DEPOSITIONAL SYSTEMS, PETROGRAPHY, AND PETROLEUM GEOLOGY OF A CADDO CONGLO- MERATE (ATOKAN) WAVE-REWORKED BRAID DELTA IN NORTH-CENTRAL TEXAS

By

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CHAPTER I

ABSTRACT

The Fort Worth Basin is a wedge-shaped foreland basin whose primary sediment fill consists of Ordovician and Mississippian carbonates and Middle (Atoka and Strawn Series) and Upper Pennsylvanian terrigenous clastic rocks. The Atokan and Strawn clastic units were deposited on the basin's structurally stable northern shelf and contain significant quantities of natural gas and liquid hydrocarbons. The Caddo conglomerates and sandstones are the second most productive interval in the Atoka Series but its depositional model and diagenetic characteristics are poorly understood by exploration geologists.

The principle sources of data employed for this study were more than 700 electric logs from which stratigraphic cross sections and subsurface maps were constructed. Production trends as determined from published data were correlated to the structural contour, net sand isolith, sandstone percentage, clastic ratio, and interval isopach maps generated by this study. Two cores from the study area were examined to determine the controls on porosity and permeability.

The Caddo conglomerate and sandstones were deposited by a hybrid high-destructive wave-dominated and braid delta

complex that prograded from northwest to southeast. The Atokan fluvial-deltaic facies initiated the deltaic sedimentation for the basin.

Porosity and permeability development in the Caddo clastic units are controlled by the absence of early-forming authigenic quartz overgrowths and calcite cementation, along with the absence of pore-filling kaolinite and chlorite. Optimum conditions exist when enlarged intergranular porosity (dissolution of detrital matrix) and secondary moldic porosity (dissolution of feldspars) are void of the pore-filling clays and allow the preservation of an effective interconnecting network of pores.

Caddo production trends correlate very well to the sandstone trends indicated on the net sandstone maps. Pure stratigraphic trapping is the major mechanism for hydrocarbon emplacement throughout the study area.

The Middle Pennsylvanian, upper Atoka Caddo clastics of the Bend Group are known prolific hydrocarbon producers within the study area. The narrow, up-dip, braided fluvial channels and the wave-dominated braid delta sequences of the Caddo clastics are therefore a prime exploratory/ development target of the petroleum industry.

Through more complete detailed mapping and better understanding of the geometry and the porosity development of these and like clastics, a more successful hydrocarbon exploration program can be anticipated.

CHAPTER II

INTRODUCTION

Location of Study

The area for investigating the Middle Pennsylvanian Atoka strata lies in portions of Clay, Montague, Jack and Wise Counties, North-Central Texas. More specifically, the study area covers approximately 1,020 square miles (2,640 sq. km.) and is located in southeast Clay, south Montague, northeast Jack and north Wise Counties (Figure 1). The geologic setting for this area is located on the northwestern flank of the foreland Fort Worth Basin.

Objectives

The goal of this research is to enlarge upon the understanding of the Middle Pennsylvanian (Strawn/Atoka) Caddo intervals as found in the subsurface of the Fort Worth Basin in Texas. Specific objectives are:

1. to identify on a regional scale the distribution of the Caddo terrigenous sandstone bodies in the subsurface and to interpret the processes responsible for their deposition;

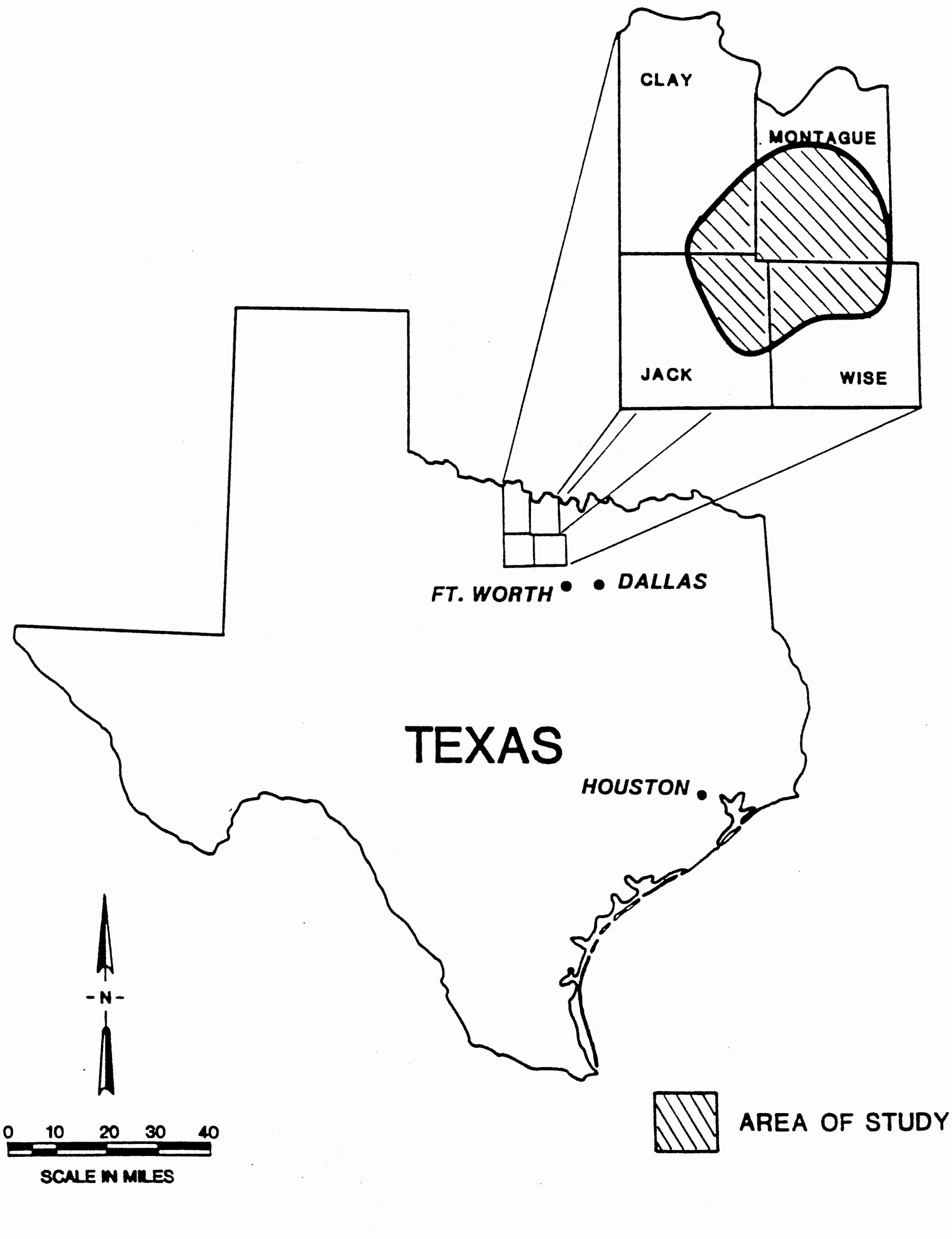


Figure 1. Geographic location of study area.

2. to determine the source area and transport direction of the Caddo terrigenous clastic sediments by examining Caddo sand body geometry and orientation;
3. to determine Caddo hydrocarbon production trends and compare these with Caddo clastic geometries for the sake of gaining a better understanding of controls on stratigraphic hydrocarbon entrapment;
4. to define the determinants of porosity and permeability development for the Caddo clastic interval by means of a petrographic analysis of two cores within the study area; and
5. to present petroleum geologists with new exploration strategies based on an original interpretation of subsurface data.

Methods

Neither the Caddo clastics nor younger Caddo carbonates crop out in North-Central Texas. Lithologic and stratigraphic relationships were therefore evaluated based on available subsurface data sources. Approximately 700 electric logs were used to define and outline the study area. Actual data were compiled from 336 of these well logs (Figure 2). Examination and interpretation of the logs allowed for the construction of a regional structure map and interval isopachous map.

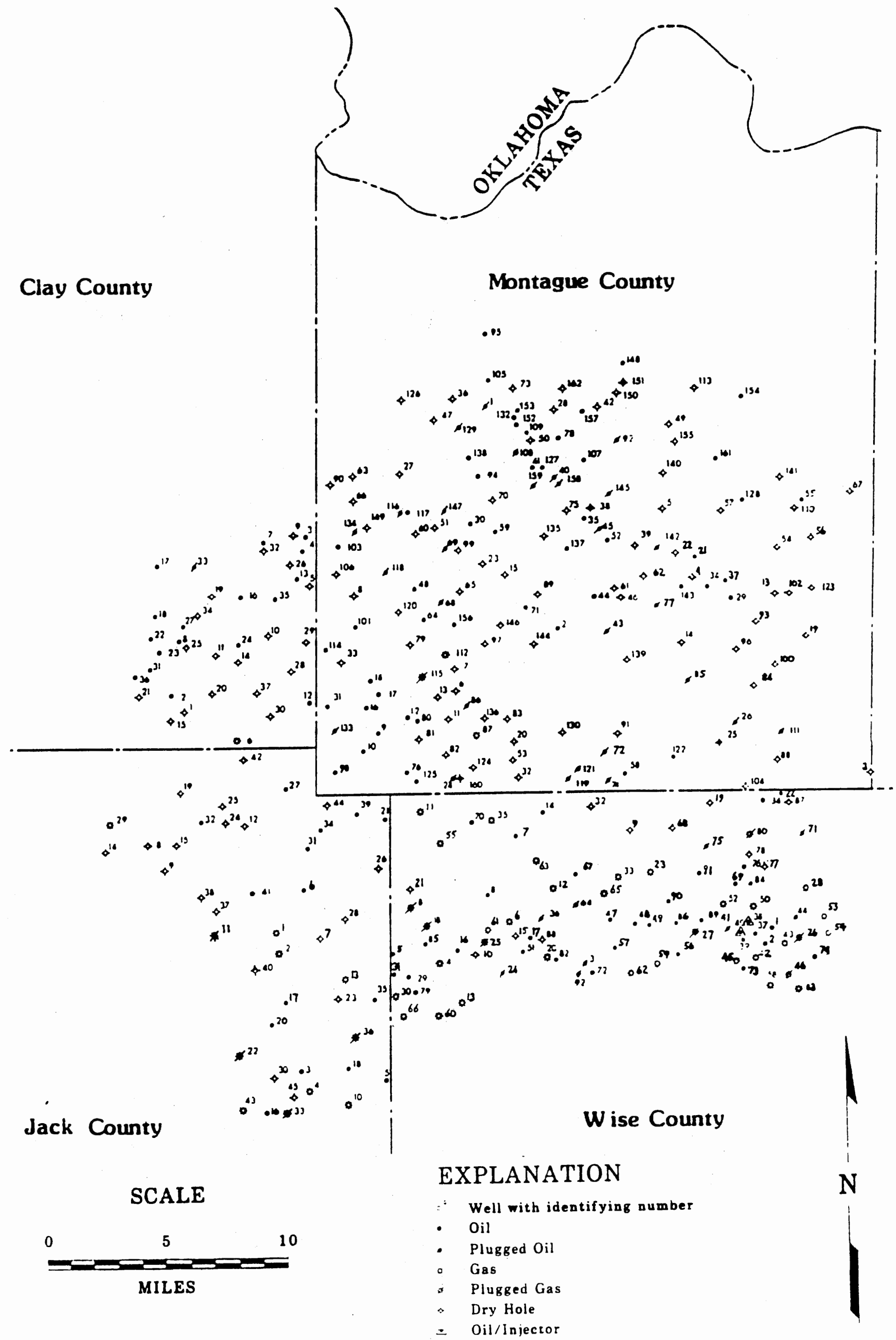


Figure 2. Base map showing distribution and types of wells.

The Caddo conglomerate and sandstone geometric features, including trend, width, thickness and boundaries, were determined by generating a sandstone isolith map, a sandstone percentage map, and a clastic ratio map.

Six stratigraphic cross sections were constructed to determine the lateral and vertical continuity of the limestone, conglomerate, sandstone, and shale components of the study interval. The four West-East strike-oriented cross sections intersect the two North-South dip-oriented cross sections to form a grid (Figure 3).

The unit of strata studied here consists of the interval between the top of the lower Strawn Caddo Limestone and a correlatable electric log marker of upper Atokan age. The Middle Pennsylvanian Strawn/Atoka Series lithologic boundary in the Fort Worth Basin has been defined as the base of the Caddo Limestone by Plummer and Moore (1921).

The western, eastern, and southern (down-dip) boundaries of the Caddo terrigenous clastics appear to be preserved as the limit of their deposition. West of the study area, the Caddo Limestone exhibits "reefal" characteristics with little or no clastic detritus present within the interval of study. The Caddo clastics along the eastern boundary were depositionally influenced by the Muenster Arch. This positive feature probably did not act as a major clastic source during Caddo time, but did act as the eastern barrier to deltaic progradation. The southern

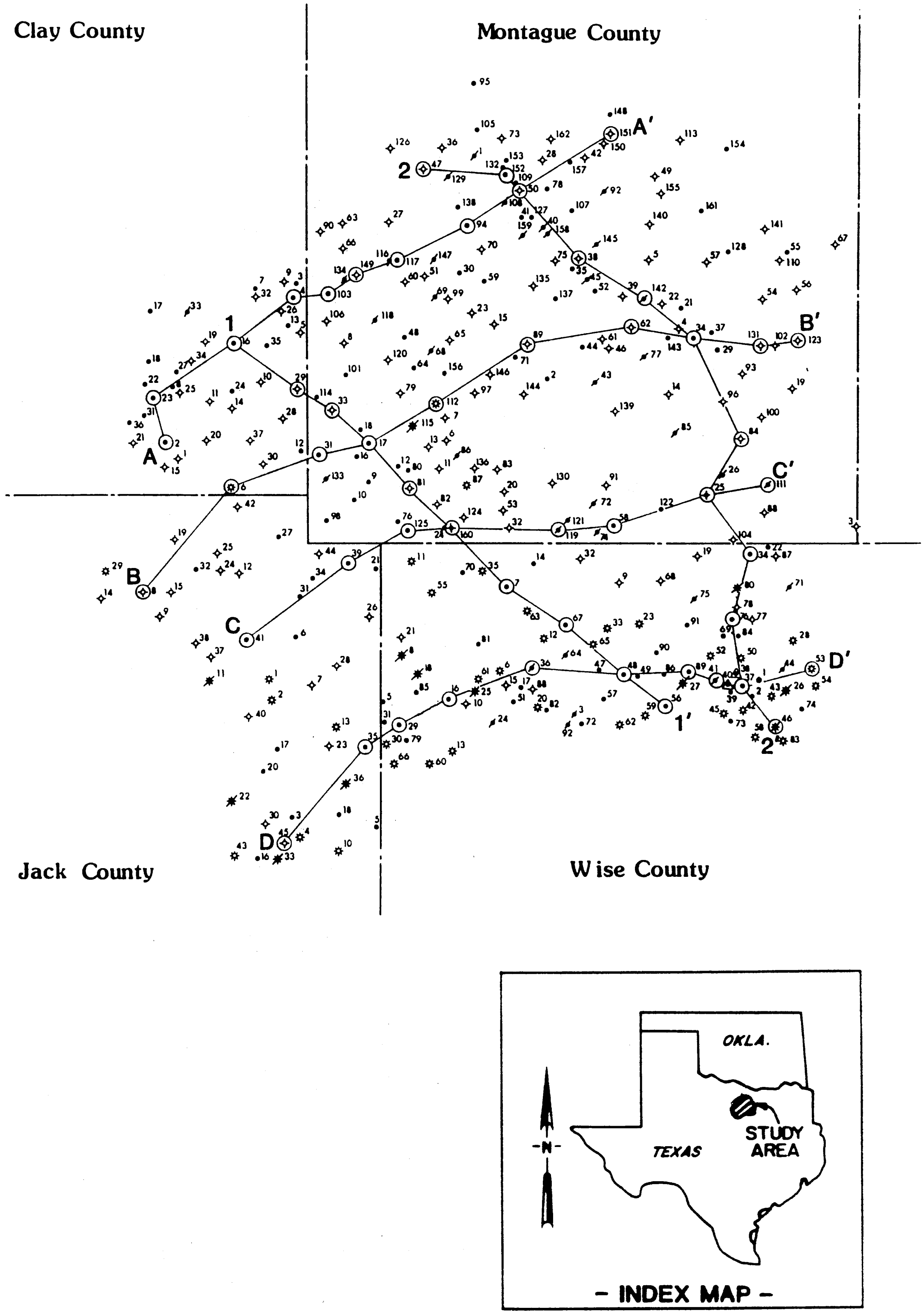


Figure 3. Locations of stratigraphic cross sections.

limit is identified by the sand-rich deltaic sequence grading abruptly into the prodelta shale sequence of the same age.

The braided fluvial Caddo clastics "pinch out" due to onlap on the southern flank of the Red River/Electra Arch complex, along the northern edge of the study area. Northeastward basin tilting during Desmoinesian time allowed for the deposition of Strawn age sediments above the Caddo units.

Figure 4 was constructed to display the geographic distribution of the professionally prepared mud logs and drillers logs, and the cores. All proved invaluable for lithologic determinations of the surrounding electric logs.

Two cores of Caddo Sandstone facies were described for this study. These cores, both drilled by Mitchell Energy Corporation, include the J.D. Ortan #4 of Montague County and the Alvord South Caddo Conglomerate Unit #3-8 of Wise County, Texas. The Caddo interval in both cores was observed to determine lithologic relationships, textures, sedimentary structures and to interpret depositional environments. Twenty-one thin sections were cut from the two cores and examined by petrographic microscope in order to identify detrital and diagenetic constituents.

A map of the Caddo conglomerate and sandstone fields with oil and gas production within the study area was prepared from data by Petroleum Information Corporation and

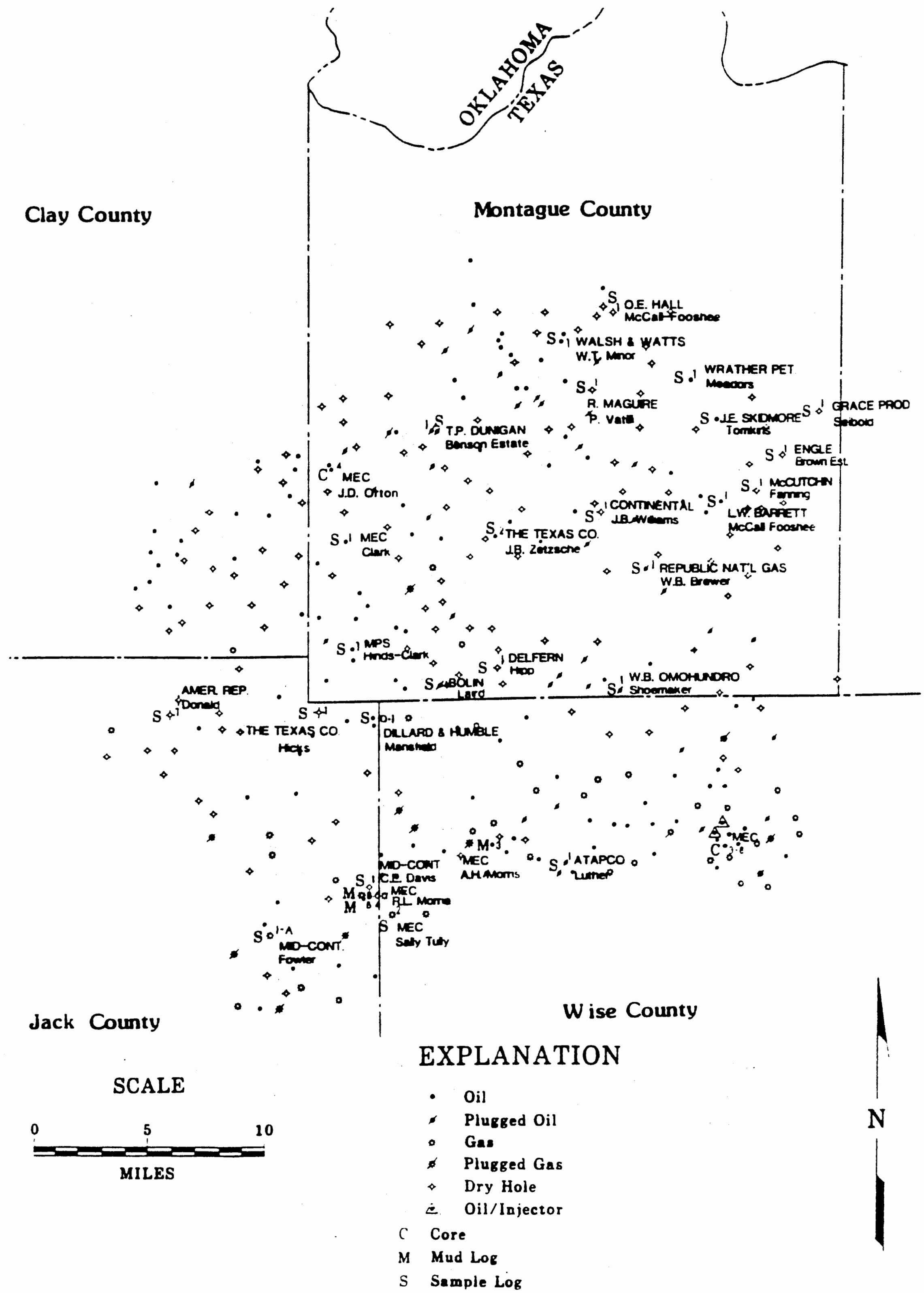


Figure 4. Base map showing location of mud logs, sample logs, and cores.

the National Oil Scouts and Landmen's Yearbooks. The distribution and relationship of hydrocarbon production to Caddo coarse clastic geometries is easily recognizable. However, analysis of internal features, especially the preservation of primary and generation of secondary porosity, is paramount to successful interpretation and development of future Caddo Sandstone prospects.

Previous Investigations

No detailed subsurface geologic work has been published in the public domain on the specific interval of strata for the geographic area encompassed in this study. However, extensive research has been carried out on rock units in the Fort Worth Basin and more specifically, the Pennsylvanian sedimentary fill of Atokan and Strawn age.

The published literature utilized for this study can be divided into two general categories. These are: 1) regional and local stratigraphic and structural geologic studies, and 2) specific subsurface Pennsylvanian stratigraphic investigations within the northern Fort Worth Basin.

Probably the most comprehensive regional study for North-Central Texas was presented by Cheney (1940). He dealt with the stratigraphy, formation lithologic descriptions, structural history and the origin, migration, and accumulation of oil in the region. A more detailed discussion of the stratigraphy of the Fort Worth Basin was furnished by Turner (1957). The text was presented as a Llano region guidebook and contains excellent lithologic descriptions of Ellenburger (Ordovician) to Cisco (Upper Pennsylvanian) rock units both in outcrop and in subsurface.

The relationship of the Ouachita Foldbelt to the North Texas area and its importance to the development of the foreland Fort Worth Basin have been investigated by many authors. Flawn and others (1961) described the regional subsurface geology of the foldbelt and adjacent craton. They were responsible for recognizing two basically parallel petrographic and tectonic provinces within the Ouachita System. Application of a plate tectonic model was proposed by Keller and Cebull (1973) to the Ouachita Foldbelt in order to remain consistent with interpretations of the Appalachian belt. A subsurface positive feature within the Ouachita System is documented by Nicholas and Rozendal (1975) and is interpreted as the edge of the Early to Middle Pennsylvanian (preorogenic) continent.

The most extensive discussions concerning the plate tectonic evolution of the southern margin of the North American plate are presented by Walper (1977, 1982). His earlier paper examined the rifting of the late Precambrian "proto-Pangaea" supercontinent which formed a proto-Gulf of Mexico and Atlantic (Iapetus) Ocean, as well as the ensuing closing of that ocean to form Pangaea. Data from many previous authors and extensive (Alabama to southwestern Mexico) field work were synthesized in this report. Walper

(1982) applies the "Wilson cycle" (the opening and subsequent closing of an ocean basin) to North-Central Texas by reconstructing the tectono-sedimentary history of the foreland Fort Worth Basin.

Brown (1969) and Galloway and Brown (1973) discuss the geometry and distribution of fluvial and deltaic sandstones of Upper Pennsylvanian and Permian age, south and west of this author's study area. Despite the age difference of the rock units, correlations can be derived as to the location of the dominant terrigenous clastic source areas, the application of depositional models, the nature of the structural framework, and the distribution of petroleum production. A regional geologic framework and lithofacies distribution of Late Pennsylvanian sediments was compiled for a twenty-five county area by Wermund and Jenkins and presented on a Dallas Geological Society sponsored field trip (1969). Brown and others also contributed to the guidebook with outcrop descriptions, facies distributions, and depositional systems of Cisco (Virgilian) rocks.

The economic importance of Atokan rocks for the development of petroleum reserves was addressed by Ng (1979). He also synthesized the Atokan geologic history of the northern Fort Worth Basin, interpreted the lithofacies relationships, and provided a hydrocarbon generation and entrapment model for the lower Atoka (Middle Pennsylvanian) clastics just south of this author's study area. A regional study by Cleaves (1982) comprised numerous cross sections, descriptive measured sections, and sandstone and carbonate isolith maps. His interpretation identified multiple depositional systems within the Strawn Group of the northern Fort Worth Basin and adjacent Concho Platform. The complex interrelationships of tectonic settings, depositional models, and the regionally distributed fluvial-deltaic clastics and carbonate lithostratigraphic units were described.

The lower Atoka (Middle Pennsylvanian) "conglomerates" were defined by Lahti and Huber (1982) as a regressive sequence of elongate deltas that prograded south from the Wichita Mountain System. They also dealt with hydrocarbon entrapment mechanisms and production history in the northern Fort Worth Basin. Lovick and others (1982) identified the Red River/Electra Arch as the source area for the lower Atoka through Cisco (Upper Pennsylvanian) clastics deposited in the northern Fort Worth Basin. Prior to these two publications most authors (including Brown and Ng) identified the Ouachita Structural Foldbelt as the major terrigenous source area for the Pennsylvanian terrigenous clastics. A regional Atoka Group subsurface study by Thompson (1982) identified the Ouachita-sourced deltaic depositional systems, the types of porosity present in the different facies, and their relationship to hydrocarbon occurrence and production. In this report, the northernmost arkosic "Atoka/Caddo subunit" was briefly described as Red River/Electra Arch-derived granite wash.

CHAPTER III

STRUCTURAL GEOLOGY AND STRATIGRAPHY

Regional Setting

The late Paleozoic Fort Worth Basin became a structural and depositional feature as a result of lithospheric plate convergence along the southern margin of North America. The present wedge-shaped, asymmetrical foreland basin has a length of approximately 200 miles (320 km) and a width that varies from a few miles at the southern edge to a maximum width of 120 miles (190 km) (Figure 5). Preserved Paleozoic sedimentary strata within the basin include rocks of Cambrian, Ordovician, Mississippian, Pennsylvanian, and Permian age with an aggregate thickness of 12,000 feet (3600 m) (Turner, 1957). Situated in North-Central Texas, the Fort Worth Basin includes all or part of approximately 30 counties.

Structural Framework

The Ouachita Structural Foldbelt is related to the Appalachian Foldbelt in that both are believed to have formed concurrently during late Paleozoic (Mississippian) closure of the Iapetus Ocean (Walper, 1977). The proto-North American continent collided with a continental mass

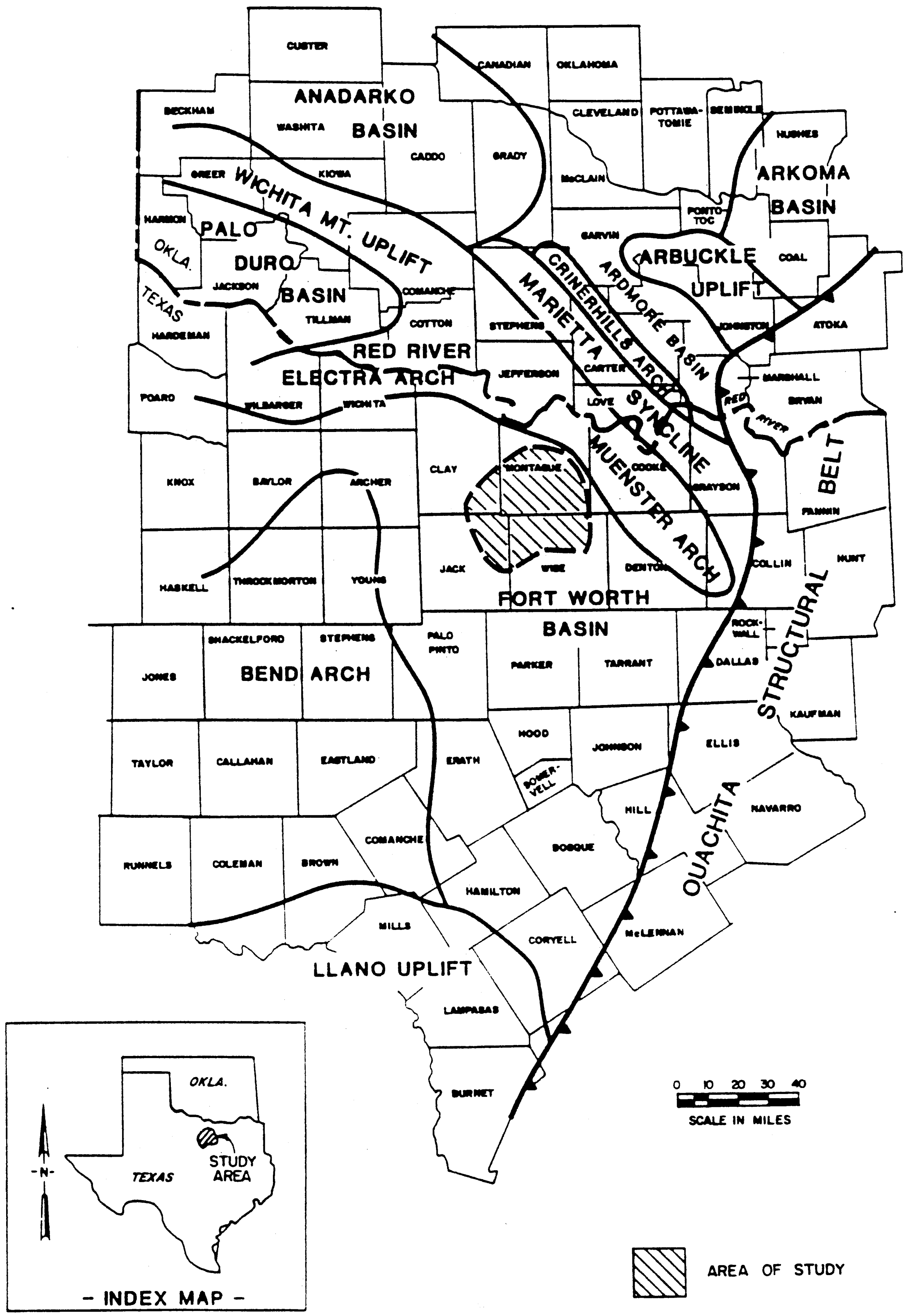


Figure 5. Structural features of North-Central Texas [modified from Lahti and Huber (1982)].

such as proto-Africa and/or proto-South America. This collision resulted in the downsweeping of the Fort Worth Basin area in front of the growing Appalachian/Ouachita orogen. The dominant compressive force associated with the collision was apparently directed from the southeast, as reflected by an average strike of 250 degrees for the few regional faults developed on the cratonic side of the evolving foreland basin. These regional faults, which display extensional deformational features, are inferred to be syndepositional; they developed in response to subsidence of the Fort Worth Basin.

The basin is asymmetrical in cross section with the axis of maximum sediment thickness being developed along the eastern margin, adjacent to the buried Ouachita Foldbelt. The axis of the basin is probably less than ten miles northwest of the thin-skinned fold and thrust belt and associated thrust faults of the Ouachita front. Several North-Central Texas subsurface studies (Brown, 1969, Galloway and Brown, 1973, Nicholas and Rozendal, 1975, Ng, 1979, Thompson, 1982, and Cleaves, 1982) interpret a Ouachita provenance for the majority of Morrow and Atoka (Lower to Middle Pennsylvanian) sediments. This corresponds to a Ouachita highland feature which contributed significant amounts of chert-rich detritus to the terrigenous depositional systems of the Fort Worth Basin. Sediment transport is dominated by a westward influx.

The northeastern and northwestern boundaries of the Fort Worth Basin are, respectively, the buried Muenster and Red River/Electra Arches (Figure 5). These make up the Wichita Mountain System of Eardley (1962). The Muenster Arch is a fault-bounded, northwest trending, Pennsylvanian uplift made up of Cambrian to Mississippian sedimentary rocks, directly overlying the Precambrian igneous and metamorphic basement. The crest of the Precambrian core is overlain by Late Pennsylvanian sediments which truncate the Cambrian to Mississippian rocks still preserved on the flanks. The southwest flank, adjacent to the Fort Worth Basin, is bounded by down-to-the-basin normal faults. Displacement across the faults is estimated by Flawn and others (1961) to be 5000 feet (1524 m).

Uplift of the Muenster Arch began in Late Mississippian and continued into the Middle Pennsylvanian (Desmoinesian) in response to the Ouachita compressional forces. Throughout this time, but specifically during early Atokan and early Desmoinesian (Flawn et al., 1961), the Muenster Arch shed coarse clastic sediments into the northern Fort Worth Basin. Sediment transport was to the southwest.

The Red River/Electra Arch (Figure 5) is an east to west trending structural element that is also a discontinuous, block faulted, Precambrian cored, Pennsylvanian uplift with similar structural features, stratigraphy, and geologic history to the Muenster Arch. Both arches were emergent and contributing arkosic sediments simultaneously; however, sediment shed from the Red River/Electra feature displays a south-southeast direction of transport. By Late Pennsylvanian (Missourian) time, uplift ceased and the Muenster/Red River/Electra System was buried by Upper Pennsylvanian (Virgilian) sediments.

The Bend Arch (Figure 5) is a broad, subsurface, north-plunging positive structure extending northward from the Llano Uplift. Precursors to this arch were a series of hingelines, outer trench rises, or arches which formed farther east of the present axis of the Bend Arch and migrated successively westward to its present positon (Walper, 1982). During Late Mississippian and Early Pennsylvanian it formed the hingeline for the subsiding Fort Worth Basin to the east and the stable Concho Platform to the west. During Middle Pennsylvanian time, the Bend Arch was either a carbonate shelf or a low relief land area and therefore does not represent a potential source area for the Caddo coarse clastics. In-filling of the basin progressed until the rate of sedimentation exceeded subsidence. By middle Desmoinesian, the basin was filled and the Bend Arch began to be covered with progradational deltaic cycles. In Late Pennsylvanian and Early Permian, North-Central Texas was tilted to the west and the Bend Arch served as the eastern shelf of the Midland Basin.

In the southern part of the Fort Worth Basin, the early Paleozic rocks are broken into a complex series of horsts and grabens by the Llano fault zone. The Llano Uplift has had intermittent positive movements since Precambrian time. The last major uplift involved block faulting and occurred during Early to Middle Pennsylvanian. This area, however, cannot be considered a significant source area and did not contribute any coarse clastics to the northern Fort Worth Basin.

Stratigraphy

Introduction

Over the years there has been a great accumulation of stratigraphic names applied to Paleozic rocks in the Fort Worth Basin. Such is particularly true for the Lower and Middle Pennsylvanian (Sutherland and Manger, 1984). It is not the purpose of this study to unravel all the problems of stratigraphic nomenclature for this area. However, one cannot ignore the existing nomenclature and generate new terminology. In this study the use of well-established lithostratigraphic names, such as Marble Falls, Atoka, and Caddo, will be followed. It might also be noted that complete lithologic sections, as idealized in Figures 6 and 7, are not preserved along the very northern margin of the Fort Worth Basin. Thinning of the terrigenous clastic section due to subsequent erosion or non-deposition is common in this area. Hence, except for the Caddo conglomerates and sandstones, the following stratigraphic descriptions

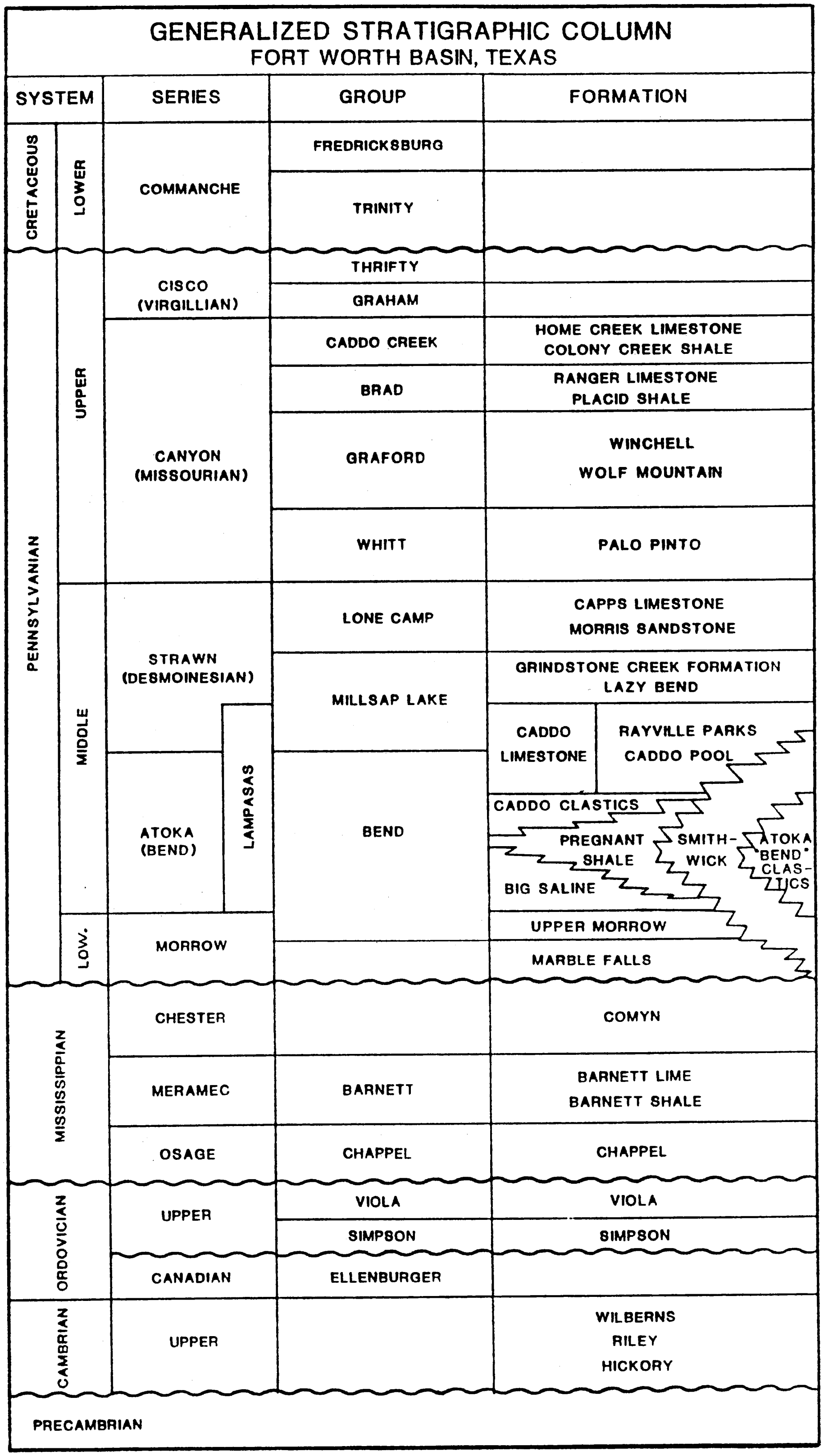


Figure 6. Generalized stratigraphic column in the northern Fort Worth Basin [Modified from GeoMap (1982)].

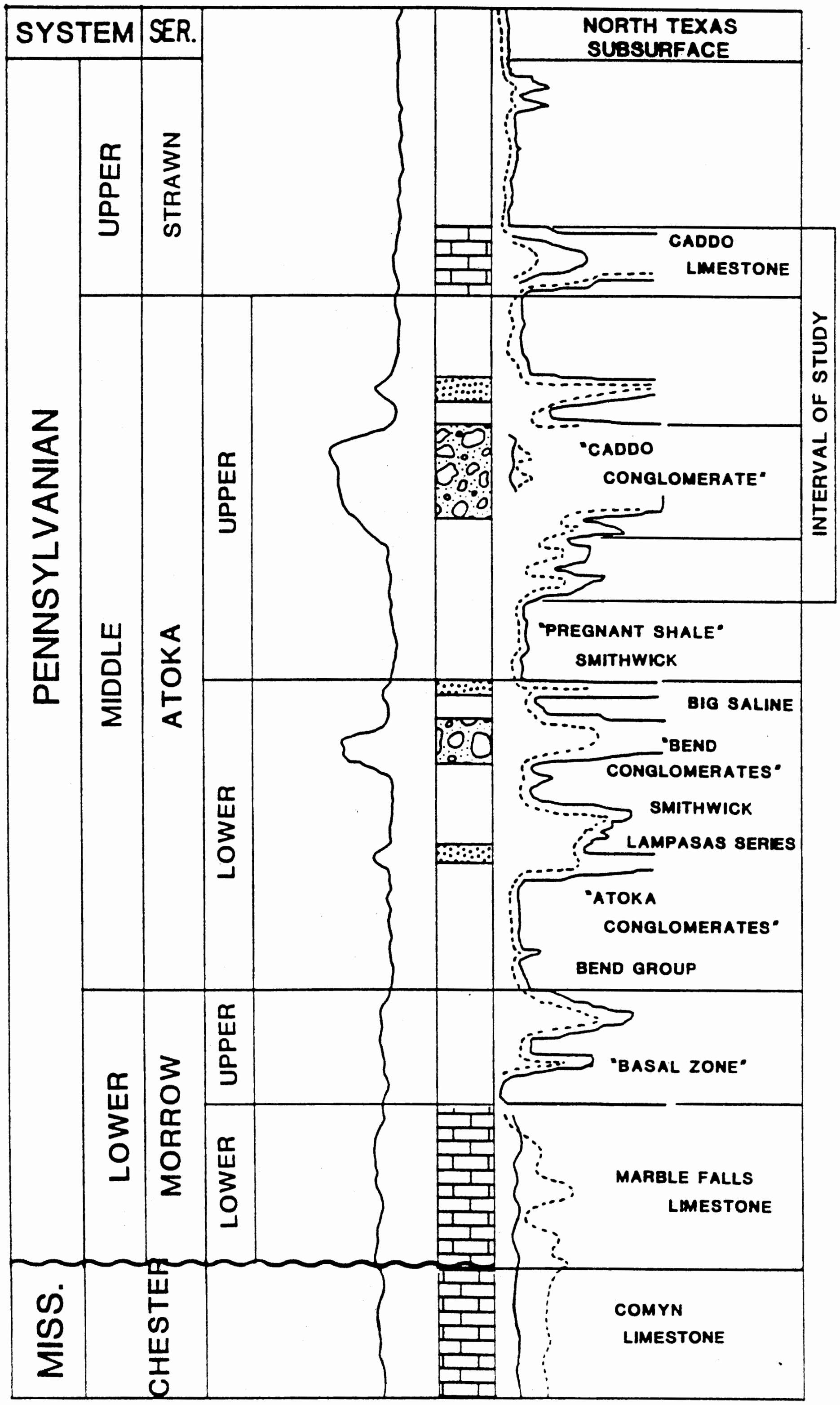


Figure 7. Generalized type log for the northern Fort Worth Basin. Strata within Interval of Study ranges from 44 to 280 feet and averages 140 feet thick throughout study area.

are more applicable to the stratigraphic column toward the axis of the basin, southeast of the study area.

Morrow Series

Marble Falls Formation

The base of the Bend Group is represented on the northern flank of the basin by the top of the Marble Falls (Figure 6). Being Lower Pennsylvanian, it is not included within the Atoka Series. Since it interfingers with the lower Atoka depositional systems, it will be briefly discussed. The siliceous, light gray, occasionally oolitic, spiculitic biomicrite was deposited as algal buildups and calcarenite shoals in normal, shallow water marine conditions (Kier, 1980). It represents a stable carbonate shelf facies.

The regionally extensive Marble Falls maintains a relatively uniform thickness throughout most of the shelf area of the northern Fort Worth Basin. It is identified as the first massive (thick) limestone below the Bend Group. From within the study area, the thickness of the interval from the top of the Caddo Limestone to the top of the Marble Falls increases from 150 feet in the northwest to 1200 feet toward the axis of the basin.

Upper Morrow

This upper Morrow unit is not present except in the axial reaches of the basin and contains some reworked Marble Falls clasts within a light to dark gray siltstone with interstratified black, hard fossil shales and thin discontinuous mottled limestones. This interval is characterized by fracture porosity and is considered a "lost circulation zone" by area oil companies.

Atoka Series

The majority of authors concerned with the stratigraphy of the Fort Worth Basin [(Brown et al., 1979), (Erxleben, 1975), (Gardner, 1960), (Kier, 1980), (Lahti and Huber, 1982), (Lovick et al., 1982), (Ng, 1979), (Sutherland and Manger, 1984), and (Thompson, 1982)] recognized the extensive lateral continuity of the disconformity used to subdivide this series into a lower and upper stage. The lower Atoka is identified as the interval of terrigenous clastics extending from above the Marble Falls to the base of the "Pregnant Shale." The base of the "Pregnant Shale" to the base of the Caddo Limestone comprises the upper Atoka interval (Figure 7).

Lower Stage of Atoka Series

The lower Atoka (Big Saline, Lampasas Series, "Atoka or Bend Conglomerates", Smithwick) directly underlies the prodelta deposits of the "Pregnant Shale" and is characterized by a thick sequence of dark shales containing numerous erratic to well-developed spontaneous potential (S.P.) patterns of conglomeratic and sandstone bodies with occasional thin, locally widespread dark, fossil-rich micritic limestones. This interfingering of terrigenous and carbonate units has been interpreted as a progradation of fluvially dominated deltaic systems into a normal, low to moderate energy marine setting. The conglomerates and coarse sandstones are usually composed of subrounded to subangular quartz clasts with feldspars and some chert. This unit also commonly includes glauconite. Whether or not they contain either siliceous or calcite cement, these moderately well-sorted coarse sediments display good reservoir rock qualities. They comprise the most productive hydrocarbon interval in the basin.

Upper Stage of the Atoka Series

The upper Atoka is defined as the clastic interval from the base of the "Pregnant Shale" to the base of the Caddo Limestone (Figure 7). This unit is predominantly a shale sequence, but contains a few discontinuous conglomerate and sandstone lenses (Caddo clastics).

The "Pregnant Shale" (upper part of the Smithwick Formation) is characterized by a distinctive electric log response involving a weak S.P. curve and a gradually upward increasing resistivity inflection that gives rise to a characteristic "bowed" shape log curve (Lahti and Huber, 1982). The fine-grained facies of the "Pregnant Shale" is made up of prodelta shales and thin, discontinuous siltstone deposits. It is the top of this "Pregnant Shale", or its stratigraphic equivalent in the northern study area, that defines the base of the format unit for the interval isopach map and the cross sections.

The upper Atoka Caddo conglomerate and sandstone interval is similar to the lower Atoka stage in that both are characterized by a dark shale sequence with interspersed coarse-grained deposits and occasional thin, local limestones. The main difference is represented by the change from the fluvially dominated depositional systems of the lower Atoka, to the marine-influenced depositional systems of the upper Atoka. This change does not necessarily reflect an increase in marine wave energy, but is a result of a reduction of basinal subsidence during late Atokan time. Rapid subsidence and infilling of the Fort Worth Basin was the dominant regime for early Atokan time. Hence the thicker, high-constructive deltaic facies of the lower Atoka are preserved. In contrast, the upper Atoka involves an overall thinner interval of marine-reworked terrigenous sediments.

Strawn Series

Caddo Limestone

The dark gray, micritic and fossil-rich Caddo Limestone (Figure 7) is interpreted as being a transgressive marine carbonate deposited in a low energy, shallow water, open marine environment. The base of this laterally persistent carbonate unit serves as the Middle Pennsylvanian marker separating the Atoka and Strawn Series. In this study, the top of the Caddo Limestone was employed as the datum for all stratigraphic cross sections, the top of the format unit for the interval isopach, and the surface for the regional structure map.

The Caddo Limestone is overlain by the remainder of the lithologically variable Strawn Series. This series consists of well-documented fluvial, deltaic, embayment, open shelf, and carbonate bank depositional environments. These are represented by carbonate, sandstone, shale, and coal lithofacies along the northern shelf of the Fort Worth Basin.

Basinal Depositional History

Subsequent to a Late Precambrian/Early Cambrian rift episode, the Fort Worth Basin area became a retreating and subsiding plate margin during Cambrian and Ordovician periods. Warm tropical seas invaded central Texas and sedimentation was dominated by a thick carbonate sequence typical of the shelf facies of the shelf-slope-rise sequence. An eastward thickening 3,500 foot (1,100 m) wedge of shelf carbonate is preserved in the axis of basin, but no record of the slope-rise facies toward the direction of the rifted margin is preserved (Walper, 1982).

During Late Devonian, closure of the Iapetus Ocean had begun. From that time through Early Mississippian, North-Central Texas was subject to periodic upwarping and general cratonic unrest. If the Fort Worth Basin area did receive significant deposits of Late Ordovician, Silurian, Devonian, and Early Mississippian sediments, erosion must have stripped most of the stratigraphic record of this interval, as evidenced by the presence of several major unconformities.

By Late Mississippian, collision approached, causing pronounced downwarping of the basin area and uplift of the Red River/Electra and Muenster Arches. Uplift also occurred in the Llano region, forming a complex series of horsts and grabens (Flawn et al., 1961). The entire region was again submerged during Late Mississippian and is characterized by deep water shale and limestone deposits.

The Fort Worth Basin sedimentation patterns had developed by Early Pennsylvanian. Subsidence was greatest during Morrow and Atokan time but had diminished during the Desmoinesian and Missourian (Greimel and Cleaves, 1979). The thick terrigenous clastics of the Atoka and Strawn Series (Middle Pennsylvanian) were shed from the east by the Ouachita Foldbelt and from the north by the Red River/Electra/Muenster Arch complex (Figure 8). The basin was essentially filled by Missourian time (Flawn et al., 1961).

Rifting and break up of Pangaea began in the Triassic and the southern edge of North America again became a retreating and subsiding passive plate margin. The North-Central Texas area remained emergent until the tropical seas of the Gulf of Mexico encroached, depositing Creta-

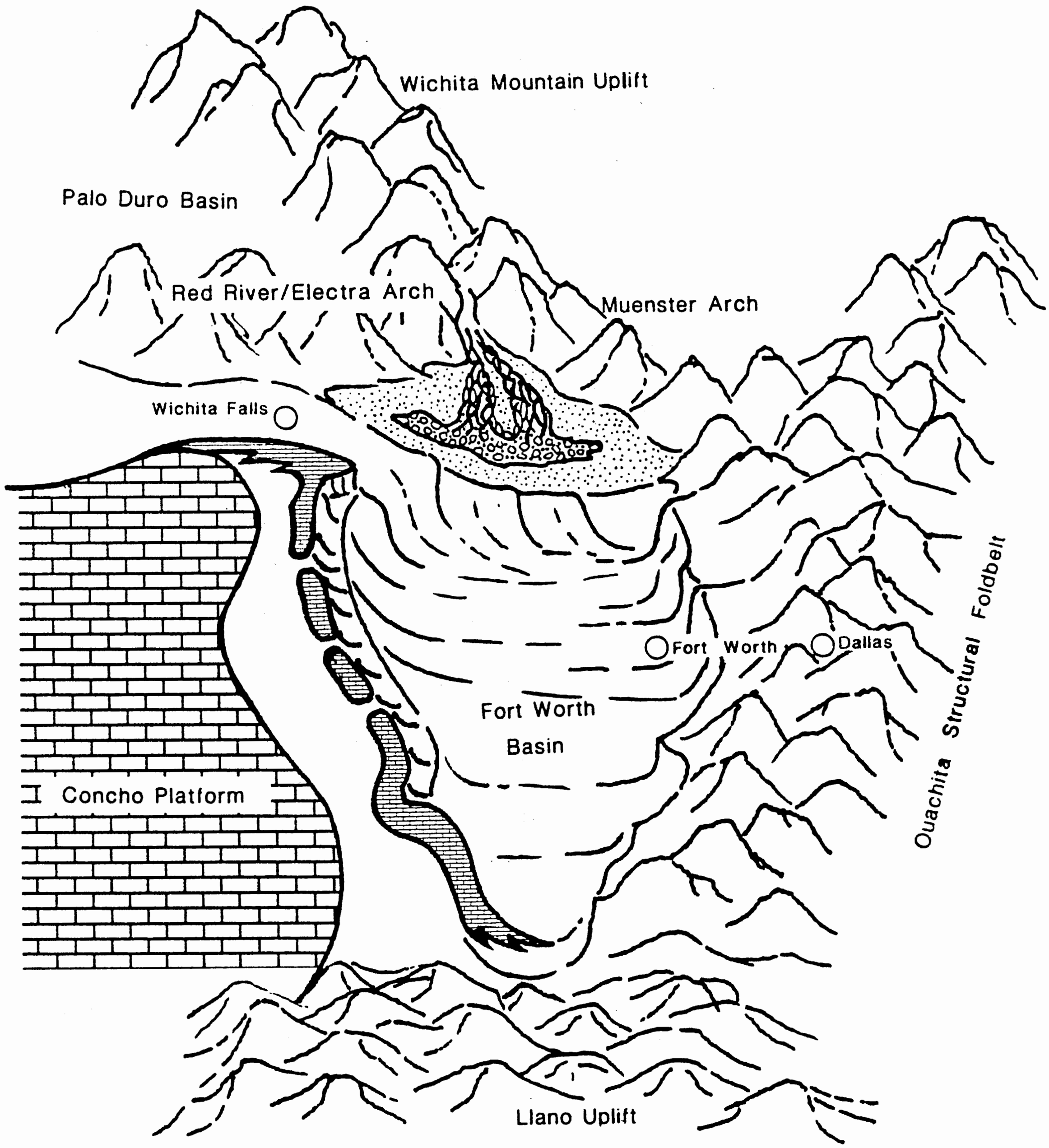


Figure 8. Atokan paleogeology of the Fort Worth Basin and surrounding area.

ceous age carbonates over the tilted and eroded Paleozic section. This transgressive sequence formed a regional unconformity, signifying the last major geological event of the Fort Worth Basin (Lovick et al., 1982).

CHAPTER IV

REGIONAL ELECTRIC LOG STUDIES

Introduction

Three hundred and thirty-six electric logs and 31 commercially prepared sample logs from the study area provided substantial control for the preparation of the subsurface maps. The type of electric log most commonly run on wells in the study area is the Dual Induction Log consisting of a spontaneous potential (S.P.) curve and three resistivity curves (laterolog, medium induction, deep induction).

The Caddo Limestone was present in all but one electric log and served as a good marker for correlations due to its characteristic log signature. Once the Caddo Limestone had been identified, it was not difficult to move directly below in the section to locate the Caddo clastic interval. In this study, the top of the persistent Caddo Limestone serves as the upper boundary to the study interval (Figure 7). The lower boundary is defined as the persistent shale break directly above the established upper/lower Atoka disconformity.

The subsurface maps employed were:

1. Structure on top of the Caddo Limestone;

2. Net sandstone isolith;

3. Net sandstone percentage;

4. Net clastic ratio and;

5. Gross isopach of the total format interval.

Stratigraphic cross sections were also prepared using selected electric logs from the study area. Six cross sections were constructed (Figure 3). Four are strike-oriented (A-A', B-B', C-C', and D-D') and two are dip-oriented (1-1' and 2-2'); these are presented on Plates III and IV.

The stratigraphic interval between the top of the upper Atoka "Pregnant Shale" and the top of the Caddo Limestone is a genetic interval of regional significance in the northern part of the Fort Worth Basin. The top of the "Pregnant Shale" is a laterally persistent prodelta shale interval that is present over most of northern flank of the basin. The restricted Caddo clastic interval is present only within the study area and represents a local regressive terrigenous cycle of sedimentation.

The study interval is capped by the laterally persistent Caddo Limestone. This marine transgressive carbonate is found over much of the basin. Such a marker-bound stratigraphic unit has been termed a Format Unit by Forgotson (1957), a Genetic Sequence of Strata by Busch (1971), and a transgressive-regressive couplet by Shelton (1973).

The principle value in defining a format unit is that all of the terrigenous clastics between the two marker units are inferred to have been deposited during one regional cycle of sedimentation. The identified conglomeratic and sandstone reservoirs were laid down as facies components of one or more essentially contemporaneous depositional systems. Subsurface maps prepared from data incorporating the complete format interval are exceedingly valuable for identifying specific depositional systems, reservoir rock units, and trends of elongation for distinct sandstone bodies. For this study, a format isopach map and a total interval net sandstone isolith map have been determined the most useful for delineating Caddo conglomerate and sandstone facies distribution.

Caddo Limestone Structure Map

The structural contour map on the top of the Caddo Limestone indicates a depositional surface modified by few major folds and no apparent faults within the study area (Figure 9). Generally, the dip is homoclinal toward the north-northeast. Dip averages 53 ft/mile but varies from approximately 20 ft/mile to 80 ft/mile. Original depositional dip on the northern flank of the Fort Worth Basin was to the southeast. Regional dip is now to the northeast as a result of Late Pennsylvanian uplift of the Bend Arch.

Caddo Net Sandstone Isolith Map

The Caddo conglomerates and sandstones were mapped with a 10 foot contour interval (Figure 10, Plate I). The geometry of the combined conglomerates and sandstones is

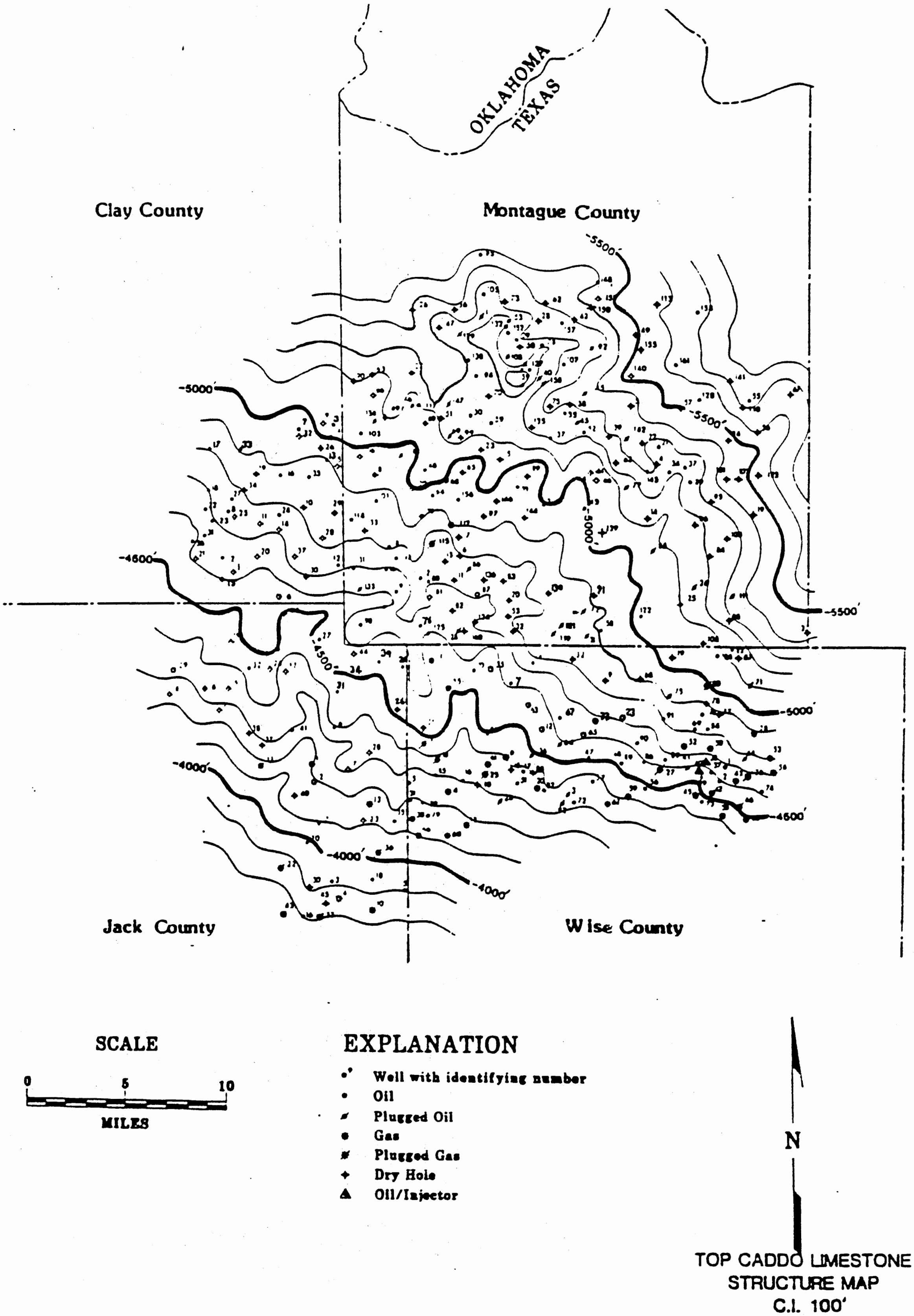


Figure 9. Caddo Limestone structure map.

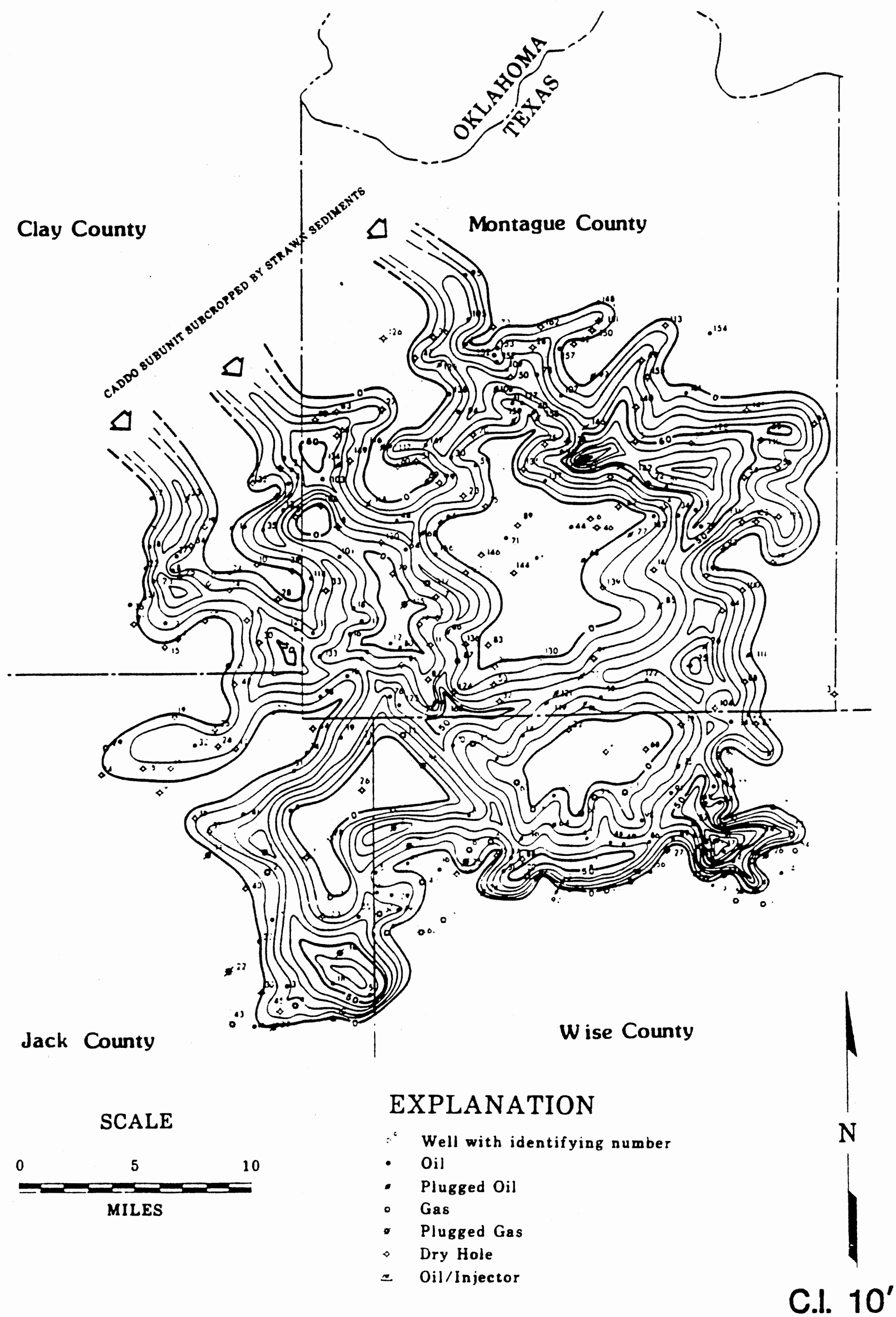


Figure 10. Caddo net sandstone isolith map.

diagnostic of a high-destructive wave-dominated deltaic system with two major "feeders" (upper delta plain fluvial complex) and one minor feeder. The northwest to southeast, dip-oriented feeder channels are interpreted as the major braided fluvial distributary channels on the proximal delta plain, whereas the strike-oriented sediments are the reworked and redistributed coalesced delta front sheet sands of the distal delta plain. These reworked sheet sands exhibit a geometry that is suggestive of moderate energy marine influence in the distal deltaic facies. The largest accumulations of sand (100+ feet) are situated within the major distributary trends and along the sites of the coalesced delta front deposits. Possible crevasse splay or sheetflood morphologies are interpreted in the following areas: north-central Jack County, southeast Clay County, northeast Wise County, southeast Montague County and two splays along the northeast edge of the clastic trend of north-central Montague County.

The overall source direction for the braid delta complex is presented as being a northwesterly one. This pattern is inferred by both the thickening of the entire format interval to the southeast (toward the axis of the basin), as well as a general thickening of the individual sandstone bodies in the down-dip direction. The major distributaries are shown in their entirety on the isolith map and do not extend out of the study area. This is suggestive of a short transport distance from the tectonically-active provenance area.

The majority of Caddo clastic hydrocarbon production occurs in the major distributary braid channels of the proximal and medial braid delta plain and in the delta front sheet sands of the distal delta plain (Figure 10). Sheet sandstones of the distal delta plain facies usually constitute the best reservoir facies in wave-dominated deltas. Production within the Caddo interval is sometimes inhibited as a result of low porosity and permeability. This reduction, even within the mapped "thicks", is possibly due to extensive calcite cementation, development of quartz overgrowths and/or the presence of detrital and authigenic clays. The Caddo conglomerates and sandstones primarily produce crude oil; however, moderate quantities of associated natural gas and condensate are produced in the Eanes Field of southeast Montague County, and the Deaver/Malone/Pryor Complex and Alvord South Caddo Conglomerate Field, both of north-central Wise County, Texas.

Caddo Net Sandstone Percentage Map

The net sandstone percentage map (Figure 11) was constructed by dividing the mapped net sand isolith value by the interval isopach value and was utilized to confirm the depositional trends that are present on the net sandstone isolith map. The dip-oriented, braided distributary channels and the strike-oriented marine-influenced coarse-

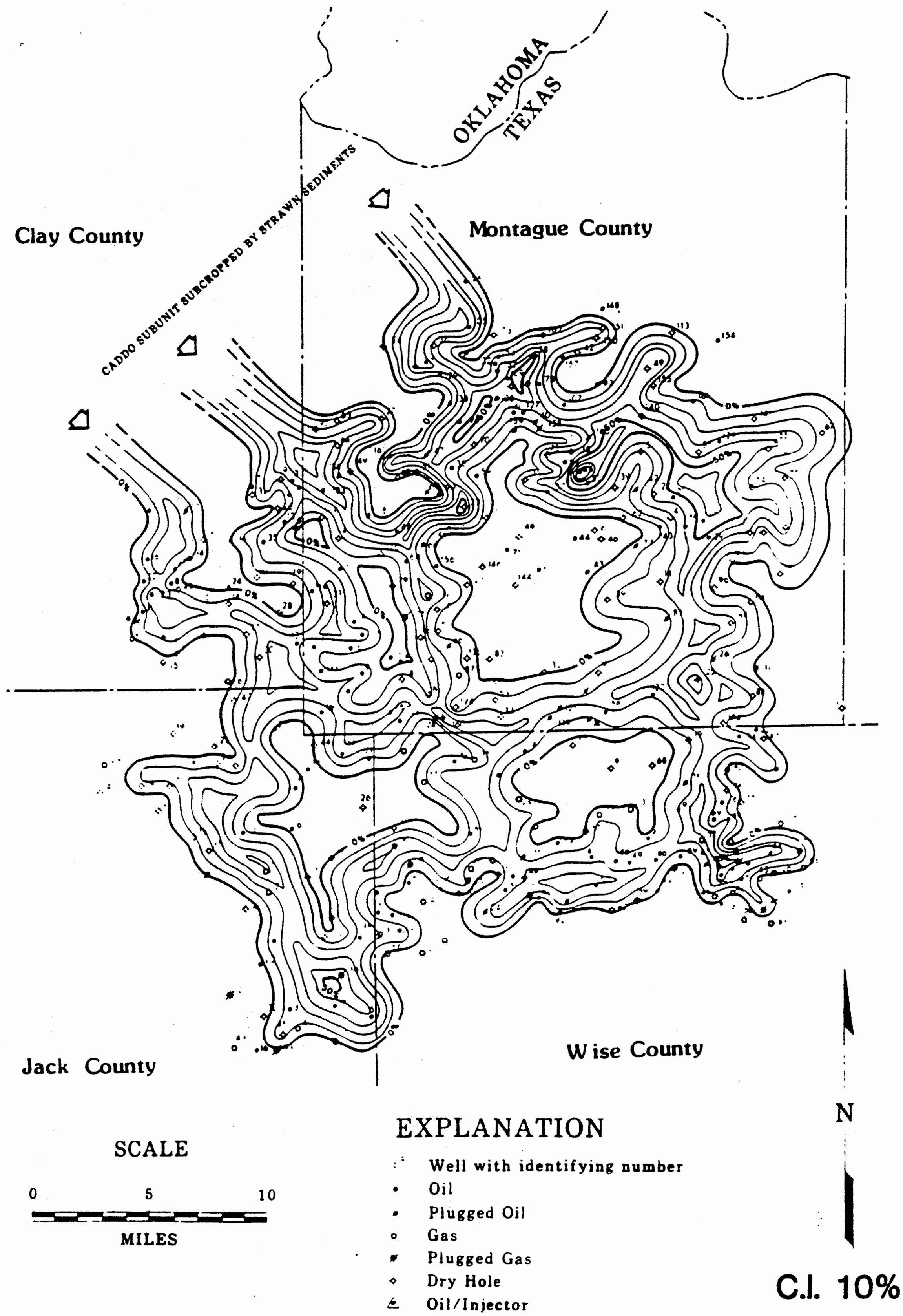


Figure 11. Caddo net sandstone percentage map.

grained facies reflect the depositional patterns of this map, and complement the net sandstone isolith.

Caddo Net Clastic Ratio Map

The net clastic ratio map is a product of coarse-grained (conglomerate and sandstone) lithologic values divided by the fine-grained (silt and shale) sediment values (Figure 12). Equally important to the petroleum geologist as the net sand isolith and percentage maps, the net clastic ratio map highlights the coarse-grained intervals and their distribution for optimal hydrocarbon exploration.

Caddo Interval Isopach Map

A gross isopach map of the study interval was also constructed (Figure 13, Plate II). The format interval isopach reflects a distinct fluvial-deltaic pattern, as well as showing an expected overall thickening towards the axis of the basin. The high value isopach areas closely resemble the maximum sandstone "thicks" of the net sandstone isolith map. The major distributary channel trends and the delta front sheet sands are represented in the areas of maximum isopach thickness. Progradation of this braid delta complex did not extend beyond the study area, as evidenced by the complete absence of Caddo coarse clastics down-dip to the sheet sands and by the extensive deposition of the surrounding prodelta shales.

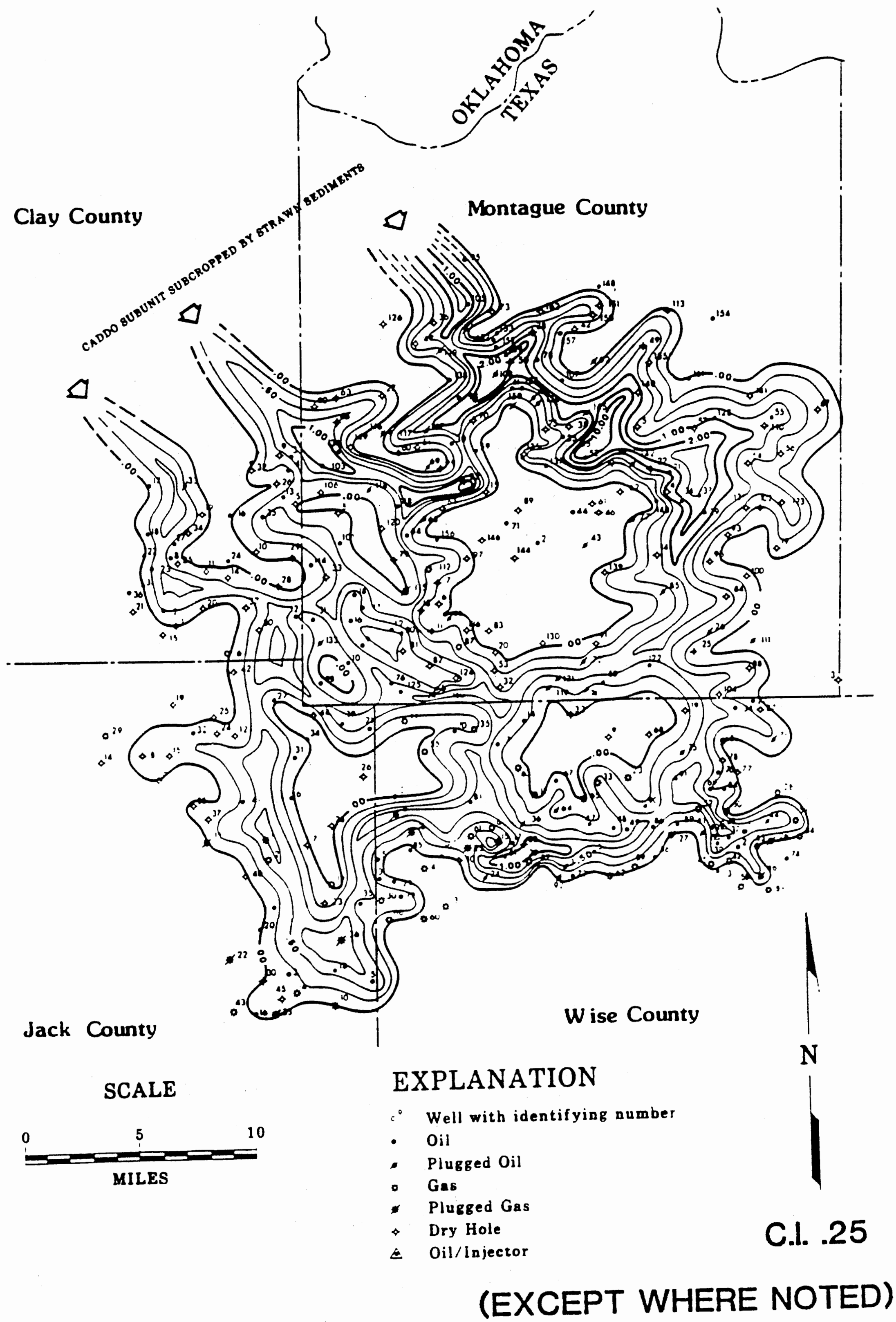
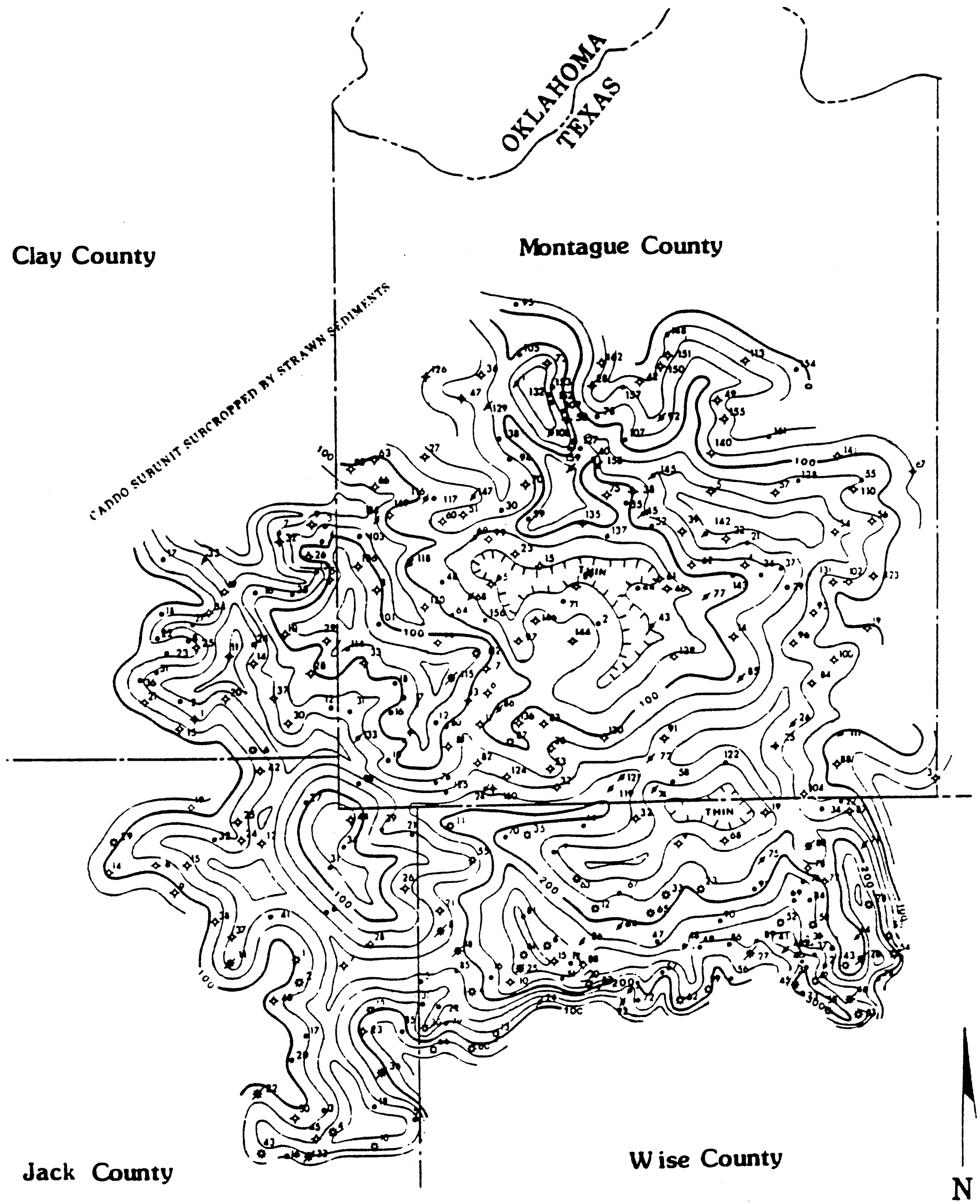


Figure 12. Caddo net clastic ratio map.



SCALE

0 5 10

MILES

EXPLANATION

- Well with identifying number
- Oil
- Plugged Oil
- Gas
- Plugged Gas
- Dry Hole
- Oil/Injector

C.I. 25′

Figure 13. Caddo interval isopach map.

Cross Sections

Six stratigraphic cross sections were used to analyze the lateral and vertical continuity of the facies present within the interval in the study area (Figure 3, Plates III and IV). The Caddo Limestone was chosen as the datum for all the cross sections.

Strike-Oriented Cross Sections

Cross section A-A' is a southwest to northeast stratigraphic cross section extending from southeastern Clay County to north-central Montague County, Texas (Plate III). It is the northernmost strike-oriented cross section of the study area.

On the western end of the cross section, especially wells Clay 2 and Clay 16, the Caddo Limestone represents a significant carbonate bank build up and a complete absence of the coarse clastic facies. The Clay 23 log, however, displays a thick (40 foot) conglomerate that is interpreted as a major distributary channel deposit. This dip-oriented conglomeratic body clearly pinches out on either side of Clay 23. An example of stacked distributary channel deposits is seen in well Mont 103. The extensive alluvial plain for the upper channel may have involved a width greater than five miles, as evidenced by continuation of this deposit in the surrounding wells. Mont 50 also records stacked distributary channels of the easternmost alluvial complex, but thinning and complete pinch out occurs immediately northeast.

Cross section B-B' is a southwest to northeast stratigraphic cross section that extends from northern Jack County to eastern Montague County, Texas (Plate III). The two distinctive features of this section are: 1) an extremely thin (less than 100 foot) isopach interval in well Mont 89; and 2) the thick dip-oriented, stacked conglomeratic distributary feeders of the middle delta plain as shown in wells Mont 34 and Mont 131. The thin interval of the Mont 89 log is interpreted as being either an interdistributary region with little sedimentation or a "paleo-high" with deposition not having occurred at all. Wells in the surrounding area also display an overall thinning of the mapped interval. Obvious pinch out of the Caddo clastics exists on the western edge of this cross section as observed in wells Jack 8 and Clay 6.

Cross section C-C' is a more east-west oriented stratigraphic cross section and extends from northeastern Jack County to southeastern Montague County, Texas (Plate III). Placement of this cross section appears to represent an area of significant interfingering of the fluvial-deltaic terrigenous sediments and the marine carbonate section. Distribution of the lowermost clastic member of the interval exceeds twenty miles and represents a laterally continuous strike-oriented conglomeratic sheet sandstone. Another coarse clastic unit directly below the Caddo Limestone is recorded over a width of ten miles. This second unit is interpreted as being braided distributary channel deposits. Well Mont 111 illustrates the eastern boundary of Caddo conglomerate and sandstone deposition, as shown by a complete "shale out" of the coarse-grained sediments within the interval. Interfingering of thin, laterally persistent carbonate sequences is also observed in the area.

The southernmost strike-oriented stratigraphic cross section is D-D'. This southwest to northeast line of section extends from east-central Jack County to northeastern Wise County, Texas (Plate III). Marine sedimentation processes are dominant within this area. The lowermost, coalesced sheet sands continue along strike for over fifteen miles. Stacking and reworking of the conglomeratic distributary channel sands is recorded in wells Wise 41 and Wise 37. A laterally equivalent, thick (up to 200 foot), dark colored, micritic and fossil-rich carbonate sequence is noted in adjacent Wise County wells along the line of section. Interestingly, the stratigraphically younger part of the Caddo Limestone displays relatively consistent thickness on the section, whereas the older, carbonate sequence shows a highly variable thickness. Neither of these carbonate intervals are hydrocarbon productive in this area.

Dip-Oriented Cross Sections

Cross section 1-1' is a northwest to southeast trending, dip-oriented stratigraphic cross section that extends from southeastern Clay County to north-central Wise County, Texas (Plate IV). This line of section intersects with all four strike-oriented cross sections. It demonstrates both the expected basinward thickening of the entire Caddo interval, as well as displaying the continuous nature of the down-dip prograding braided distributary feeder channels. This cross section clearly illustrates the vertical and lateral variations in the facies and associated lithologies. Beginning in the northwest, the facies tract is interpreted as a thin proximal deltaic plain, complete with sheetflood deposits (Clay 29) and interdistributary silts and muds (Mont 81). The stacked distributary channels, having been reworked and redistributed along depositional strike, are reflected in well Mont 160 as medial to distal deltaic sediments. Further down-dip, shallow water marine carbonates interfinger with a strike-oriented laterally coalesced conglomeratic sheet sand (Wise 48). The absence of the coarse clastics and the preservation of the stratigraphic equivalent prodelta shales (Wise 56) completes the depositional environment scenario.

Stratigraphic cross section 2-2' has an almost north-south orientation. It extends from northwestern Montague County to north-central Wise County, Texas (Plate IV). This cross section basically displays the same pattern of facies as observed in Section 1-1'. The main visible difference is the existence of a thicker, conglomeratic distributary feeder channel complex along the eastern margin of the study area (logs Mont 34 and Mont 84).

Electric Log Patterns for Individual Wells

Use of electric log signatures (especially S.P. and resistivity) is a common practice for the identification of specific facies within terrigenous clastic systems. The observed log signature is a result of the measurement of the electrical properties of the rock, which is influenced by the texture of the rock and the nature of the included pore fluids. Texture is defined as the size, shape and arrangement of the component minerals of a rock. Texture is, in part, a function of the hydrodynamic conditions in the final environment of deposition. The S.P. curve is particularly helpful, as it can be used to estimate the relative thickness of sandstone versus shale in a given interval. Identification of log signatures that display coarsening-upward sequences, fining-upward sequences and a multitude of hybrid combinations is also best done with the S.P. curve. An interpretation of the facies present in a given area should be consistent with the known overall depositional system's facies tract, and should be supported by mineralogic data from thin sections, sedimentary structures, and biological evidence. Several examples of environmentally significant log signatures for the Caddo clastic interval are illustrated in Figure 14.

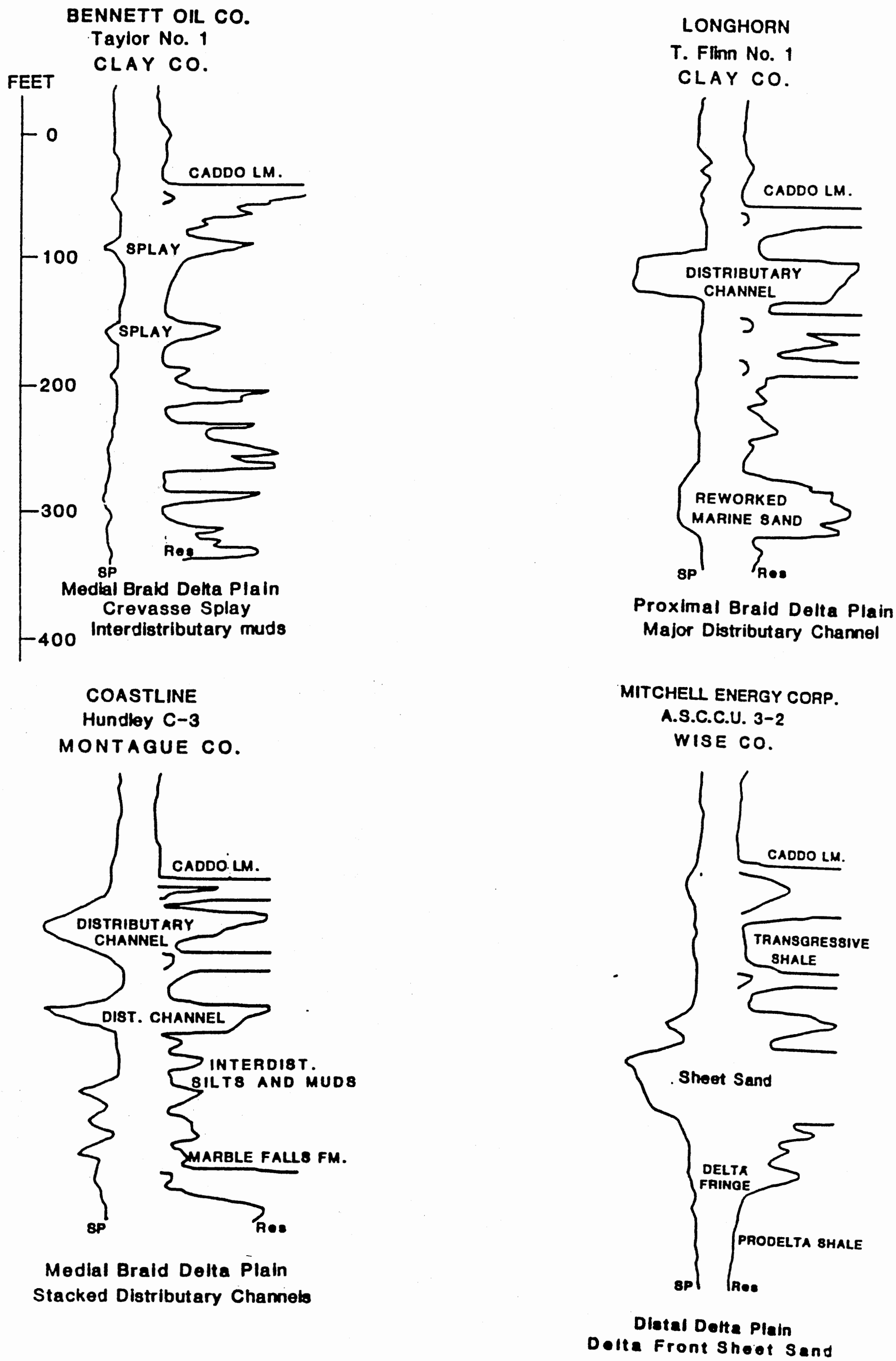


Figure 14. Caddo conglomerate and sandstone electric log signatures and depositional environments.

CHAPTER V

FACIES ANALYSIS OF THE CADDO INTERVAL

Introduction

Several environmental interpretations of the Atokan units in the Fort Worth Basin have been discussed by Brown (1969), Brown and others (1979), Cheney (1940), Cleaves (1982), Erxleben (1975), Galloway and Brown (1973), Gardner (1960), Greimel and Cleaves (1979), Hodgen and Martin (1974), Lahti and Huber (1982), Lovick and others (1982), Ng (1979), and Thompson (1982).

The late Atokan conglomerates and sandstones were deposited on the structurally stable, northern shelf of the Fort Worth Basin as a result of numerous episodes of fluvial-deltaic deposition. The area was characterized by prograding deltaic systems that originated from a northern or northwestern source area.

These deltaic events were interrupted regularly by marine transgressions resulting in carbonate and marine clastic sedimentation. A hypothetical vertical sequence of sedimentation and idealized depositional model for a cratonic fan delta is shown in Figure 15.

The Caddo delta complex, which displays a major braided fluvial system that has undergone considerable

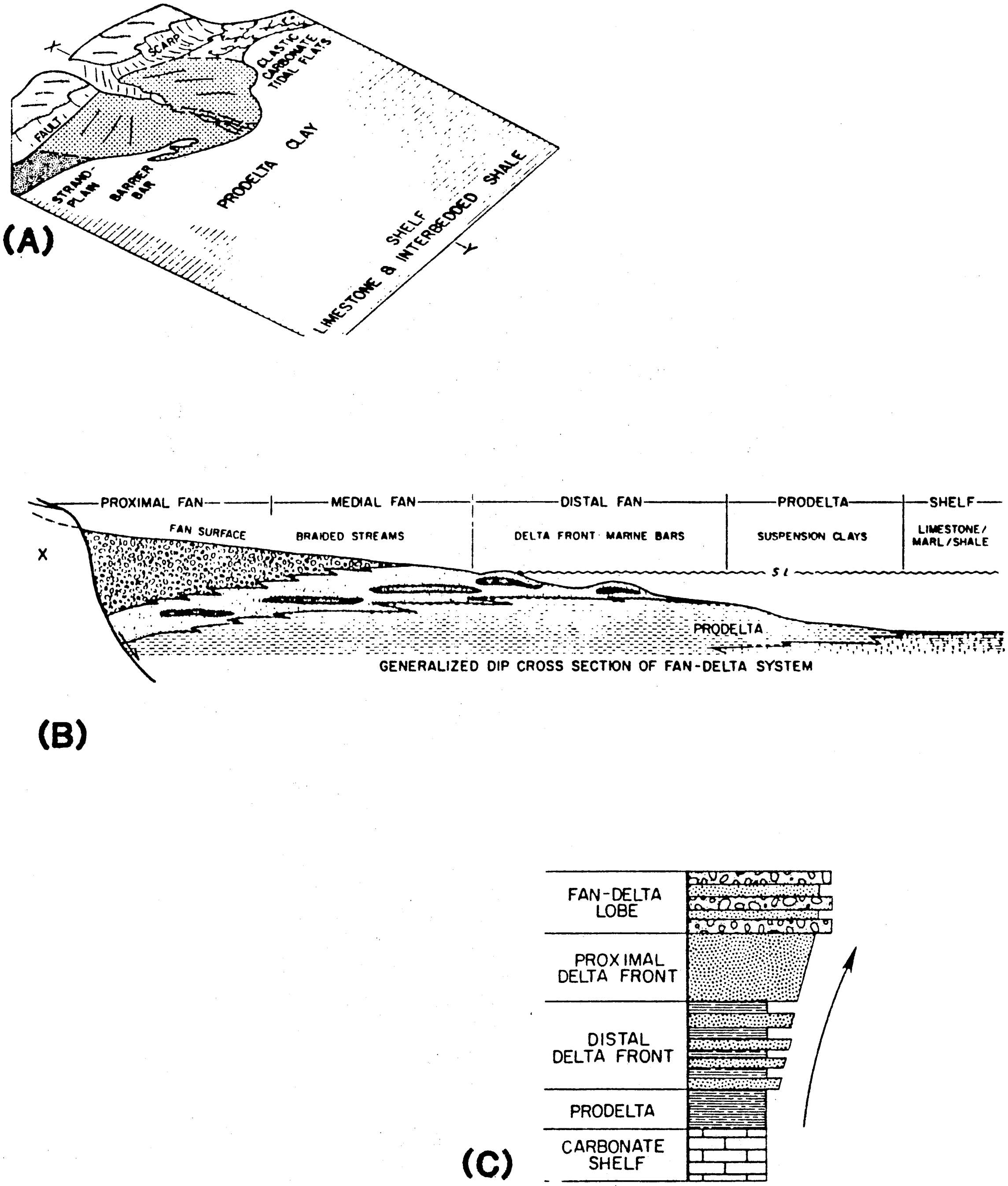


Figure 15. Fan delta model: (A) block diagram, and (B) generalized cross section (from Brown, 1980), and (C) idealized vertical sequence (from Thompson, 1982).

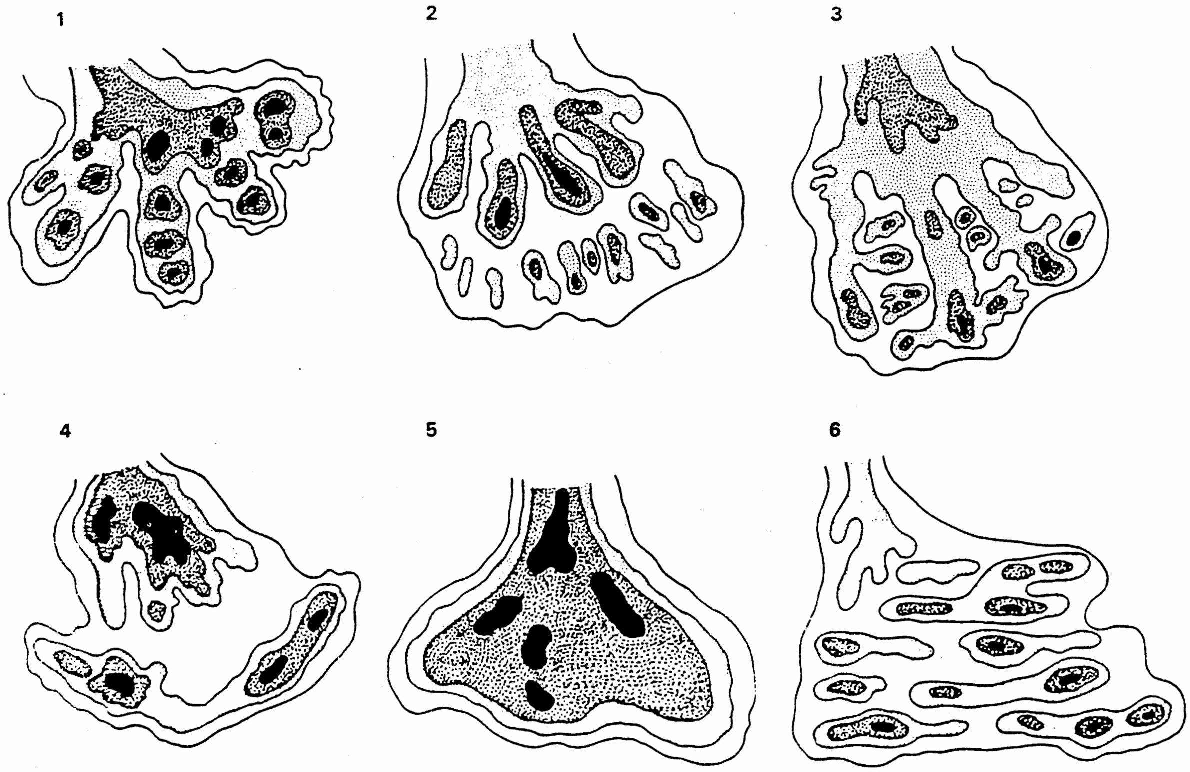
reworking by marine wave processes, was active in the study area during latest Atokan time. Its basinward progradation (southeasterly) over transgressive carbonates and marine clastics was halted either by delta lobe abandonment or by an eustatic rise in sea level. This statement is supported by the presence of the transgressive marine Caddo Limestone overlying the fluvial-deltaic sands.

Delta Models and Facies

Several classification schemes have been devised for categorizing deltas. Three of the most comprehensive will be discussed in detail.

Based upon a statistical analysis of thirty-four modern deltas, Coleman and Wright (1975) introduced a spectrum which comprises six distinct deltaic models. The sand isolith distribution pattern characteristic of the different delta models are illustrated in Figure 16. Each deltaic type is identified by the predominant sedimentary components in each environment. This classification also provides for single, idealized representation of the expected vertical change in texture and sedimentary structures for each of the six delta models.

Another valuable and effective classification scheme was first introduced by Fisher (1968, 1969) and was later refined by Galloway (1975). Vertical sequences of texture, sedimentary structure, areal facies distribution, and sand body geometry are utilized to define Fisher's deltaic mod-



TYPE 1
Conditions: low wave energy, tidal range, and littoral drift, low offshore slope, fine-grained sediment load.
Characteristics: widespread, finger-like channel sands normal to the shoreline.
Example: modern Mississippi delta.

TYPE 2
Conditions: low wave energy, high tidal range, normally low littoral drift, narrow basin.
Characteristics: finger-like channel sands passing offshore into elongate, tidal current ridge sands.
Examples: Ord, Indus, Colorado, Ganges-Brahmaputra deltas.

TYPE 3
Conditions: intermediate wave energy, high tides, low littoral drift, shallow stable basin.
Characteristics: channel sands normal to shoreline, connected laterally by barrier–beach sands.
Examples: Burdekin, Irrawaddy and Mekong deltas.

TYPE 4
Conditions: intermediate wave energy, low offshore slope, low sediment yield.
Characteristics: coalesced channel and mouth bar sands fronted by offshore barrier islands.
Examples: Apalachicola and Brazos deltas.

TYPE 5
Conditions: high, persistent wave energy, low littoral drift, steep offshore slope.
Characteristics: sheet-like, laterally persistent barrier-beach sands with up-dip channel sands.
Examples: São Francisco and Grijalva deltas.

TYPE 6
Conditions: high wave energy, strong littoral drift, steep offshore slope.
Characteristics: multiple elongate barrier-beach sands aligned parallel to the shoreline with subdued channel sands.
Example: Senegal delta.

Figure 16. Modern delta models: increase of tone indicates increase in sand thickness (from Coleman and Wright, 1975).

els. His approach delineates the relative effects of fluvial versus marine processes, which in turn influence the facies patterns and delta morphology.

Fisher qualitatively identifies the high-constructive deltas as being dominated by fluvial and fluvial-influenced processes, whereas high-destructive deltas are dominated by basinal processes such as tides, longshore drift and marine wave reworking. Galloway's classification refines the Fisher classification by using a ternary diagram (Figure 17) to identify general fields of fluvial, wave, and tide-dominated deltas.

The third classification scheme presented here deals with the alluvial fan and associated fan delta deposits, as well as the braided river and its braid delta sequences. Figure 18 illustrates the four basic divisions for McPherson's classification of fan and braid deltas. A fan delta may be described as a coarse-grained gravel-rich delta that forms where an alluvial fan system, sourced from an adjacent highland, is deposited directly into a standing body of water (Holmes, 1965). A newly introduced subdivision to the coarse-grained delta species was proposed by McPherson and others (1987). This new term, the braid delta, is defined as a coarse-grained delta comprised predominantly of gravel and coarse sand-sized clasts that forms as a result of a braided fluvial complex that progrades into a standing body of water (McPherson et al, 1987). The basic difference between the fan delta and the braid delta is

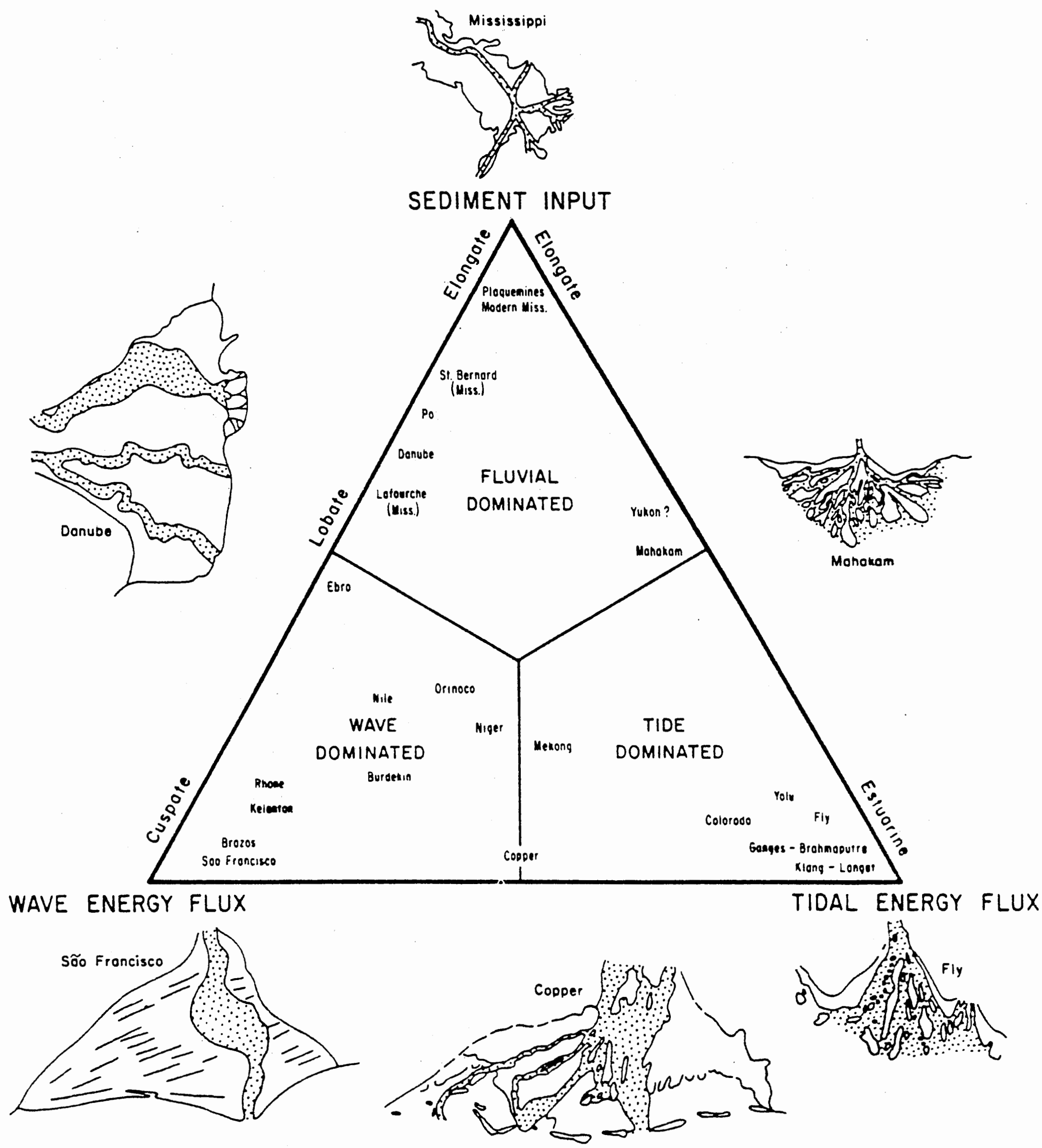


Figure 17. Ternary diagram of delta types, based on relative intensity from marine and fluvial processes (from Galloway, 1983).

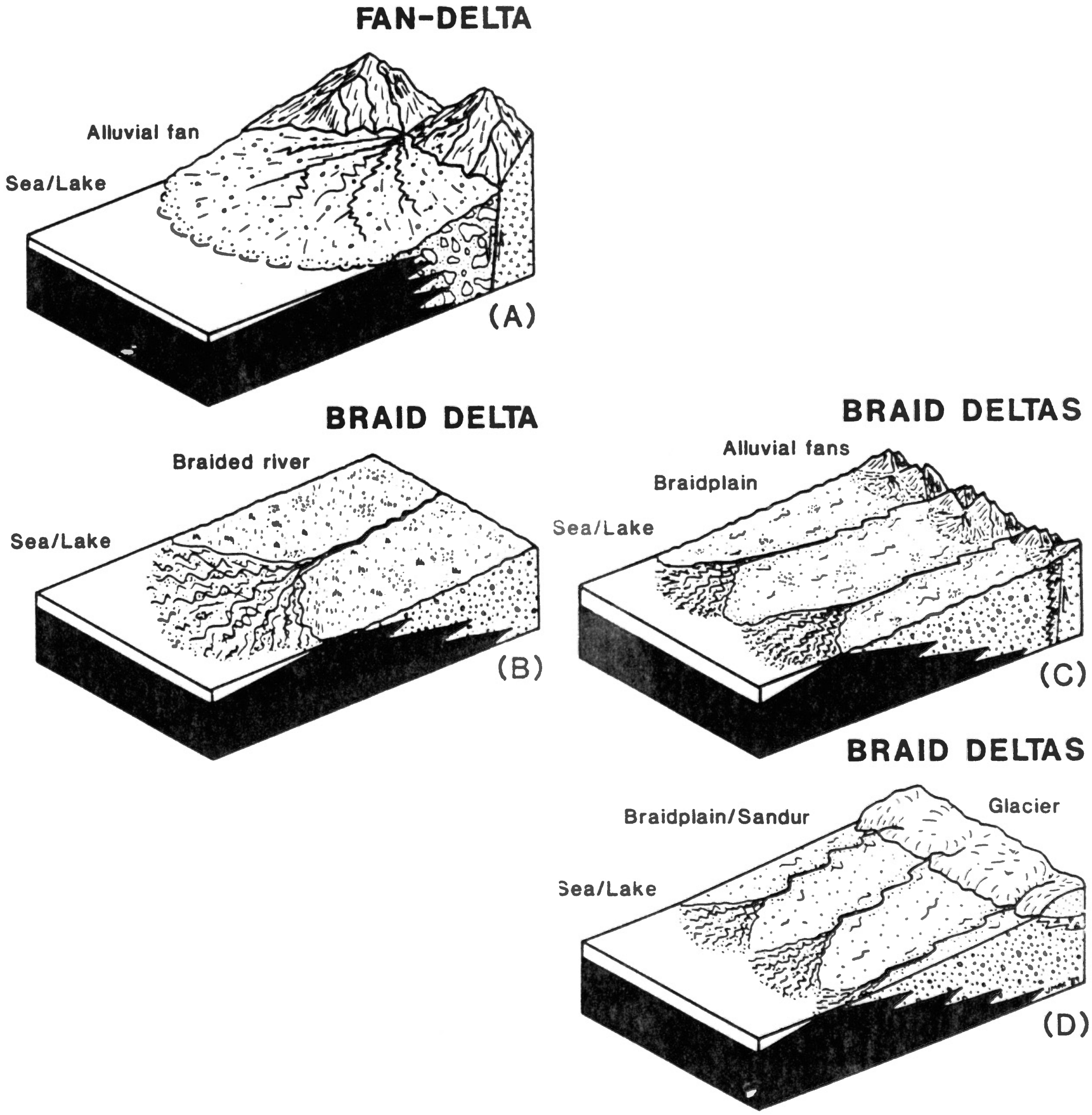


Figure 18. Coarse-grained delta models: (A) arid fan delta; (B) braid delta with distant source; (C) coalesced braid deltas with extensive braid plain and ; (D) coalesced braid deltas of fluvialglacial outwash plain (from McPherson et al., 1987).

that a fan delta has a subaerial alluvial fan facies with its associated morphology, lithologies, and sedimentary structures. This association is not, however, incorporated in the braid delta facies. It is common that the subaqueous components of these two delta sequences are similar, given comparable lacustrine or marine depositional processes. It should be noted that Fisher's classification can be applied to both the fan delta and the braid delta with respect to the high-constructive or high-destructive distal facies of these sequences.

For the purpose of this study, a combination of Fisher's classification and McPherson's classification will be utilized. Figure 19 illustrates the four basic divisions for Fisher's classification of marine deltas. High-constructive deltas can be subdivided into two major types based on coastal morphology (modern deltas) and net sandstone isolith trends (ancient delta systems).

Elongate deltas are formed by extensive basinward progradation of fluvial and fluvial-influenced constructional facies into a low energy marine environment. The well-defined, dip-oriented digitate sandstone bodies characteristic of these deltas, are ordinarily the preserved distributary channel fill and channel mouth bar (bar fingers) encased in the thick prodelta mud facies. Preservation of these prograded sand facies is common, leaving little sand available for marine reworking and redistribution. Destructional facies are therefore an

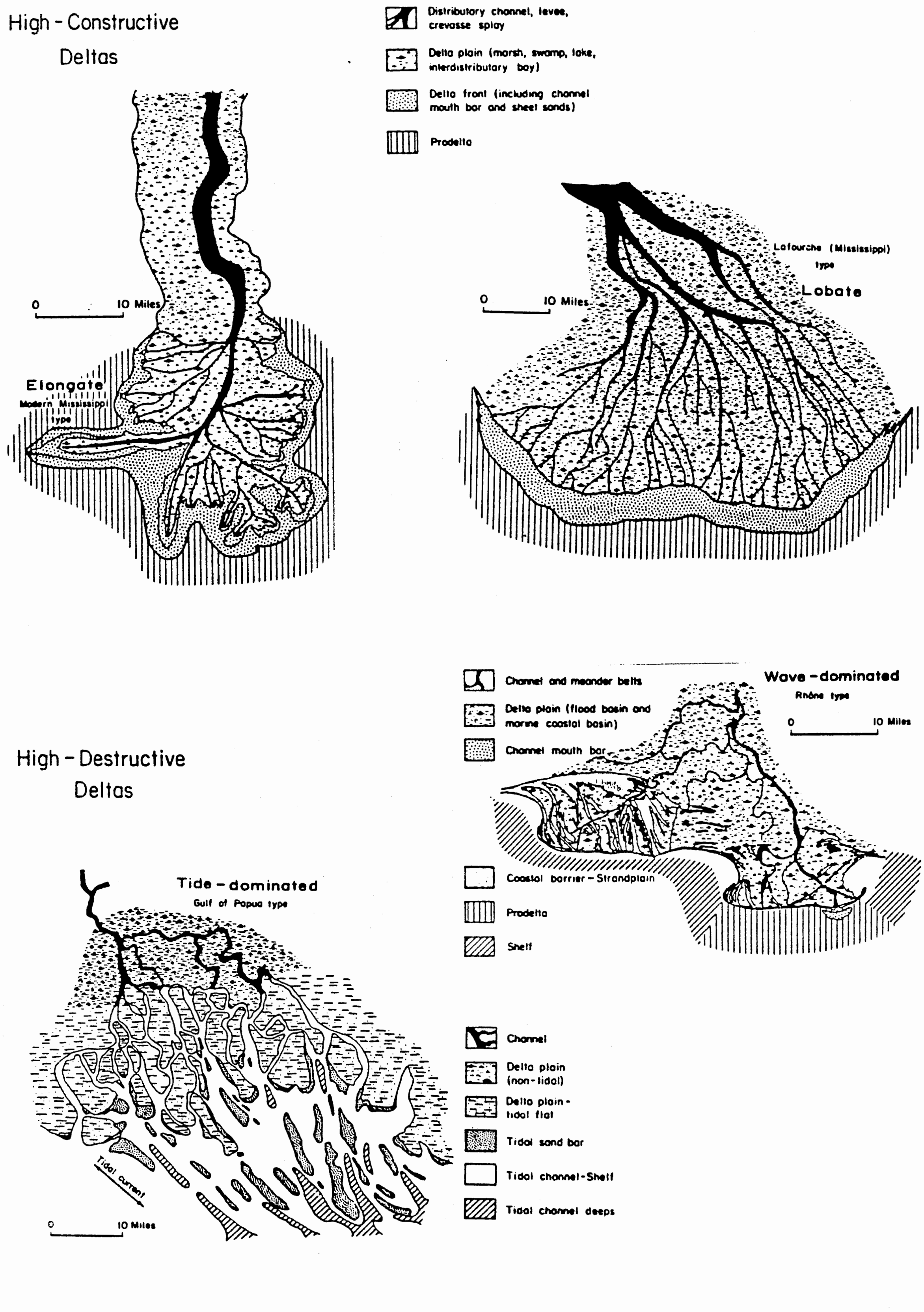


Figure 19. Modern delta types (from Coleman and Wright, 1975).

insignificant part of the elongate delta sandstone bodies. The best Holocene example of a high-constructive elongate delta is the highly documented, presently active lobe (Balize Lobe) of the Mississippi delta complex (Coleman, 1967). Another modern example is the Colorado River delta in Matagorda Bay, Texas. Ancient high-constructive elongate deltas include the Rockdale delta system (Eocene, Lower Wilcox Group) of the Texas Gulf Coast (Fisher and McGowan, 1969). The lateral facies distribution of an elongate delta complex is illustrated in Figure 20.

High-constructive lobate deltas differ from elongate delta species in that the well-defined bar fingers have been reworked and redistributed to form a coalesced delta front fringe sheet sand. Lobate deltas are commonly underlain by thin prodelta shales due to progradation into shallow water. Consequently, they do not undergo as much compactional subsidence as that seen with elongate deltas. This slower rate and overall quantity of subsidence allows for extensive marine reworking of the distributary channel fill and channel mouth bar to form these coalesced sheet sands (Fisher, 1969). The Lafourche Lobe of the Holocene Mississippi delta complex is an example of a high-constructive lobate delta. An ancient example identified is the Brazos River Formation (middle Strawn) of North-Central Texas (Cleaves, 1982). Figure 21 illustrates the lateral distribution of facies and an expected net sandstone isolith map of a lobate delta system.

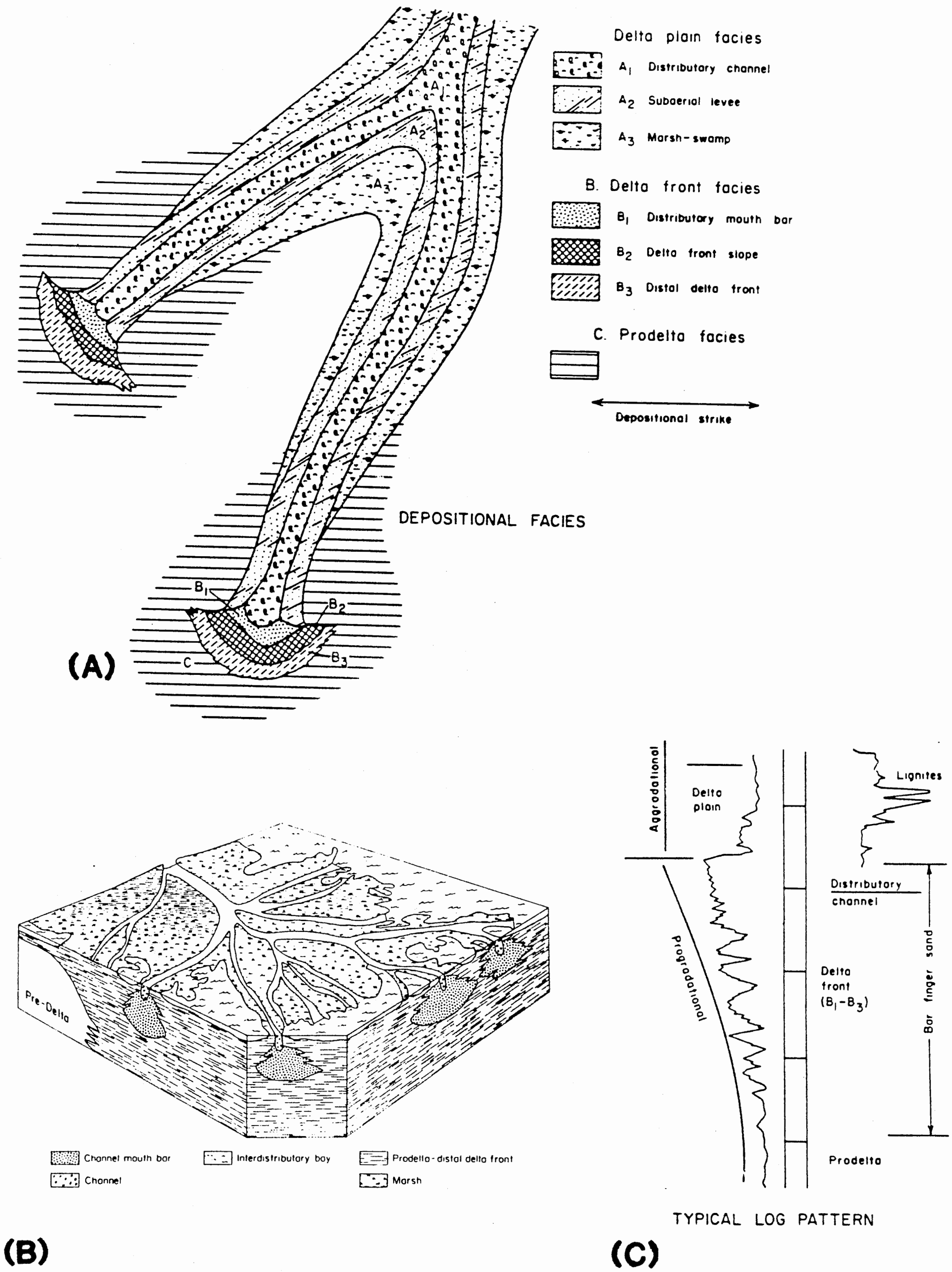


Figure 20. Elongate delta model: (A) depositional facies; (B) block diagram and; (C) typical log pattern (from Fisher, 1969).

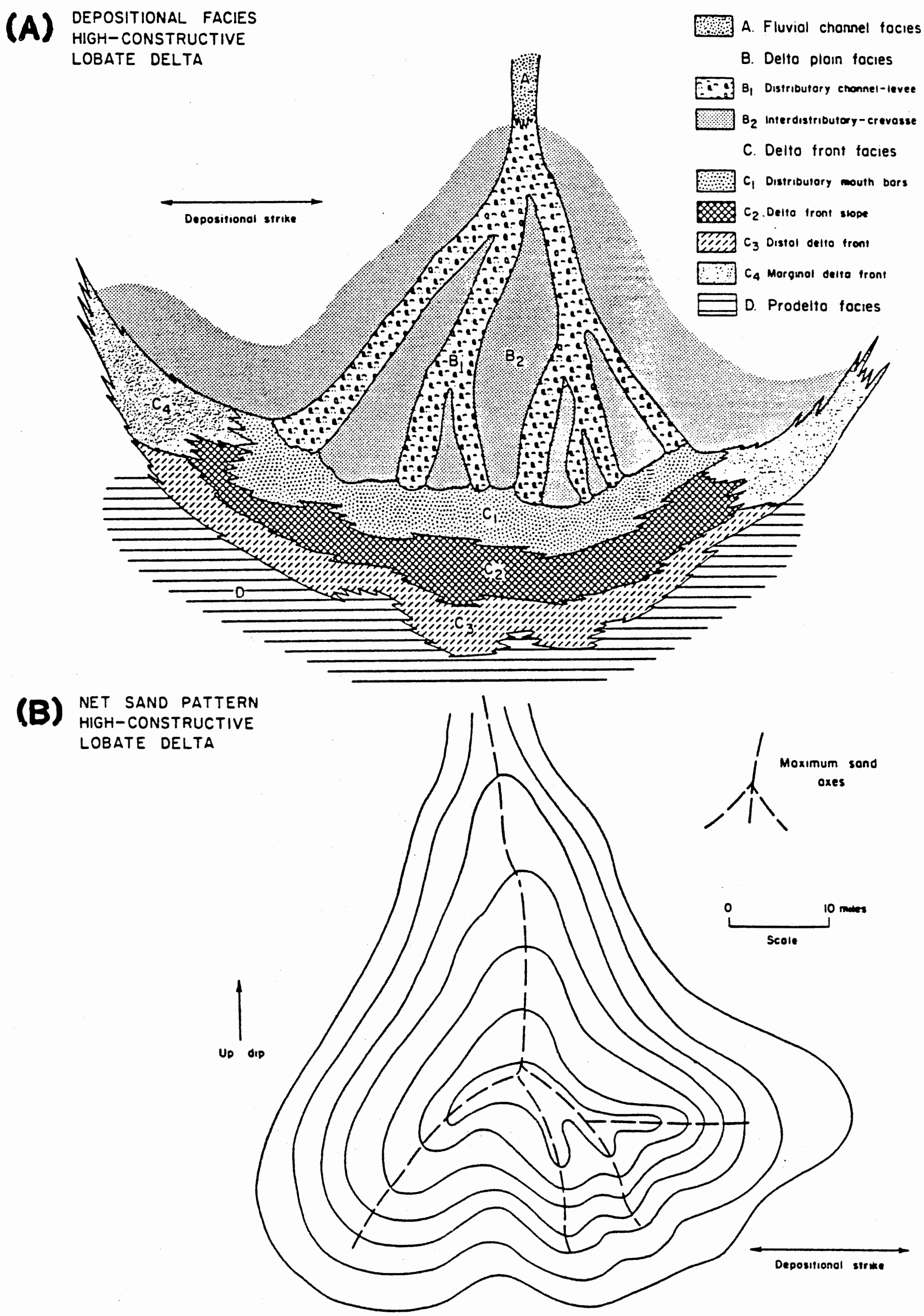


Figure 21. Lobate delta model: (A) depositional facies and; (B) idealized net sand pattern (from Fisher, 1969).

High-destructional deltas are characterized by the dominance of marine processes that control the formation and distribution of the principle sand facies. The specific type of marine process determines the delta species; this may be either high-destructional wave-dominated or tide-dominated. The distinct lateral and vertical sand facies of the high-destructive wave-dominated deltas are a result of fluvially derived sediments that have been reworked by the action of marine processes. Orientation of these redistributed sands, when reworked by waves, is parallel to strike and the delta takes on a cuspate morphology. Such cuspate deltas normally display one or two major distributaries up-dip, but the principle sand facies of the delta plain occurs as a series of strandplain beach ridges. Down-dip progradation of the deltaic distributaries and the sheet sand is not significant. The Brazilian São Fransico delta complex and the Po Delta, western Gulf of Venice (Fisher, 1969) are Holocene examples of cuspate, wave-dominated deltas. Ancient wave-dominated delta systems include the Upper Wilcox (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). The lateral facies distribution and idealized net sand isolith map are illustrated on Figure 22. The vertical sequence of the facies and sedimentary structures for the São Fransico delta is shown in Figure 23.

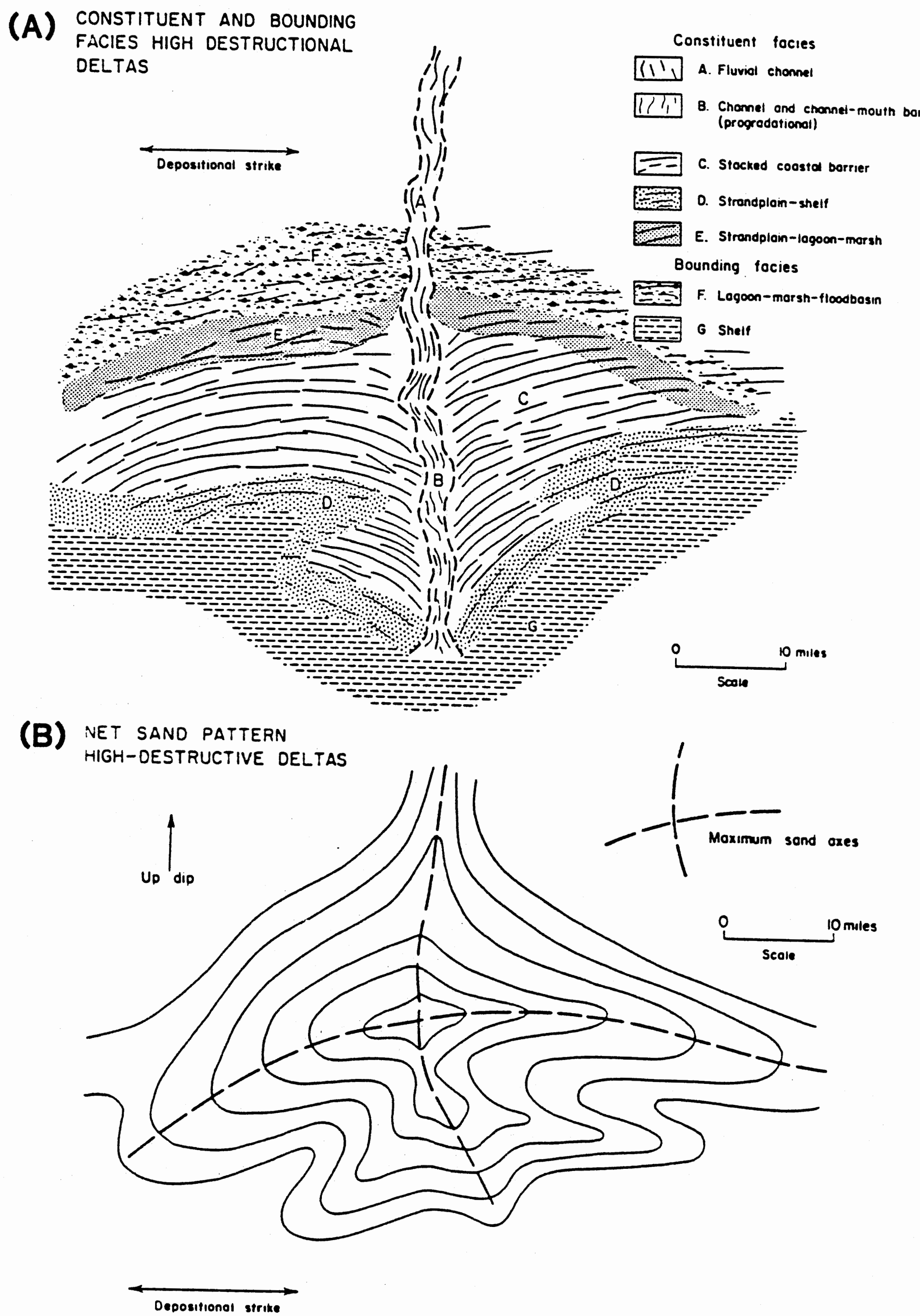


Figure 22. Wave-dominated delta model: (A) depositional facies and; (B) idealized net sand pattern (from Fisher, 1969).

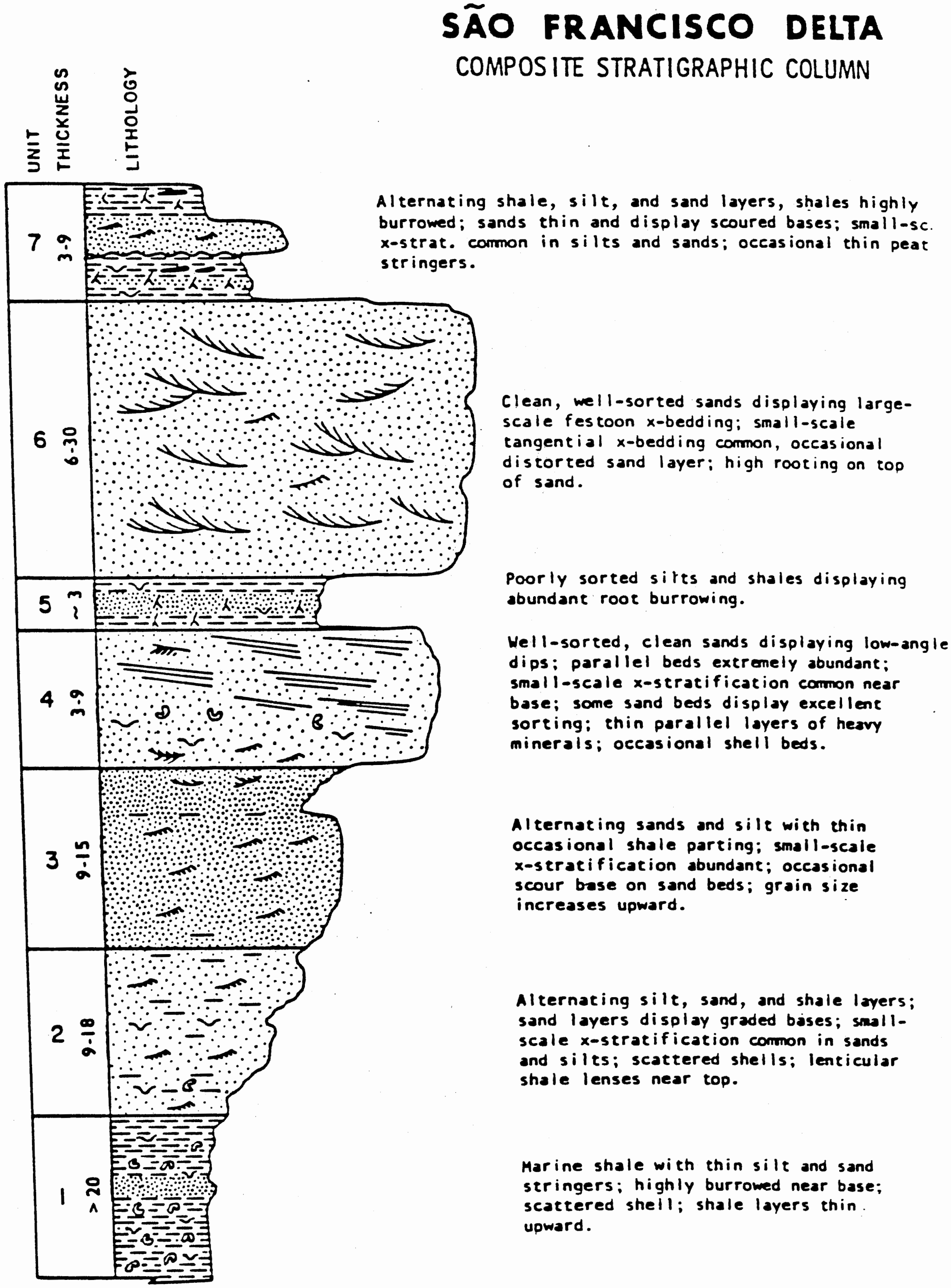


Figure 23. Stratigraphic column of the wave-dominated São Francisco (Brazil) river delta (from Coleman, 1981).

High-destructive tide-dominated deltas are the least understood of Fisher's four principle delta species. A definitive example of an ancient tide-dominated delta system has not been described in the geologic literature. A conclusive interpretation from the stratigraphic record is rendered difficult because of the highly variable geometries of the delta front. Models of Holocene tide-dominated deltaic systems include the Klang (Malaysia) and Ord (Australia) deltas, both of which have been described by Coleman (1981). The Gulf of Papua (New Guinea) is another well-documented example of a tide-dominated delta (Figure 24). A hypothetical net sandstone isolith map that could indicate a tide-dominated deltaic environment is also represented in Figure 24.

The major facies of the tide-dominated delta are the coarse-grained, dip-oriented, digitate distributary channel sands and the isolated subaqueous tidal sand ridges present seaward from the shoreline. The distributary channels frequently exhibit scoured bases and bi-directional cross-bedding, whereas the offshore linear sand bodies form by tidal reworking and redistribution of the channel mouth bar sediments. With narrow, open-ended seaways, these tidal ridges may parallel depositional strike. More commonly they are dip-oriented, where the seaway is narrow and closed at one end. The high-destructional tide-dominated environmental regime includes low wave energy, a high tidal range and narrow, restricted depositional basins that are indented

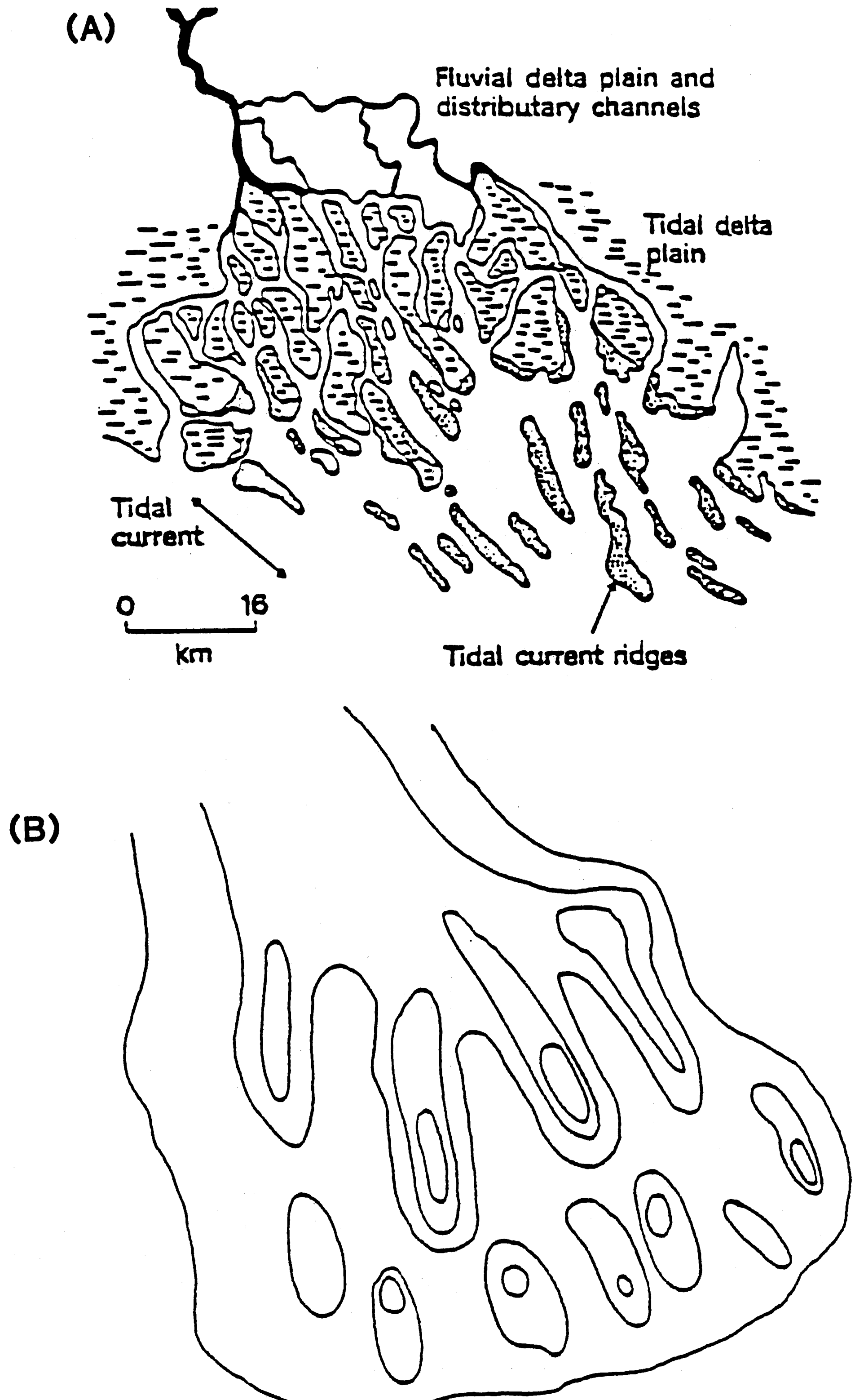


Figure 24. (A) The Gulf of Papua (New Guinea) a modern example of a tide-dominated delta, and (B) an idealized net sandstone isolith for a tide-dominated delta (from Fisher, 1969).

into the coast (Coleman, 1981). An anticipated vertical sequence of these facies and sedimentary structures for the Klang Delta is displayed in Figure 25.

The association of coarse-grained terrigenous clastics, interfingered with contemporaneous carbonate facies, is restricted to a few depositional environments. The fan delta and the braid delta provide a mechanism for this relationship.

Generally, fan deltas exhibit limited areal extent, but may display exceptional thickness due to proximity to the high relief source area. Poorly sorted, angular to subrounded, clast and matrix-supported breccias and conglomerates with intercalated mudstones (mud flows) are the dominant lithofacies. Oxidation profiles are also common due to subaerial exposure. These coarse clastic, wedge-shaped to lenticular geometries are usually poor hydrocarbon reservoirs.

Fan deltas are usually confined to tectonically active areas and display a cone shape when observed in map view. Fan delta sequences have a subaerial component that is an alluvial fan facies comprised of interbedded sheetflood, debris flow and braided channel deposits (McPherson et al., 1987). Sheetflood sediments are blanket-shaped deposits of sand or gravel, usually occurring near the distal fan. They form as a result of flood water surges. These fining-upward deposits are fairly well-sorted, may display parallel laminations from upper flow regime deposition and are

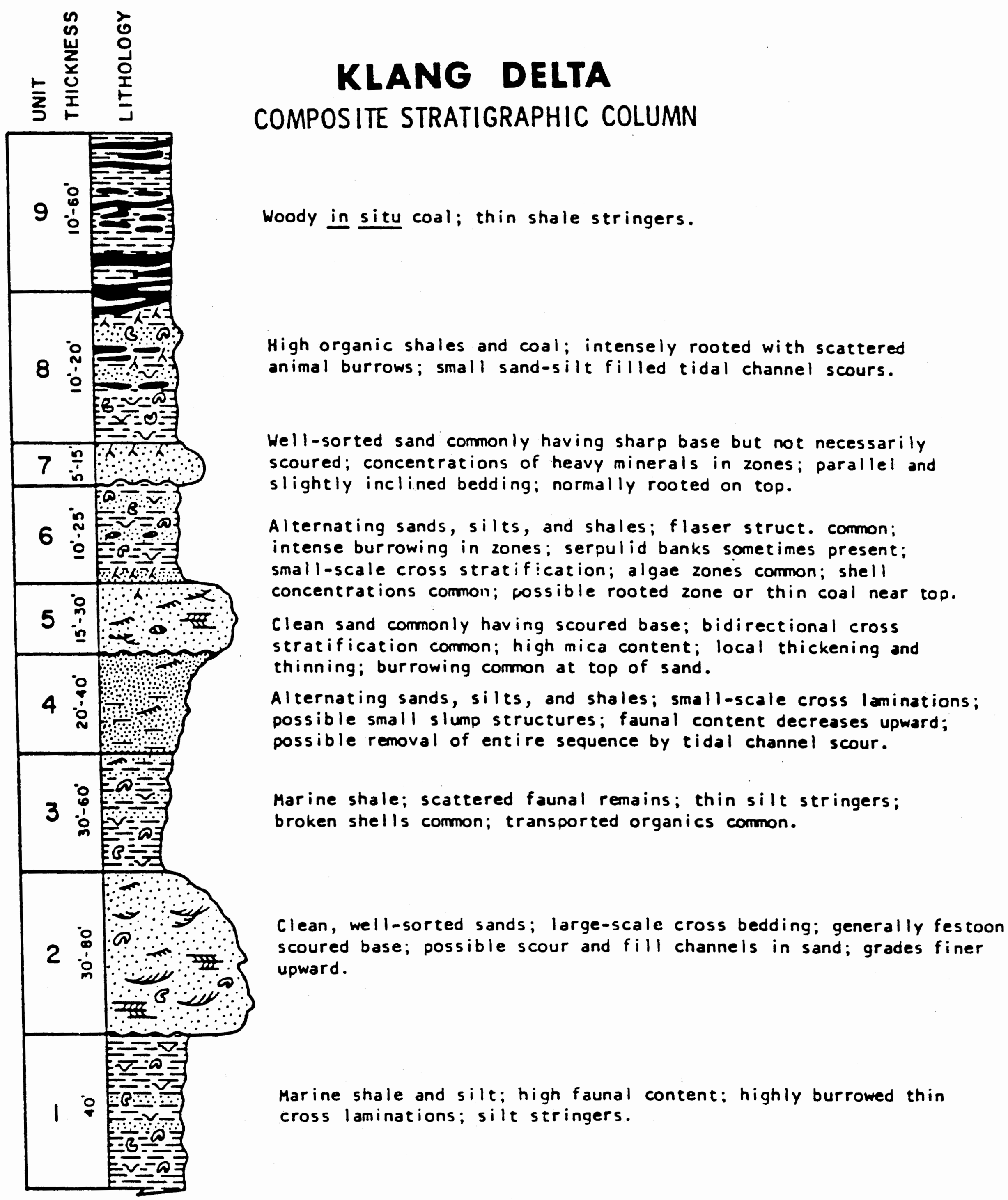


Figure 25. Stratigraphic column of the tide-dominated Klang (Malaysia) river delta (from Coleman, 1981).

normally interstratified with interfan silts and muds (Alberta, 1987). Sheetflood sequences are considered equivalent to deltaic crevasse splay deposits.

Debris flow sequences are transported as mass gravity flows and are normally deposited near the fan apex (proximal fan). These sediments are characterized by poorly sorted, disorganized beds with few preserved sedimentary structures and an abundance of muddy matrix (Nilsen, 1982).

The braided channel sediments commonly develop on the surface of the fan delta complex. These deposits are characterized by high gradients, frequent but low volume flash flood discharge, and a high sediment to bed load ratio. The braided channel deposits are normally flat bedded, discontinuous, lenticular to tabular sheet sands with abrupt lower and upper contacts (Figure 26). The sedimentary structures preserved are horizontal bedding, some tabular cross-bedding, and rare ripple cross-laminations. Longitudinal and transverse bars are the major depositional features of the braided species. These channelized bar areas of sedimentation can reflect ribbon to sheet-like geometries (Alberta, 1987). Within the fan delta, the braided channel sediments are ordinarily very poorly sorted, matrix-rich, and have low available porosity and permeability.

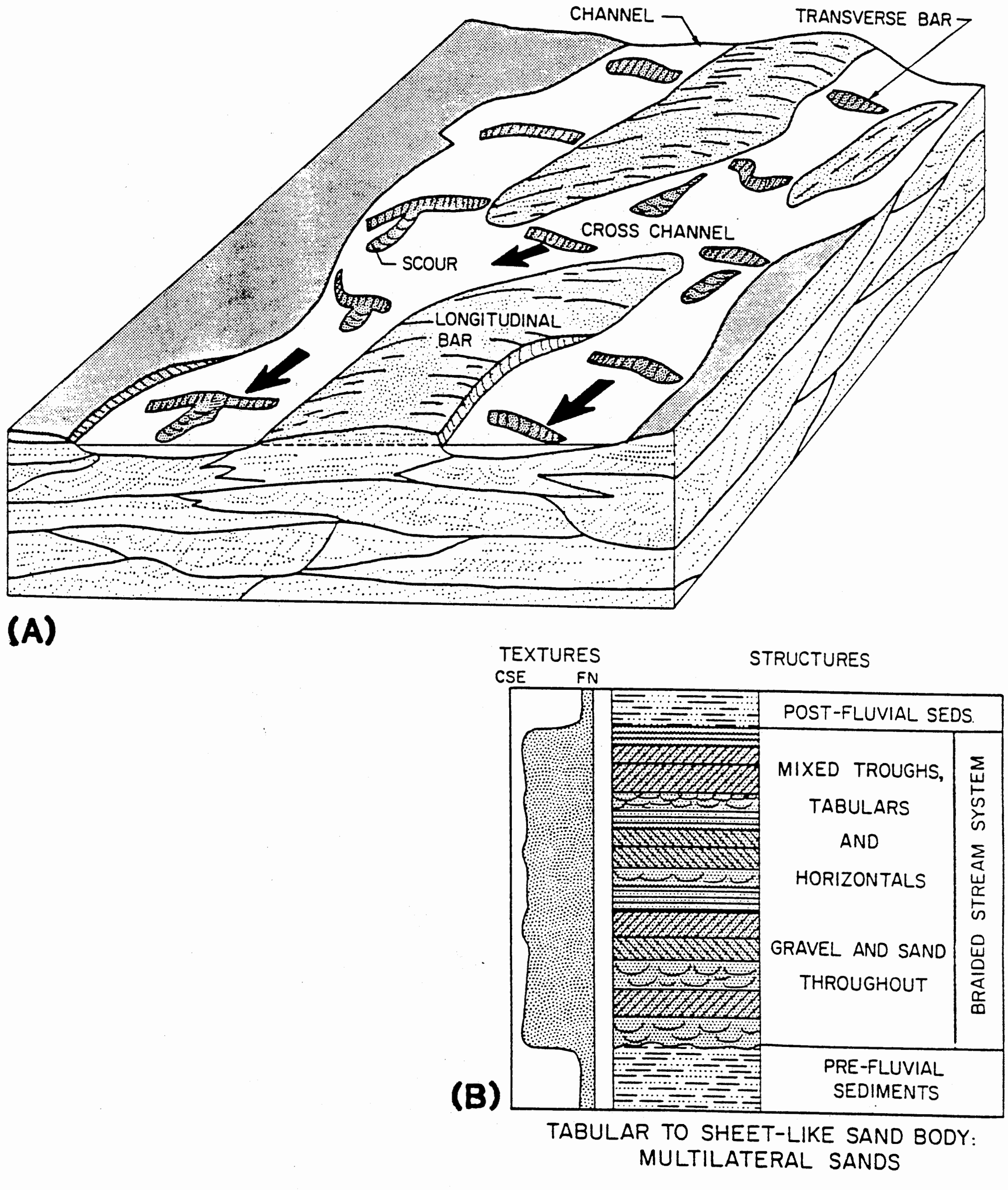


Figure 26. Braided fluvial system: (A) depositional model, and (B) idealized vertical sequence (from Brown, 1979).

The fan delta of the Dead Sea Rift and the Yallahs fan delta of Jamaica (McPherson et al., 1987) are well-documented modern examples of fan deltas. Ancient examples of fan deltas include the upper Miocene Violin Breccia of the Ridge Basin, California (Link, 1984) and the middle Tertiary Simmler Formation of central California (Ballance, 1984).

The subaerial component of the braid delta complex displays marked sedimentologic differences from the fan delta deposits. These differences are a result of the channelized character of braided rivers and the more sustained or constant flow of the fluvial system (McPherson et al., 1987). Moderate to well-sorted subrounded to rounded, clast-supported conglomerates and sandstones are the dominant subaerial lithofacies. Oxidation profiles and soils are uncommon. The moderate to high lateral continuity of the braided channel geometries, identified as sheet-like coarse-grained bodies over the length and width of the floodplain, provide for good to excellent hydrocarbon reservoir targets.

Modern examples of braid delta complexes include a lacustrine braid delta from Chignik Lake, southeastern coast, Alaska Peninsula and a strike-oriented, wave-reworked braid delta from Scoresby Sound, on the east coast of Greenland (McPherson et al., 1987). Some well-documented ancient examples of fan deltas that have been recently classified as braid deltas by McPherson and others

(1987) are the Triassic Ivishak Formation of Alaska (McGowen and Bloch, 1985) and the Pennsylvanian/ Mississippian Lower Fountain Formation (Lawford and Fishbaugh, 1984) of Colorado.

Fisher's classification of deltaic models has been applied to several Middle (Atoka and Strawn) and Upper (Canyon and Cisco) Pennsylvanian subsurface deltaic sequences in the Fort Worth Basin. Lahti and Huber (1982), Lovick and others (1982), and Ng (1979) have all given descriptions of lower Atoka (Bend Group) terrigenous clastic units that can be interpreted as representing Fisher's high-constructive delta model. Fisher's actual classification scheme for high-constructive elongate deltas has been employed by Brown (1969, 1973) in the lower Cisco, Cleaves (1982) for portions of the Strawn, and the Canyon Group of Erxleben (1975) in the lower Atoka. The Cisco Group of Brown (1973), the upper Strawn/lower Canyon of Cleaves (1982), and sections of the Canyon Group of Erxleben (1973) are identified as having high-constructive lobate delta systems in North-Central Texas. Regarding the high-destructive cuspate species, Thompson (1982) interpreted the Ouachita-sourced upper Atoka sandstones as wave-reworked coastal barrier facies within her North-Central Texas study area.

Thompson (1982) also identified a hybrid high-constructive fan delta sequence in the lower Atoka on the northern shelf of the Fort Worth Basin.

McPherson's (1987) classification has been applied to Middle and Upper (Atoka and Canyon Series) Pennsylvanian subsurface deltaic sequences in the Fort Worth Basin. Based on the fan delta/braid delta sedimentologic properties, McPherson and others reclassified the Henrietta fan delta (Canyon Group) of Erxleben (1975) and the Atoka Group of Thompson (1982) as braid deltas.

Delta Exploration Targets

Introduction

Deltaic environments are well-documented prolific hydrocarbon producers. Deltaic facies provide an excellent setting for petroleum accumulation as they contain 1) reservoir quality rocks; 2) organic-rich source rocks; and 3) trap mechanism sealing rocks. Thus, in the stratigraphic record, deltas are a self-sufficient, hydrocarbon producing and trapping system. The high-destructional braid delta model is interpreted as being appropriate for the Caddo conglomerates and sandstones of North-Central Texas. The coarse-grained facies of this delta and their relationships to petroleum accumulation and exploration will now be discussed.

The framework (coarse-grained) facies of the wave-dominated braid delta include braided distributary channels, channel mouth bars, crevasse splays, and laterally reworked delta front sheet sands.

Braided Distributary Channels

Braided distributary channel deposits usually contain clean (matrix-poor), moderately sorted, medium to coarse-grained and gravel-sized detritus. When laterally continuous, the deposits constitute good reservoir quality rocks.

Braided sand bodies are multilateral with high width to thickness ratios and have large bedload to suspended load ratios. They normally display no definite vertical variations in grain size. The complex braid channel geometries of the medial plain are created by the frequent and rapid lateral shifting of channels within the poorly developed levees of the high width alluvial plain. This lateral migration provides for the stacked nature of these deposits. On the lower braid delta plain, these channels may be rather stable and tend not to display significant lateral migration. This straightening of the channels is a result of channel subsidence within the distal plain silts and muds. Except in the marine-reworked distal delta sequences, the distributary channel trends normally conform to a down-dip orientation.

As a result of the erosional, progradational process of the braided sand deposits, they are laterally equivalent to the levee, crevasse splay, marsh, swamp, and lake deposits of the interfan and deltaic plain setting. They can be overlain by either the aggradational delta front, alluvial deposits, or transgressive marine sediments.

Channel Mouth Bar

The distributary mouth bar is the site of great sand accumulation in the braid delta environment. These clean, moderate to well-sorted, fine to coarse-grained sandstones and conglomerates, usually with high porosity and permeability, provide another prolific hydrocarbon producing facies. This thick, strike-oriented accumulation of an overall coarsening-upward sequence of sediments is preserved as a result of compaction of the relatively thin prodelta muds. The upper portion of the channel mouth bar sequence frequently contains large quantities of organic debris, transported downstream during floodstage. The channel mouth deposits are overlain by levee and delta plain sediments and often interfinger with the laterally adjacent interdistributary sands, silts and muds.

The channel mouth bar is incised by the prograding distributary channel during the depositional phase. Brown (1979) has described scouring by the distributary channel so extensive as to leave only remnants of the mouth bar on either side of the channel. As the distributary channel is abandoned, it fills with fine-grained sediments forming a clay plug.

Crevasse Splay

Crevasse splays break off the main distributaries and infill interdistributary bays between or adjacent to the major channels. Crevasses develop from a breach of the channel levee during flood stage and deposit a system of relatively thin, fan-like bodies of sediment.

Although these individual, fining-upward deposits are thin, continued subsidence and the repetition of levee breaching result in the stacking of the crevasse deposits, and may eventually build a thick sequence of sediment. After the process of crevasse sedimentation becomes inactive, marine waters advance as a result of compactional subsidence and the interdistributary area reverts to a bay environment. This completes its sedimentary cycle.

Most common to high-constructive deltaic environments, crevasse splays are another important hydrocarbon bearing facies. Crevasse deposits can provide good stratigraphic traps since the individual sand facies pinch out against depositional dip.

Sheetflood Deposits

The sheetflood deposit is the fan delta/braid delta equivalent to the distal delta plain crevasse splay deposit. Both units display similar geometries, lithologies, and sedimentary structures. The basic difference is the relative position within the wave-reworked, braid delta system that the process is observed. For the purpose of this study, sheetflood deposits will be defined as occurring only within the subaerial proximal or medial braid delta, where the major braided channels and subaerial interbraid plain are dominant. The down-dip equivalent crevasse splay will then be identified as breached deposits occurring within the distal delta plain; these display marine-related controls and processes.

The subaerial proximal and medial braid plain are normally not organic-rich. However, their relationship and proximity to lower deltaic reservoir quality rocks and organic-rich distal delta plain and prodelta muds provide for another stratigraphic hydrocarbon target within the study area.

Delta Front Sheet Sands

High-contructional lobate and high-destructional wave-dominated deltas both display wave reworked and redistributed sand bodies parallel to depositional strike along the distal delta fringe. These coalesced sheet sands connect up-dip to the bifurcating distributary mouth bar system. Fisher (1969) documents over 200 foot (60 m) thicknesses of these coastal sand bodies within the high-destructional wave-dominated Upper Wilcox (Eocene) along the Gulf Coast of Texas. This well-sorted coarse-grained facies commonly displays a coarsening-upward sequence overall. These delta front sheet sands overlie prodelta and interdistributary bay muds and are overlain in turn by destructional marine facies, delta plain sediments, or a transgressive carbonate sequence. Oriented normal to the distributary channel and mouth bar facies, these coarse-grained sands also constitute good reservoir rock qualities. The delta front sheet sands are encased within the organic-rich lagoonal and prodelta muds, and therefore provide excellent hydrocarbon-bearing stratigraphic traps.

CHAPTER VI

PETROLOGY AND DIAGENESIS OF THE CADDO SANDSTONES

Introduction

The two cores used in this study are the J.D. Ortan #4 and the Alvord South Caddo Conglomerate (A.S.C.C.U.) #3-8 (Figure 27). Both were drilled by Mitchell Energy Corporation as stratigraphic tests.

The J.D. Ortan #4 is located in the Anson-Ortan Field, Texas Emigration Land Survey, Montague County, Texas. Total depth reached was 6105 feet and the well was completed in the week of September 13, 1975. Production was established in the Caddo conglomerate with an initial flow rate of 170 BOPD.

The A.S.C.C.U. #3-8 is located in the Alvord South Caddo Conglomerate Field, K. Lofton Survey, Wise County, Texas. Total depth reached was 5900 feet and the well was completed during the week of August 10, 1984. Caddo production was established with an initial flow rate of 70 BO and 35 MCFGPD.

The two cores used in this study were logged and described on a scale of 1" = 10 feet. Samples were

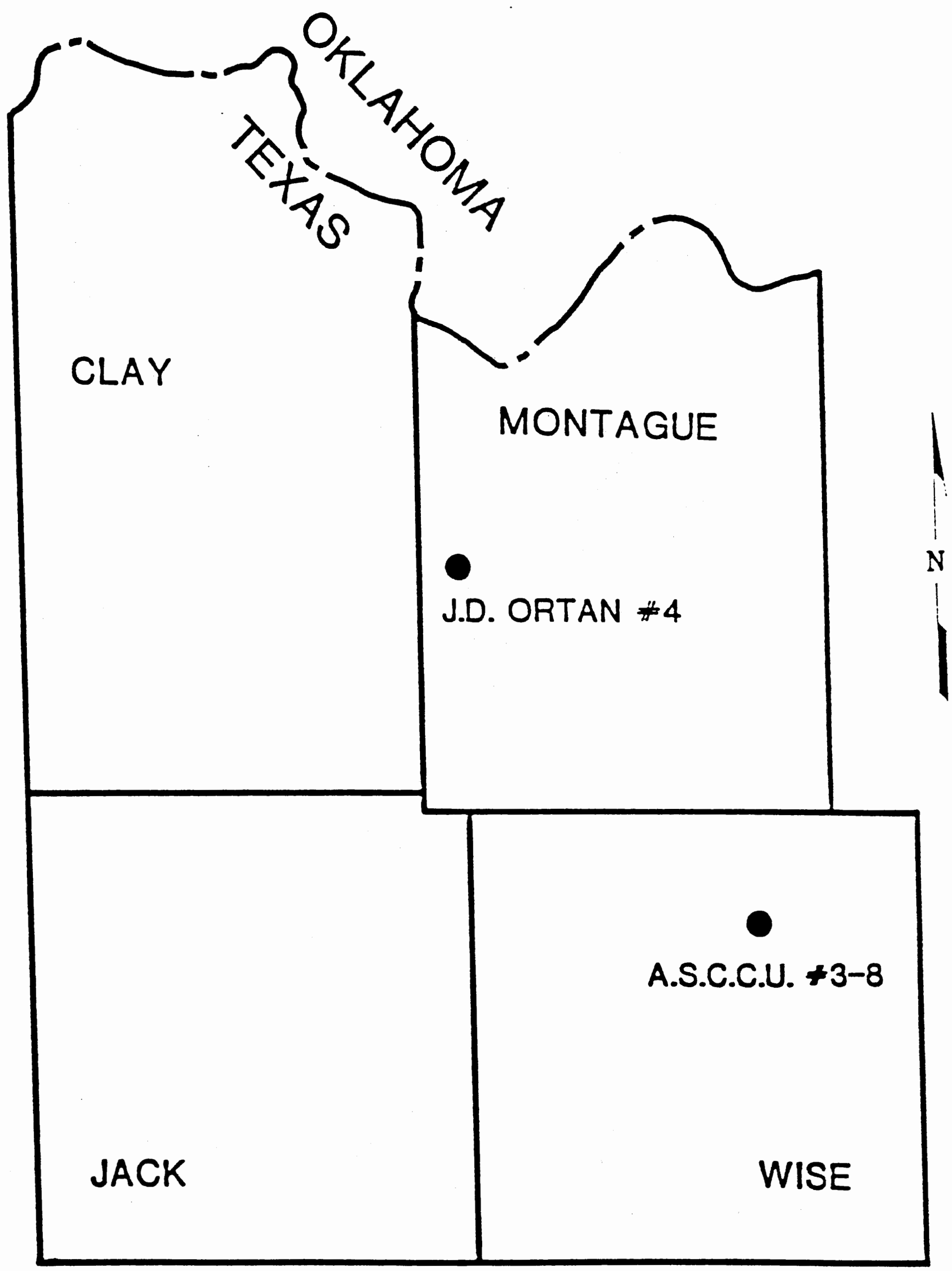


Figure 27. Location of cores used in study.

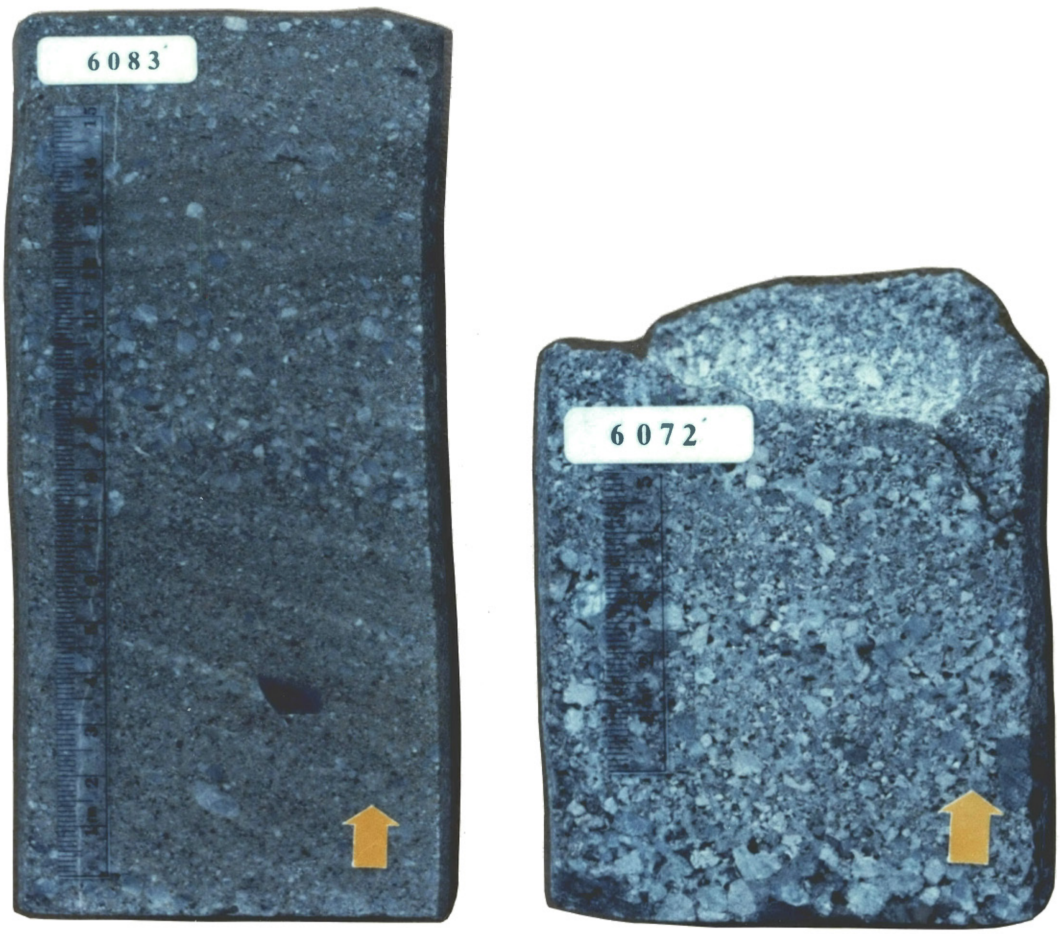
removed from the core for the preparation of thin sections.

Core Descriptions

The J.D. Ortan #4 includes the interval from a measured depth of 6054' to 6104'. It displays an overall coarsening-upward sequence of thirty-eight feet of Caddo siltstone, sandstone, and conglomerate. These clastics are overlain in turn by a five foot thick section of transgressive Caddo Limestone. The light colored, massive conglomerates contain subangular, unsorted floating pebble and cobble-sized clasts (Figure 28). This suggests deposition by a high energy braided distributary channel within the proximal or medial delta plain. A well-developed spontaneous potential curve, with sharp lower and upper contacts and the presence of organic debris, are all indicative of a fluvial channel deposit.

The conglomeratic facies are generally poorly sorted, whereas the fine to coarse-grained sandstones display fair to good sorting. The porosity is diagenetically controlled, but is also observed to increase with the grain size of the clastics. The porosity varies from one to 17 percent within the interval (at 6073', the porosity is 17.3 percent with 769 md. permeability).

The erosional basal contact of the Caddo conglomerate directly overlies wavy bedded interdistributary shales. The upper contact with the superjacent Caddo Limestone also



(A) (B)

Figure 28. Photograph of the J.D. Ortan #4 core showing (A) individual graded beds of light gray, subangular pebble and cobble-sized clasts, and (B) cobble-sized clasts floating in a very coarse sandstone.

displays an erosional contact, as indicated by limestone rip-up clasts within a very disturbed shaly sequence (Figure 29). Higher, this dark gray, micritic limestone was deposited in a low energy, open marine, shallow water environment and contains crinoids, brachiopods, bryozoans and Foraminifera.

The siltstones of the Caddo clastic unit display wavy bedding (Figure 30), water escape pipe features, and burrowing. In contrast, the coarse sands and conglomerates are generally horizontal bedded and contain graded beds. Small to medium scale tabular cross-bedding and organic debris are also observed in the coarse clastics. The occurrence and vertical distribution of these sedimentary structures and their lithologic relationships are documented on the petrologic log (Figure 31).

The Alvord South Caddo Conglomerates Unit #3-8 ranges in depth from 5745' to 5878' and contains 102 feet of fine-grained sandstone to pebble and cobble-sized conglomerate. Two distinctive coarsening-upward sequences, from 5752' to 5822' and from 5834' to 5856', as well as the presence of small scale trough cross-bedding, suggest deposition of a strike-reworked delta front sheet sand on the lower margin of a delta plain. These coarsening-upward deposits also display well-developed spontaneous potential log patterns and can be interpreted as a progradational delta front sequence. The poorly sorted light gray, predominantly sub-

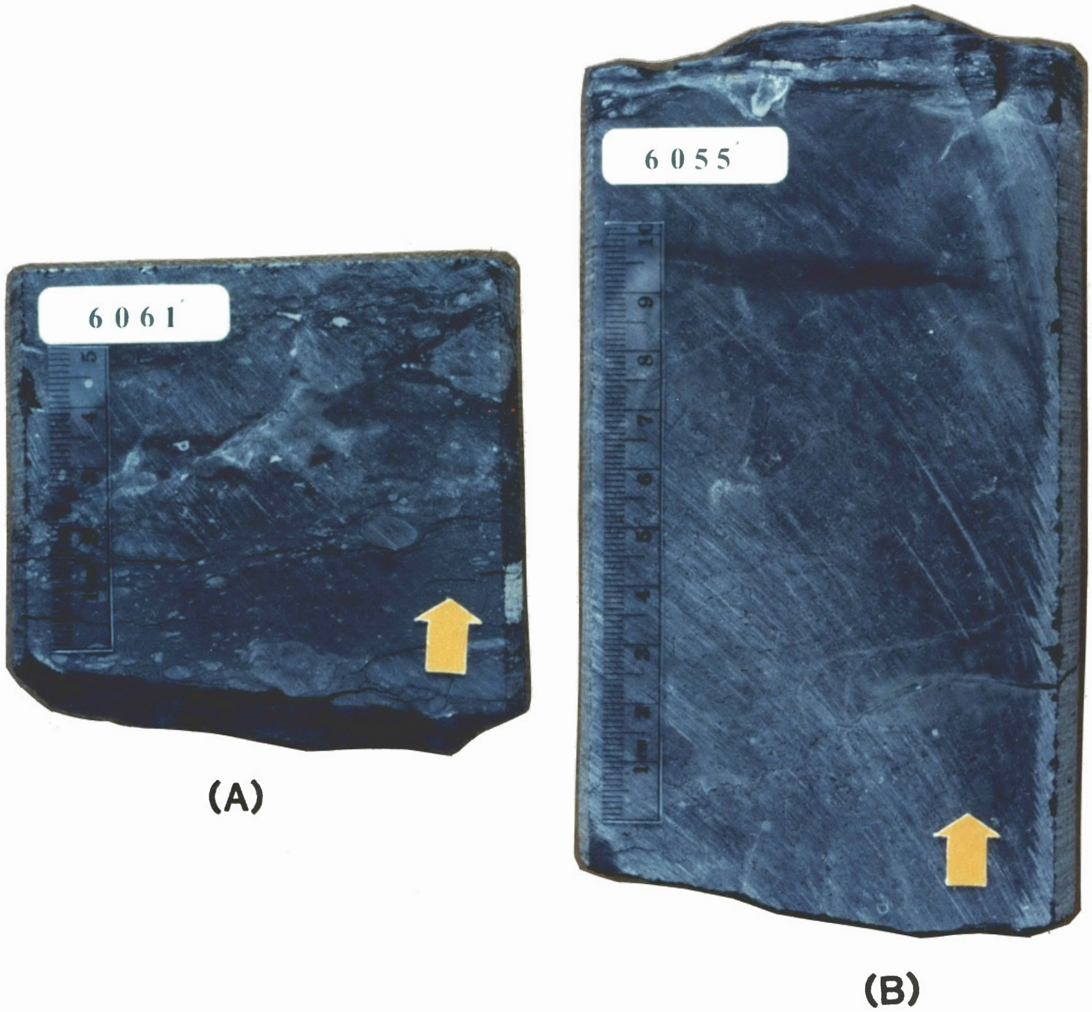
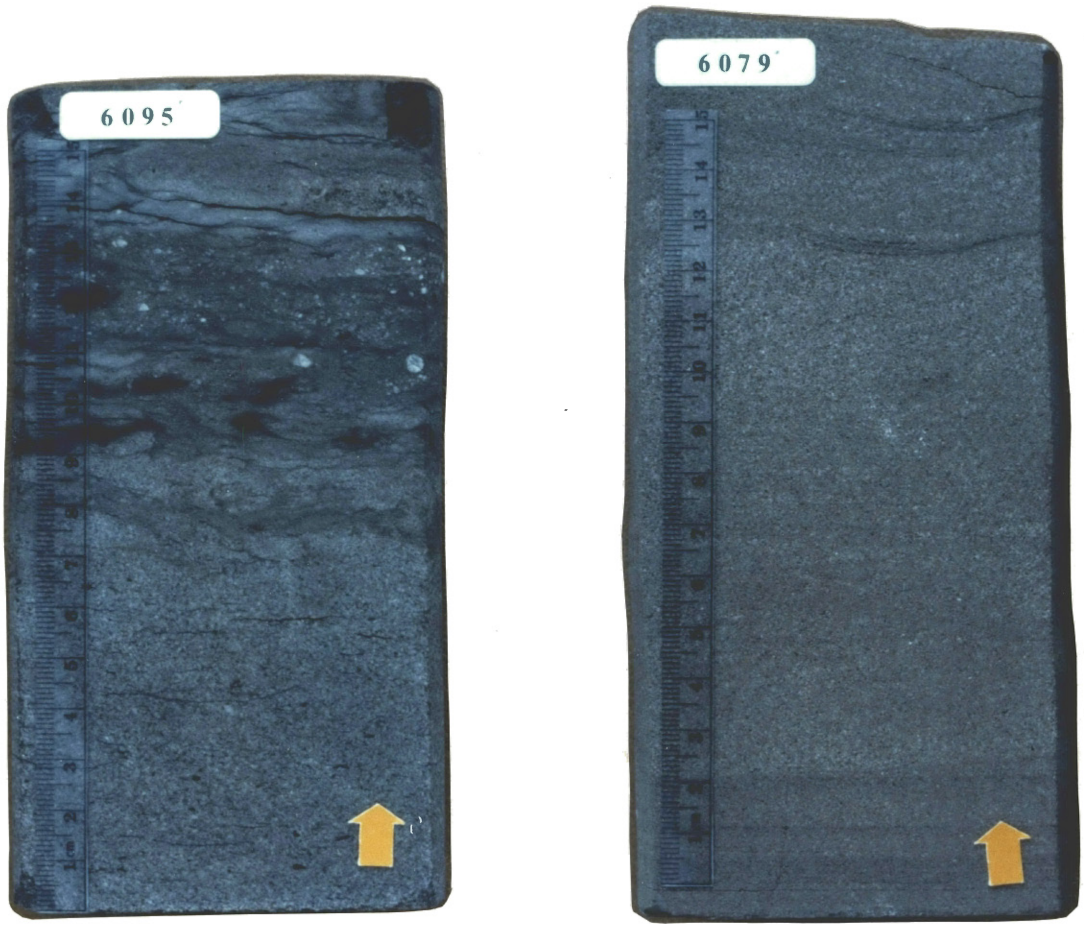


Figure 29. Photograph of the J.D. Ortan #4 core showing (A) Caddo Limestone rip-up clasts and macrofossils in a wavy bedded shale sequence, and (B) the overlying dark gray carbonaceous Caddo Limestone.



(A) (B)

Figure 30. Photograph of the J.D. Ortan #4 core showing (A) a horizontal bedded coarse sandstone overlain by a fossil-rich, wavy bedded siltstone, and (B) a medium-grained sandstone with planar bedding with small scale cross-sets.

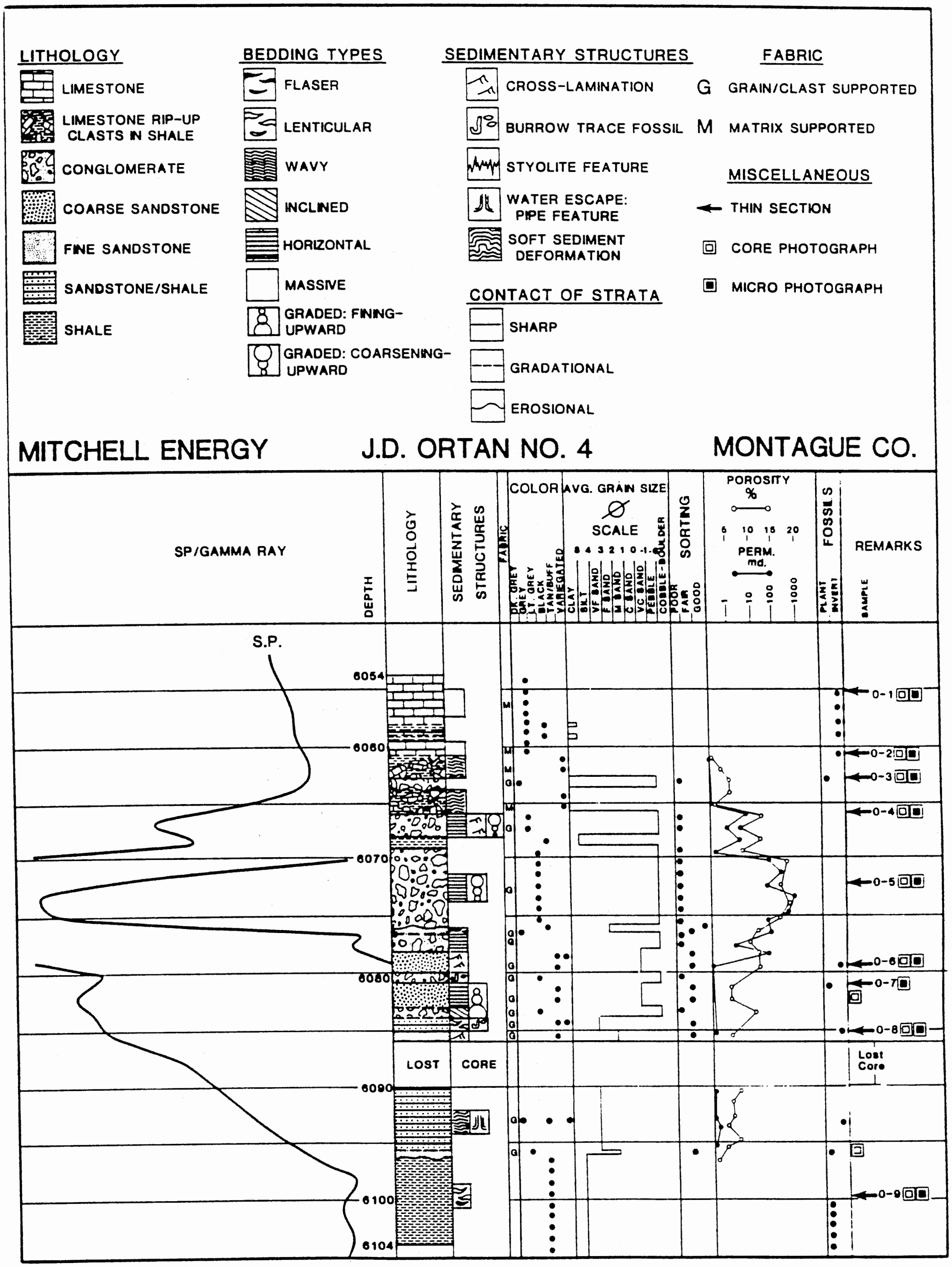


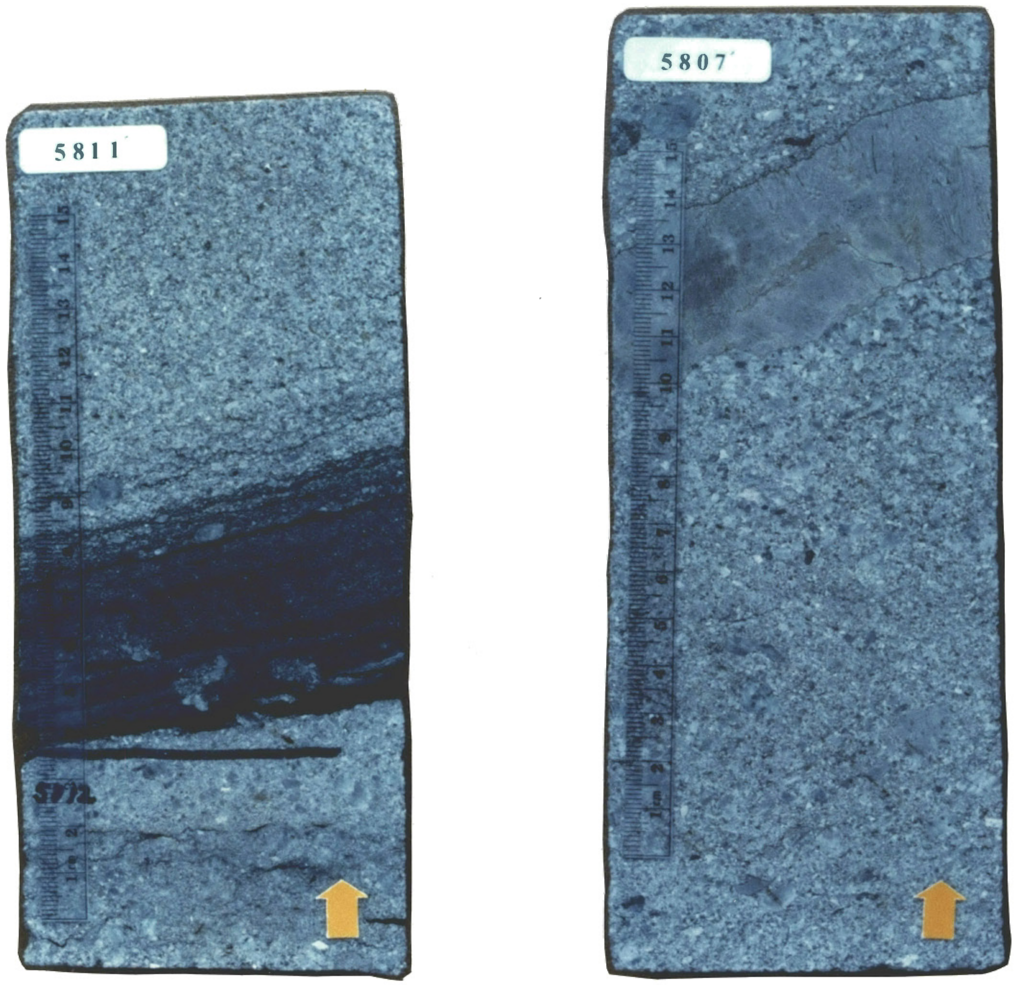
Figure 31. J.D. Ortan #4 petrologic log.

angular, pebble and cobble-sized clasts are contained between a gradational lower and a sharp upper contact.

The poorly sorted conglomerate facies displays maximum porosity values of 16 percent. The coarse-grained sediments normally contain higher porosities. However, it was observed in this core, and verified in the thin sections, that diagenetic processes can obliterate all available pore space.

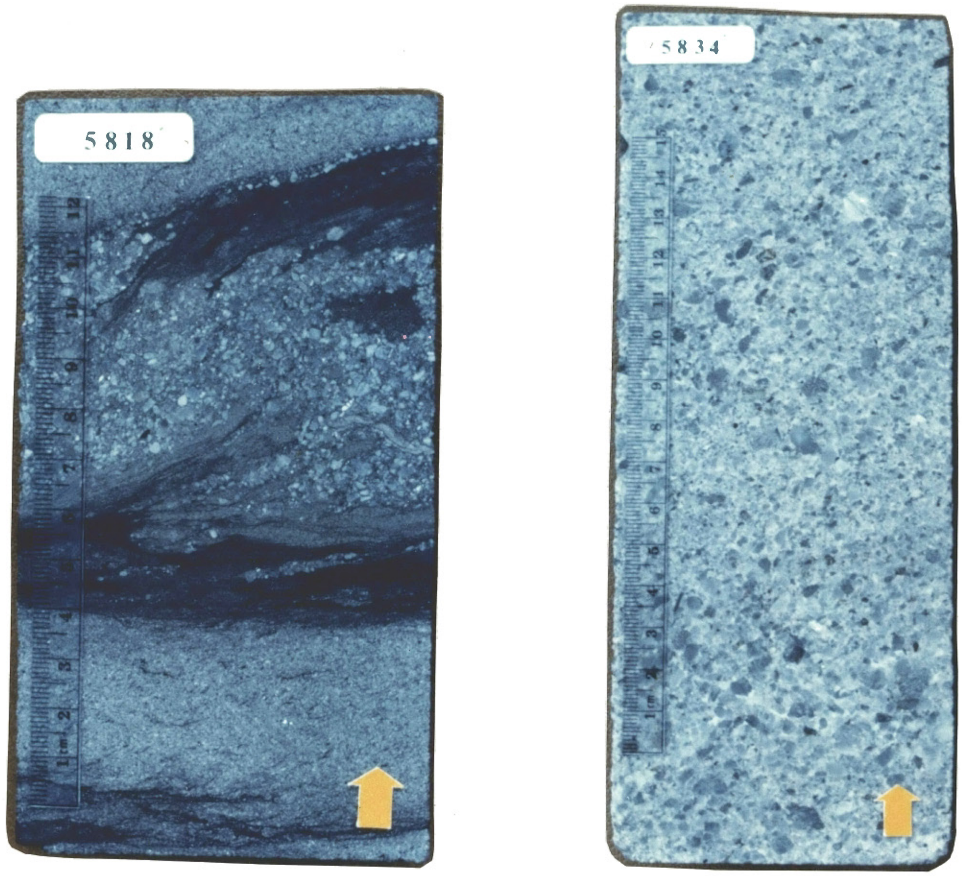
The Caddo conglomerates and sandstones coarsen upward from the horizontal bedded organic-rich prodelta shales. The basal contact of the coarse-grained deposits is gradational. The sharp upper contact with the transgressive shales and Caddo Limestone is not observed in the core, but can be inferred as sharp due to distinct spontaneous potential inflections seen on the electric log.

Sedimentary structures in the finer grained facies include wavy to inclined bedding (Figure 32), small scale trough cross-bedding, burrowing and soft sediment deformation (Figure 33). Medium scale trough cross-bedding, compaction features, and stylolization are observed in the coarse sands and conglomerates. The occurrence and distribution of these sedimentary structures and their lithologic relationships are documented on the petrologic log (Figure 34).



(A) (B)

Figure 32. Photograph of the A.S.C.C.U. #3-8 core showing (A) a burrowed shale interval overlain by a massive, coarse-grained sandstone that grades to (B) a light gray conglomerate that contains a large bryzoan fragment.



(A) (B)

Figure 33. Photograph of the A.S.C.C.U. #3-8 core showing (A) a carbonaceous fine-grained sandstone grading to shale, disturbed by a coarse-grained crevasse deposit, producing flame structures (flowage from right to left), and (B) the overlying light colored pebble to cobble-sized delta front sheet sandstone.

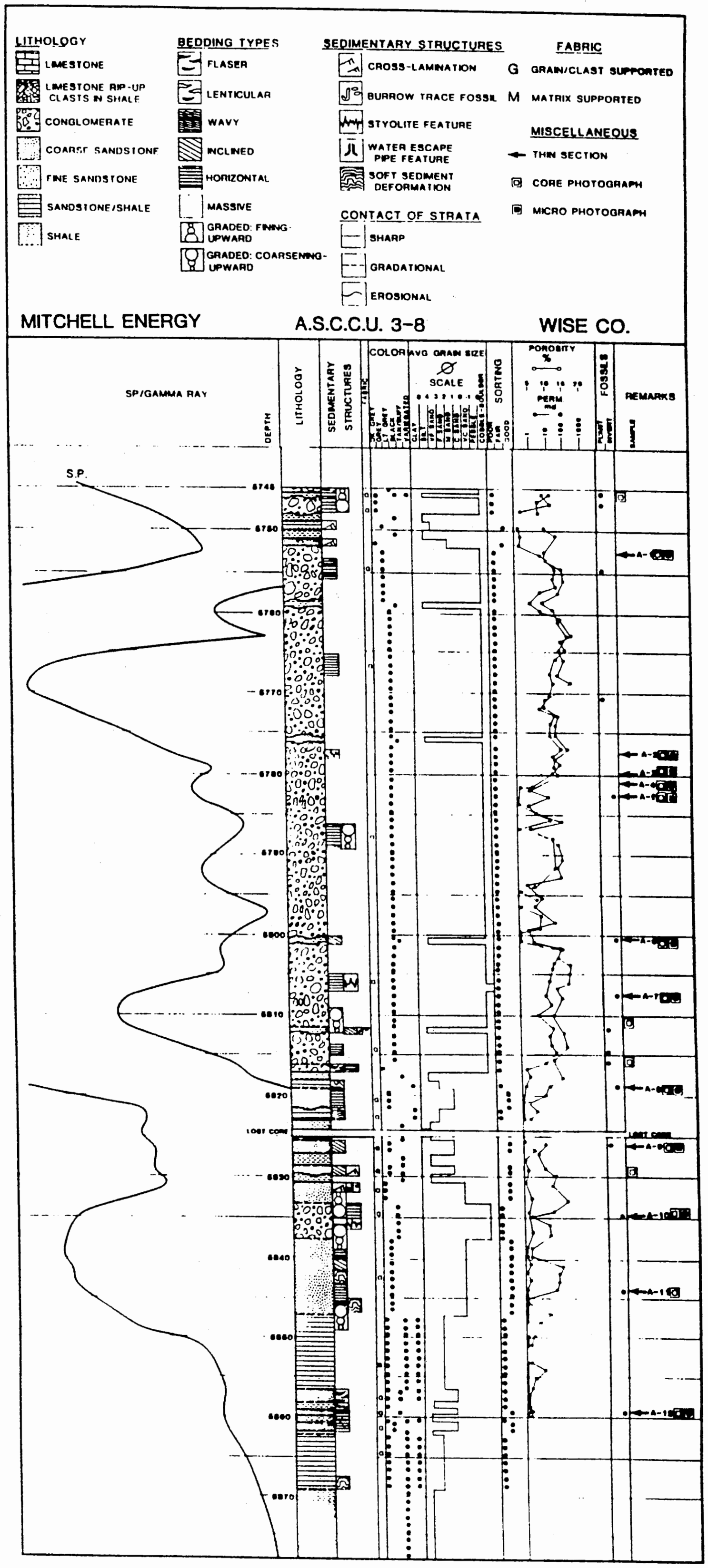


Figure 34. A.S.C.C.U. #3-8 petrologic log.

Composition and Classification of the Caddo in the J.D. Ortan #4

Plotted on a Q-F-R diagram without regard for metastable constituents now dissolved or replaced, the average composition of the Caddo in the J.D. Ortan #4 core falls within the arkose subdivision of the Q-F-R triangle (Figure 35). Based upon the common dissolution of feldspar grains, it seems likely the original sediment was an even more feldspar-rich arkose.

In general, the coarse clastic sediments of both cores display moderate to poor sorting of subangular to sub-rounded pebble-sized clasts.

Detrital Constituents

The types of detrital constituents observed within the Caddo conglomerates and sandstones of the J.D. Ortan #4 core were also common to the A.S.C.C.U. #3-8 core. The J.D. Ortan #4 core contained an average of 51 percent quartz (porosity included), 25 to 75 percent of which was polycrystalline (Figure 36). Feldspars were the second most common detrital grain, accounting for 41 percent of the bulk volume (Figure 37). Plagioclase was the most abundant feldspar, with microcline, albite, perthite, and orthoclase (in descending order of occurrence) also observed. Accurate identification of the extensively altered feldspar grains was, in most instances, difficult. Sedimentary rock fragments, which comprised an average of

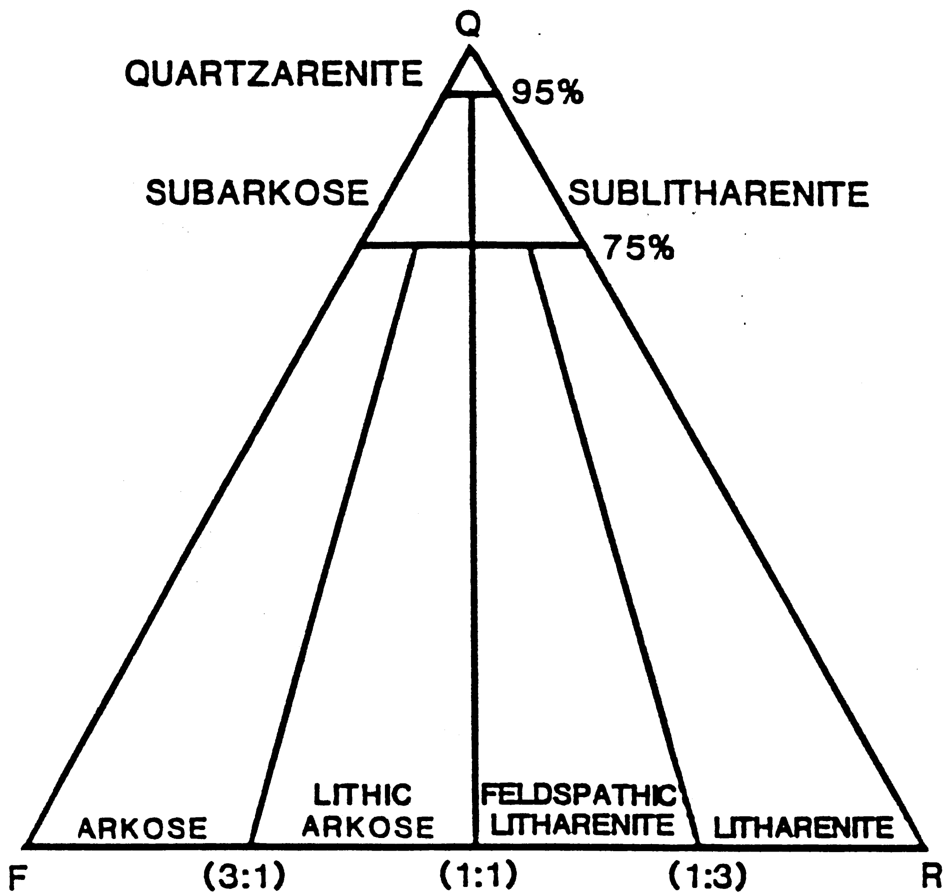
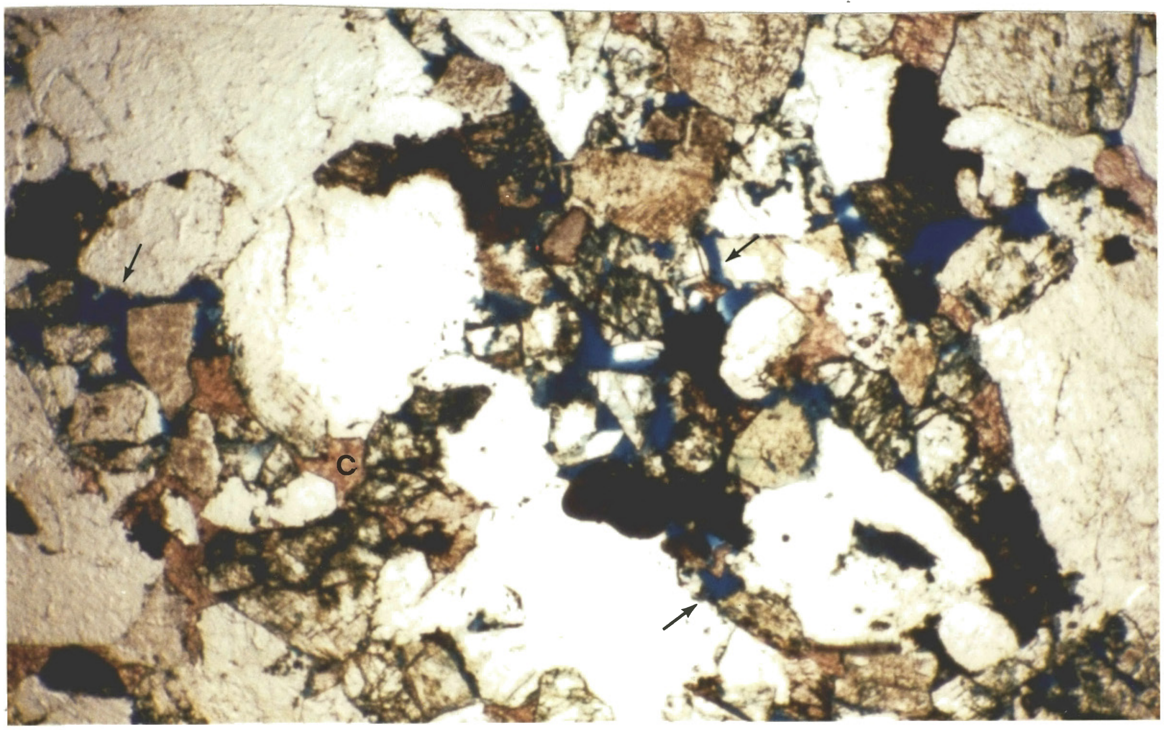
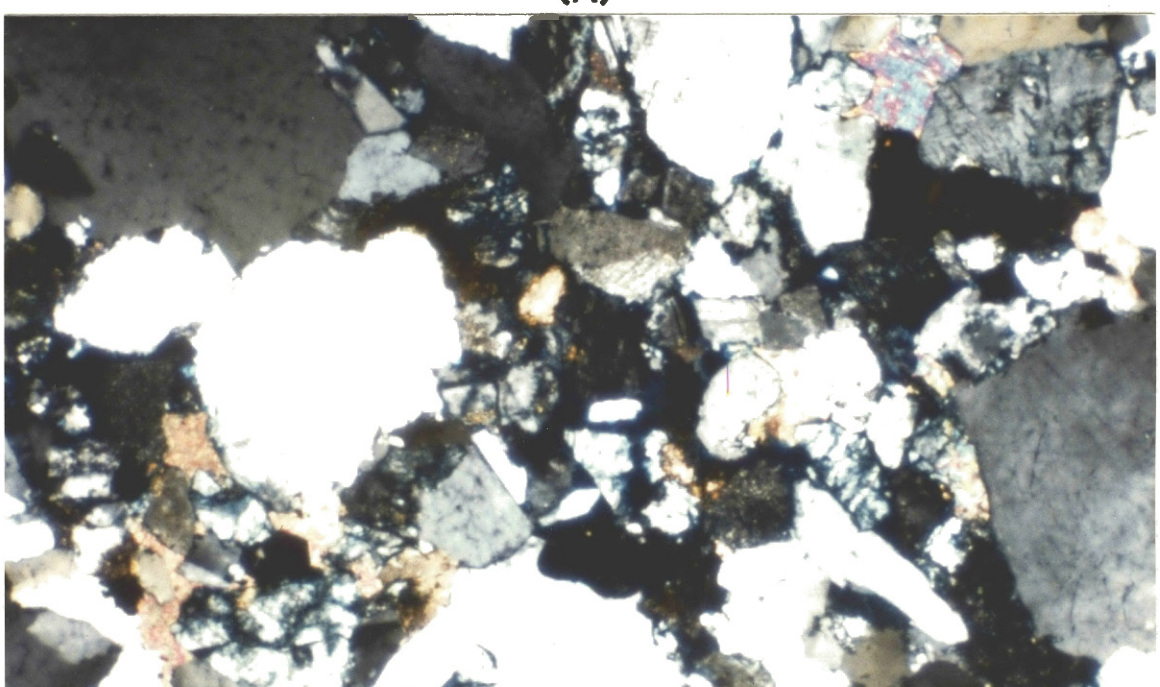


Figure 35. Classification of the Caddo clastics in the Mitchell Energy, J.D. Ortan #4 cores.

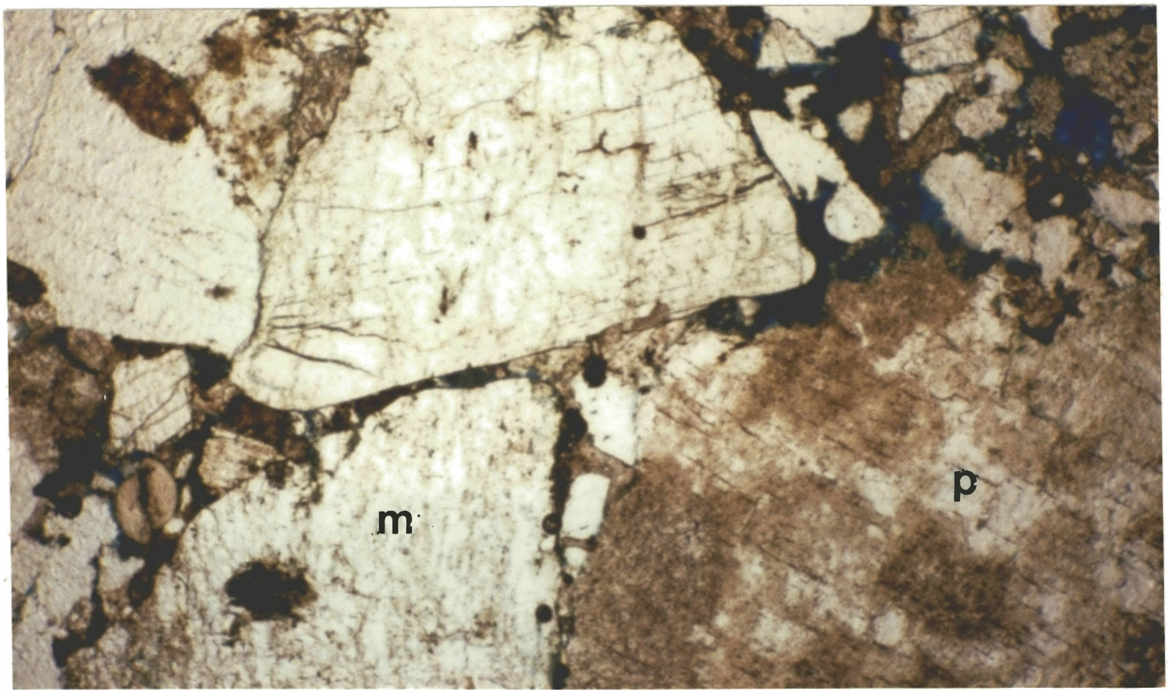


(A)

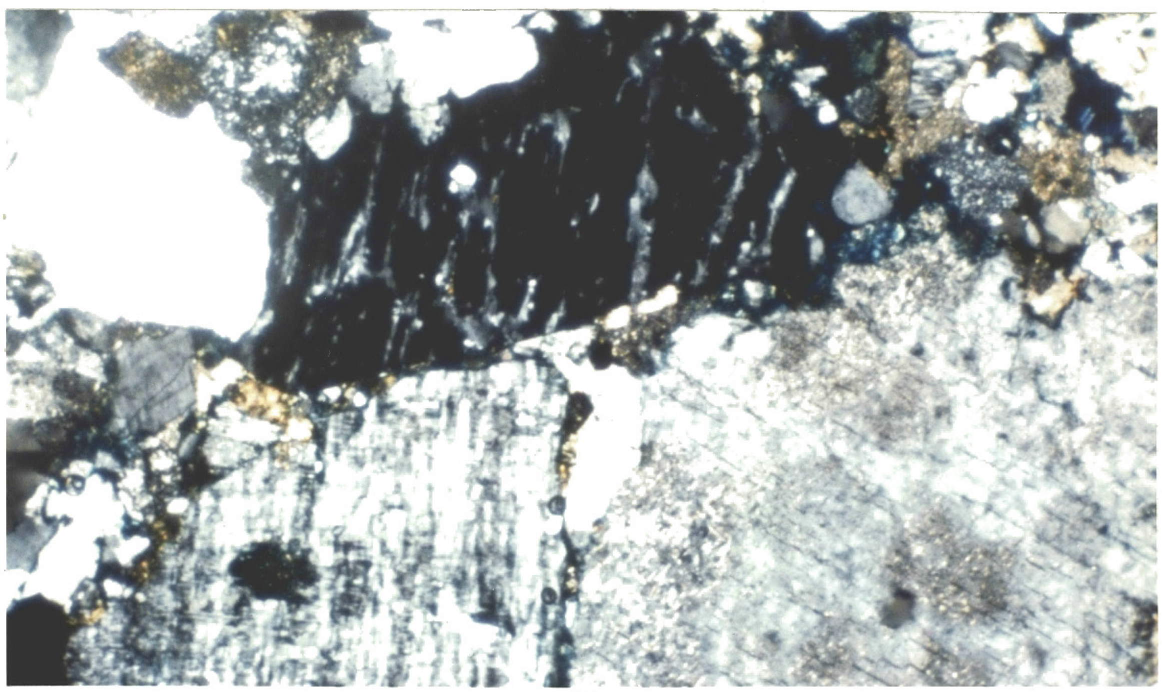


(B)

Figure 36. Photomicrograph of monocrystalline quartz-rich conglomerate with enlarged intergranular porosity (arrow) and calcite cement (c): (A) 20X,PP and (B) XN (J.D. Ortan #4, 6066 feet).



(A)



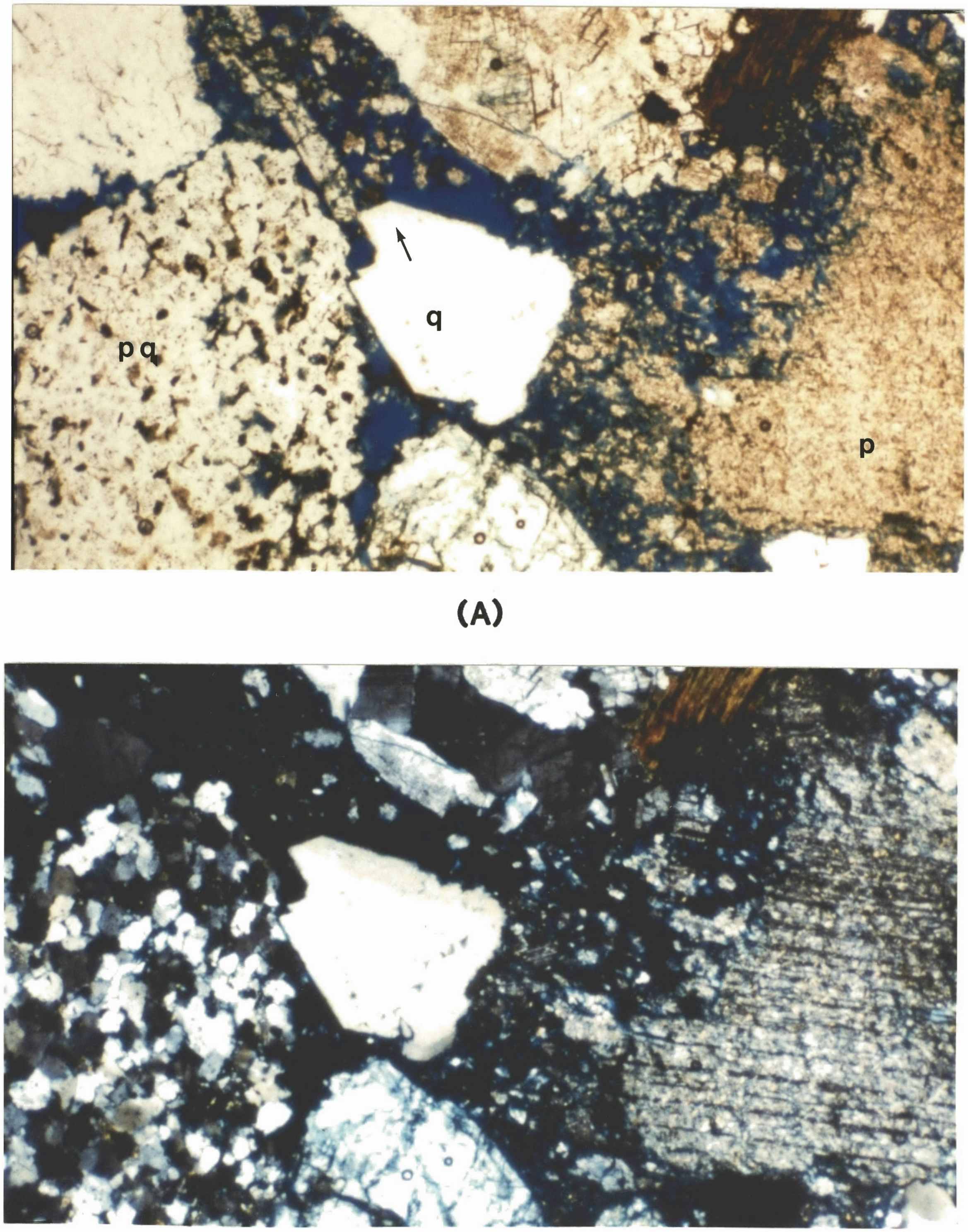
(B)

Figure 37. Photomicrograph of microcline (m) and altered plagioclase (p): (A) 20X,PP and (B)XN (J.D. Ortan #4, 6066 feet).

eight percent, include biomicritic carbonate clasts and chert grains. Trace amounts of metamorphic and igneous rock fragments were also documented. Other detrital grains present were glauconite (trace), fossils (up to three percent) and biotite (trace). Accessory minerals, which were rarely seen more than as a trace, include epidote, zircon and tourmaline. Detrital matrix, where present, was chlorite and ranged from a trace to four percent.

Diagenetic Constituents

The diagenetic constituents present within the Caddo conglomeratic and sandstone intervals are very similar in both the J.D. Ortan #4 core and the A.S.C.C.U. #3-8 core. The following diagenetic constituents and their average percentages are found in the J.D. Ortan #4 core: calcite cement (15 percent), quartz overgrowths (five percent), chalcedonic and microquartz cement (two percent), kaolinite (one percent), pyrite (one percent), "dead oil" residue and carbonaceous insolubles (four percent), and chlorite (one percent). The quartz overgrowths were associated mostly with the coarser grained monocrystalline units, but were observable throughout the core (Figure 38). Calcite cement represents the post-depositional marine influx that occurred in the study area, whereas the authigenic kaolinite is inferred to have been precipitated as a result of the degradation of the framework feldspar grains. The major authigenic clays were pore-filling kaolinite and



(A)

(B)

Figure 38. Photomicrograph of dissolved plagioclase (p), monocrystalline quartz grain (q) with syntaxial overgrowth (arrow), and polycrystalline quartz grain (pq): (A) 20X,PP and (B) XN (J.D. Ortan #4, 6073 feet).

pore-filling/pore-lining chlorite. The principle physical processes are fracturing of the framework grains, pressure solution along grain boundaries, and minor stylotization.

Composition and Classification of the Caddo in the Alvord South Caddo Conglomerate Unit #3-8

Plotted on a Q-F-R diagram without regard for metastable constituents now dissolved or replaced, the Caddo clastics in the A.S.C.C.U. #3-8 core falls within the arkosic subdivision of the Q-F-R triangle (Figure 39). Based upon the common dissolution of the framework feldspar grains, it seems likely the original sediment was an even more feldspar-rich arkose.

Detrital Constituents

For the Alvord South Caddo Conglomerate Unit #3-8 core, the detrital constituents comprise monocrystalline (52 percent) and polycrystalline (48 percent) quartz for an average of 53 percent of the total volume (including porosity). Several of the monocrystalline and a few composite quartz grains appear angular due to syntaxial overgrowths, but are actually subround (Figure 40). The next most common framework grains were feldspars, making up 37 percent of the rock (Figure 41). Again, plagioclase was the common feldspar with microcline, albite, perthite, and orthoclase (in decreasing order of occurrence) also present. Alter-

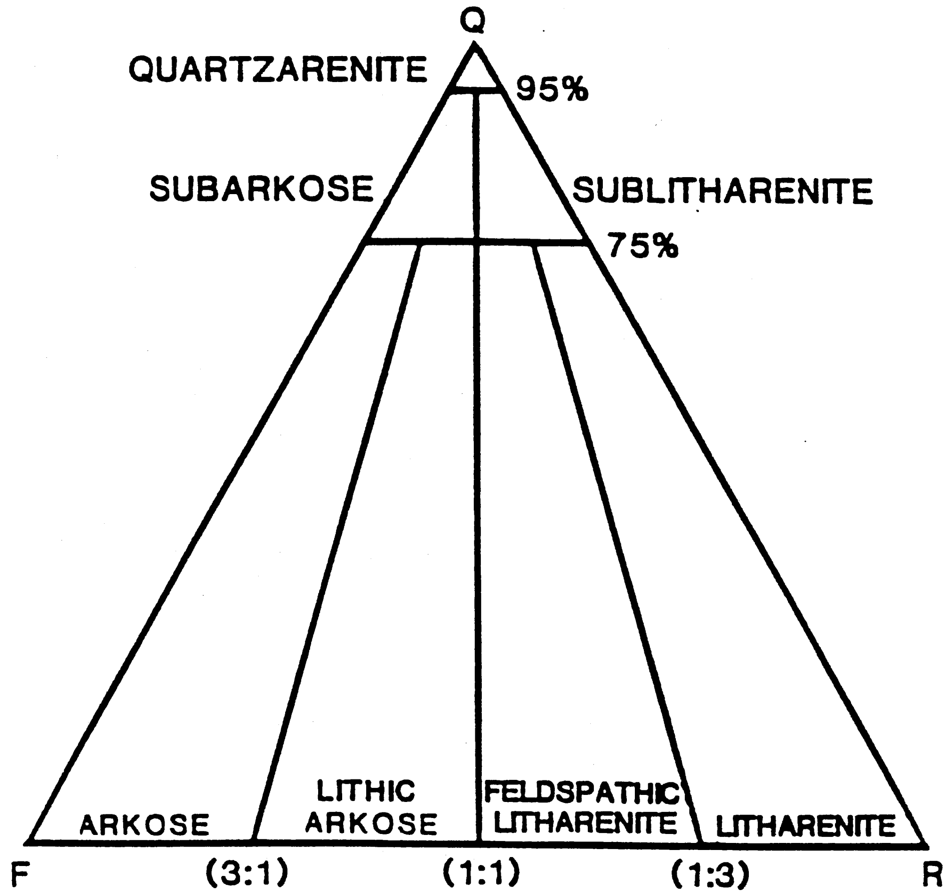


Figure 39. Classification of the Caddo Clastics in the Mitchell Energy, A.S.C.C.U. #3-8 core.

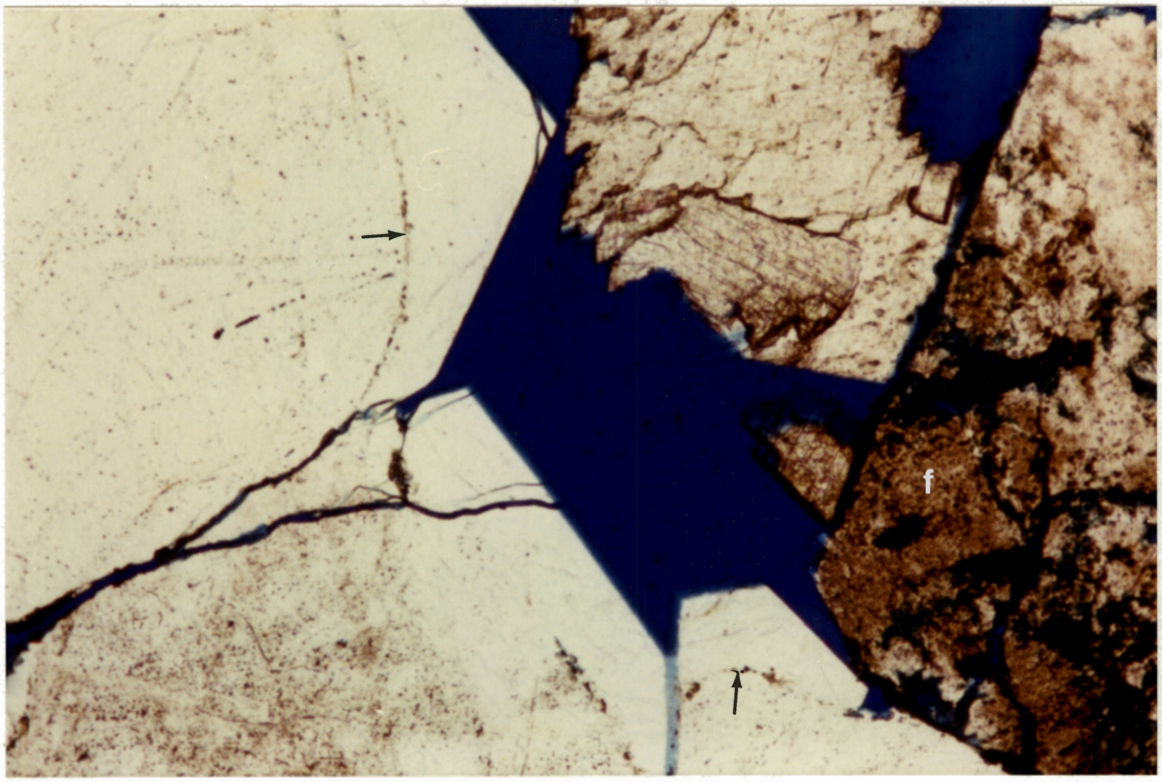
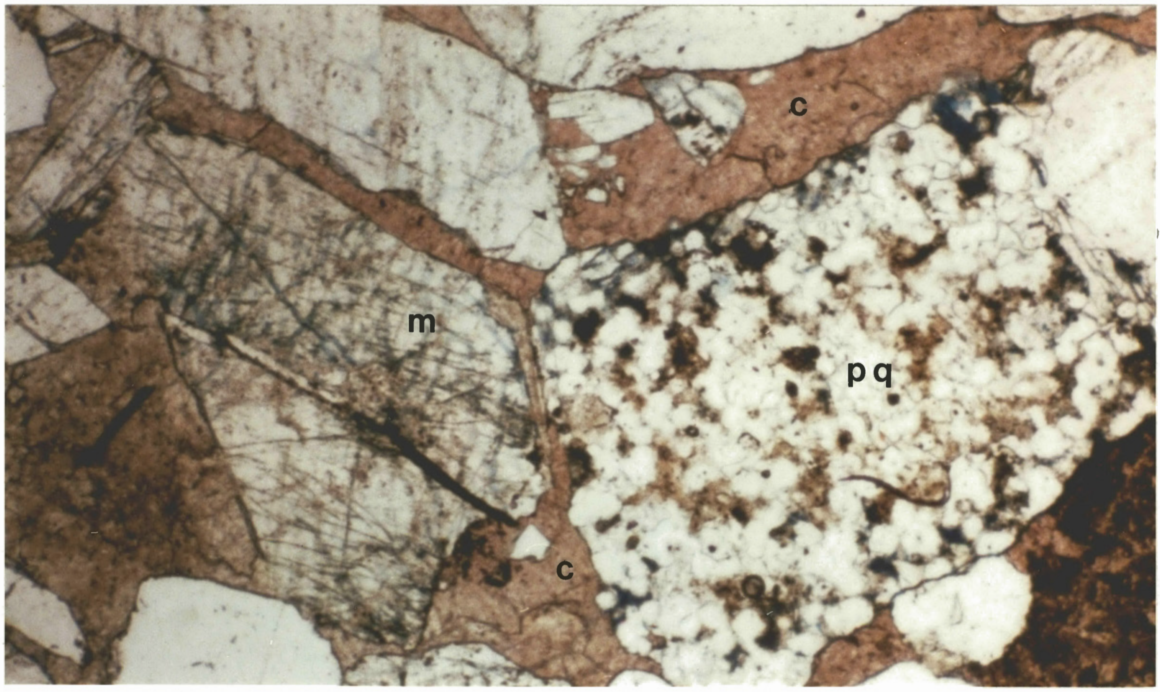
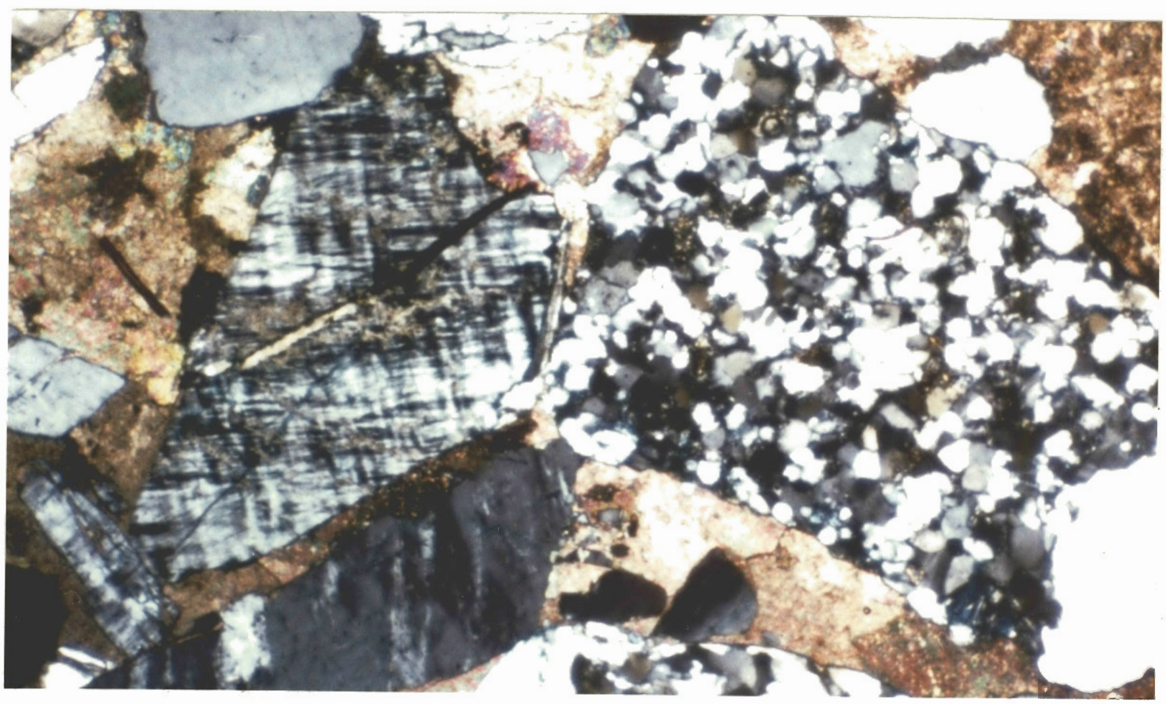


Figure 40. Photomicrograph of degraded feldspar (f), enlarged intergranular porosity (blue), and syntaxial quartz overgrowth (arrow): 40X,PP (A.S.C.C.U. #3-8, 5,752 feet).



(A)



(B)

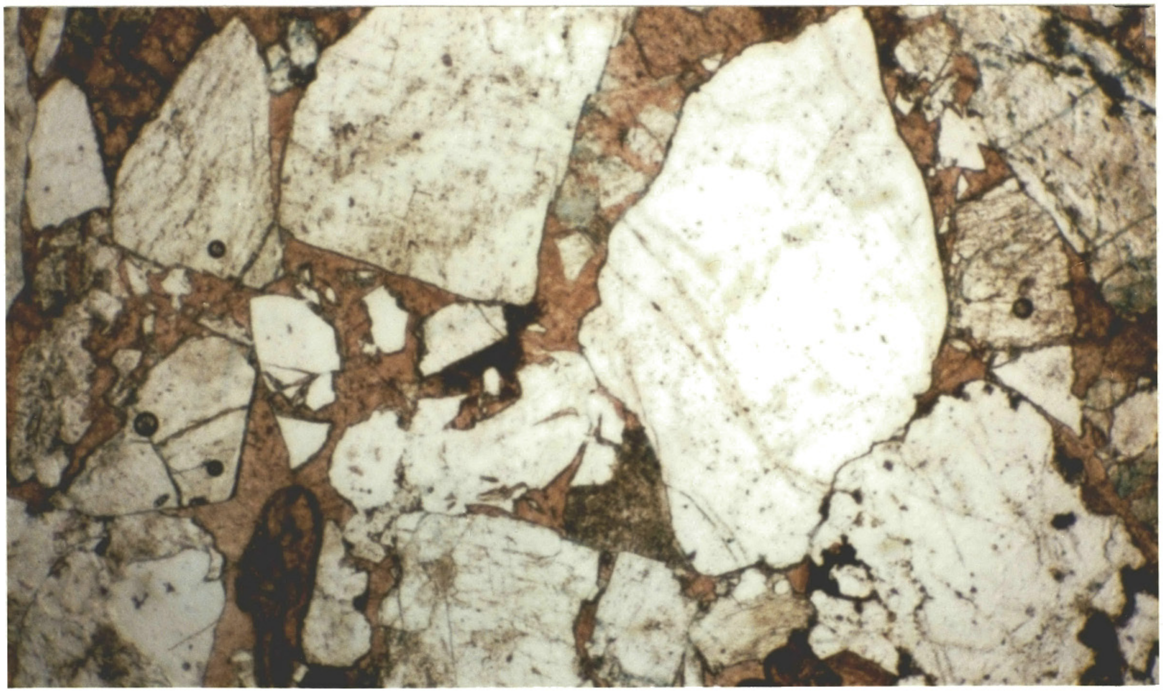
Figure 41. Photomicrograph of a fractured microcline grain (m) and a polycrystalline quartz grain (pq) completely cemented by calcite (c): (A) 20X,PP and (B) XN (A.S.C.C.U. #3-8, 5,780 feet).

ation of the feldspars in this core appears to be more extensive, making some of the feldspar grains very difficult to identify.

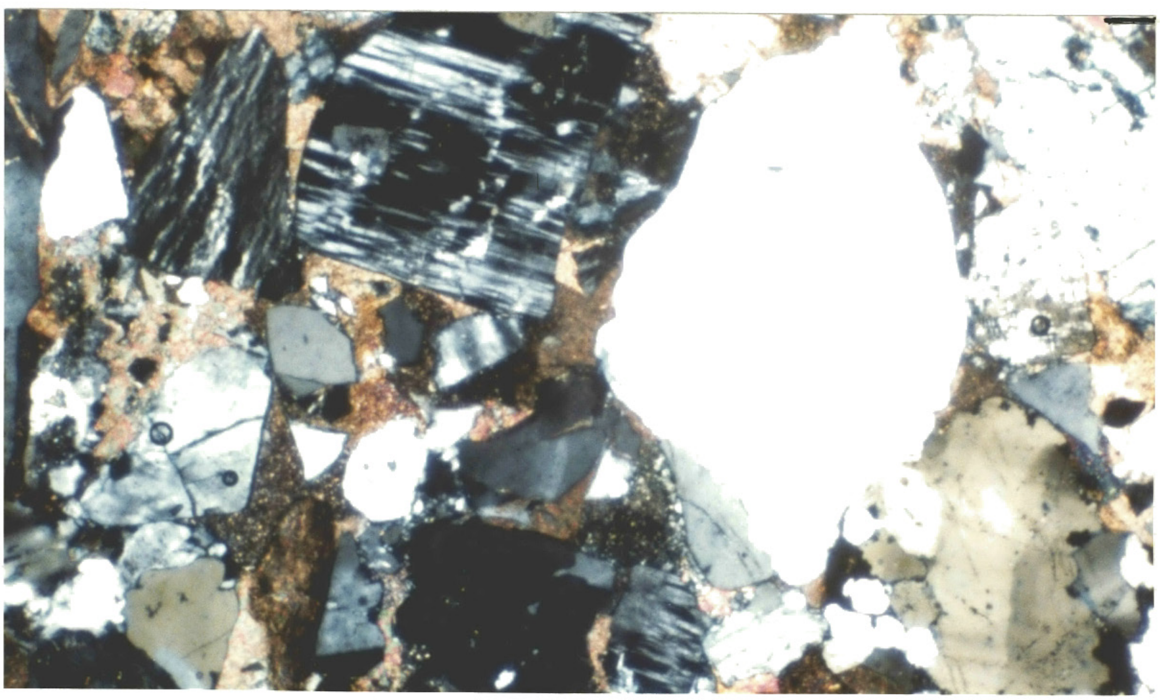
An average composition of 10 percent rock fragments was observed in this core. Primarily sedimentary rock fragments, they include biomicritic carbonate grains and chert clasts. Metamorphic and igneous rock fragments also occurred. Other detrital grains present were glauconite (up to two percent), fossils (trace), and biotite (trace). Accessory minerals include epidote, zircon, and tourmaline. These minerals were observed only in trace amounts.

Diagenetic Constituents

The average percentages of diagenetic constituents for the A.S.C.C.U. #3-8 core are as follows: calcite cement (16 percent), quartz overgrowths (10 percent), chalcedonic and microquartz cements (two percent), kaolinite (two percent), dead oil residue and carbonaceous insolubles (6 percent), and chlorite (one percent). The coarse sand and pebble-sized monocrystalline quartz grains were the common precipitation site for syntaxial quartz overgrowth, but the overgrowths were seen throughout the core. As in the J.D. Ortan #4 core, common calcite cement is the result of marine porewaters percolating through these distal delta front sediments (Figure 42). Dissolution of the feldspar grains provided the diagenetic reaction necessary to precipitate



(A)



(B)

Figure 42. Photomicrograph of quartz and feldspar framework grains completely cemented by calcite: (A) 20X,PP and (B) XN (A.S.C.C.U. #3-8, 5,800 feet).

the authigenic kaolinite. The major authigenic clays were pore-filling kaolinite and pore-filling/pore-lining chlorite. The principle physical processes are fracturing of the framework grains, pressure solution along grain boundaries, and minor styotization (Figure 43).

Porosity Types and Evolution

The porosity in the Caddo conglomerates and coarse sandstones analyzed in this study are restricted to secondary types. The porosity types include: 1) moldic, developed as a result of the dissolution of framework grains; 2) enlarged intergranular, developed through the dissolution of detrital matrix; 3) fracture porosity, a physical component of porosity generation; and 4) microporosity.

The amount of porosity developed in the two studied cores was highly variable, mostly related to the amount of dissolution in each of the samples. The abundance of dissolution (secondary) porosity that was observed is controlled by several factors. The two major factors are the amount of metastables present, and the amount of detrital matrix originally present.

The most common secondary porosity type was moldic, followed by enlarged intergranular. The highest porosities and permeabilities were observed when these two porosity types were prominent. Effective permeability was inhibited by the precipitation of pore-lining and pore-filling authi-

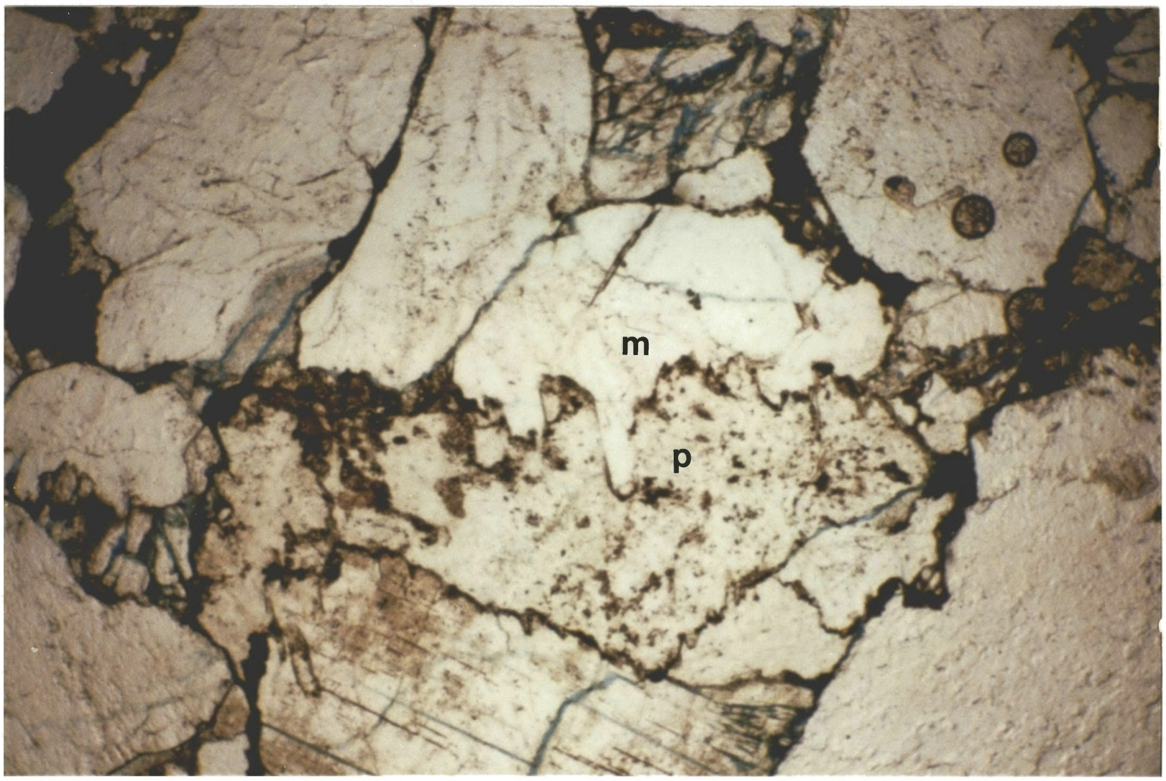


Figure 43. Photomicrograph of monocrystalline quartz grain (q) and plagioclase grain (p) displaying pressure solution: 20X,PP (A.S.C.C.U. #3-8, 5,782 feet).

genic clays. Effective porosity and permeability were also inhibited by the presence of detrital matrix and the development of calcite cementation and syntaxial quartz overgrowths, thereby infilling moldic and intergranular pore space.

Fracture porosity developed as a result of extreme pressure along framework grain boundaries, enough to physically fracture the larger grains. Unfortunately, most available fracture porosity has been infilled by calcite cementation.

Observed microporosity from these two cores is interpreted as incomplete dissolution of a framework grain, or a pre-moldic stage of secondary porosity. As expected, the feldspars display the majority of the occurrence of microporosity.

Conclusions

Several secondary porosity types exist within the Caddo conglomerates and coarse sandstones. These include: 1) moldic; 2) enlarged intergranular; 3) fracture; and 4) microporosity. The presence or absence of the effective porosity and permeability is a result of the three-dimensional relationship of these porosity types. Interconnection of these four secondary porosity types will produce relatively high permeabilities. In low permeability intervals, diagenetic cements and authigenic and detrital clays have partially or completely filled these interconnected zones.

CHAPTER VII

PETROLEUM GEOLOGY OF THE CADDO INTERVAL

Introduction

The Fort Worth Basin of North-Central Texas is an attractive area for oil and gas exploration for a number of reasons:

1. the presence of up to 15 recognized Ordovician through Upper Pennsylvanian pay zones allows for a multiple target exploration strategy;
2. a comparatively high success rate ranging from 10 to 49 percent for wildcat wells;
3. the lower exploration risk, shallow reservoirs that have average depths of 5,900 feet result in relatively low drilling costs (before the recent price collapse, at prices of $4.20 per Mcf, payout was within six months for wells at this depth producing 500 MCF per day);
4. few drilling and completion problems, and;
5. with the mature development of few horizons in limited areas, the late Paleozoic play in the

Fort Worth Basin retains abundant potential for new discoveries, as well as development opportunites.

The first documented gas well of the northern Fort Worth Basin was drilled by Clayco Oil and Pipeline in northern Clay County in October of 1907. This well initiated the deliberate search for natural gas to supply the Dallas-Fort Worth area. The 1,500 foot well flowed 8 to 10 MMCFD from an Upper Pennsylvanian (Cisco) reservoir (Shaw, E.W., 1916). By 1909, 56 additional producing gas wells were drilled in the area and a pipeline was constructed. Eleven years later the Petrolia Field had produced 90 to 105 BCF (Shaw, E.W. and P.L. Ports, 1921) with an estimated 12 to 15 BCF remaining in place.

For the next 50 years, exploration was slow. During this time, oil and gas record keeping was basically unheard of, although area operators had established hydrocarbon production from the Ellenburger (Lower Ordovician) through the Cisco (Upper Pennsylvanian).

The 1970's and early 80's proved to be extremely prolific times for the northern Fort Worth Basin/Bend Arch area, as well as for the petroleum industry overall. In 1975, the region ranked fifth in the Top Geologic Provinces of the Nation in new field wildcats drilled (389 wells) and their associated rates of success (13 percent). These new discoveries include Sow Branch, Necessity, J.J.H., Josh Thompson and six other Strawn (Middle Penn.) fields. Other horizons successfully explored were the Ellenburger (Ordovician) and Chappel (Mississippian). In Clay, Jack, Montague, and Wise Counties, a total of 15 fifteen new field discoveries were made; 13 oil fields (average initial potential, 96 BOPD) and two gas fields (average I.P., 1,788 MCFPD), with an average wildcat depth of 6,014 feet.

For 1976, a total of 1,880 wells were drilled in North-Central Texas. Jack County led the region with six new field discoveries from 31 exploratory wells. In the four county study area, 12 new fields (10 oil, two gas) were discovered at an average drill depth of 5,575 feet. The average initial production rate for the new oil fields was 141 BOPD.

In 1979, the Bend Arch/Fort Worth Basin was ranked sixth in the Top Geological Provinces with 4,392 total wells drilled, 579 of which were new field wildcats. By comparison, the number one ranked Appalachian Basin had 6,462 total wells but only 111 pure exploratory. Forty-three new fields, 41 of which involved Pennsylvanian rocks, had been discovered in Clay, Jack, Montague, and Wise Counties. Twenty-six were oil fields (average I.P., 82 BOPD) and the other 17 were gas. Bennett Production's #2 Palmer of Jack County recorded an initial flow rate of 196 BOPD from less than 5,800 feet.

New field wildcats and new field discoveries were up 20 and 33 percent, respectively, in 1980. Sixty-four new fields (48 oil, 16 gas) were developed from an average depth of 6,171 feet in the four county study area. In Clay County, the Hopkins "B" 1-L, drilled by Consolidated Oil Company, flowed 322 BOPD while the Taylor Operating Co. #1 Hilburn "B" flowed 210 BOPD with associated 200 MCFPD of gas. The most prolific gas discovery in North Texas for 1980 was the American Quasar Petroleum #1 Petro-Lewis-Kusch. The well tested at 15 MMCFPD plus 816 barrels of condensate per day from the Viola (Ordovician) at a depth of 12,198 feet.

Statistically, the petroleum industry enjoyed a record setting pace during the 1980-81 years. The national completion record set in 1980 was surpassed in 1981 with over 92,000 wells completed. Fueled by the removal of crude oil price controls, drilling and completion activity reached new record levels. In North Texas, a total of 3,727 wells were drilled with a 74 percent rate of success. In the four county study area alone, 1,232 wells were drilled, with 178 being pure exploratory wells. Drilled to an average depth of 6,095 feet, 62 new fields were discovered for a wildcat rate of success of 35 percent. At the time, the national new field well success rate was 17.7 percent.

The domestic petroleum industry was clearly in trouble by 1985, but the magnitude of problems in the following years would prove even more severe. A dramatic drop in world oil prices and dwindling markets for natural gas, combined with aggressive merger and takeover activity and continued uncertainty over tax reform, caused U.S. drilling and exploration activity to slide to modern lows (Petroleum Information Corp., Resumé 1986).

Clay, Jack, Montague, and Wise Counties saw no new field discoveries in 1986 or 1987. Despite the unsuccessful wildcats, a total of 125 gas and 394 oil wells were successfully completed during those two years. This is a substantial amount of activity relative to the entire U.S. for a four county area. At present, the Pennsylvanian play in the Fort Worth Basin is far from over, and the potential for future successful exploration and development appears excellent. Operators in the basin believe the Fort Worth "boom" has only been temporarily suspended and will resume when the price of oil and gas climb again.

Historical Development of Caddo Fields

In November of 1942, Sinclair Praire Oil Co. drilled the Eanes Field discovery well, the J.H. Eanes #1, and became the earliest Caddo conglomerate hydrocarbon producer on the northern flank of the Fort Worth Basin. The Eanes Field today has produced over 28 BCF of natural gas from 123 wells. The largest field in the study area (225 wells, 28 MMBO) is the Hildreth Field in central Montague County. The discovery well, the A.R. Dillard #1 J.T. Lawson was drilled in December 1942 and holds the largest initial production rate (1,836 BOPD) for the six Caddo fields. Continental Oil Co. drilled the J.M. Hundley #1 through the

Caddo in east-central Montague County in July of 1944. This well led to the discovery of oil and gas production (962 BOPD and 685 MCFPD, initial potential) and subsequent development of 42 additional wells by area operators. The discovery well for the Anson-Ortan field is recorded as the Anson Petroleum #1 B.L. Foster, drilled in December of 1950. The Anson-Ortan is the smallest of the Caddo fields with 26 wells producing 1.6 MMBO and 3.5 BCF. The Deaver/ Malone/Pryor Complex has produced 20 BCF and 6 MMBO from 51 wells since August, 1954. The discovery well for the unitized field is the Christie, Mitchell and Mitchell #1 J.I. Caswell; it had an initial flow rate of 225 BOPD. The latest Caddo field discovered was the Alvord South Caddo Conglomerate Field in north-central Wise County. Christie, Mitchell, and Mitchell drilled the discovery well Viola Perkins #1 in September of 1961. The 85 well field has produced over 25 MMBO and 16 BCF from the Caddo conglomerate interval.

Distribution of Caddo Fields and Trapping Mechanisms

Exploration has primarily been carried out by independents and smaller exploration companies, and has been concentrated in the shallow,low risk, multiple objective targets on the northern shelf of the Fort Worth Basin and Bend Arch areas. However, there has also been a moderate distribution of exploratory and development wells over the rest of the basin. Large amounts of subsurface information are available in the form of electric logs, driller's (sample) logs, and scout data. Subsurface mapping of the Caddo conglomerates and sandstones, through net sand isoliths and detailed stratigraphic cross sections, accompanied by production histories and hydrocarbon "show" information, can delineate trend geometries and potential offset drill sites.

The two primary factors controlling the entrapment of hydrocarbons within the northern Fort Worth Basin are stratigraphic and diagenetic. The lenticular nature of the Caddo clastics is a result of the lateral shifting of the fluvial braid channels and redistribution of the distal delta sediments. Diagenetic porosity and permeability within the sandstones and conglomerates will vary with the degree of cementation and dissolution. It is interpreted that the hydrocarbons have been trapped as a result of porosity and permeability pinch out within the beds as well as the shale out of lenses within individual coarse clastic sand bodies.

Figure 44 shows the distribution of Caddo fields overlain by the net sandstone isolith map. In short, this figure is a synthesis of the data collected in the course of this study. By superimposing these, an attempt has been made to correlate hydrocarbon production to net sand geometries.

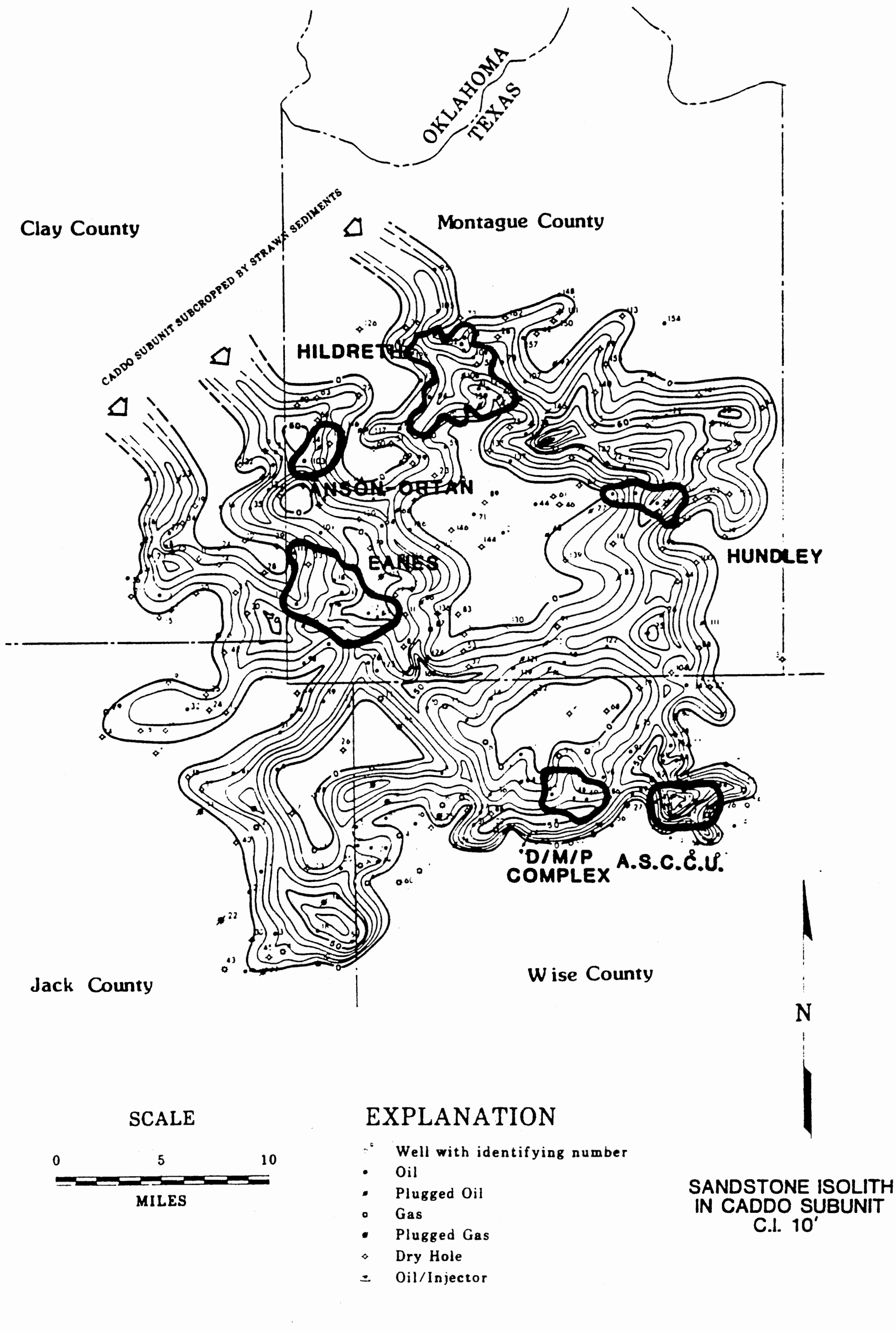


Figure 44. Caddo hydrocarbon fields and their relationship to the net sandstone isolith map.

Production in the study area can be broadly separated into two categories. First, there is production from the fluvial braid channels associated with the middle braid delta plain. These fields, in general, produce from dip-oriented braid channels that are characterized by little quartz overgrowth cementation and a plentiful supply of metastable components for secondary, dissolution porosity development. Proximity to source area provides the feldspar grains necessary, but the fluvial channel environment also produces an abundance of fine-grained detrital matrix and clays. Examples of these fields are the Anson-Ortan, Eanes, Hildreth and Hundley Fields.

Secondly, there are the down-dip (southeasterly) fields of the distal portions of the braid delta complex. These productive fields are interpreted as being associated with the marine-reworked channel mouth bar and delta front sheet sands. These coarse clastic reservoirs are characterized by fewer detrital metastable components that can generate secondary porosity. Degradation of the feldspars through transportation and reworking has removed substantial amounts of these metastables. In addition, the wave-reworking tends to winnow much of the finer-grained detrital matrix and clays. These high primary porosity reservoirs can also display extensive quartz overgrowth where the marine-generated calcite cement is absent. The A.S.C.C.U. Field and the Deaver/Malone/Pryor Complex are examples of these fields.

In summary, the quality of the Caddo clastic reservoirs is dependent on both the primary depositional environment and the post-depositional modifications of the detrial grains, cements, and pore space. The high energy depositional regime of the channel mouth bars and delta front sheet facies of wave-reworked deltas has provided moderate-sorted, clean (little matrix) sands with high porosity. However, it is important to have an ample amount of clays and feldspars present during initial deposition to aid in the development of secondary porosity. Presence of too many metastables, especially detrital clays, can strongly inhibit the development of secondary porosity. Hence, a proper portion of clean, well-sorted sands and metastable grains is desirable for optimal reservoir quality rock.

Production Statistics

Summaries of Caddo conglomerate and sandstone hydrocarbon production by fields in North-Central Texas for 1987 are given in Table I. Table I contains statistics for Texas published in the Annual Production Report by Petroleum Information Corporation.

Hydrocarbon production from the Caddo conglomerates and sandstones is predominantly crude oil with associated natural gas. The largest amounts of crude oil have been produced from the Hildreth Field of central Montague County and the Alvord South Caddo Conglomerate Field of north-central Wise County. The largest produced amounts of natural gas have come from the Eanes Field of southwestern Montague County and the Deaver/Malone/Pryor Complex and the A.S.C.C.U. Field, both located in northern Wise County. The six fields studied all produce from the Caddo interval.

TABLE I

MIDDLE PENNSYLVANIAN (CADDO) PRODUCTION STATISTICS IN NORTH-CENTRAL TEXAS FOR 1987*

Field Name	Oil (bbls)	Gas (Mcf)
Montague County		
Anson-Orton	1,552,930	3,509.176
Eanes	8,223,120	27,604,067
Hildreth	27,796,746	1,061,568
Hundley	5,071,036	107,430
Wise County		
Alvord South Caddo Conglomerate Unit	24,342,446	15,709,308
Deaver/Malone/Pryor Complex	5,636,739	20,422,817
Cumulative production	72,623,017	68,414,366

*Compiled from 1987 Annual Production Report, published by Petroleum Information Corporation.

CHAPTER VIII

SUMMARY AND CONCLUSIONS

The subsurface facies analysis of the distribution, depositional environment, and diagenetic overprint of the Caddo conglomerates and sandstones has yielded evidence upon which several conclusions can be drawn. The conclusions are:

1. The coarse-grained Caddo clastics were deposited on the northern shelf of the Fort Worth Basin in a hybrid high-destructive wave-dominated braid delta environment.
2. The dip-oriented, stacked, braided channels of the medial braid delta plain signify the dominant fluvial process, and are observed in the northwestern study area.
3. The thick accumulation of the distal Caddo braid delta channel mouth bar and delta front sheet sands exhibit a preferred orientation parallel to depositional strike. This configuration is indicative of wave influence.
4. The Caddo conglomerate and sandstone bodies had a plutonic source, interpreted here as the Red River/Electra Arch complex, as evidenced by the

predominance of monocrystalline and polycrystalline quartz and potassium feldspar. There is a lack of substantial amounts of metamorphic and sedimentary rock fragments.

5. Orientation of the mapped sand bodies and their relationship to depositional strike and dip is also indicative of the Red River/Electra Arch source.
6. Based upon petrographic analysis of the Caddo coarse clastics from the two cores studied, original primary porosity has been diminished to irreducible levels. Existing porosity is entirely secondary and results from the dissolution of metastable grains and detrital matrix.
7. The amount and degree of dissolution experienced in the Caddo conglomerates and sandstones is dependent on both the primary depositional setting of the rock unit and on the post-depositional modifications of the detrital grains, cements, and pore space. A proper proportion of clean, well-sorted sands and metastable grains is not necessary, but desired, for optimal reservoir quality rock.
8. Secondary porosity and permeability development within the coarse clastic interval are partially to completely occluded when authigenic quartz overgrowths, calcite, microquartz, kaolinite,

chlorite, and pyrite infills and/or lines the enlarged intergranular and oversized dissolution pores.

9. The entrapment of hydrocarbons within the studied interval is controlled by stratigraphic and diagenetic factors. The lenticularity of the individual Caddo sand bodies and the porosity and permeability pinch out within the beds create the trapping mechanisms for the hydrocarbons.
10. Hydrocarbon exploration began in the early 1900's in the northern Fort Worth Basin and, along with other domestic petroleum provinces, has undergone periods of cyclic activity. At present, the current Fort Worth Basin/Bend Arch play is far from over, as the region still maintains abundant potential for the exploration and development of crude oil and natural gas.

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APPENDIX

WELL INFORMATION AND MAP VALUES

WELL INFORMATION AND MAP VALUES

[a] = Structural Map
[b] = Net Sand Isolith
[c] = Net Sand Percentage
[d] = Net Clastic Ratio
[e] = Interval Isopach

Well Code	Operator	Lease	Well No.	TD (ft)	Map Values SM[a]	NSI[b]	NSP[c]	NCR[d]	II[e]
Clay 1	Bennett Oil Co.	Continental Oil Co.	1	5950	-4632	0	.00	.00	146
Clay 2	Bennett Oil Co.	Cont'l-Newmont	1	6616	-4623	16	.10	.25	168
Clay 3	Bennett Oil Co.	A. Davis	1	6756	-5055	33	.30	.53	111
Clay 4	Bennett Oil Co.	Orton	1	7142	-5026	18	.16	.24	110
Clay 5	Bennett Oil Co.	H.A. Pace	2	6192	-4957	0	.00	.00	90
Clay 6	Bennett Oil Co.	Taylor	1	5950	-4530	0	.00	.00	142
Clay 7	Bennett Oil Co.	L. Wilson	1	6963	-4980	0	.00	.00	146
Clay 8	Best Petroleum	R. Scott	1	6800	-4774	6	.05	.07	110
Clay 9	D.L. Borders	O.J. Orton	1	6900	-5046	26	.19	.27	136
Clay 10	L.T. Burns	A. Farmer	1	6952	-4868	2	.02	.02	86
Clay 11	L.T. Burns	L.M. Wells	1	6050	-4759	14	.08	.11	181
Clay 12	J.R. Caswell	Hickman	1-A	6804	-4718	30	.21	.27	140
Clay 13	Coastal	McFarling	1	6300	-4911	36	.22	.40	163
Clay 14	Continental	S. Donnell	1	7020	-4722	20	.12	.17	166
Clay 15	Crawford Energy	C.R. Gifford	1	6625	-4608	0	.00	.00	108
Clay 16	Dallas Sunbelt Oil & Gas	E.R. Crump	1	6909	-4885	0	.00	.00	130
Clay 17	De Cleva	Carl Mayfield	1	6475	-4822	0	.00	.00	140
Clay 18	De Cleva	West	1	6480	-4717	20	.16	.21	124
Clay 19	Henry Energy	M.E. Davis	1	6906	-4835	8	.05	.07	152
Clay 20	Kinnebrew	Burns-Scott	1	6809	-4644	0	.00	.00	164
Clay 21	Teague Oil & Gas	M. Harlan	1	6570	-4630	0	.00	.00	125
Clay 22	Teague Oil & Gas	Perkins	3	6555	-4683	0	.00	.00	131
Clay 23	Longhorn	T. Flinn	1	6570	-4711	29	.23	.41	126

Well Code	Operator	Lease	Well No.	TD (ft)	Map Values SM[a]	NSI[b]	NSP[c]	NCR[d]	II[e]
Clay 24	Longhorn	D.H. Sanders	1	6900	-4742	0	.00	.00	188
Clay 25	Longhorn	R. Scott	3-H	6672	-4731	21	.17	.21	124
Clay 26	MWJ Corp.	G.L. Welch	2-A	6300	-4991	2	.03	.03	80
Clay 27	Mayco Oil	L.R. Scott	1	6698	-4782	16	.10	.12	156
Clay 28	T.B. Owens	G. Blakely	1	7165	-4858	0	.00	.00	102
Clay 29	Paine Oper.	Monroe	1	7005	-4856	0	.00	.00	92
Clay 30	Richey Expl.	W.C. Gilbert	1	6871	-4710	32	.23	.50	140
Clay 31	Roadrunner	Browning	1-A	6574	-4620	0	.00	.00	158
Clay 32	Stanolind	C.A. Cray	1	7133	-4977	14	.09	.13	160
Clay 33	Star Oil Co.	Miller	2	6680	-4930	26	.16	.21	164
Clay 34	Toltec Oil & Gas	Waggoner	1	6800	-4807	12	.10	.13	122
Clay 35	Tuthill & Barbee	J.L. Patterson	2	6900	-4859	30	.22	.47	136
Clay 36	W.T. Waggoner	J.B. Fuller	1	6533	-4588	0	.00	.00	142
Clay 37	World Production	A. McNatt	1	6175	-4768	16	.10	.12	156
Mont 1	ATAPCO	S.L. Henry	2	6319	-5188	0	.00	.00	50
Mont 2	Ada Oil	Kranow	1	7005	-5012	0	.00	.00	74
Mont 3	Claude Ayres	Chrestman	1	6700	-5449	0	.00	.00	50
Mont 4	Baker-Bailey-Doak	J.H. Jester	1	7950	-5224	28	.25	1.36	110
Mont 5	Bay Petroleum	W.W. Bell	1-B	6705	-5388	46	.29	.72	156
Mont 6	Bay Petroleum	A.B. Ford	1	6990	-4825	10	.09	.14	112
Mont 7	Bennett Oil Co.	Bowie Clinic Hospital	1	6980	-4897	16	.15	.24	108
Mont 8	Bennett Oil Co.	Brashear Bros.	1	7102	-4952	13	.14	.20	92
Mont 9	Bennett Oil Co.	Daube	C-1	6937	-4682	19	.19	.24	102
Mont 10	Bennett Oil Co.	Donald & Donald	3	6910	-4595	12	.11	.15	113
Mont 11	Bennett Oil Co.	Ford	1	6925	-4745	14	.14	.25	104
Mont 12	Bennett Oil Co.	G.C. Green	1	6728	-4716	0	.00	.00	96
Mont 13	Bennett Oil Co.	Haught	1	6982	-4769	11	.11	.16	100
Mont 14	Bennett Oil Co.	B. Henderson	1	6212	-5127	32	.27	.57	118
Mont 15	Bennett Oil Co.	John Hunt	1	6903	-5067	0	.00	.00	50
Mont 16	Bennett Oil Co.	J.B. Irons	1-A	6700	-4707	10	.11	.12	92

Well Code	Operator	Lease	Well No.	TD (ft)	Map Values				
					SM[a]	NSI[b]	NSP[c]	NCR[d]	II[e]
Mont 17	Bennett Oil Co.	Morgan Jones Est.	B-7	6785	-4772	26	.26	.35	100
Mont 18	Bennett Oil Co.	Percy-Jones	2-A	6821	-4830	17	.15	.18	110
Mont 19	Bennett Oil Co.	C.F. Wilson	1	7959	-5437	6	.05	.05	116
Mont 20	Benson Bros.	Riley	1	7203	-4783	4	.03	.06	134
Mont 21	Bettis-Boyle-Stovall	Tate	1	6630	-5289	62	.42	.94	148
Mont 22	Bolin Oil Co.	Gannon-McCall	1	6563	-5341	66	.41	.93	160
Mont 23	Bolin Oil Co.	Giles	1	6948	-5071	31	.53	2.07	58
Mont 24	Bolin Oil Co.	Laird	1	5917	-4691	16	.10	.15	164
Mont 25	Bridwell	J.A. Doak	1	6500	-5103	18	.12	.17	154
Mont 26	L.T. Burns	Brashear	1	8050	-5133	30	.20	.25	152
Mont 27	L.T. Burns	Brown	E-1	6602	-5161	15	.23	.29	66
Mont 28	Butcher & Bundy	Clinging Smith	8	7270	-5255	24	.52	1.14	46
Mont 29	B.G. Byers	Perryman	1	6532	-5229	66	.46	1.74	144
Mont 30	J.R. Caswell	F.W. Slayden	1	6870	-5167	18	.25	.33	73
Mont 31	Caswell & Boatwright	Hichman	4	6785	-4707	22	.15	.18	142
Mont 32	Caswell Bros.	Whitaker	1	6905	-4811	36	.21	.47	168
Mont 33	E.B. Clark	Deweber	1	6957	-4814	24	.21	.30	114
Mont 34	Coastline	Hundley	C-3	8000	-5232	46	.40	1.00	114
Mont 35	Conoco	W.D. Hardison	3	8000	-5265	32	.34	.70	94
Mont 36	Cont'l. & Omdhunde	J.W. Corpening	1	6628	-5302	15	.27	.60	55
Mont 37	Cont'l. & Sinclair	Golightly	3	6550	-5214	59	.53	2.19	122
Mont 38	Continental	M.G. Catter	2	6618	-5329	30	.31	.56	98
Mont 39	Continental	Fry	1	7930	-5308	36	.28	.51	130
Mont 40	Continental	H.C. Gadberry	2	6501	-5152	18	.18	.45	98
Mont 41	Continental	Hildreth	1	7189	-5126	16	.21	.36	78
Mont 42	Continental	Latham	3	6570	-4347	0	.00	.00	30
Mont 43	Continental	H.A. Richardson	1	6570	-5000	0	.00	.00	54
Mont 44	Continental	Scheller	1	7270	-5003	0	.00	.00	60

Well Code	Operator	Lease	Well No.	TD (ft)	Map Values SM[a]	NSI[b]	NSP[c]	NCR[d]	II[e]
Mont 45	Continental	Walthall	1	7919	-5286	104	.84	13.0	124
Mont 46	Continental	J.B. Williams	1	7386	-5029	0	.00	.00	72
Mont 47	Continental	J.F. Yowell	1	7101	-5170	18	.38	.60	48
Mont 48	Corpening	Boedeker-Clark	2	7212	-5020	26	.29	.59	90
Mont 49	Cox Drilling	Beck	1	6730	-5495	28	.47	.86	60
Mont 50	Credo Oil & Gas	Terry Crozier	1	7228	-5149	36	.45	1.50	80
Mont 51	Dallas Prod.	Gilmore	5	6900	-5185	0	.00	.00	59
Mont 52	DeCleva	Coulson	1	7285	-5264	56	.56	3.11	100
Mont 53	Delfern	S.H. Hipp	1	7100	-4779	18	.16	.29	114
Mont 54	Devlp. Drlgs. of Dallas Inc.	Arlington-Steadman	1	7069	-5492	48	.31	.52	154
Mont 55	Engle & Douglas	O.W. Embry	3	7000	-5732	52	.42	.98	124
Mont 56	G. Engle	Brown	1	7305	-5642	36	.27	.47	132
Mont 57	Enterprises Unltd.	R. Raymond	1	6895	-5514	58	.43	1.38	136
Mont 58	Felderhoff	J.E. Elrod	1	6233	-4971	26	.17	.28	152
Mont 59	Felderhoff	Hall	1	7075	-5129	12	.09	.20	134
Mont 60	Fryer & Hanson	Heath	1	6715	-5078	0	.00	.00	62
Mont 61	Gadsco	Spillman	1	7700	-5023	0	.00	.00	52
Mont 62	E.P. Gallagher	L. Roberts	1	7200	-5286	0	.00	.00	118
Mont 63	Goldstar	Hudspeth Heirs	1	6270	-5138	19	.19	.31	102
Mont 64	Grace & Phillips	Velma Moore	3	6713	-4950	16	.16	.26	101
Mont 65	Jack Grace	Golden Unit	1	7263	-4980	0	.00	.00	54
Mont 66	Jack Grace	Rucker	2	6228	-5051	45	.38	.69	120
Mont 67	Jack Grace	Seibold	1	9100	-5633	14	.19	.35	74
Mont 68	Jack Grace	Skinner-Jackson	2	6750	-4997	10	.13	.21	77
Mont 69	Grace Petroleum	Coffield	1	6883	-5126	0	.00	.00	78
Mont 70	Great Western Op.	Parker	2	6950	-5120	19	.30	.44	64
Mont 71	W. Guest	M. Griggs	1	7265	-4968	0	.00	.00	62
Mont 72	Gulf	A.B. Hall	1	7582	-4896	28	.18	.29	156
Mont 73	Jim C. Heydrich	Hodges	1	7010	-5231	0	.00	.00	56

Well Code	Operator	Lease	Well No.	TD (ft)	Map Values				
					SM[a]	NSI[b]	NSP[c]	NCR[d]	II[e]
Mont 74	Higgs & Cunningham	Shoemaker	1	7135	-4942	12	.09	.12	140
Mont 75	Horton Oil	M.S. Roberts	1-H	7850	-5325	24	.31	.52	78
Mont 76	Humble Oil	Percy Jones	1	5970	-4651	38	.30	.50	128
Mont 77	Hundahl	Proctor	1	6415	-5115	6	.07	.17	84
Mont 78	Lafton Oil	Minor	1	7234	-5196	34	.29	.57	84
Mont 79	Longhorn	J.K. Brite	2	6885	-4915	0	.00	.00	86
Mont 80	Longhorn	Coffield	1	5900	-4730	0	.00	.00	114
Mont 81	Longhorn	Moore Estate	1	6781	-4690	16	.14	.19	112
Mont 82	Longhorn	Williamson	1	6848	-4673	14	.10	.23	138
Mont 83	McCommons	C.L. Belcher	1	6844	-4775	0	.00	.00	111
Mont 84	McCommons	Boyd Heirs	1	6917	-5208	46	.35	.58	130
Mont 85	McCommons	Donald	1	6251	-5094	20	.18	.38	112
Mont 86	McCommons	Fred Ford	2	6710	-4772	16	.16	.22	98
Mont 87	McCommons	Bula Mae Gandy	1	5950	-4748	17	.16	.33	106
Mont 88	McCommons	Glen Lynch	1	6422	-5309	20	.20	.29	98
Mont 89	McCommons	Roberts	1-A	7320	-4992	0	.00	.00	60
Mont 90	McCommons	Threadgill	1	6700	-5112	24	.23	.37	104
Mont 91	Gene McCutchin	J.W. Harbour	1	6135	-4902	24	.15	.23	162
Mont 92	Madison Oil	Jameson	1	7500	-5246	0	.00	.00	68
Mont 93	J.C. Man Jr.	Perryman		7085	-5345	0	.00	.00	132
Mont 94	Marshall Pipe & Supply	Ida Matney	1	6400	-5171	26	.42	1.00	66
Mont 95	Marshall Pipe & Supply	T.P. Skinner	1	6858	-5400	17	.19	.29	88
Mont 96	Tom Medders	Reynold	1	6599	-5196	12	.09	.13	132
Mont 97	Tom Medders	Wheeler	1	6836	-4988	4	.07	.10	58
Mont 98	Miami Prod.	Donand & Donald	3	6200	-4634	14	.11	.14	128
Mont 99	Miami Prod.	Van Vacter	2	6927	-5136	0	.00	.00	62
Mont 100	Mid-Continent	L. Orrell	1	7900	-5253	18	.14	.16	132
Mont 101	Mitchell Energy	Clark	1	7205	-4892	13	.15	.25	88

Well Code	Operator	Lease	Well No.	TD (ft)	Map Values				
					SM[a]	NSI[b]	NSP[c]	NCR[d]	II[e]
Mont 102	Mitchell Energy	Littell	1	7306	-5549	16	.13	.20	120
Mont 103	Mitchell Energy	J.D. Orton	2	6285	-5037	42	.40	.95	104
Mont 104	Mitchell Energy	C. Yates	1	8177	-5077	16	.12	.27	132
Mont 105	Mobil	Hinds-Clark	1	6820	-5130	31	.37	1.07	84
Mont 106	W.A. Moncrief	Lewis	1	7250	-4999	0	.00	.00	80
Mont 107	Montague Res.	Chandler	1	6820	-5228	16	.19	.50	84
Mont 108	Murdick	Benton-Moore	1	6208	-5126	30	.43	5.0	70
Mont 109	Murdick	I.P. Matney	1	6230	-5166	34	.43	2.13	80
Mont 110	National Pet. Co.	Jackson	1	7067	-5717	40	.35	.77	114
Mont 111	National Pet. Co.	H.F. Sledge	1	6551	-5325	0	.00	.00	104
Mont 112	Oil Creek	Barren	1	7200	-4905	23	.31	.47	74
Mont 113	W.B. Omohundro	Fenoglio	1	6618	-5449	4	.09	.18	46
Mont 114	Orm	C. Orm	1	6947	-4860	10	.12	.13	86
Mont 115	Osage Oil	Brooks	1	7273	-4773	0	.00	.00	72
Mont 116	Perkins	Turner	A-1	6800	-5097	0	.00	.00	80
Mont 117	Perkins	Wales	2	7286	-5111	18	.20	.36	92
Mont 118	Phillips Pet.	Blackmon	A-1	6793	-4998	10	.10	.16	98
Mont 119	Phillips Pet.	Glass	A-1	7300	-4830	28	.15	.24	182
Mont 120	Phillips Pet.	Jarrell	A-1	6965	-5005	12	.10	.15	115
Mont 121	Phillips Pet.	Rave	1	6150	-4819	37	.30	.46	184
Mont 122	Phillips Pet.	Rose	1-A	7870	-5018	30	.20	.29	148
Mont 123	Resources Investment	C.A. Willis	1	9866	-5554	36	.32	.51	112
Mont 124	Dave Rhone	J.W. Hogue	A-1	5867	-4646	10	.07	.12	144
Mont 125	Sabre	Hines-Clark	1	6900	-4617	48	.29	.62	164
Mont 126	Shillelaugh	Leeper	1	6494	-5289	0	.00	.00	26
Mont 127	Sinclair-Prairie	Middleton	2	7194	-5089	26	.23	.57	112
Mont 128	J.E. Skidmore	Tompkins	1	8531	-5528	49	.37	1.04	132
Mont 129	J.E. Skidmore	O. Yowell	1	6448	-5194	14	.20	.37	70
Mont 130	T.M. Slagle	K.E. Webb	1	7305	-4873	0	.00	.00	105

Well Code	Operator	Lease	Well No.	TD (ft)	Map Values				
					SM[a]	NSI[b]	NSP[c]	NCR[d]	II[e]
Mont 131	Sohio-Ugland	Littell	1	7125	-5436	26	.25	.36	106
Mont 132	C.D. Speed	Brown	1	7208	-5083	14	.28	.64	50
Mont 133	Stanolind	W.F. Gossett	1	7100	-4662	20	.14	.14	142
Mont 134	Star Oil	J.A. Brite	2	6690	-5025	32	.25	.89	128
Mont 135	Star Oil	L. Garrington	1	7074	-5249	20	.20	.29	98
Mont 136	Star Oil	Goss	1	7115	-4762	8	.07	.13	112
Mont 137	Star Oil	L.A. Johnson	1	6918	-5272	12	.16	.21	77
Mont 138	Star Oil	Elta Matney	1	6625	-5189	7	.09	.14	78
Mont 139	Star Oil	G.J. Morris	1	7190	-5040	10	.13	.24	78
Mont 140	L.A. Stemmons	Corado	1	6815	-5519	38	.44	1.58	86
Mont 141	Sunray Mid Cont.	Redman	1	7117	-5736	18	.18	.28	100
Mont 142	Sunray	Zahn Unit	1	6588	-5319	48	.28	.75	170
Mont 143	Ben Taylor	Parr Estate	1-A	7160	-5302	6	.06	.09	94
Mont 144	Texaco	E. Egenbacher	1	6900	-4977	0	.00	.00	84
Mont 145	Texaco	A.H. Fenoglio	1	6830	-5350	37	.28	.79	134
Mont 146	Texaco	Hoeldtke-Young	1	7434	-4979	0	.00	.00	86
Mont 147	Texaco	J. Jackson	1	6420	-5137	24	.30	.63	80
Mont 148	Texaco	C.S. McCall	1	7320	-5397	0	.00	.00	30
Mont 149	Tyron Oil & Gas	Foster	1	7025	-5108	16	.18	.27	88
Mont 150	Vaughn Pet.	H. Goodspeed	1	6567	-5414	6	.15	.30	40
Mont 151	Vaughn Pet.	McCall	1	6670	-5451	8	.18	.31	44
Mont 152	Walsh & Watts	Bonnie	2	6200	-5131	14	.25	.70	56
Mont 153	Walsh & Watts	Brown	C-1	6225	-5183	20	.24	.42	82
Mont 154	Walsh & Watts	Collier	4	8085	-5663	0	.00	.00	16
Mont 155	Walsh & Watts	A. Fenoglio	1-C	6850	-5514	10	.16	.19	62
Mont 156	Walsh & Watts	Hankins	2	6925	-4956	7	.09	.16	81
Mont 157	Walsh & Watts	Wood	1-B	7300	-5261	0	.00	.00	68
Mont 158	Whitaker	Boedecker	2	6485	-5171	24	.19	.34	126
Mont 159	Whitaker	Gadberry	3	6256	-4990	26			
Mont 160	Wolsey	Laird Estate	1	6888	-4697	55	.36	.76	170

Well Code	Operator	Lease	Well No.	TD (ft)	Map Values				
					SM[a]	NSI[b]	NSP[c]	NCR[d]	II[e]
Mont 161	Wrather	Meadow	1	7010	-5615	8	.14	.16	58
Mont 162	Youngblood-Foree	Quillen	1	7261	-5333	7	.13	.18	54
Jack 1	Akers & Fultz	Cherryhomes	D-7	5811	-4193	41	.39	.75	104
Jack 2	Akers & Fultz	Cherryhomes	14F	5762	-4203	18	.16	.60	116
Jack 3	Akers & Fultz	J. Durham	4	5650	-3950	13	.12	.16	112
Jack 4	Akers & Fultz	Durham	5	5794	-3892	14	.08	.10	170
Jack 5	Amco Energy	Huffines	1-A	5830	-3972	62	.36	.59	170
Jack 6	Amer. Drilling Corp.	Cherryhomes	8	5850	-4413	0	.00	.00	150
Jack 7	M.E. Andrews Ltd. & Amer. Drlg. Co.	Cherryhomes	1	5860	-4315	0	.00	.00	186
Jack 8	Bennett Oil Co.	B. Zuber	1	6455	-4325	8	.07	.08	112
Jack 9	Bennett Oil Co.	B. Zuber	2	5964	-4301	0	.00	.00	95
Jack 10	Blalock & Walter	W. Laird	1	5602	-3875	0	.00	.00	150
Jack 11	Bridwell	M. Kirk	1	5910	-4207	0	.00	.00	156
Jack 12	Bridwell	W.O. Long	1	6720	-4384	10	.06	.07	166
Jack 13	B.M. Burns	R. Lipton	1	5790	-4190	0	.00	.00	100
Jack 14	Carter Energy	Boyd	1	5700	-4291	0	.00	.00	105
Jack 15	Carter Energy	Deaton Trust	1	5850	-4345	8	.06	.07	134
Jack 16	H.A. Chapman	Cherryhomes	1	5716	-3818	0	.00	.00	122
Jack 17	Circle Seven	Ellis	1	5830	-4152	16	.14	.20	111
Jack 18	Cities Service	Kempner	2	5829	-3971	58	.34	.57	170
Jack 19	Cleary Pet. Corp.	J.M. Bonner	1	6550	-4492	0	.00	.00	96
Jack 20	Cox Drilling	C.R. Schneider	1	5681	-4004	0	.00	.00	102
Jack 21	Dillard & Humble	M. Mansfield	D-1	6838	-4541	10	.07	.26	134
Jack 22	Gage Energy	W.B. Stephens	1A	5589	-3881	0	.00	.00	120
Jack 23	Jack Grace	L. Chapman	1	5458	-4175	0	.09	.16	102
Jack 24	Great West Oper.	L. Kirk	2	6000	-4442	12	.09	.11	128
Jack 25	Hammon	Gilliland	1	6664	-4515	0	.00	.00	138
Jack 26	J.W. Harris Drlg.	Harris-Davenport	1	5925	-4527	0	.00	.00	146

Well Code	Operator	Lease	Well No.	TD (ft)	Map Values				
					SM[a]	NSI[b]	NSP[c]	NCR[d]	II[e]
Jack 27	E.C. Johnston	S.B. Flint	2	6754	-4541	0	.00	.00	140
Jack 28	Ladd Pet.	E. Collier	2	6000	-4334	0	.00	.00	149
Jack 29	League Oil & Gas	Boyd	1	6365	-4347	0	.00	.00	94
Jack 30	Lone Star	M. Durham	1	5750	-3942	0	.00	.00	112
Jack 31	Longhorn	E.M. Craft	7-B	6823	-4458	7	.09	.11	80
Jack 32	Longhorn	E.W. Starke	1	6652	-4488	12	.08	.10	148
Jack 33	Mitchell Energy	Durham	3	6200	-3825	0	.00	.00	148
Jack 34	Mitchell Energy	R.R. Gilley	6	6770	-4538	0	.00	.00	84
Jack 35	Mitchell Energy	R.L. Morris	B-4	6718	-4145	22	.22	.39	98
Jack 36	Moncrief & Sons	H.H. McConnell	2	6705	-4309	22	.15	.19	150
Jack 37	Nunley & Hale	Kirk	1	5930	-4309	22	.15	.19	150
Jack 38	Nunley & Hale	E.W. Lewis	1	5821	-4304	9	.09	.10	102
Jack 39	Ranger	W. Cox	2	6940	-4515	32	.23	.52	142
Jack 40	Richey Expl.	J.H. Faires	1	6000	-4179	0	.00	.00	118
Jack 41	Riddle & Gottlieb	J.D. Craft	5	6225	-4313	18	.14	.26	132
Jack 42	Roberts & Hammack	Thompson	1	5990	-4503	12	.09	.11	128
Jack 43	R.H. Seigfried	T.H. Cherryhomes	1-X	5562	-3761	0	.00	.00	140
Jack 44	Texaco	J.W. Jolly	1	5990	-4609	0	.00	.00	68
Jack 45	Youngblood-Foree	T.H. Cherryhomes	1	6738	-3836	16	.12	.17	138
Wise 1	ATAPCO	A.S.C.C.U. E.U.	4-7	6100	-4761	70	.29	.56	240
Wise 2	ATAPCO	A.S.C.C.U. E.U.	19-6	6011	-4665	42	.18	.29	270
Wise 3	ATAPCO	C.D. Luther	1	5493	-4375	39	.25	.58	156
Wise 4	American Drlg.	Appling	1	5836	-4295	0	.00	.00	186
Wise 5	3rd M.E. Andrews & Amer. Drlg. Co.	Tom Davis	2	5750	-4275	6	.04	.10	166
Wise 6	Armour	Rhyne Unit	1	5900	-4438	18	.08	.43	216
Wise 7	Bennett Oil Co.	C. Smith	1	6000	-4654	19	.12	.31	158
Wise 8	Birdwell	R.W. Henson	1	5946	-4502	44	.27	.88	166
Wise 9	A.A. Britton	B.O. Collins	1	6218	-4886	0	.00	.00	162
Wise 10	Burk Royalty	McGuire	1	5820	-4337	0	.00	.00	230

Well Code	Operator	Lease	Well No.	TD (ft)	Map Values				
					SM[a]	NSI[b]	NSP[c]	NCR[d]	II[e]
Wise 11	L.T. Burns	Collier	1	6817	-4550	19	.09	.17	203
Wise 12	Caswell Bros.	Pan Amer. Lite	1	7072	-4543	0	.00	.00	182
Wise 13	Cities Service	Davenport	2-B	5952	-4201	0	.00	.00	116
Wise 14	Cleary Pet.	Carl Berg	2	5960	-4802	20	.11	.26	184
Wise 15	Crawford Energy	Jack B. Cox	1	6046	-4428	0	.00	.00	206
Wise 16	Crawford Energy	W.B. McGuire	1	5850	-4354	0	.00	.00	216
Wise 17	Crawford Energy	Marlett	1	6044	-4410	29	.13	.57	220
Wise 18	Crestmont	J. Dickie	1	6000	-4415	13	.07	.22	197
Wise 19	Dallas Prod.	Covington	A-1	6417	-5031	10	.07	.19	134
Wise 20	De Cleva	Road	1	5995	-4357	47	.21	.96	225
Wise 21	Federal Energy Dev.	Donald	1	5904	-4540	0	.00	.00	152
Wise 22	C.L. Gage Jr.	Ryan	1	8045	-5157	10	.07	.15	134
Wise 23	Gateway	A.N. Pace	1	6050	-4756	7	.04	.35	190
Wise 24	E.B. Germany & Sons	Traister	1-A	5715	-4305	19	.17	.36	110
Wise 25	Jack Grace	Carl Waston	1	5863	-4390	23	.10	.40	220
Wise 26	Guernsey	C.A. Waller	1	6451	-4754	0	.00	.00	184
Wise 27	Gulf Oil	D.C. Riley	B-1	6090	-4618	0	.00	.00	246
Wise 28	Ruben B. Knight	J.R. Singleton	1	6444	-4934	0	.00	.00	242
Wise 29	Ladd Pet.	R.L. Morris	4-C	6196	-4235	12	.08	.18	160
Wise 30	Ladd Pet.	R.L. Morris	5-C	6200	-4135	26	.18	.41	148
Wise 31	Ladd Pet.	R.L. Morris	13C	5829	-4238	11	.08	.14	134
Wise 32	Liberty Oil & Gas	G. Fairchild	1	6150	-4859	0	.00	.00	172
Wise 33	Liberty Oil & Gas	B.M. Nivens	1	5885	-4705	18	.09	.60	196
Wise 34	Loch & Tracy Eng.	Lynch	1	8060	-5097	24	.18	.38	132
Wise 35	McCommons	M.S. Rogers	1-A	6950	-4574	20	.11	.22	184
Wise 36	Maynard	W.C. Hodge	1	5850	-4509	20	.09	.48	214
Wise 37	Mitchell Energy	A.S.C.C.U. W.U.	3-2	7765	-4661	80	.29	.51	280
Wise 38	Mitchell Energy	A.S.C.C.U. W.U.	5-10	6775	-4708	94	.40	.98	234
Wise 39	Mitchell Energy	A.S.C.C.U. W.U.	8-7	5925	-4586	88	.32	.65	276
Wise 40	Mitchell Energy	A.S.C.C.U. W.U.	9-2	7600	-4647	78	.28	.53	282

Well Code	Operator	Lease	Well No.	TD (ft)	Map Values				
					SM[a]	NSI[b]	NSP[c]	NCR[d]	II[e]
Wise 41	Mitchell Energy	A.S.C.C.U. W.U.	20-1	8050	-4691	34	.13	.20	272
Wise 42	Mitchell Energy	Ed Caraway	3	6600	-4594	0	.00	.00	290
Wise 43	Mitchell Energy	P.A. Claborn	1	6600	-4690	0	.00	.00	168
Wise 44	Mitchell Energy	E.B. Clark	1	8420	-4857	48	.30	.63	158
Wise 45	Mitchell Energy	Bertha Collins	2	6250	-4497	16	.05	.08	302
Wise 46	Mitchell Energy	Jim Deaton	1	8280	-4560	14	.05	.07	264
Wise 47	Mitchell Energy	Deaver	2-1	5900	-4535	28	.13	.38	222
Wise 48	Mitchell Energy	Deaver	6-4	5950	-4516	32	.13	.37	244
Wise 49	Mitchell Energy	Deaver-Pryor Unit	2	5994	-4561	34	.15	.59	232
Wise 50	Mitchell Energy	Lizzie Elrod	1	8143	-4794	0	.00	.00	226
Wise 51	Mitchell Energy	G.Y. Gann	1		-4358	40	.18	1.70	286
Wise 52	Mitchell Energy	Joe C. Hanna	1	6530	-4739	58	.22	.50	262
Wise 53	Mitchell Energy	Hudson-King	2	6938	-4857	32	.21	.36	156
Wise 54	Mitchell Energy	Gomer Lee	1	6900	-4788	0	.00	.00	228
Wise 55	Mitchell Energy	Mathis & Gregory	1	5851	-4519	8	.05	.20	152
Wise 56	Mitchell Energy	H.N. Nikirk	1	7554	-4507	0	.00	.00	212
Wise 57	Mitchell Energy	J. O'Neal	2	5840	-4405	54	.27	.50	200
Wise 58	Mitchell Energy	W.H. Portwood	2	6650	-4495	0	.00	.00	282
Wise 59	Mitchell Energy	C.P. Smith	B-1	5928	-4442	0	.00	.00	210
Wise 60	Mitchell Energy	J.W. Smith	2		-4182	0	.00	.00	96
Wise 61	Mitchell Energy	Joe N. Smith	2	6000	-4396	18	.08	.31	216
Wise 62	Mitchell Energy	Clifford Taylor	1	5821	-4399	0	.00	.00	222
Wise 63	Mitchell Energy	Daisy Taylor	2	6024	-4553	6	.04	.12	158
Wise 64	Mitchell Energy	T.J. Tinney	1-A	6200	-4616	8	.04	.12	212
Wise 65	Mitchell Energy	T.J. Tinney	4	6100	-4620	0	.00	.00	192
Wise 66	Mitchell Energy	Sally Tulley	1	5775	-4148	0	.00	.00	66
Wise 67	Mitchell Energy	Zigler	1	6066	-4632	4	.02	.08	176
Wise 68	Mote	W.A. Calvert	1	6247	-4938	0	.00	.00	146
Wise 69	Mote	C. Vollintine	2	6449	-4872	33	.14	.29	236
Wise 70	Natural Energy	T.H. Wheeler	1	5950	-4597	28	.15	.31	184

Well Code	Operator	Lease	Well No.	TD (ft)	Map Values				
					SM[a]	NSI[b]	NSP[c]	NCR[d]	II[e]
Wise 71	Perkins Oil Co.	Bennett	1	8472	-5135	16	.09	.19	180
Wise 72	Quest Pet.	Howell	1	5800	-4374	0	.00	.00	182
Wise 73	Richey	Perkins	1	6390	-4510	0	.00	.00	282
Wise 74	Richey	Portwood	1	6550	-4678	0	.00	.00	194
Wise 75	Ryder-Scott	Evans	1	6304	-4934	22	.12	.40	186
Wise 76	Sauder Management	Scott	2	6800	-4834	36	.16	.32	230
Wise 77	Sauder Management	J. Vollintine	1	6689	-4969	0	.00	.00	204
Wise 78	Sauder Management	Wise	1	6825	-4985	20	.11	.23	186
Wise 79	Siegfried Oil	R.L. Morris	9A	5590	-4195	18	.16	.47	116
Wise 80	Sun	E. McGaughey	1	8285	-5007	0	.00	.00	152
Wise 81	Taylor Oper.	Browning	1-A	5850	-4518	20	.10	.83	200
Wise 82	Taylor Oper.	Davis	1	5870	-4409	0	.00	.00	174
Wise 83	Taylor Oper.	A. Deaton	1	6400	-4549	0	.00	.00	288
Wise 84	Taylor Oper.	Hodges	7	6575	-4853	48	.21	.41	234
Wise 85	Teal Petroleum	J.T. Hunt	1	6030	-4346	0	.00	.00	172
Wise 86	Texaco	P. Truitt	2	6200	-4632	38	.16	.51	236
Wise 87	Van Guard Expl.	R.S. Lynch	1	6450	-5179	9	.06	.10	150
Wise 88	S. Viatis	Stemmons-Cox	1	5891	-4410	29	.13	.57	220
Wise 89	J.S. Waggoner	J.N. Elrod	1	6330	-4703	14	.06	.14	250
Wise 90	Waymar Oil & Gas	Alvord Town Unit	1		-4672	18	.08	.33	230
Wise 91	Waymar-Pool & Robertson	John T. & Lula New	1	6230	-4817	38	.20	.76	190
Wise 92	Western States Oil	D. Cox	1	5800	-4363	0	.00	.00	150

VITA 2

Alan David Ammentorp

Candidate for the Degree of

Master of Science

Thesis: DEPOSITIONAL SYSTEMS, PETROGRAPHY, AND PETROLEUM GEOLOGY OF A CADDO CONGLOMERATE (ATOKAN) WAVE-REWORKED BRAID DELTA IN NORTH-CENTRAL TEXAS

Major Field: Geology

Biographical:

Personal Data: Born in Lubbock, Texas, March 13, 1959, the son of Mr. and Mrs. W.F. Ammentorp.

Education: Graduated from Thomas A. Edison High School, Tulsa, Oklahoma, in June, 1977; received the Bachelor of Science degree in Geology from Oklahoma State University in May, 1982; completed requirements for the Master of Science degree at Oklahoma State University in December, 1988.

Professional Experience: Geologist, Reynolds Exploration, Tulsa, Oklahoma, summers 1981 and 1982; Geologist, Nortex Gas and Oil Co., Tulsa, Oklahoma, summer 1983; Geologist, Mitchell Energy Corp., The Woodlands, Texas, January, 1984 to October, 1986. Member American Association of Petroleum Geologists and Energy Minerals Division of AAPG.

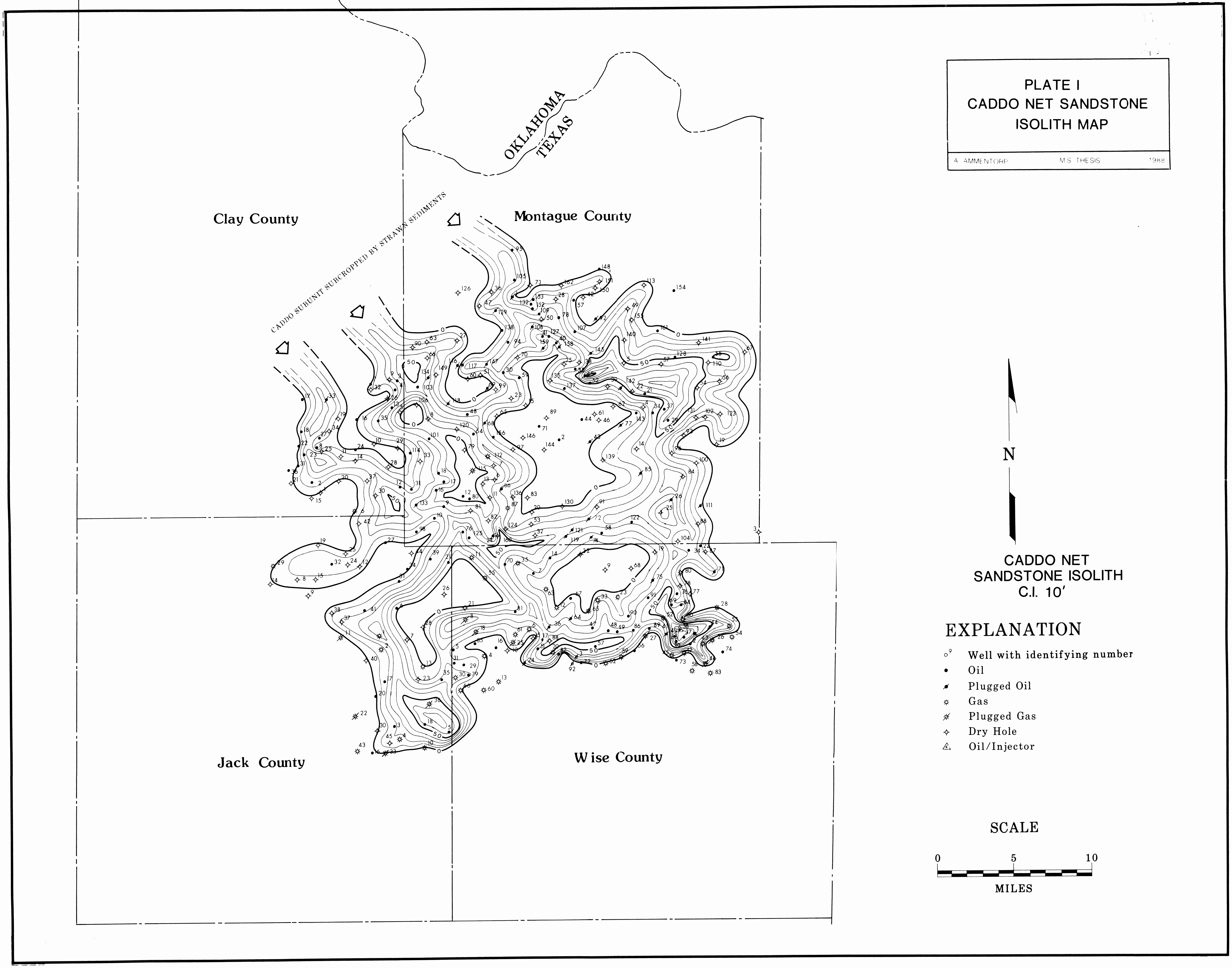
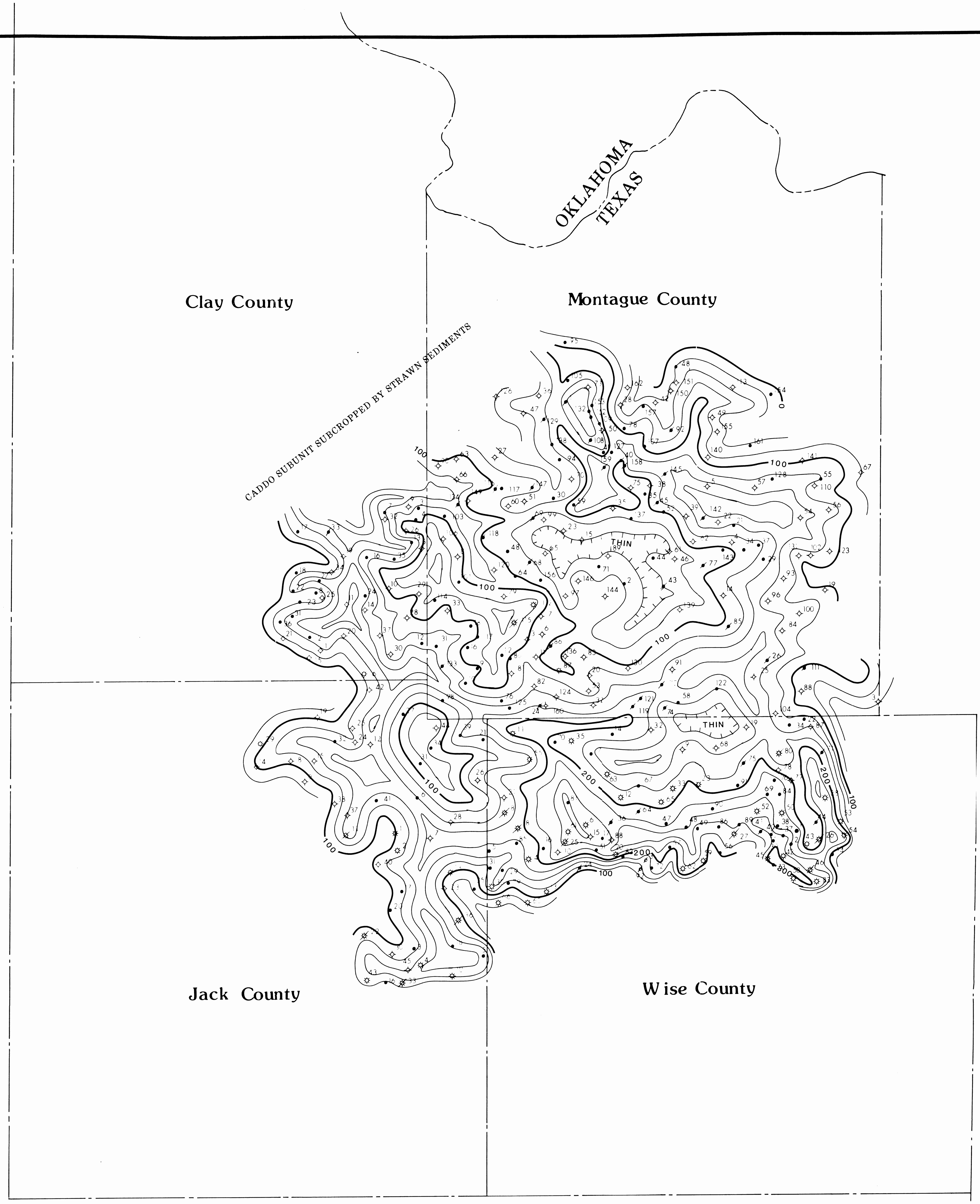


PLATE I
CADDO NET SANDSTONE
ISOLITH MAP
A. AMMENTORP
M.S. THESIS
1988
OKLAHOMA
TEXAS
Clay County
Montague County
Jack County
Wise County
CADDO SUBUNIT SUBCROPPED BY STRAWN SEDIMENTS
N
CADDO NET
SANDSTONE ISOLITH
C.I. 10'
EXPLANATION
Well with identifying number
Oil
Plugged Oil
Gas
Plugged Gas
Dry Hole
Oil/Injector
SCALE
0
5
10
MILES

PLATE II
CADDO INTERVAL
ISOPACH MAP

A. AMMENTORP M.S. THESIS 1938



CADDO INTERVAL ISOPACH
C.I. 25′

EXPLANATION

- Well with identifying number
- Oil
- Plugged Oil
- Gas
- Plugged Gas
- Dry Hole
- Oil/Injector

SCALE

0 5 10

MILES

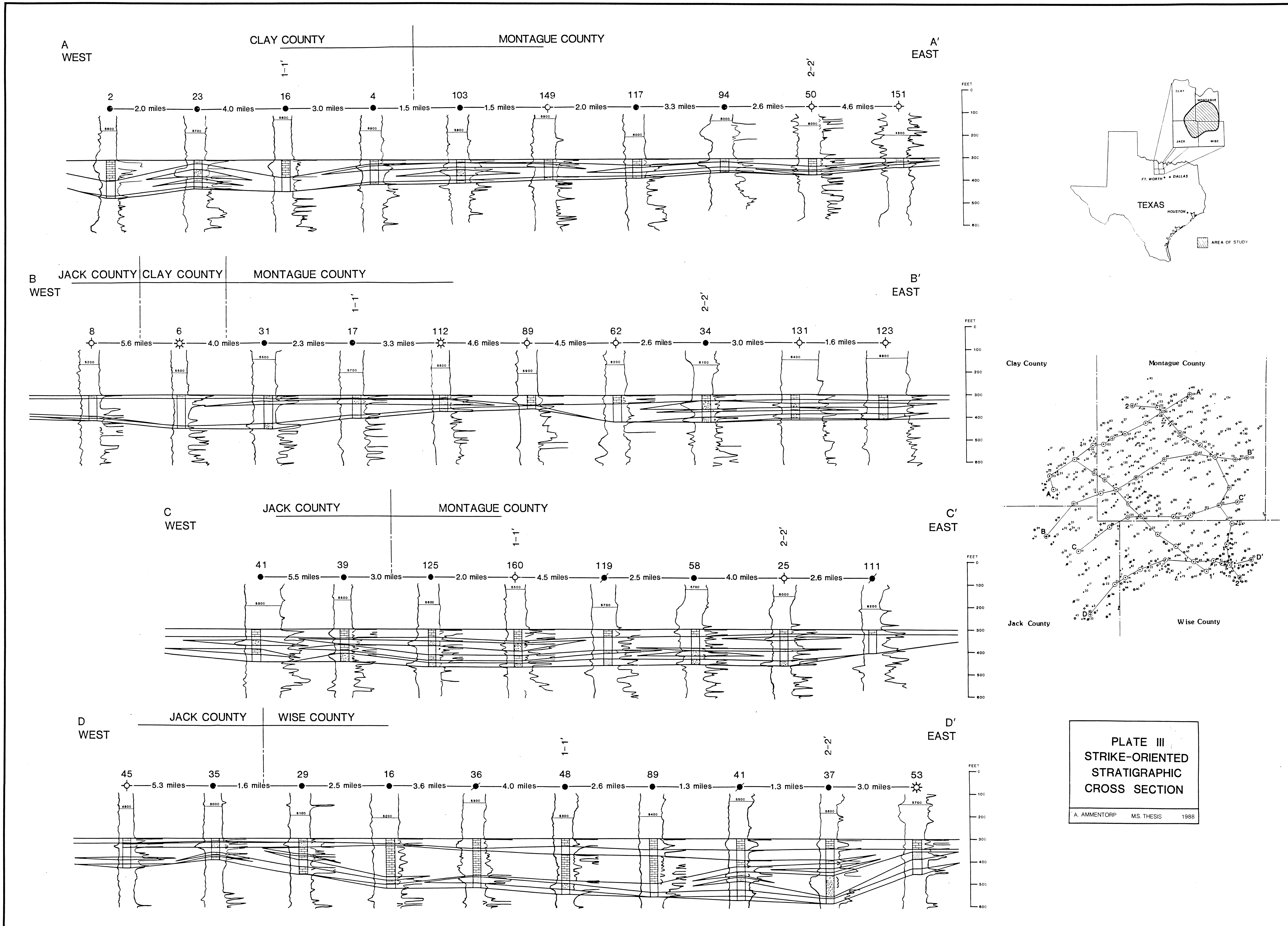
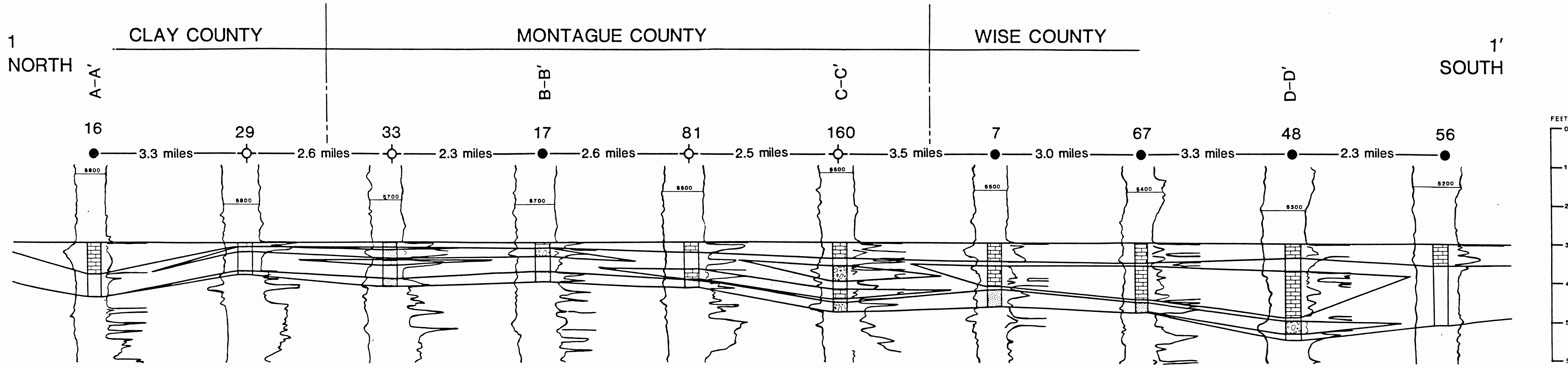
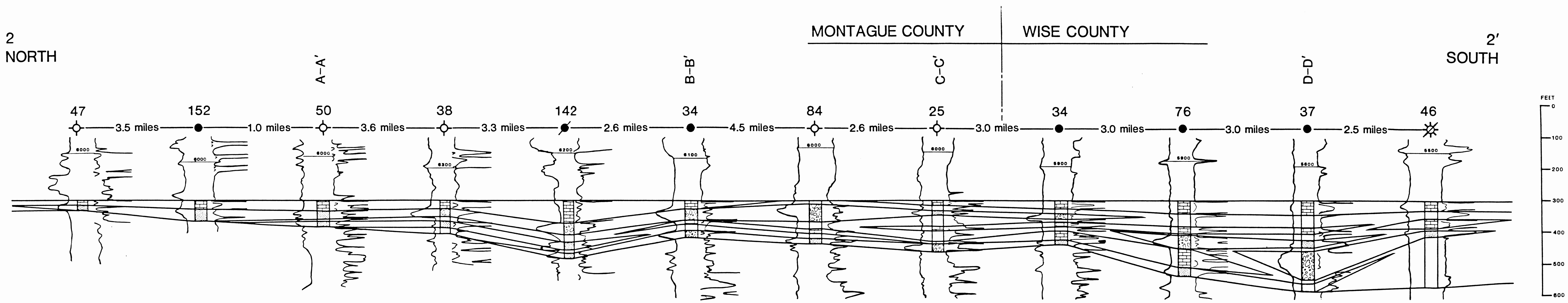
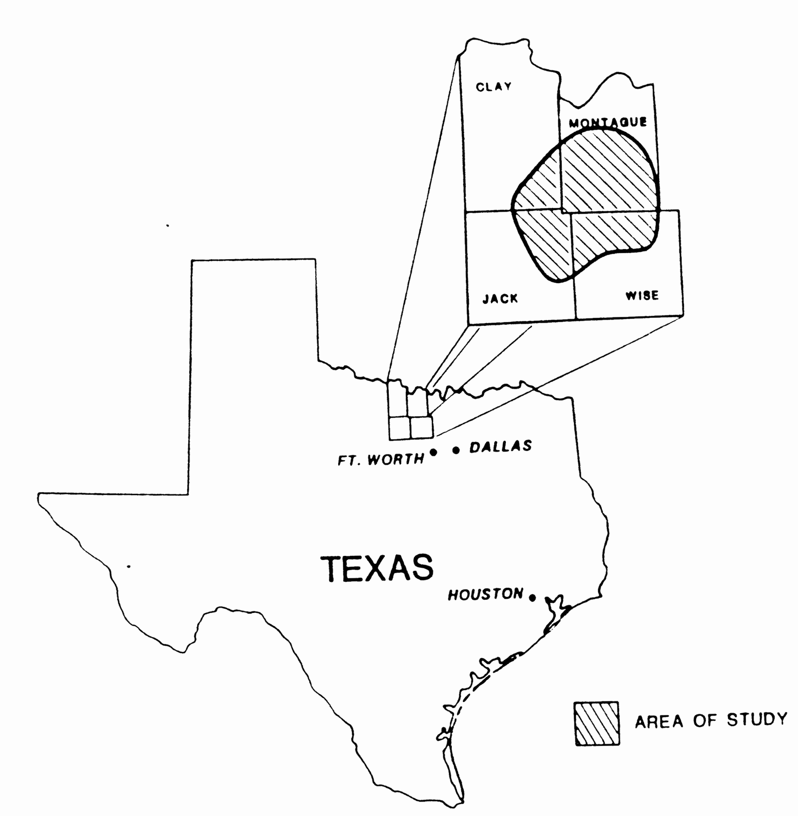


PLATE III
STRIKE-ORIENTED
STRATIGRAPHIC
CROSS SECTION

A. AMMENTORP MS. THESIS 1988







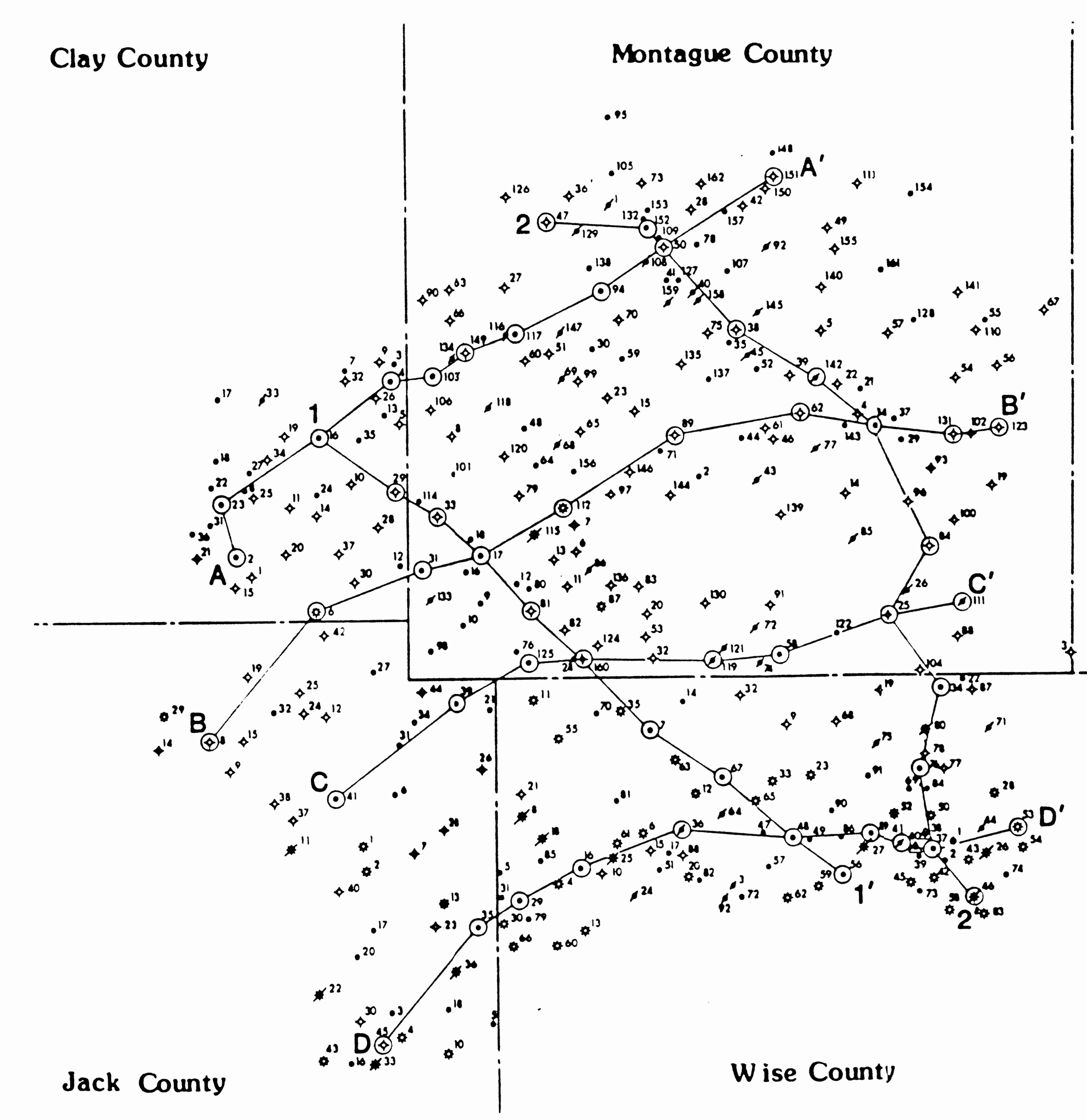


PLATE IV
DIP-ORIENTED STRATIGRAPHIC CROSS SECTION

A. AMMENTORP M.S. THESIS 1988