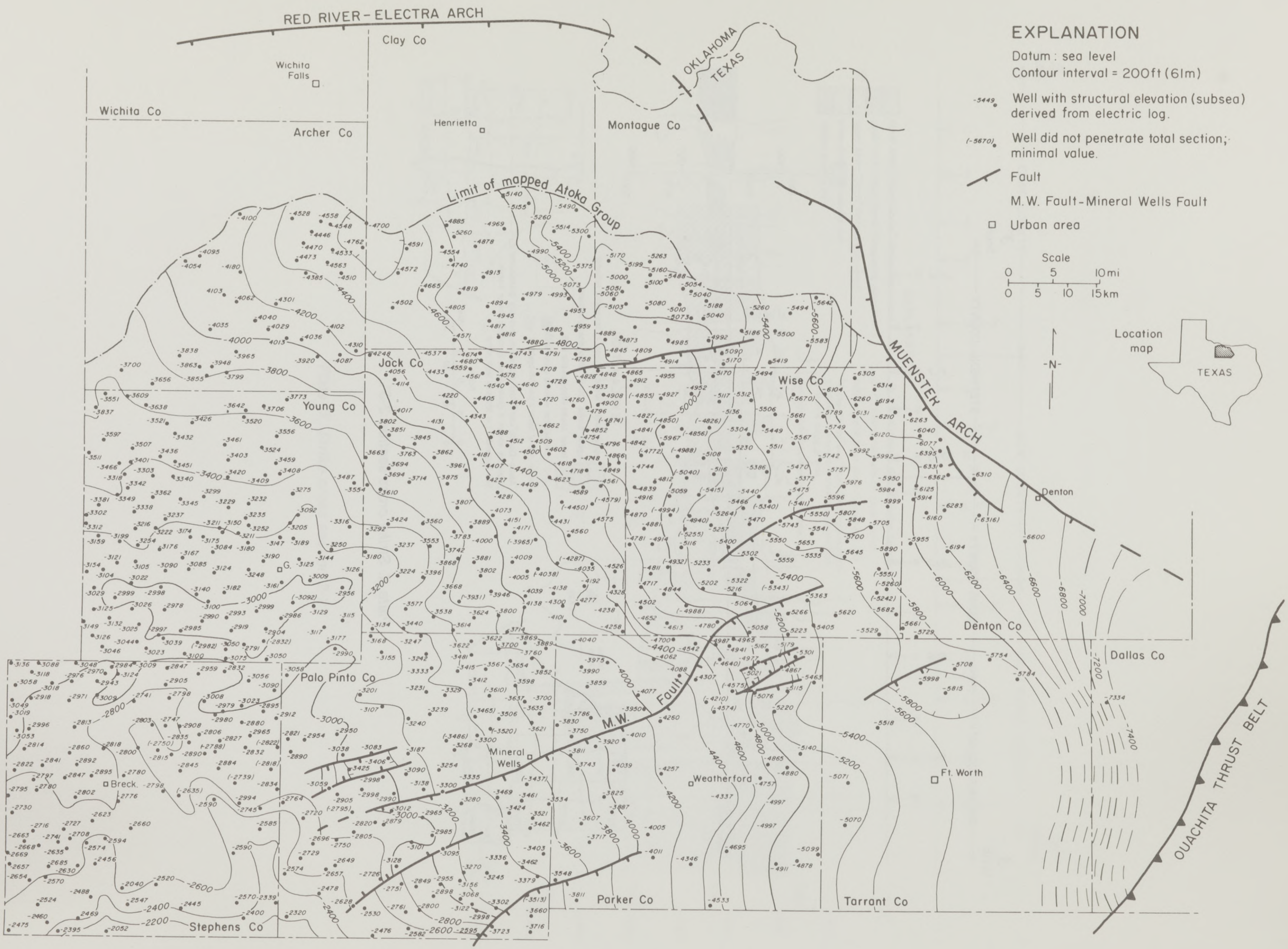

Plate XI. Structure map, top of pre-Atoka strata.

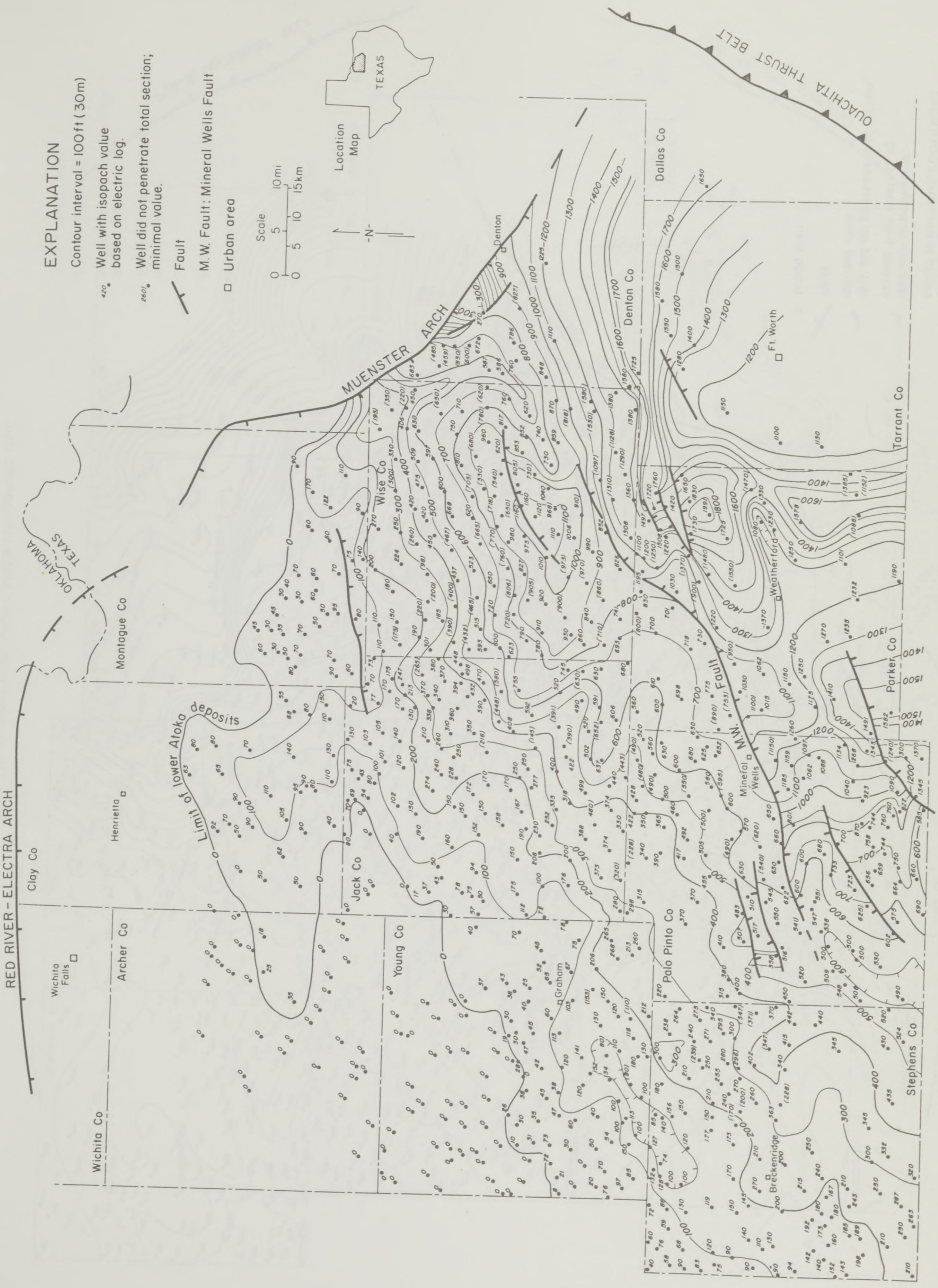

Plate XII. Isopach map, lower Atoka lithogenetic unit.

Plate XIII. Isopach map, upper Atoka lithogenetic unit.

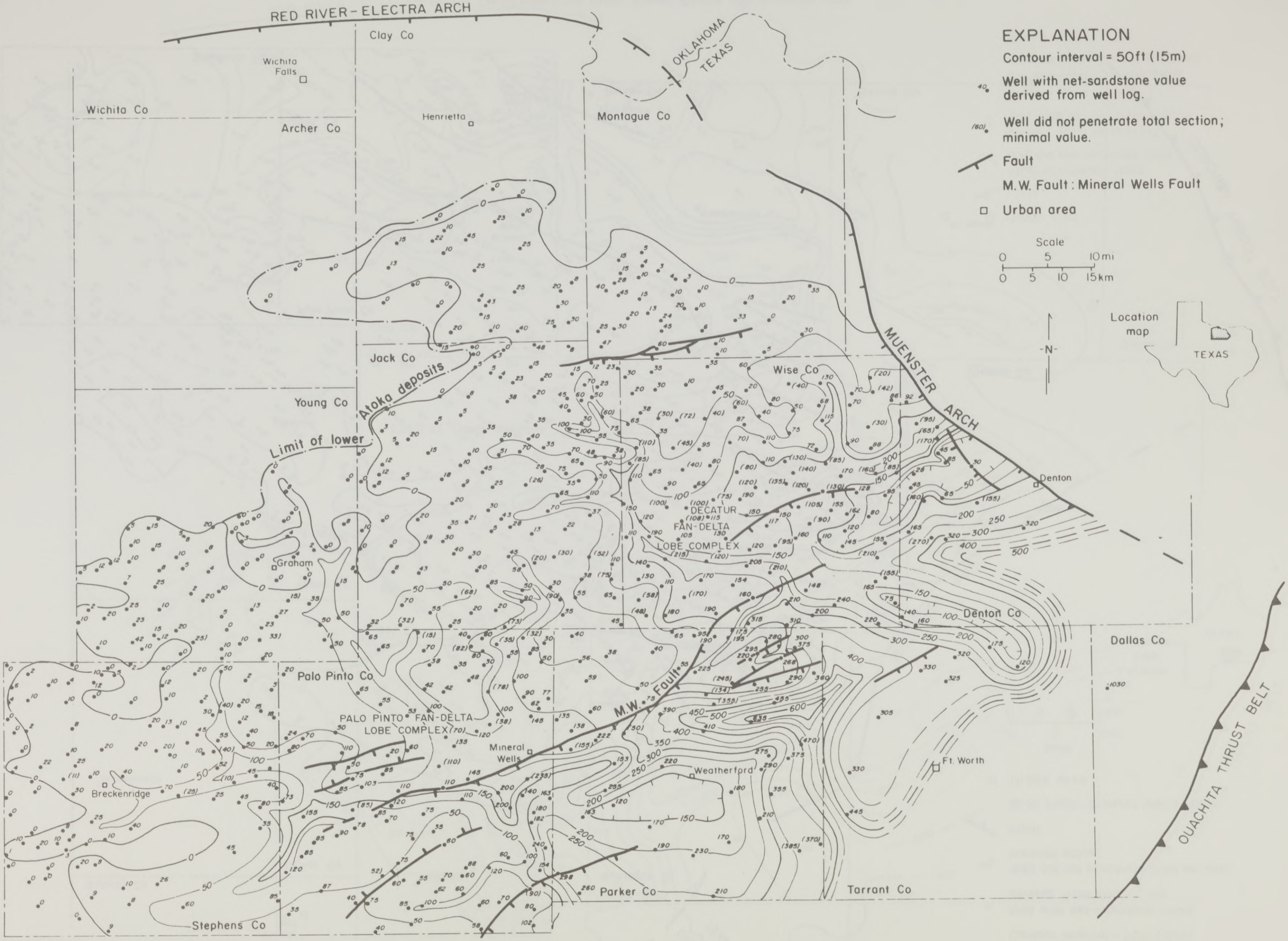

Plate XIV. Net-sandstone map, lower Atoka lithogenetic unit.

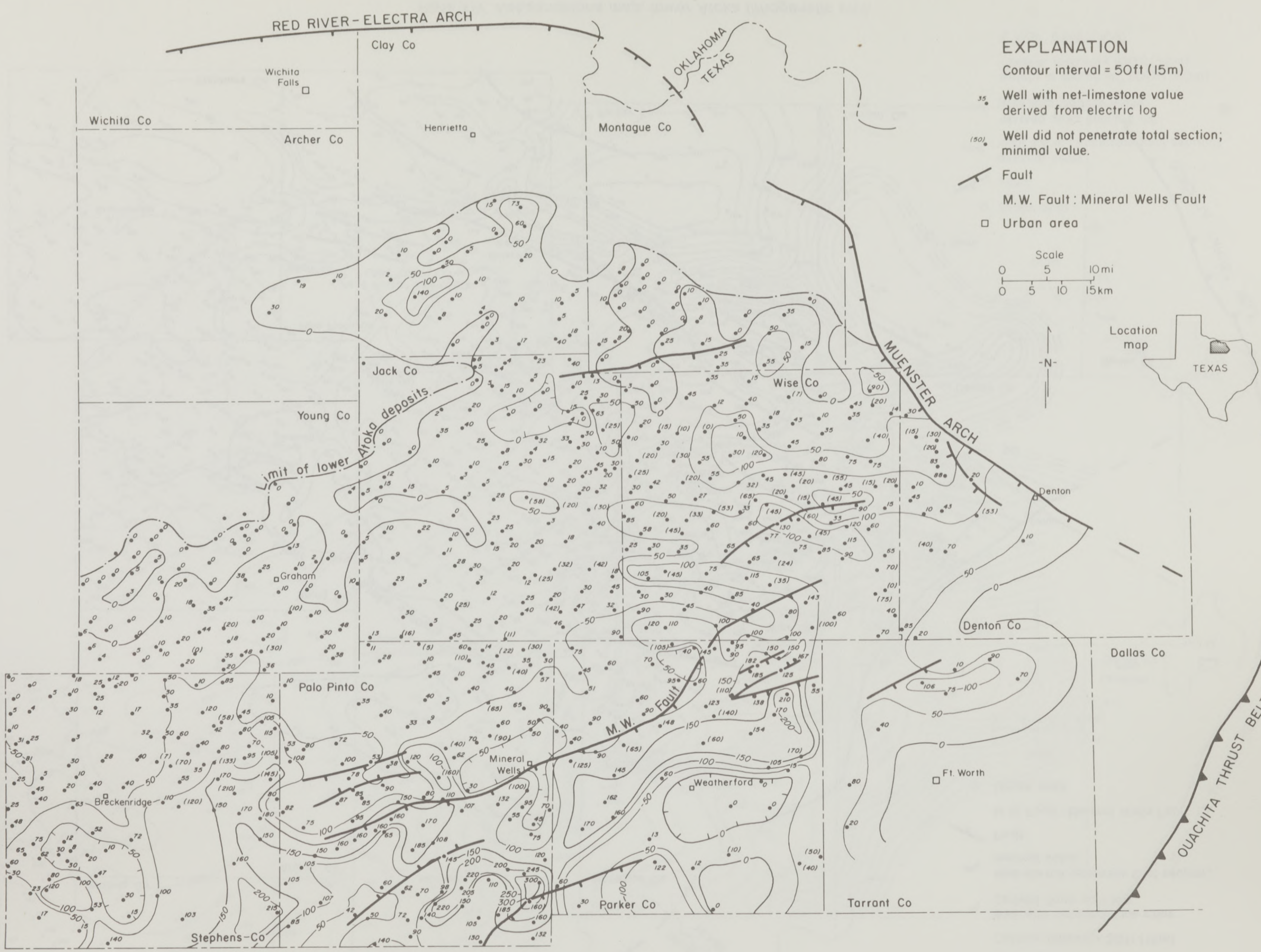

Plate XV. Net-limestone map, lower Atoka lithogenetic unit.

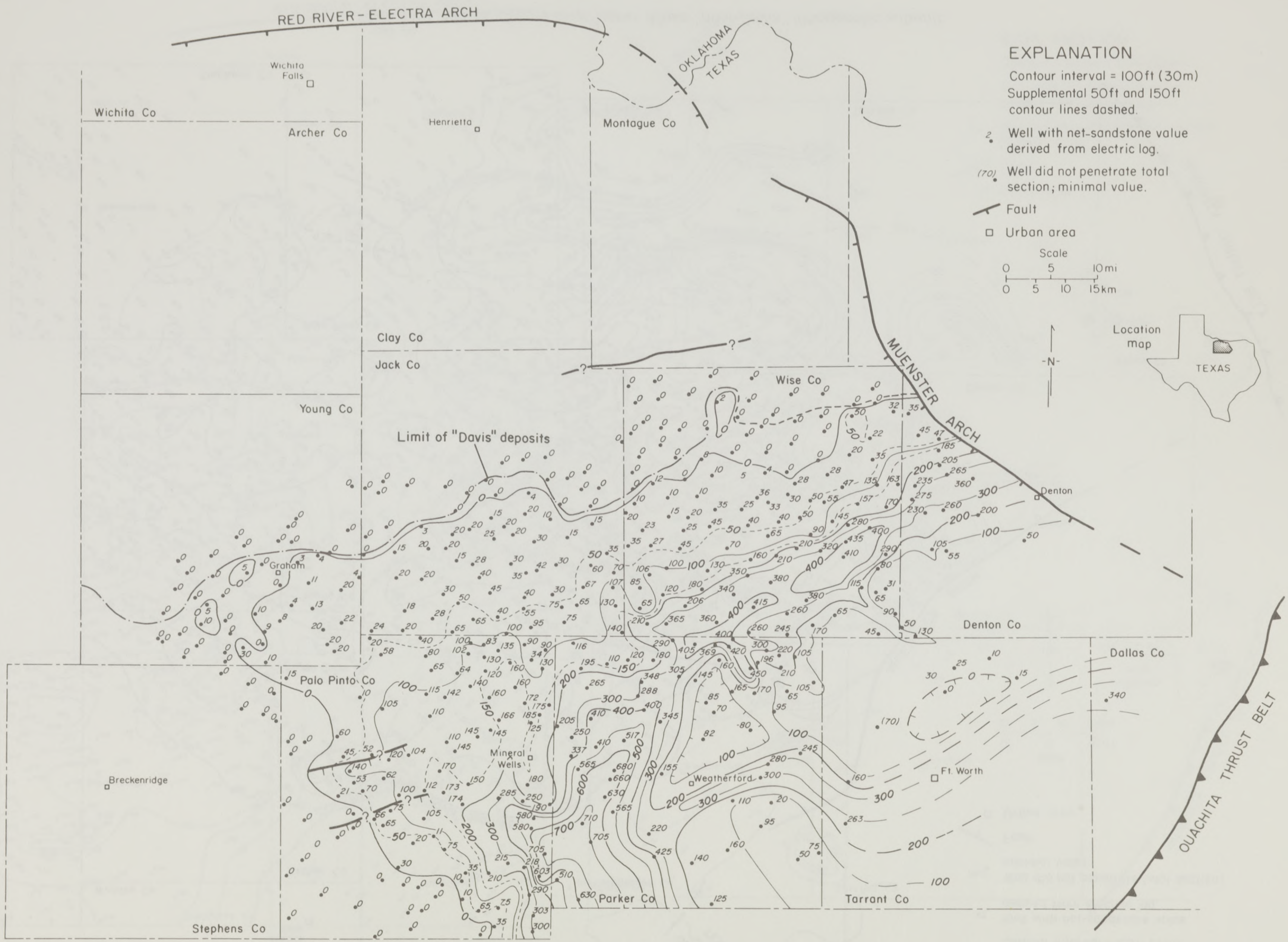

Plate XVI. Net-sandstone map, upper Atoka "Davis" lithogenetic subunit.

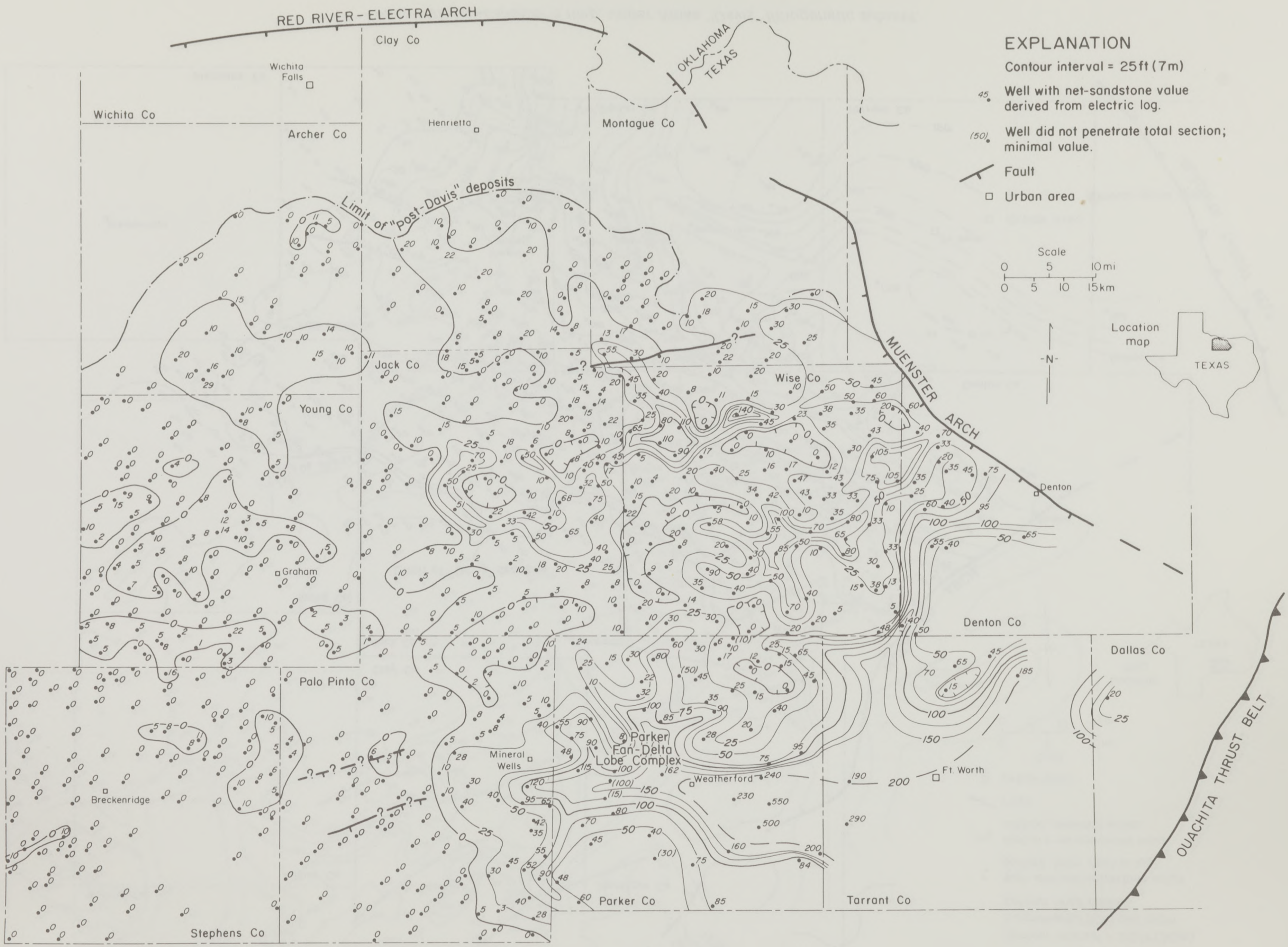

Plate XVII. Net-sandstone map, upper Atoka "post-Davis" lithogenetic subunit.

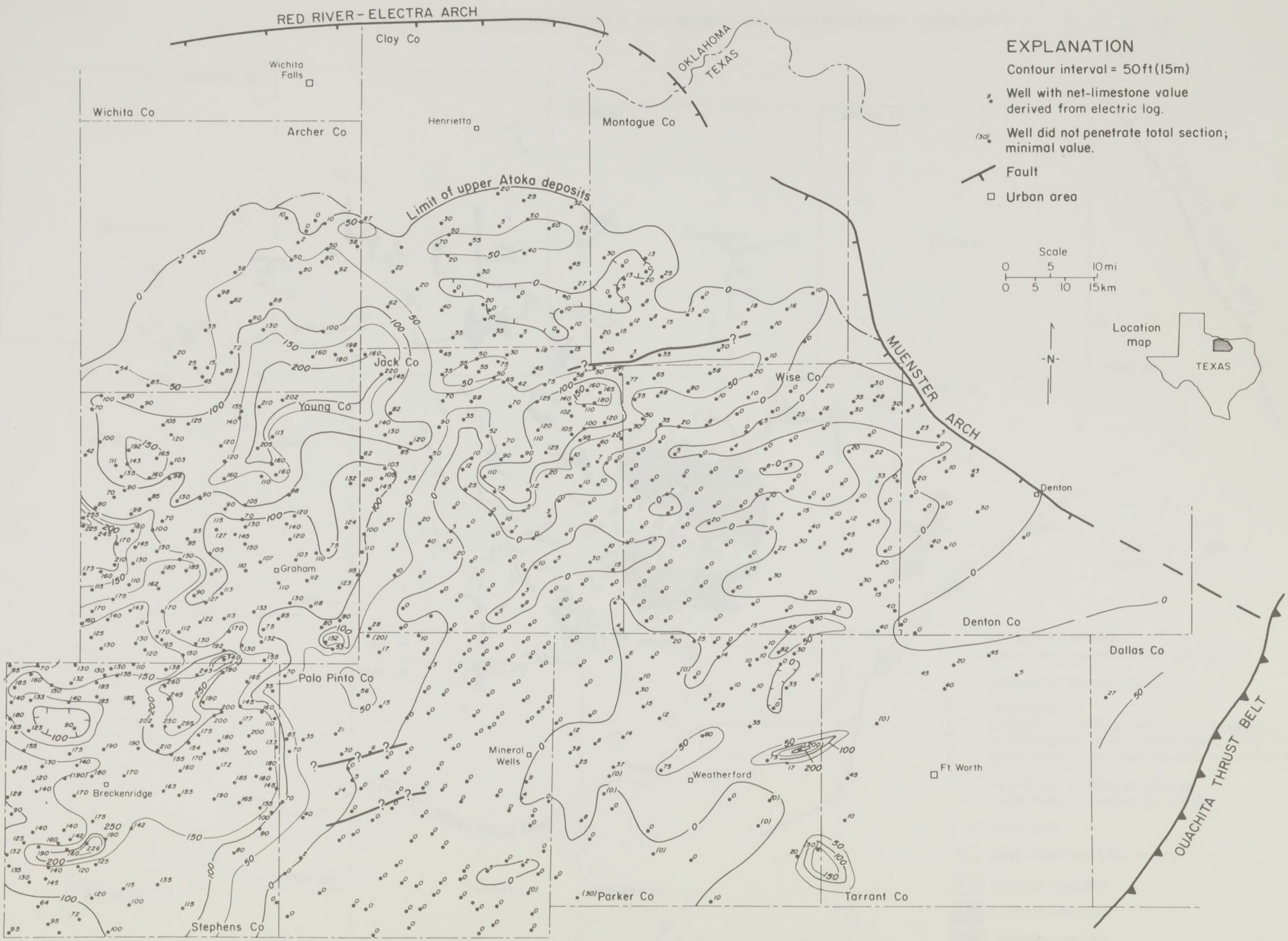

Plate XVIII. Net-limestone map, upper Atoka lithogenetic unit.

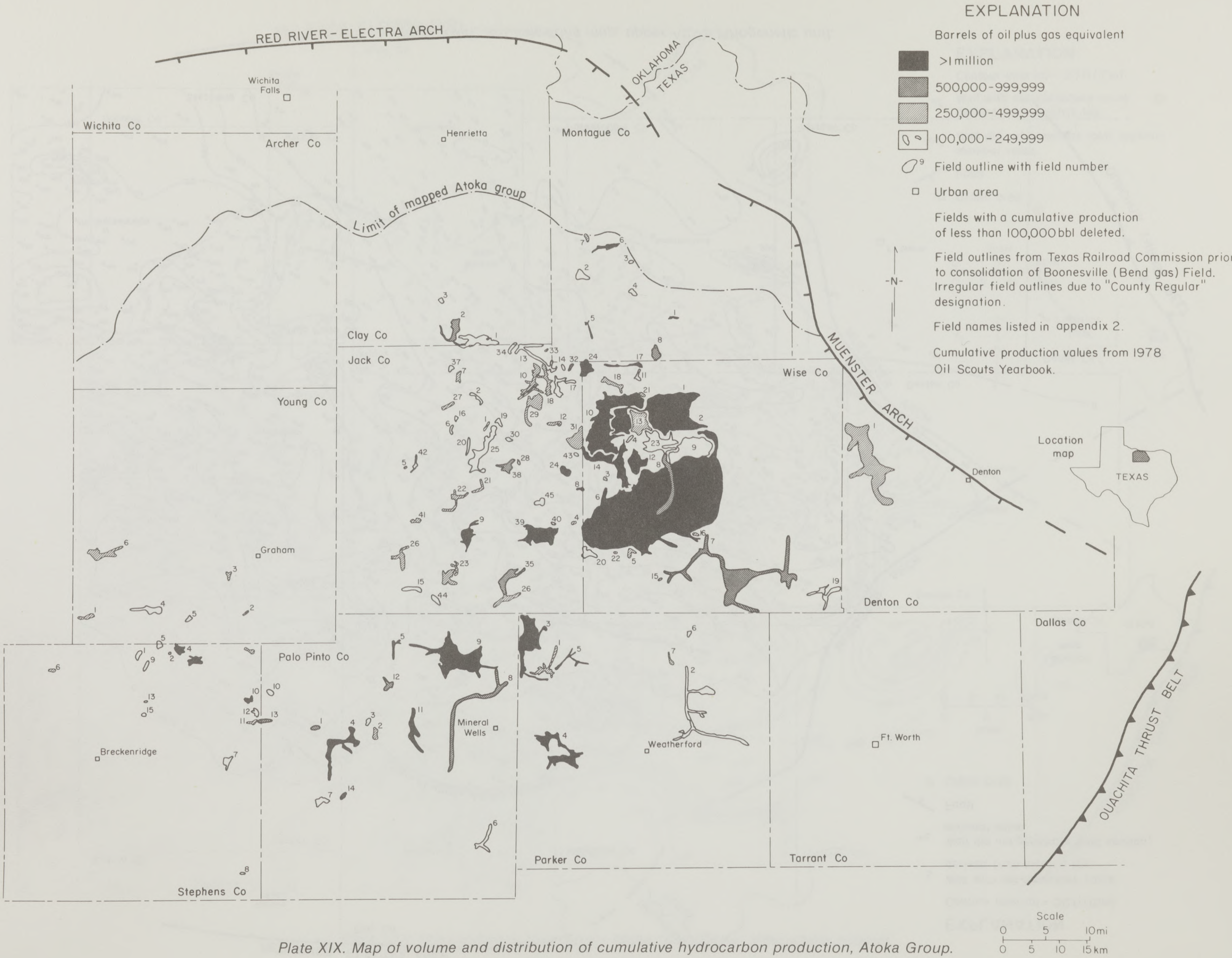

Plate XIX. Map of volume and distribution of cumulative hydrocarbon production, Atoka Group.