STRATIGRAPHY, DEPOSITIONAL ENVIRONMENT, PETROLOGY AND DIAGENETIC CHARACTER OF THE MORROW RESERVOIR SANDS, SOUTHWEST CANTON FIELD, BLAINE AND DEWEY COUNTIES, OKLAHOMA

By

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PREFACE

This study is concerned with the Early Pennsylvanian Morrow Formation on the Anadarko Basin Shelf in the Southwest Canton Field area, Northwestern Oklahoma. With respect to the Morrow Formation in the Canton study area, the primary objectives were to: (1) unravel the Early Pennsylvanian stratigraphy; (2) interpret the depositional environment; (3) characterize the petrology of the producing and non-producing sand types; (4) define the diagenetic evolution of the reservoir sands; (5) evaluate the impact of diagenetic processes on the generation of secondary porosity, and (6) discuss the thermal history of the Morrow Formation with respect to oil and gas maturation.

The author wishes to express his sincere appreciation to his major adviser, Dr. Zuhair Al-Shaieb, for his invaluable interest, advice, and support throughout all phases of this project. Appreciation is also expressed to Dr. Gary F. Stewart and Dr. John W. Shelton for their assistance in the stratigraphic portion of this study. I also express gratitude to Dr. Nowell Donovan and Dr. Arthur W. Cleaves for their helpful comments and discussion concerning depositional environments.

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Grateful appreciation is also expressed to Roy Hille, Robert Brooke, George Ecker, and Bob Neil of Amoco Production Company, all of whom helped to provide assistance in one form or another when it was needed, and which ultimately resulted in funding for this study.

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CHAPTER I

INTRODUCTION

Location and General Characteristics

The Southwest Canton Field produces oil and gas from the Lower Pennsylvanian Morrow Formation in the Anadarko Basin. The field is located in Blaine and Dewey Counties (T18N, R13-14W), Oklahoma, and is part of the Northwest-Southeast trending Watonga gas trend across the Anadarko shelf (Figure 1). The limits of the Southwest Canton Field have expanded rapidly since its inception in the sixties. Drilling in the field and surrounding area was very active between 1975 and 1981 in accordance with the rapid escalation of petroleum prices.

The Southwest Canton Field has produced 7,083,260 bbls of oil and 40.61 bcf of gas through January, 1982. This field is unusual because it produces oil within the gas dominated Watonga trend. Oil to gas ratios are high in the Canton area relative to other areas long the Watonga trend. Due to the recent decrease in gas prices, the Canton area has retained recent exploration interest.

The purpose of this study is to examine the stratigraphic, sedimentologic, petrologic, and diagenetic character of the producing Lower Morrow interval in the Southwest Canton Field area. The principal objectives of this study involve: (1) characterizing the Early Pennsylvanian stratigraphy of the area; (2) delineating the environment of deposition of the Morrow producing interval; (3) characterizing the

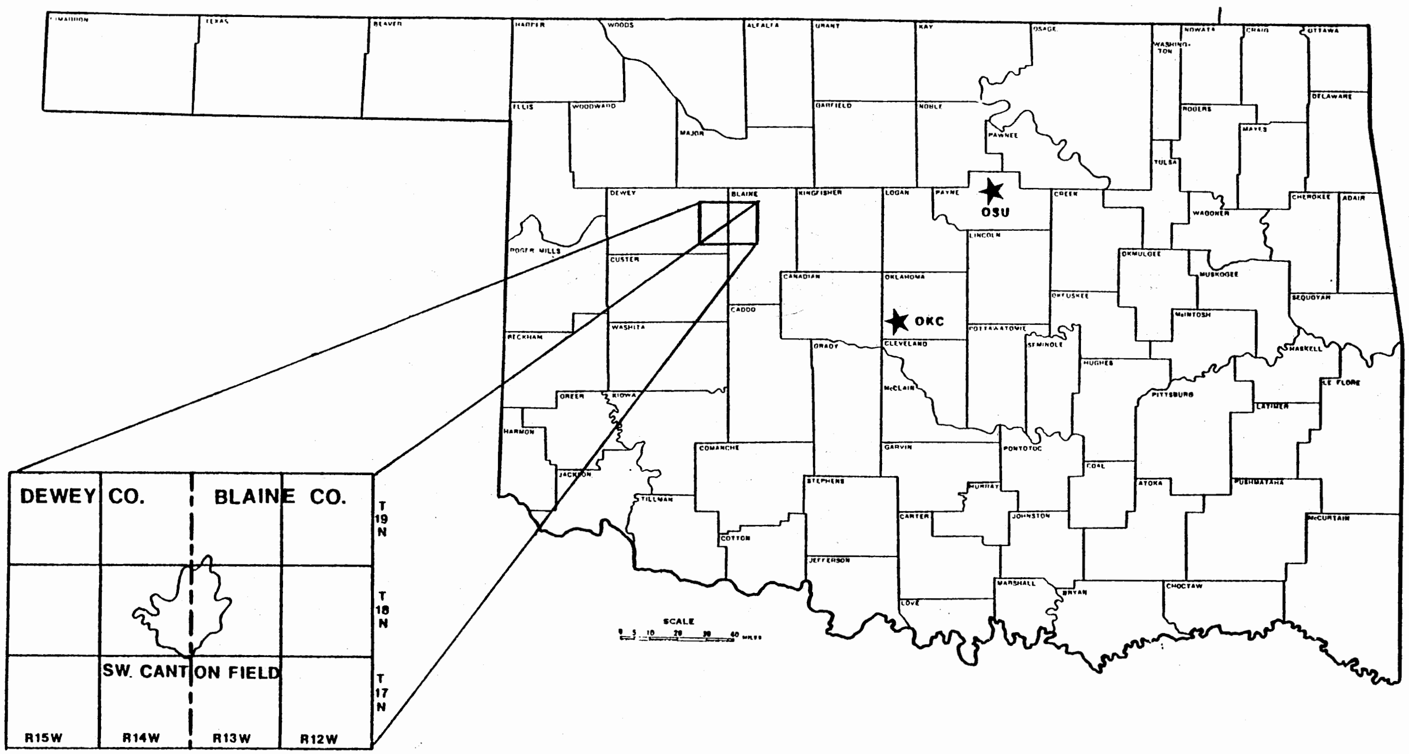

Figure 1. Index Map of the Study Area

petrology of the producing and nonproductive sand types; (4) achieving a better understanding of the diagenetic processes and diagenetic evolution of the Morrow reservoir, and (5) evaluating the impact of the diagenetic processes on porosity generation and the reservoir quality.

Previous Investigations

Regional studies of the Upper Mississippian and Pennsylvanian sedimentary section in the Mid-Continent region have been made by several investigators. Huffman (1959) reviewed the general stratigraphy and structural framework of Pre-Desmoinesian sedimentary deposits in the Mid-Continent area. The major structural and stratigraphic features of the Mid-Continent region with respect to petroleum potential were overviewed by Adler (1971). Brown (1979) and Galloway and Dutton (1979) related specific depositional environments to certain structural regimes in the Mid-Continent region. Regional paleogeographic interpretations by Moore (1979) illustrate the paleozoic environmental and geographic character of the Mid-Continent region. The Anadarko Basin area is included in all of the above studies.

Within the context of the Anadarko Basin, Evans (1979) reviewed general stratigraphy, delineated Morrow sand trends, and characterized structural style in the basin. Davis (1971) published examples of producing Morrow-Springer areas in the Oklahoma and Texas Panhandles and deep basin areas. The general stratigraphy and structural character of the Anadarko Basin with respect to oil and gas generation and accumulation is reviewed by Hill and Clark (1980).

Several subsurface studies using conventional mapping techniques and aimed at defining the stratigraphy, geometry, and depositional environment of the Morrow Formation producing sands in the northern Anadarko shelf region have been published. Forgotson, Stadler and David (1966) and Forgotson (1967) characterized the structural framework, stratigraphy and depositional history of the Morrow Formation in the Oklahoma Panhandle and northwestern Oklahoma regions. Curtis and Ostergard (1980) defined the Morrowan stratigraphic framework and sand geometry in southeastern Texas County, Oklahoma. In north-central Texas County, Benton (1972) illustrated the geometry and stratigraphic behavior of producing Morrow sands. Eastward in Beaver, Harper, Ellis and western Woodward Counties, Oklahoma, Khaiwaka (1968) interpreted the depositional environment of the Morrow sands based on stratigraphic, petrologic and geometric evidence. The petroleum geology, stratigraphy and geometry of Morrow sands in northern Harper County, Oklahoma, and Clark and Comanche Counties, southwestern Kansas is characterized by Mannard and Busch (1974). Bloustine (1975) studied the Lower Morrow petroleum potential in southern Ellis County, Oklahoma.

Characterization of the Morrow Formation depositional environment through detailed core examination along with conventional subsurface techniques was accomplished by Swanson (1979) and Kasino and Davies (1979). Swanson (1979) identifies distinct producing Upper Morrow sand facies in the Oklahoma Panhandle, northern Texas Panhandle, and southwestern Kansas regions. Kasino and Davies (1979) characterized the depositional environment of Upper Morrow reservoir sands in Cimarron County, Oklahoma.

In the literature, a few workers investigated the Morrow Formation in the Canton area. Clement (1977) used siesmic modeling techniques to delineate the geometry of productive Morrow sands in the Geary area, southeast of Canton (in T13N, R10W). Davis (1974) illustrated the attractiveness of high pressure Morrow sand reservoirs in the northeast Carlton (T18N, R12W), Hitchock (T17N, R11W) and north Geary (T14N, R11W) areas along the Watonga trend in Blaine and Canadian Counties. Davis and Nondorf (1974) also examined over-pressure zones in Blaine and Canadian Counties, and included Bougner gravity and magnetic maps of the area. Breeze (1971) mapped the regional distribution of subsurface pressures within the Morrow interval in the eastern Oklahoma Panhandle region and northwestern Oklahoma area, which included the Canton area. Zanier and Timko (1970) used well log derived salinities as indicators of initial potential quality in Blaine, Canadian, and Dewey Counties, Oklahoma.

Until recently, good petrographic and diagenetic studies of the Morrow Formation sands in the Anadarko shelf region were rare. Adams (1964) studied the petrographic and diagenetic character of Lower Morrow sands west of the Canton area in Ellis, Woodward, and Dewey Counties, Oklahoma, and the northeast Texas Panhandle. He recognized secondary porosity and the importance of understanding the diagenetic processes effecting the Morrow Formation. Khaiwka (1968) examined the petrology of Morrow sands to support his environmental interpretations. More recently, Simon, Kaul and Culbertson (1979) examined cores from the Morrow Formation in the Anadarko Basin for the purpose of modifying well stimulation practices to suit specific Morrow sand lithologic types. Kasino and Davies (1979) published a detailed diagenetic evaluation of Upper Morrow sands in conjunction with their characterization of depositional environment in Cimarron County, Oklahoma. These workers recognized a distinct diagenetic sequence and recommended well stimulation techniques that matched the diagnetic character of the Morrow Formation.

Methods and Procedures

Characterization of the Lower Pennsylvanian stratigraphy was accomplished through a network of five stratigraphic cross sections (Plates 2-9). The location of this network with respect to the Southwest Canton Field is shown in Figure 2. The position of the network reflects an attempt to utilize the available cores which supplemented the stratigraphic interpretation.

Net sand and pososity maps were constructed to illustrate the geometry of the Morrow reservoir sands. The methodology used to construct these maps is discussed in Appendix A.

A suite of seven cores and core plugs from two additional wells was examined. The location of these cores and plugs with respect to the Southwest Canton Field is also shown in Figure 2. Detailed core examination was useful in delineating the depositional environment of the Morrow Formation. Eight of the nine cores were cut within the Morrow Formation. The Pan-American Wiley No. 1 core (SW NE 33-18N-12W) was logged to characterize the lithology of the Atokan unit in the study area. Strip logs were used to describe the lithology of the Upper Mississippian Chester unit. A total of 484 feet of core was examined. Core plugs at one-foot intervals were logged from 106 feet of original core. Calibration of the gamma ray log signature to the lithology of each core in the Morrow Formation was made. Detailed logs of the cores and core plugs examined are illustrated in Appendix B.

Methods used to determine the petrologic and diagenetic character of the Morrow Formation were: Routine thin section examination,

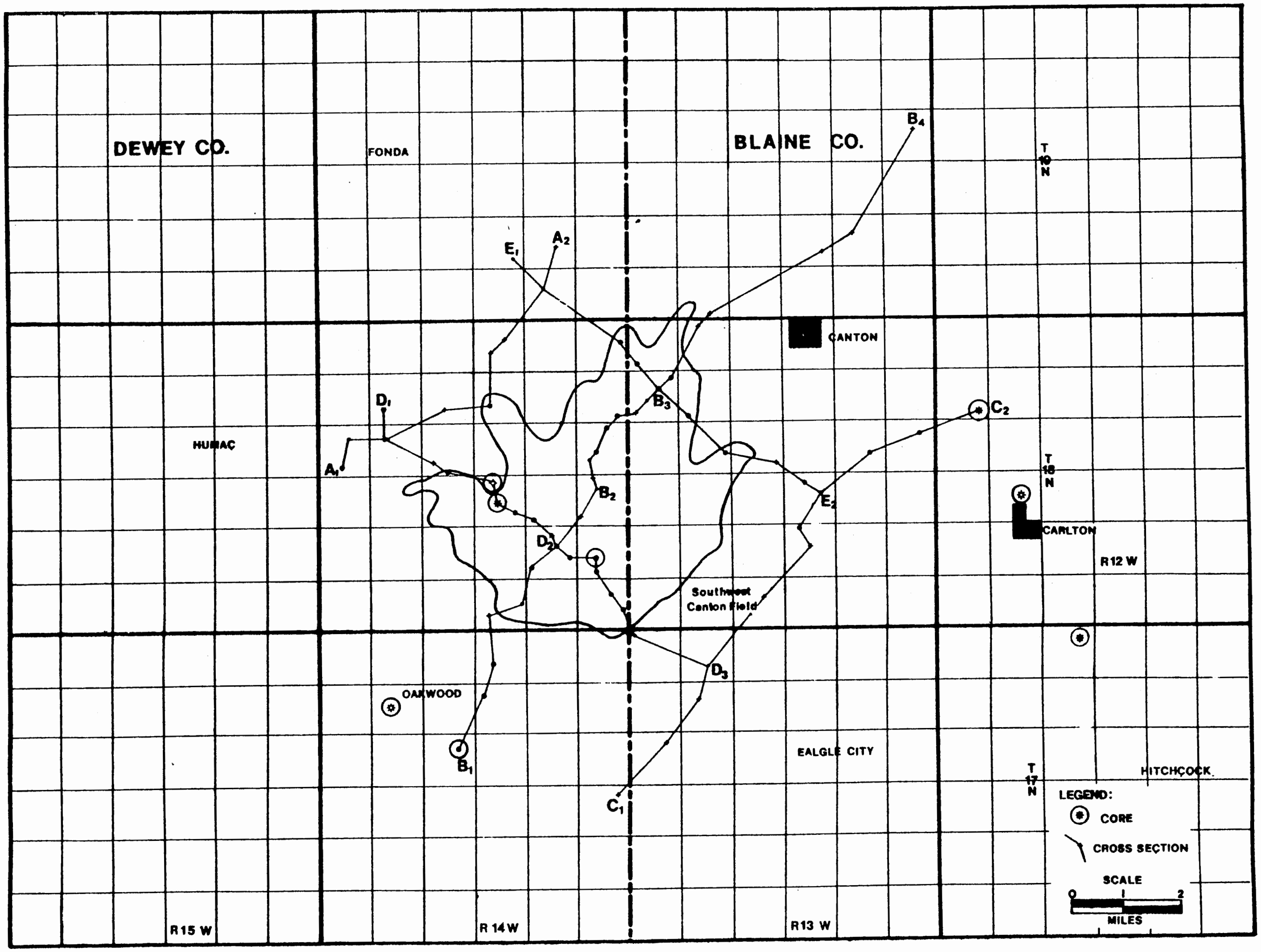

Figure 2. Study Area Showing Location of Cross Sections and Cores

scanning electron microscopy (SEM) and x-ray diffraction of powdered and "clay extracted" (Kittrick, Parrick and Hope, 1963) samples. Thin sections permit quantitative determination of mineralogy along with visual inspection of porosity types and petrofabric character. SEM analysis permits visual inspection of the reservoir rocks and non-productive sands at extreme magnifications. An energy dispersive x-ray analyzer (EDXA) was used with the SEM for elemental analysis of specific minerals. X-ray diffraction was used for qualitative identification of minerals in powdered samples. Qualitative identification of mineralogy and semiquantitative analysis of clay mineral percentages was determined from clay extracted samples. These samples were x-rayed in the natural, glycolated and heated (to 500^{o}C) states, respectively.

One hundred and two thin sections were sampled from Morrow sands in eight different cores. Both reservoir and nonreservoir sands were sampled. This insured a suite of thin sections representative of the Morrow sands in the Canton area. For each thin section, more than 300 points were counted. The counted amount of each constituent type was then averaged. Sample locations in the respective cores are shown on the core logs in Appendix B.

Thirteen samples were clay extracted and analyzed by x-ray diffraction, with fifteen samples analyzed by SEM and EDXA techniques. Four samples from each Southwest Canton Field core and samples from cores in the Northeast Carlton area were examined. In addition, three cores were sampled for vitronite reflectance in the study area. The location of all samples on core logs is shown in Appendix B.

Semi-quantitative values for each clay mineral present were determined by identifying the clay mineral components from intensity peaks, calculating the area under these intensity peaks and using these areas in Equations 1 and 2 below. These equations are used to determine the approximate percentage of each clay type (Equation 3).

1. Three clay minerals present:

$$I_{i-s}(.29) + I_{ch}(.55) + I_k(.15) = cI_{Total}$$

2. Two clay minerals present (i.e., kaolinite and illite):

$$I_{i-s}(.29) + I_k(.15) = cI_{Total}$$

3. Example of chlorite percentage:

$$\frac{I_{ch}(.55)}{cI_{Total}} \times 100 = \%\ \text{chlorite}$$

where

I_{i-s} = area under mixed layer illite-smectite

I_{ch} = area under chlorite curve

I_k = area under kaolinite curve

cI_{Total} = total area

(.29), (.55), and (.15) = absorbtion coefficients for respective clays (personal communication, Al-Shaieb, 1983).

CHAPTER II

STRUCTURAL FRAMEWORK

Regional

Figure 3 shows the location of the Canton study area within a Mid-Continent structural framework. Geographically, the study area occurs on the Anadarko Shelf approximatly 60 miles east of the Nemaha Ridge and 50 miles northeast in a perpendicular direction of the west-northwest trending axis of the Anadarko Basin.

The major positive structural features bordering the Anadarko Basin are the northward trending Nemaha Ridge and northwest trending central Kansas uplift to the east and northeast, respectively (Huffman, 1959; Khaiwka, 1968). The northeastern trending Las Animas Arch occurs northwest of the Anadarko Basin in southeastern Colorado (Huffman, 1959; Khaiwaka, 1968). The western Anadarko Basin border is defined by the Cimarron Arch-Keyes Dome, which trends north across the Oklahoma Panhandle (Huffman, 1959; Khaiwaka, 1968). On the southern Anadarko Basin margins, the northwest-southeast trending Amarillo-Wichita Uplift and the Arbuckle Uplift define the southwestern and southern borders of the basin, respectively (Huffman, 1959; Kaiwaka, 1968). The Anadarko shelf area occurs on the northern-northeastern flank of the Anadarko Basin south of the central Kansas uplift and east of the Nemaha Ridge along northern Oklahoma into the Hugoton area in southwestern Kansas.

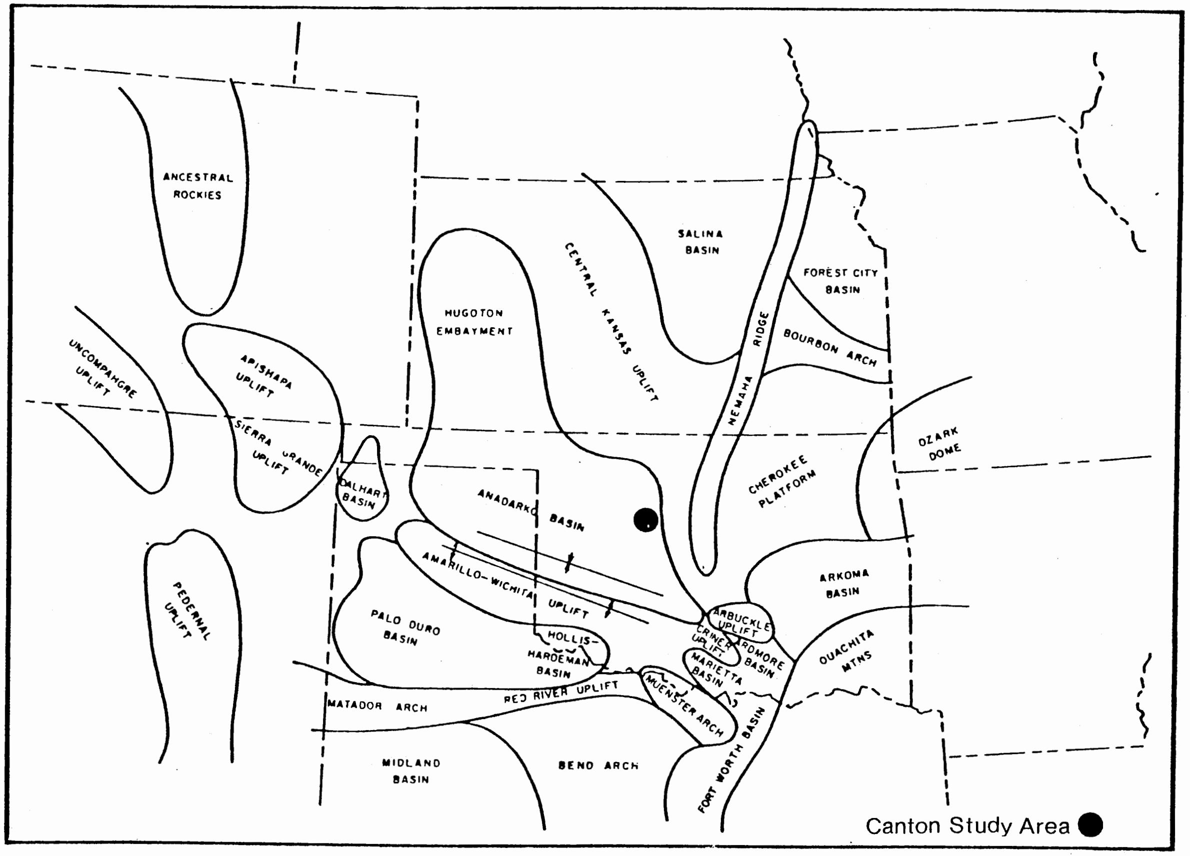

Figure 3. Major Pennsylvanian Structural Features in the Southern Mid-Continent (after Moore, 1979)

Huffman (1959) described the major tectonic features of the Mid-Continent region and their influence on the distribution and thickness of Pre-Desmoinesian strata. Only those features within immediate proximity of the study area will be described briefly herein.

The Nemaha Ridge is a post-Mississippian major structural feature that trends northward from Oklahoma through Kansas to Nebraska (Huffman, 1959). In Oklahoma, the structure flanks the northeast Oklahoma platform to the east and the Anadarko Basin to the west (Huffman, 1959). On top of the structure, a major unconformity separates eroded and tilted Mississippian to Precambrian rocks from Desmoinesian Cherokee strata (Huffman, 1959). The Desmoinesian strata are the earliest Pennsylvanian rocks deposited on the eroded Mississippian to Precambrian surface on structure (Huffman, 1959). Stratigraphic relations suggest the dominant movement was during post Mississippian, pre-Middle Pennsylvanian time, and was probably post Morrowan (Huffman, 1959; Kaiwka, 1968).

The central Kansas Uplift in north central Kansas is a major post-Mississippian feature (Huffman, 1959). Eroded Ordovican and older rocks are overlapped by Missourian rocks that are the earliest Pennsylvanian rocks on the structure (Huffman, 1959). The Anadarko shelf is actually a southern extension of the central Kansas Uplift (Huffman, 1959).

The Amarillo-Wichita Uplift is predominately, although not exclusively, a post Morrowan tectonic feature. Growing during Morrowan time, the uplift shed limestone conglomerates from its sedimentary cover late in Morrowan time before its granitic core was exposed (Moore, 1979). In Atokan time, the uplift eroded to its crystalline core and shed a thick (>15,000 ft) clastic wedge of granitic conglomerates (i.e., "granite wash") into the southern Anadarko Basin throughout Pennsylvanian time and into the Permian (Moore, 1979). On structure, Cambrian to Precambrian crystalline rocks are directly overlain by Middle Permian strata locally (Huffman, 1959).

The west-northwest trending Amarillo-Wichita Uplift and Anadarko Basin fit into a larger west-northwest structural trend that dominates southern Oklahoma and northern Texas. Several west-northwest trending basins and uplifts--the Marietta, Ardmore and Hollis basins; Muenster, Red River, Arbuckle and Amarillo-Wichita Uplifts--are axially aligned relatively parallel to the Anadarko Basin axis (Figure 3). This axial alignment creates a conspicuous furrowlike structural trend that extends at a high angle from the Ouachita fold belt in the southeast into the Texas Panhandle northwestward. This general tectonic pattern along with the anomonously thick Paleozoic sedimentary section (>40,000 ft in the Anadarko Basin) and sedimentary facies character has led many workers to define the overall structural evolution of the Anadarko Basin in terms of Schatski's (1946) aulocogen model within a plate tectonic framework (Burke and Dewey, 1973; Hoffman and others, 1974; Brewer, 1982).

Local

Mid-Continent Structural Type and Sedimentary Character

Sedimentary accumulation, distribution and facies character ultimately reflect and are governed by the structural context within which they exist. This is a fundamental geologic concept, and is often applied for example, when unraveling ancient structural regimes through the analysis of sedimentary clastic wedges. The important interrelationship of sedimentary character and structural style has been reviewed in the Mid-Continent region by several workers (Brown, 1979; Galloway and others, 1979; Moore, 1979). It is useful to consider the fundamental structural types in the Mid-Continent-Anadarko Basin region and place the Canton Area into an appropriate local structural context.

Brown (1979) classified and described four distinct structural types in the Mid-Continent-Anadarko Basin region:

1. fault bounded uplifts
2. stable cratonic shelves and platforms
3. less stable subsiding shelves
4. deep basins and continental slopes

Brown (1979) also related sedimentary facies, accumulation and distribution character to certain definite structural modes and cited examples in the Mid-Continent region. Galloway and Dutton (1979) recognized similar tectonic settings with depositional systems that developed in response to certain structural settings.

Examples of Brown's (1979) fundamental structural types in the Anadarko Basin area are as follows:

1. Fault bounded uplifts include the Amarillo-Wichita Uplift. Uplifts of this type shed conglomeratic clastic wedges with braided streams and fan deltas basinward (Brown, 1978).

2. Stable cratonic shelf/platforms include the northeast Anadarko shelf area (Moore, 1979). The principal clastic sedimentary facies occur within a shallow, marginal marine context. Depositional types include small deltas with thin delta front sands, fluvial point bars and valley fill sandstones with conglomerates landwards (Brown, 1979).

3. Less stable subsiding shelves occurred in the northwest

Anadarko shelf area during Morrowan time (Moore, 1979). This structural type provides the framework for major deltaic activity. Relatively large cratonic delta systems flank a number of Mid-Continent basins with periodically subsiding shelves (i.e., Forest City, Anadarko, Palo Duro, Arkoma, and Midland Basins) (Brown, 1979).

4. Deep basins and continental slopes include the deep Anadarko Basin and hingeline. Sediments are submarine fan turbidites that enter the basin via shelf margin deltaic buildups (Brown, 1979).

Moore (1979) generalized the paleogeographical-environmental setting of the Mid-Continent area during Morrowan time, shown in Figure 4. The map represents the predominant sedimentary scenario throughout most of Morrowan time as interpreted by Moore (1979). Within the context of Moore's (1979) and Brown's (1979) interpretations, the Canton area Morrow sediments were deposited in a relatively stable structural regime on a cratonic shelf platform. With respect to Figure 4, shallow marine clastics were deposited basinwards of a low lying land area to the north within the Canton study area. The large areal distribution of thick deltaic sediments northwest of Canton implies a relatively less stable structural regime with enhanced shelf subsidence. This deltaic facies stops near the western fringe of the study area and may have influenced Canton area Morrow deposition. Conglomeratic clastic wedge sediments of the Amarillo-Wichita Uplift are generally confined to the southern Anadarko Basin margins away from the Anadarko shelf-Canton area.

A structure map of the Southwest Canton Field study area is shown in Plate 1. This map is contoured on top of the Atokan 13 Finger Limestone--an excellent time equivalent stratighaphic horizon in the area. Other time equivalent markers within or bounding the Morrow section

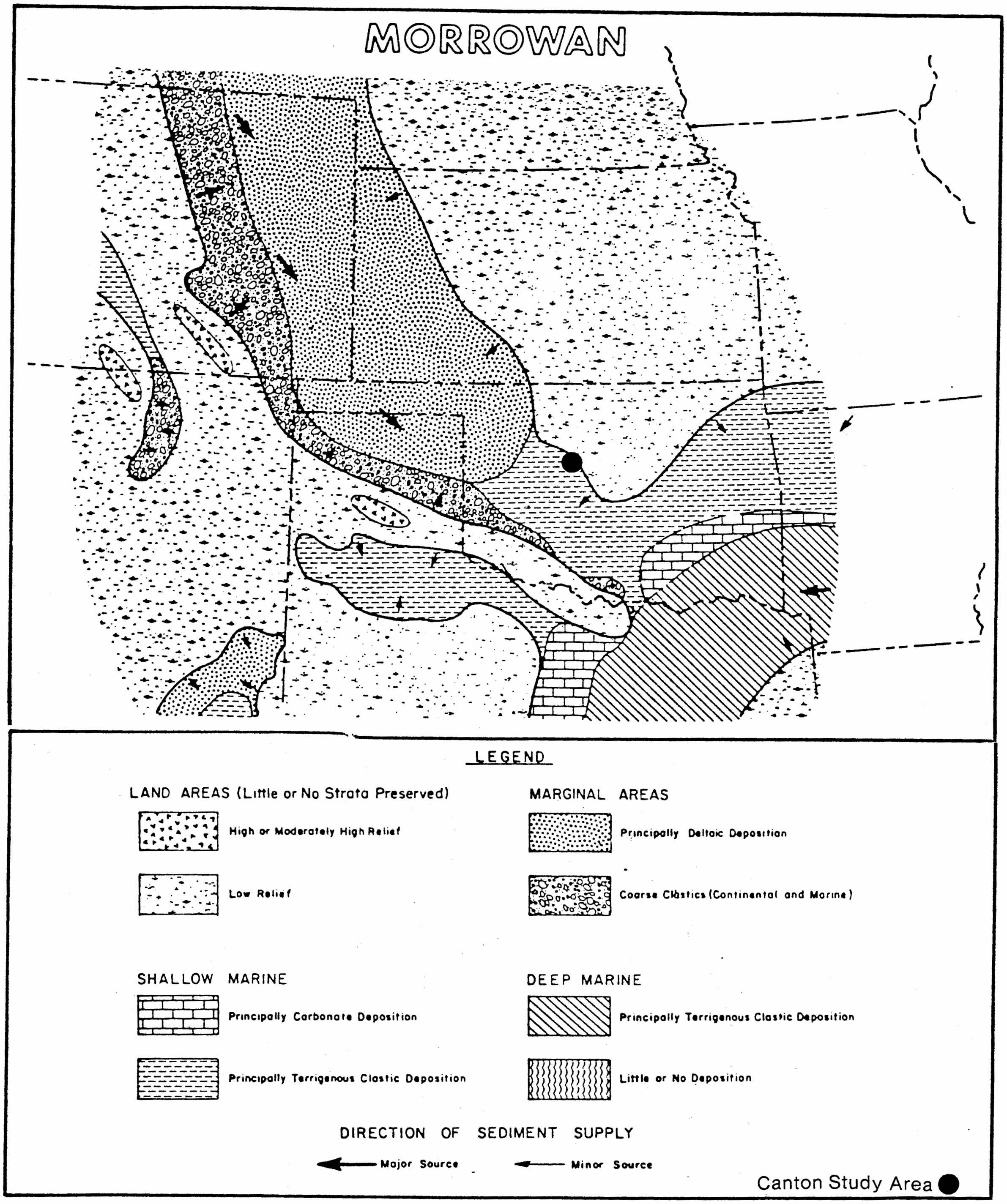

Figure 4. Moore's (1979) Interpretation of the Morrowan Paleogeography and Depositional Environment

(i.e., Pennsylvanian-Mississippian or the Morrowan-Atokan boundaries) were not contoured into structure maps due to the uncertainty involved in lateral correlations.

Plate 1 reflects a regional structural warping style that is characteristic of the Anadarko shelf region. Structural strike is to the west-northwest at N80-60°W. Structural dip steepens basinward to the southwest from 100 ft/1½-2 miles in the northeast (T19N, R12W) to 100 ft/mi in the southwest (T17N, R15W). Tightening of the contour line spacing in the extreme southwest corner of Plate 1 suggests proximity to the Anadarko Basin hingeline. Positioning the Anadarko Basin structural hingeline in the southwest corner of the Canton study area agrees with Evans' (1979) placement of the Anadarko Basin structural hingeline.

No major tectonic features were delineated in the Canton study area other than regional warping. Gentle folding that trends perpendicular to structural strike is reflected in slightly sinuous to irregular valleys and ridges. Morrow sandstone thickness distribution patterns and production rates are not modified by these folds. For example, the gentle anticlinal nose in sections 35 and 36 T18N, R14W produces oil and gas on and off the structure. Moreover, thinning and thickening of sands on gentle synclinal and anticlinal noses, respectively, is a common occurrence in the area. No consistent relationship between Morrow sand thickness and the structural configuration of the Atokan surface exists. This implies the gentle secondary folding shown on the Thirteen Finger horizon occurred in post-Morrowan time and had no influence on Morrow sand deposition.

The structure map (Plate 1) supports a stratigraphic trapping mechanism for Morrow production in the Southwest Canton Field and surrounding area. No significant structural closures occur in the area. The gentle basinward warping and lack of faulting suggests a relatively stable Anadarko shelf structural context for the Canton study area.

CHAPTER III

STRATIGRAPHIC FRAMEWORK

Introduction

The type log in Figure 5 shows the stratigraphic position of the Early Pennsylvanian Morrow Formation in the Canton area with respect to the Pennsylvanian-Mississippian boundary. Here, Morrowan age siliclastic sands,skeletal sands and shales unconformably overlie Upper Mississippian Chesterian carbonates and shales across the Pennsylvanian-Mississippian system boundary. Another unconformity defines the top of the Morrow Formation which separates Morrowan strata from overlying Atokan interbedded carbonates and shales. The Atokan strata is appropriately named the "Thirteen Finger Limestone" because it shows a distinctive "finger-like" character on electric logs.

Cross Section Network

In the Southwest Canton Field area, a network of three NNE-SSW and two NNW-SSE stratigraphic cross sections was constructed to 1) insure reliable correlations; 2) establish the regional stratigraphic framework within which the Southwest Canton Field exists; 3) illustrate the electric log character of the Morrow interval and producing sand types; 4) characterize and compare the vertical stratigraphic position, lateral correlations and cross section morphology of the different

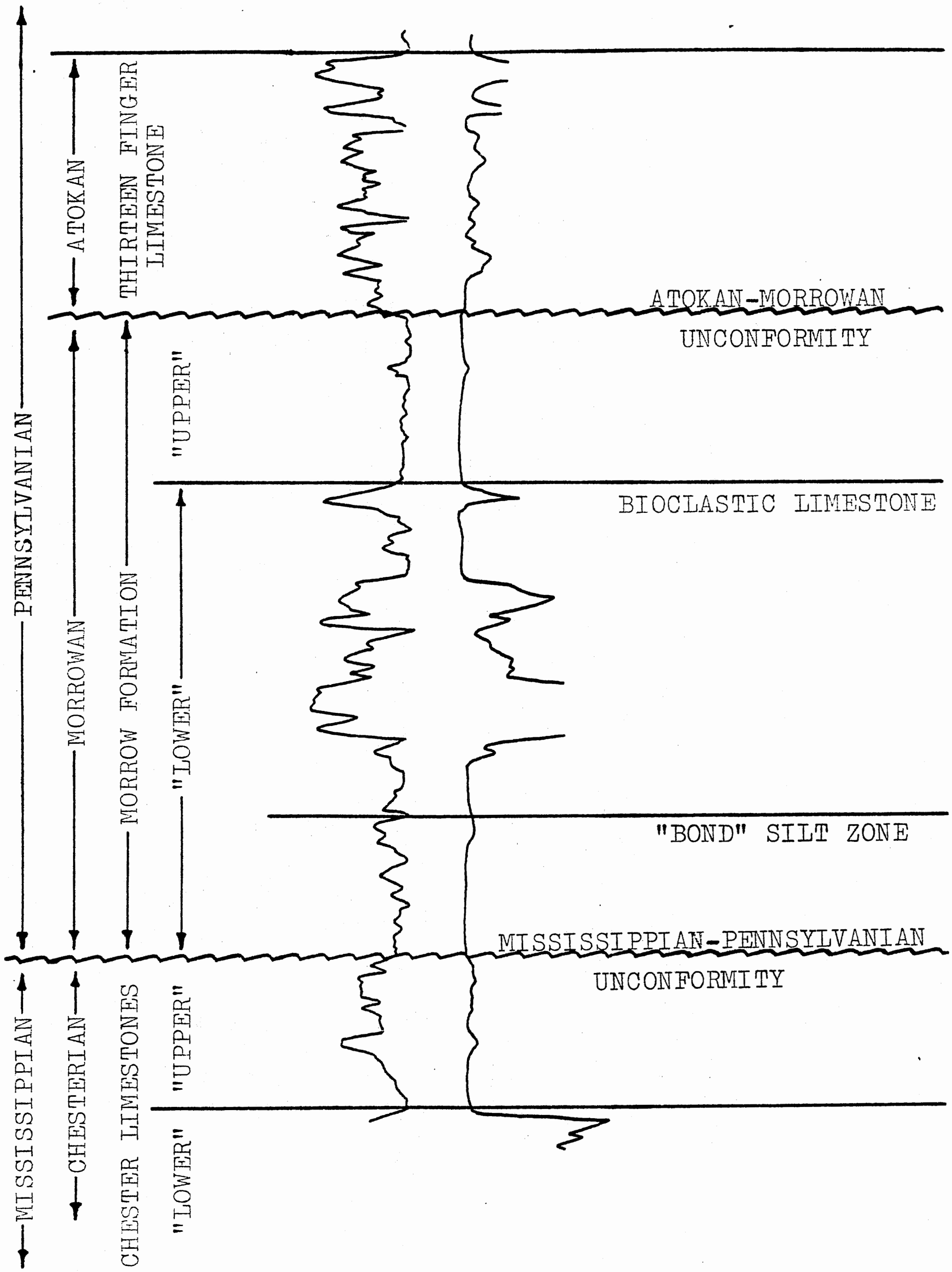

Figure 5. Type Log, Pan-American-Burghart No. 1, SE NW 24-18N-14W, Dewey County

Morrow sand types along different orientations, and 5) best utilize available core data for reliable Morrow lithologic and facies characterization in the Southwest Canton Field area. This cross section network is illustrated in Plates 2-9, and the location of each section with respect to the Southwest Canton Field is shown in Figure 2.

The reference datum for each stratigraphic cross section is the top of the Thirteen Finger Limestone, an excellent chronostratigraphic marker horizon in the Canton area. Other features correlated in the cross section network include the Atokan-Morrowan and Chesterian-Morrowan unconformable contacts, marker horizons A, B, and C in Atokan strata, a bioclastic Morrow unit, an early Morrow siltstone unit called here the "Bond" silt zone, marker horizons 1, 2 and 3 in Chesterian strata and a limestone unit at the bases of all cross sections termed Lower Chesterian in this study. All named markers and divisions of Atokan, Morrowan and Chesterian strata used in this study were delineated for local descriptive and stratigraphic use within the study area context. Applications of these local correlatable markers and divisions into areas outside of this study is not possible without the construction of more regional cross sections.

The NNE-SSW and NNW-SSE orientation of the cross sections in the network occurs perpendicular and parallel to the regional structural strike, respectively. (See the structure map of the Canton area, Plate 1.) Dip oriented cross sections (Plates 2-6) best illustrate basin to shelfward stratigraphic relationships among Atokan, Morrowan and Chesterian strata. Stratigraphic features such as shelfward onlap and thinning of Atokan strata, shelfward thinning and erosional truncation of the Morrow Formation, basinward erosional truncation of the Upper

Chester Limestone and Lower Morrow "Bond" silt zone shelfward onlaps are characteristic of the NNE-SSW shelf-to-basinward cross sections. Dip-oriented cross sections were especially useful in delineating the stratigraphic position of the Mississippian-Pennsylvanian unconformity in the area. In contrast, cross sections oriented parallel to strike (Plates 7-9) show relatively constant Morrow Formation thicknesses along section and a tendency toward more consistent bioclastic marker lateral correlations compared to dip-oriented sections where this marker unit more readily pinches out into shales and is more difficult to correlate laterally.

The stratigraphic relationships observed from contrasting the two cross section orientations suggest the average Morrowan depositional strike (average orientation of the Morrowan strandline) is parallel to the structural strike in the area. The Morrow Formation thickening basinward with corresponding basin subsidence, onlap of the "Bond" silt zone shelfward and more consistent lateral correlations of the bioclastic marker along strike (see Chapter IV) are suggestive of a Morrowan strandline that was relatively parallel to the present-day structural strike. Hence the orientation of the cross sectional network occurs parallel and perpendicular to both structural and depositional strike which appear relatively equivalent in the Canton area.

Atokan Stratigraphy

Atokan strata in the Canton area consists of interbedded limestones, silty limestones, limestone conglomerates and shales that reflect a depositional environment conducive to alternating carbonate and shale deposition. An average of three to five distinct limestone beds occur in the Atokan Thirteen Finger Limestone which shows an electric-log pattern of alternating 2-15 foot thick shale beds. Correlations between individual limestone and shale beds in the Thirteen Finger Limestone resulted in the delineation of three chronostratigraphically equivalent Atokan marker horizons A, B and C that were used to illustrate the shelfward onlap character of the Thirteen Finger Limestone on the Morrow Formation. These correlations helped determine the exact position of the Atokan-Morrowan unconformity contact in the Canton area. (See stratigraphic cross sections, Plates 2-9.)

Strip logs and cores observed (Wiley No. 1, Appendix B) in the Canton area show that the Thirteen Finger limestones are grey to green-grey argillaceous fine calcirudite-calcarenite skeletal wackestones and crystalline mudstones. The carbonate wackestones and mudstones contain silty quartz grains, sparse limestone pebbles, irregular silty shale laminea and are locally bioturbated. The limestone conglomerates in Wiley No. 1 (Appendix B) are characterized by grey limestone pebbles in an argillaceous, crumbly carbonate mudstone. The interbedded finer grained rocks in the Thirteen Finger interval include calcareous siltstones and black shales.

The contacts between the carbonates and shales within the Thirteen Finger interval are generally transitional in the Wiley No. 1 core, yet are distinctive enough to generate sharp limestone and shale lithologic contrasts on electric logs throughout the Canton area (Plates 2-9). Thicker, more laterally consistent individual limestone beds occur in the upper portions of the Thirteen Finger Limestone with thinner, more argillaceous and less correlatable limestones in the lower portions near the Morrow unconformity surface in the Canton area.

The Thirteen Finger Limestone thins shelfward to the northeast. This is illustrated in dip-oriented cross sections A_1-A_2, B_1-B_4, and C_1-C_2 (Plates 2-6), where the Thirteen Finger unit thins from its basinward to shelfward extremes by 36, 39, and 54 feet, respectively. The total thickness of the Thirteen Finger Limestone in the Canton area varies from approximately 100 feet on the basinward extremes of cross sections A_1-A_2, B_1-B_4, and C_1-C_2 to 31 feet at the shelfward extreme of cross section B_1-B_4 (Plate 5).

Morrow-Atoka Unconformity

The contact between Morrow and Atoka strata in the Canton area occurs at the base of the Thirteen Finger Limestone, identified on electric logs by highly resistive basal Atokan limestones in contact with Upper Morrow shales. (See Plates 2-9 and type log, Figure 5.) Although the elctric log character of this contact is obvious in some wells (Plate 4), it is not so obvious in other wells due to casing shoes near the contact which affect electric-log curves, and/or Upper Morrow limestone beds which are difficult to distinguish from Atokan limestone on electric logs. Because of this, the Atokan marker horizons A, B, and C were correlated to insure a consistent lateral stratigraphic position of the Atokan-Morrowan contact throughout the cross section network.

The Atokan marker horizons A, B, and C are defined by correlating limestone beds that are assumed to be equivalent chronostratigraphically. The marker horizons where correlated sequentially down section from the top of the Thirteen Finger Limestone datum and their stratigraphic position is insured three dimensionally by the cross section network. Errors, if they exist, are most probable in the C marker horizon which occurs lower in the Atokan section where the individual limestone units are thinner, more argillaceous and not as laterally consistent as limestone beds in the upper portions of the Thirteen Finger interval. If these errors occur, they are negligible and do not influence the positioning of the Morrow-Atoka contact in the cross section network or diminish the usefulness of the C marker horizon with respect to illustrating the onlapping character of the Thirteen Finger Limestone. (See Plates 2-9.)

In the Canton area, the behavior of the Atokan marker horizons and Morrow Formation markers in a shelfward direction suggests the presence of an unconformity between Morrow and Atoka strata. Onlap of the early Atokan C marker on the Morrow Formation is observable in all dip-oriented cross sections (Plates 2-6), with the stratigraphically higher Atokan B marker onlapping the Morrow surface shelfward of the Atokan C marker in section B_3-B_4 (Plate 5). The onlapping character of the Atokan markers generates a "shingling effect" where progressively younger basal Atokan strata contacts Morrowan age rocks.

This relationship suggests the contact between the Thirteen Finger Limestone and Morrow Formation in a shelfward direction is unconformable and records the boundary between Morrowan and Atokan deposition in the Canton area. However, this contact is not chronostratigraphically equivalent because the "shingling effect" implies contemporaneous basinward Atokan age deposition and shelfward erosion during Thirteen Finger Limestone deposition in the Canton area.

The behavior of the Morrow Formation below the Atokan Thirteen Finger Limestone is best illustrated on cross section B_1-B_4 (Plates 3-5) which trends northeast of the Southwest Canton Field and farther shelfward of any cross section in the network (Figure 2). In the shelfward extreme of this cross section, both the Morrowan-Chesterian unconformable contact and the Morrowan age bioclastic marker are truncated by the pre-Atokan unconformity surface. This results in Atokan strata unconformably contacting Chesterian strata shelfward of the Morrow Formation subcrop. Here, the Morrow truncations are angular and suggest that an angular unconformity separates Atokan and Morrowan strata at the shelfward limits of the Morrow Formation in the Anadarko Basin shelf area. A schematic diagram of the unconformity and its relationship to Atokan and Morrowan strata is shown in Figure 6.

Chesterian Stratigraphy

The type log in Figure 5 shows the stratigraphic position and electric-log character of the Upper Mississippian Chesterian strata below the Morrow Formation. Two limestone zones separated by a 30-to-40 foot shale characterize the Chesterian strata in the area. The author divided the Chesterian strata immediately below the Morrow Formation into Upper and Lower units based on the presence of two distinct Chesterian limestone units below the Morrow interval (Figure 5). Although this division agrees in part with scout-ticket information in the area, the author does not know how applicable a stratigraphically equivalent Upper and Lower Chesterian division is regionally or how consistent this division is with that of other workers in the Anadarko shelf area. However, it is useful to consider the Chesterian strata immediately below the Morrow Formation in terms of Upper and Lower to delineate stratigraphic relationships at the Pennsylvanian-Mississippian contact in the Canton area. The terms Upper and Lower Chester are purely descriptive terms

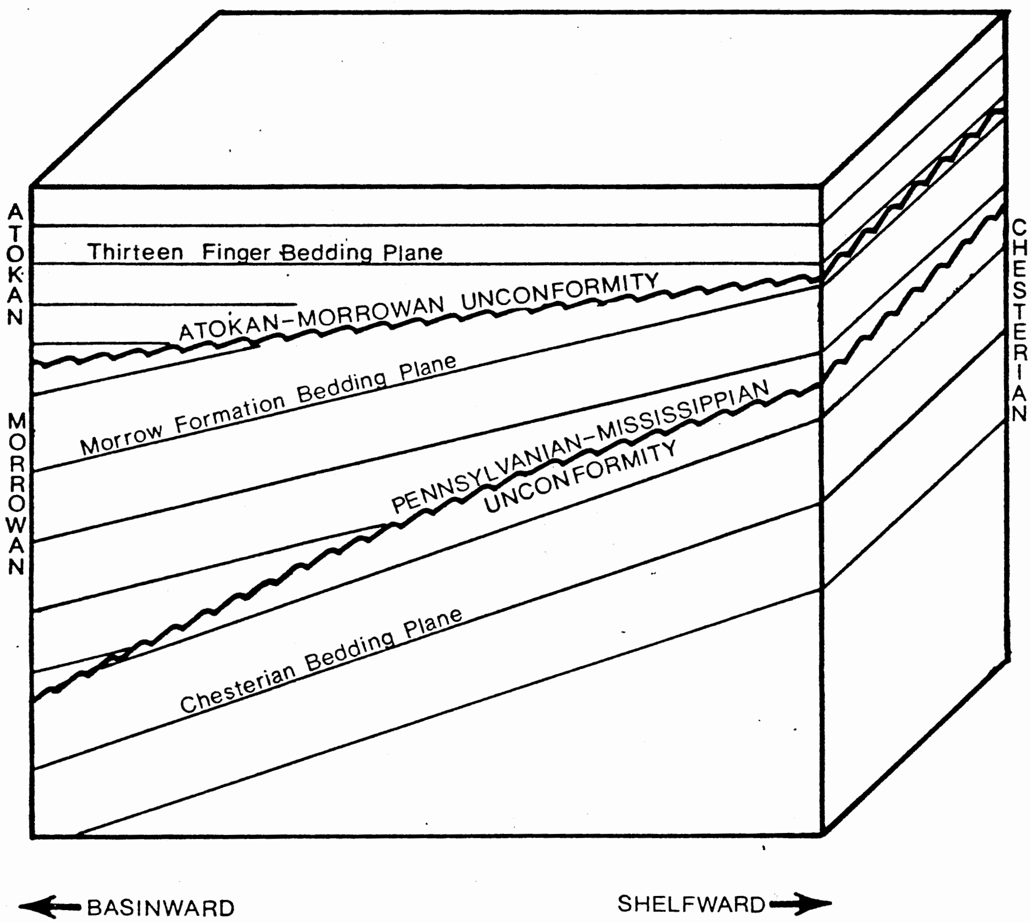

Figure 6. Schematic Diagram of the Late Mississippian-Early Pennsylvanian Stratigraphy, Canton Area

as used in this study and imply no regional stratigraphic significance. Applications of this terminology elsewhere in the Anadarko Basin should not be made without regional correlations.

Lithologically, the Upper and Lower Chesterian units show a different character. Strip logs in the area show the Upper Chester zone to be interbedded thin (1-15 ft) grey to green-grey argillaceous limestone and grey calcareous silts and shales. The Upper Chesterian argillaceous carbonates have a sharp contact with the Morrowan shales and sands, and are gradational downsection into grey to brown-grey calcareous silts and splintery shales.

Lower Chester rocks are lighter colored buff to light grey limestones that are texturally slightly granular to finely crystalline and chalky. These rocks contain oolite zones and are slightly argillaceous. A 10-to-20 ft thick limestone unit occurs in the upper portion of the Lower Chester, which sharply contacts Upper Chesterian shales. This contact is a consistent marker in the area when well penetration is deep enough and is the deepest horizon correlated in the cross section network (Plates 2-9).

The different lithologic character between Upper and Lower Chesterian strata reflects different environmental conditions prevailing in Late Mississippian time. The presence of oolitic zones in the Lower Chester carbonates suggests periodic high energy conditions in supersaturated shallow marine tropical waters. The more argillaceous Upper Chesterian limestones and shales imply a greater siliclastic influence later in Chesterian time before Morrowan deposition.

The basinward-shelfward stratigraphic behavior of the Chester carbonates below the Morrow Formation is best illustrated on dip-oriented cross sections A_1-A_2, B_1-B_4, and C_1-C_2 (Plates 2-6). A schematic representation of Chesterian stratigraphy is shown in Figure 6. In a basinward direction the Upper Chester carbonate and shale interval thins by 40, 70, and 70 feet in sections A_1-A_2, B_1-B_4, and C_1-C_2, respectively. In the Upper Chester zone, the argillaceous carbonates above the shales thin basinward to zero thickness, leaving only Upper Chesterian shales above Lower Chester carbonates in the southwest portion of the Southwest Canton Field (see, for example, wells 6, 7, and 8, Plate 3). The basinward thinning of the Upper Chester limestones is contrary to the regional Chesterian and Morrowan series trend of basinward thickening in the Anadarko Basin (Shelton, 1982) and is suggestive of basinward erosional truncation of the Upper Chester in the Canton area (Figure 6). Shelfward in cross section B_3-B_4, the Upper Chesterian section thins from 100 feet to 50 feet at B_4 northeast of the Southwest Canton Field. This thinning is caused by 1) erosional truncation of Upper Chesterian strata shelfward of the Morrow Formation truncation, where Chesterian strata unconformably contact Atokan strata, and 2) shelfward thinning by onlap of Upper Chesterian strata on Lower Chesterian strata, as seen between wells 20 and 21 in B_3-B_4. Here the Upper Chester thins shelfward from approximately 95 to 60 feet along a 2½-mile distance.

Pennsylvanian-Mississippian Unconformity

A review of published documents in northwestern Oklahoma and the Texas/Oklahoma Panhandle regions suggests a certain degree of variability occurs with respect to the exact stratigraphic position of the Pennsylvanian-Mississippian unconformity between Chesterian and Morrowan strata. Most workers in their study areas picked the

Mississippian land surface at the top of the first massive limestone unit in the Chesterian series (Forgotson, 1967; Khaiwka, 1968; Davis, 1971; Mannard and Busch, 1974; and Shelby, 1980). Swanson (1979) and Curtis and Ostergard (1980) published type logs representative of their study areas with the Pennsylvanian-Mississippian unconformity picked at the base of the oldest distinct Morrow sand. However, a close inspection of their published stratigraphic cross sections shows the unconformity is commonly picked at the top of the Chesterian limestones where a basal Morrow sand is not present or as a result of the unconformity varying in stratigraphic position laterally.

Clement (1977) picked the unconformity at the bottom of the basal Springer sand in the Geary area (T13N, R10W) southeast of the Canton area, in the Watonga trend. Clement (1977) mentioned that his inconformity pick is not certain because Chesterian age flora were found in a Springerian core in the Geary area.

A similar disparity occurs in unpublished industry reports. An unpublished Amoco report in the Canton area shows the Mississippian unconformity at the base of the lowermost Morrow sand. Conversely, 1978 unpublished cross sections from Bunker Exploration Company in Dewey County (T18N, R18W) 15 miles west of the Canton study area show the Mississippian unconformity at the top of the first massive limestone below Morrow sands and shales in the Upper Chester.

Pennsylvanian-Mississippian Unconformity in the Canton Area

Figure 6 shows the stratigraphic character of the Pennsylvanian-Mississippian unconformity on the Anadarko shelf, Canton area. The cross sectional network (Plates 2-9) illustrates the stratigraphic position of the Mississippian-Pennsylvanian unconformity in the Canton area. Here, the Pennsylvanian-Mississippian boundary is positioned on top of the Upper Chesterian argillaceous carbonates where they exist. Basinward to the southwest, the Upper Chester argillaceous carbonates thin to zero thickness, leaving the Mississippian boundary in shales between Lower Chester limestones and Lower Morrow sands (Plates 2-6).

The stratigraphic position of the Pennsylvanian-Mississippian boundary in the Canton area is based largely on the stratigraphic relationships between Morrowan and Chesterian strata illustrated on the cross sectional network. The stratigraphic evidence for the existence of an unconformity between Morrow and Chester strata is convincing in the Canton area. This evidence is as follows:

1. Basinward thinning of the Upper Chester Limestone is contrary to the regional Chesterian series and Morrowan series trend of basinward thickening toward the Anadarko Basin axis. Resistivity and gamma ray markers 1 and 2 in the Upper Chester are truncated basinward in all dip-oriented cross sections, suggesting that erosional truncation is a mechanism responsible for basinward Upper Chesterian thinning. (See wells 4-6, C_1-C_2; wells 8-13, B_1-B_3; wells 5-8, A_1-A_2; in Plates 2-6.)

2. Upper Chesterian strata thins shelfward of the Morrow Formation truncation where cleaner, more resistive Atokan Thirteen Finger limestones unconformably contact less resistive Upper Chesterian argillaceous limestones (see cross section B_3-B_4). Here, markers in the Upper Chesterian limestones show Upper Chester thinning by erosional truncation shelfward, which is recorded along the Atokan-Upper Mississippian unconformable contact.

3. Lithologic contrasts between Chesterian and Morrowan strata are supportive of an unconformity existing between Chesterian and Morrowan rocks. Cores in the Canton area (Appendix B) show that the Lower Morrow Formation consists primarily of arenaceous quartz-dominated sands and carbonaceous coaly shales above the carbonate and shale dominated Chesterian section. This different lithologic character suggests that different environmental contexts existed in Morrowan and Chesterian time. This difference may have occurred with a major erosional period.

4. Lower Morrow "Bond" zone silty sands onlap onto the Upper Chester limestones shelfward in dip-oriented cross sections B_1-B_4 and C_1-C_2 (Plates 3-6). Where this onlap occurs, the stratigraphic position of the Pennsylvanian-Mississippian unconformity is pinpointed on top of the Upper Chesterian limestones (see wells 5-6, C_1-C_2; wells 14-15, B_2-B_3).

Basinward of the Upper Chesterian argillaceous carbonate truncation, the position of the Morrowan-Chesterian unconformity is difficult to pick. Basinward correlations in dip-oriented cross sections B_1-B_4 and C_1-C_2 (Plates 3-6) show the unconformity at the base of a relatively low-conductivity zone approximately 30-40 feet above Lower Chester carbonates in shales. The position of the unconformity here is based on shelfward lateral correlations from the top of the Upper Chester limestone. A subtle gamma-ray curve increase may also accompany the decreased conductivity curve. Northwestward, at the basinward extremes of cross section A_1-A_2, the unconformity is picked approximately 75 feet above the Lower Chester. Although these correlations are consistent within the cross-section network, the exact position of the Pennsylvanian-Mississippian unconformity basinward of the truncated Upper Chester limestones is questionable, because the unconformity is in shales and may vary vertically upsection or downsection. Additional palynologic and paleontologic data are needed to pinpoint the exact position of the unconformity basinward of the Southwest Canton Field, where it occurs in shales.

Springeran Strata in the Canton Area

In this study, the entire interval between the basal Atokan unconformity and the Pre-Pennsylvanian unconformity is termed Morrowan, with no reference to the Springeran strata. Springeran rocks exist in the deeper portions of the Anadarko Basin between Lower Morrow sands and shales and Chesterian carbonates. The exact age of Springer rocks--whether they are Mississippian or Pennsylvanian or both--is debated among different workers in the Basin. Clement (1977) noted floral assemblages characteristic of Chesterian strata in a core through the Springeran interval north of the Geary area (T13N, R10W).

Most workers agree that Springeran rocks do not exist in the Canton area because they subcrop basinward of the Southwest Canton Field near the Anadarko Basin hingeline (Clement, 1977; Shelton, 1982).

The author cannot guarantee that no Sprinteran strata exist in the study area. If Springeran strata do exist, they probably occur in the southern extremes of the study area, basinward of the Upper Chesterian truncation in shales above the Lower Chester carbonates. Regional correlations from known Springeran areas into the Canton area are required to substantiate the presence or absence of Springeran rocks in the study area.

Morrowan Stratigraphy

Strata of the Morrow Formation in the Canton area were the first Pennsylvanian rocks deposited on Mississippian Chester carbonates in the study area. Cores in the study area show the Morrow interval consists primarily of quartz sands, shales and thin bioclastic carbonate units. The stratigraphic character of the Morrow Formation in the Canton area is shown schematically in Figure 6.

All dip-oriented stratigraphic cross sections (Plates 2-6) illustrate basinward thickening of the Morrow Formation across the study area from northeast to southwest. In cross section B_1-B_4 (Plates 3-5), the Morrow Formation is truncated to zero feet thick 5½ miles northeast of the Southwest Canton Field near B_4, and thickens basinward to approximately 450 feet three miles southwest of the field at B_1.

In the Canton study area, the Morrow Formation is divided into lower and upper zones based on:

1. a different lithologic character between stratigraphically lower and stratigraphically higher Morrow sediments, and

2. the presence of a correlatable bioclastic limestone marker that forms a boundary between and separates the Upper and Lower Morrow sediments (Plates 2-9). Although other workers in northwestern Oklahoma have divided the Morrow Formation similarly (Curtis and Ostergard, 1971; Swanson, 1979; and Shelby, 1980), the terms Upper and Lower Morrow in this study have no regional significance and are purely descriptive terms for local use within the study area context.

The Upper Morrow interval consists primarily of grey, partly fissile, splintery shales and sparse thin arenaceous and argillaceous limestones. The shales generally comprise about 80% of the Upper

Morrow section in the area. Strip logs indicate that the shales may be arenaceous and marly, with the carbonate sands generally less than 10 feet thick. The thin limestones are buff-to-brown lenticular units with sharp basal and upper contacts. An example occurs in Well 21, cross section E_1-E_2, where a 9-foot thick limestone 10 beet below the Atokan unconformity pinches out laterally to zero feet in well 4, two and three-fourths miles southeast. No quartz-dominated sands were identified from strip logs in the Upper Morrow interval. Thickness of the Upper Morrow ranges from approximately 160 feet in the basinward extreme of cross section C_1-C_2 to zero feet shelfward, where it is in unconformable contact with Atokan strata.

The Lower Morrow interval in the study area is between the bioclastic limestone marker and Pre-Pennsylvanian unconformity correlated in the cross section network. This unit consists of quartz sands, carbonate sands and shales. The shales occur above, within and below the sandiest portion of the Lower Morrow (called here, the Lower Morrow sand zone). At many places, this sandy zone is marked by a lowermost Morrow sand that occurs above shales and the Pre-Pennsylvanian unconformity (see type log, Figure 5). Oil and gas production in the Southwest Canton Field is restricted to the Lower Morrow interval, which is reflective of better sand development in the Lower Morrow sediments compared to the Upper Morrow sediments.

A general increase in the total thickness of sands and shales in the Lower Morrow is reflected in basinward thickening of the interval. Cross section B_1-B_4 shows the Lower Morrow interval thickens from 0 feet to approximately 250 feet southwest and basinward along the section.

Correlatable Morrowan Units

Correlatable units in the Morrow Formation in the Canton area include a thin bioclastic limestone unit and the "Bond" silt zone. The lowermost Morrowan sands were not correlated because they vary in stratigraphic position and are not chronostratigraphically equivalent. (See well 13 in cross section D_2-D_3; wells 10-13 in B_2-B_3, which show the channels downcutting into deeper stratigraphic levels.) All correlated markers are shown on the cross sectional network (Plates 2-9).

Cores and strip logs indicate that the bioclastic marker is a shoaling shallow marine unit characterized by skeletal debris, ooliths and cross bedding. This marker unit is generally no thicker than 5 feet, and is more consistently correlatable along strike-oriented sections D_1-D_3 and E_1-E_2 than dip-oriented sections A_1-A_2, B_1-B_4, and C_1-C_2. The marker unit pinches out laterally into shales between wells 4 and 6 in B_2-B_3, is difficult to trace between wells 4 and 8 in section C_1-C_2 (due to the presence of stratigraphically equivalent sand bodies), and is almost totally shale along the entire length of section A_1-A_2. The lenticular nature of the bioclastic marker along dip-oriented sections versus easier correlations along strike-oriented sections suggests that use of the marker as a mappable chronostratigraphic horizon in the study area is questionable. Stratigraphic maps of this horizon were not constructed because of the difficulty and uncertainty in lateral correlations.

The "Bond" silt zone consists of a basinward thickening (from 1 foot to 30 feet in Plates 3-4), dark grey clayey siltstone unit that occurs locally in Morrow shales below the lowermost Morrow sand in the

Southwest Canton Field area. This unit onlaps the Pennsylvanian-Mississippian unconformity in the southern portion of the Southwest Canton Field (see Plates 3-6), and pinches out laterally to the northeast (see Plate 7). Although this unit is important for locating the position of the Pennsylvanian-Mississippian unconformity in the Canton area, its use as a mappable horizon is restricted because of its limited areal extent in the Canton area.

Stratigraphic Summary in the Canton Area

A summary of the stratigraphic features in the Canton area include the following:

1. Stratigraphic evidence from the cross-section network suggests that Morrow deposition occurred following a Pre-Pennsylvanian erosional event that truncated Chesterian strata. Truncated Upper Chesterian strata occur basinward on all dip-oriented cross sections.

2. Early Pennsylvanian basin subsidence accompanied by Morrow depostition resulted in a thicker Morrow section basinward. Onlap of the Bond silt zone in the Lower Morrow suggests that shelfward thinning by onlap was a factor.

3. Regional warping tilted Morrow strata before Atokan deposition but after withdrawal of Morrowan seas, which exposed Morrowan strata to erosion. This resulted in a shelfward truncation of Morrow strata and the angular unconformity relationship shown on section B_3-B_4.

4. Atokan deposition was initiated basinward after transgression, but the shelf area was still exposed and undergoing erosion. Chronostratigraphically younger Atokan beds contact Morrowan strata shelfward. This indiates that the Morrow-Atokan boundary is not

chronostratigraphically equivalent, for erosion and deposition were occurring contemporaneously early in Atokan time.

5. Continued shelfward onlap and basinward thickening of the Thirteen Finger limestones reflects basin subsidence and transgression.

CHAPTER IV

SEDIMENTOLOGIC CHARACTER AND DEPOSITIONAL ENVIRONMENT

Introduction and Morrowan Genetic Units

Five distinct genetic units were identified in the Morrow Formation from cores observed in the Canton area. Shales, quartz-dominated channel sands, skeletal-dominated channel sands, skeletal buildup banks and highly bioturbated quartz wacke sands occur consistently in the area. The sands form a Lower Morrow sand zone which produces oil and gas in the Canton area (see cross-section network, Plates 2-9).

Quartz Dominated Channel Sands - Type 1

The quartz-dominated channel sands are represented in most of the cores observed. A photograph of this sand type is shown in Figure 7. Type examples characteristic of the area occur in Tidball No. 4, DeMoss A-1, Frank Schafer No. 1, and Thomas No. 1 core (Appendix B). Characteristic features of this genetic unit include sharp-to-erosional basal contacts, upward fining grain size, and a light-to-dark grey sand color. The sandstone in these rocks is quartz arenite, which may grade through quartz wacke sandstone to clayey sandstone and coaly black shales containing wood fragments upsection (as in Tidball No. 4 and Paul Willis A-5, Appendix B).

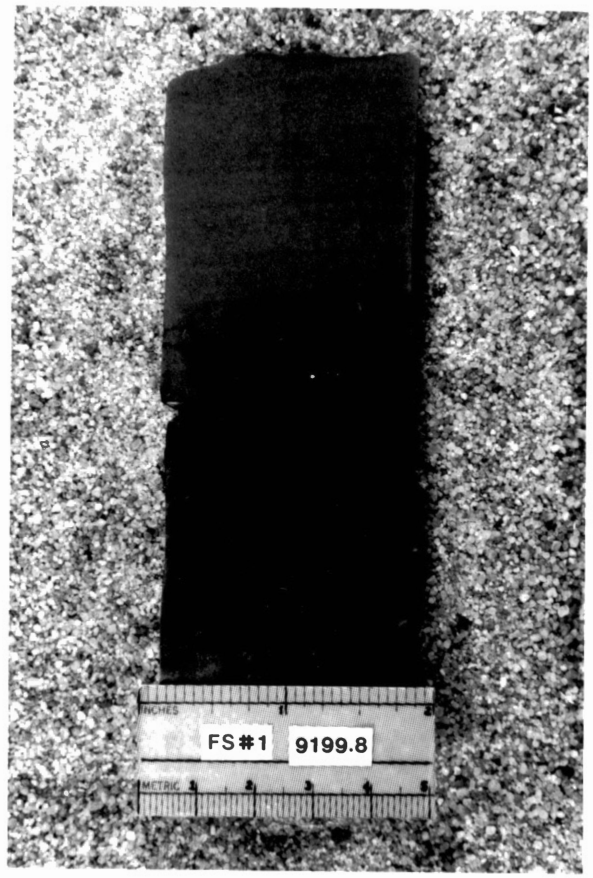

Figure 7. A Type 1 Terrestrial Channel Sand. (Note the carbonaceous styolites and initial dip [cross?] bedding. Photograph is of the Frank Schafer No. 1 core.)

The quartz-dominated channel sands are divided into different types based on inherent lithologic differences, the presence or absence of a conglomeratic base, and stratigraphic position in the Lower Morrow.

Type 1 quartz-dominated channel sands are characterized by lithic pebble sandy conglomerate basal zones that grade upsection into nonfossiliferous medium to very fine grained siliclastic sands. The conglomerates are polymitic and consist of subrounded siderite, dolomite, skeletal limestone, collophane, siltstone-shale and black skeletal shale pebbles in a coarse to fine grained quartz matrix. The multiple pebble types suggest more than one source area. Sedimentologically, the conglomerates are generally massive, fine upwards and may show repetitive scour based upward fining zones with pebble imbrication. The conglomerates may also have interbedded light green-to-grey zones containing subhorizontal coaly vitrainized carbonaceous laminations. The basal conglomerates are generally less than five feet thick in the area (see Appendix B), and may be slightly fossiliferous (2% in Tidball No. 4) to nonfossiliferous (DeMoss No. 1).

Sedimentary structures in the channel sands include horizontal bedding, medium scale trough crossbedding and ripples. Massive strata are also common. Carbonaceous and black shale influx in the form of carbonaceous wisps, carbonaceous styolitic laminations, and occasional horizontal siltstone to shale laminations are common in this channel type. In Tidball No. 4, the sands were occasionally burrowed with some minor penecontemporaneous deformation near interlaminated shale zones. Scour and fill structures with clay drapes along the scoured surfaces occur in the dirtier quartz wacke sands of Tidball No. 4. In the DeMoss A-1 core, occasional intraformational clay pebbles were scattered throughout the producing sand unit which erosionally rests on black shale containing wood fragments.

Channel sands of this type show differences in the character of the upper genetic unit contact and degree or rate of upward fining between individual sand units. For example, the basal channel sand in Tidball No. 4 grades upsection from conglomerates into medium to very fine grained sands that are cross and horizontally-bedded, then into bioturbated clayey sands with silts and finally into coaly wood fragmented black shales. This gradation occurs in about 25 to 30 feet in Tidball No. 4 and occurs in 19 feet of quartz arenite and quartz wacke sandstone. However, the quartz arenitic sands in DeMoss No. A-1 show a relatively consistent fine to very fine grain size above the basal conglomerates with a log curve suggestive of a sharper, less gradational upper genetic unit contact. The sandstone here is 36 feet thick and does show a bell-shaped upward fining gamma ray curve in the upper six feet of the genetic unit.

The type 1 quartz dominated channel sands are interpreted as terrestrial point bars and/or small delta distributary channel fill sandstones. The erosive basal contacts, basal conglomerates, upward fining grain sizes, trough cross stratification, thickness and lenticular morphologies in cross section are features characteristic of channel sands. In core (i.e., Tidball No. 4, DeMoss A-1 and Frank Schafer No. 1, Appendix B), the type 1 sands contain carbonaceous styolites, are characterized by a nonfossiliferous, nonglauconitic petrographic character, and occur in stratigraphic association with black shales that consist of coal and wood fragments. These features imply the type 1 sands where perhaps deposited in an environment associated with terrestrial sediments.

Goetz (and others, 1977), in efforts to distinguish sand types on electric-logs, suggested it is possible to differentiate point bar and delta distributary fill channel sands from borehole evidence (i.e., electric-logs ± core). In accordance with Goetz (and others, 1977), delta distributary channels have a more consistent grainsize upsection and a sharper, less gradational upper contact (as in DeMoss A-1, Appendix B) than point bar channels. Conversely, point bar sands show distinct upward fining grain sizes and more transitional upper contacts into organic shales (as in Tidball No. 4, Appendix B) ideally.

In the Canton area it is difficult to specify conclusively whether a particular type 1 channel sand is actually a point bar or a delta distributary fill sand based on borehole evidence alone. Under certain geologic conditions it may be possible to generate point bar channel sands with relatively consistent grain sizes and sharper upper contacts. However, because of their terrestrial channel-like character, the type 1 sands are interpreted as one of the two types--point bar or delta distributary channel fill sands--or some combination of both.

The type 1 channel sands were probably deposited in very small deltas or subareal lowland coastal settings. Electric logs and cores representing the Morrow Formation show a lack of thick, delta-like upward coarsening sequences in the Canton area. Moreover, as discussed in Chapter II, the Canton area occurs within a relatively stable structural context where subsidence rates were low and not condusive to major deltaic development.

Quartz Dominated Channel Sands - Type 2

Type 2 quartz dominated channel sands differ from type 1 above because they may or may not have a conglomeratic base, show local skeletal influx zones, contain glauconite and generally occur at a higher stratigraphic position within the Lower Morrow interval than the type 1 quartz dominated channel sands. Otherwise the type 2 and type 1 quartz dominated channel sands are quite similar in a lithologic and sedimentologic sense.

Characteristic examples of type 2 quartz dominated channel sands occur in the Frank Schafer No. 1 core at 9,200 feet and the Thomas No. 1 plugs at 9,520 feet (Appendix B). Sandstone types include quartz arenites, skeletal quartz arenites, quartz wackes, and local arenaceous skeletal packstone zones. These rocks fine upwards from fine to very fine grained in Frank Schafer No. 1 (a trend which is not discernible on electric log curves). In Thomas No. 1, the very fine quartz grain size is consistent throughout the genetic unit. The skeletal grains decrease in percent and maximum size from fine calcirudite to fine calcarenite upsection. Characteristic features in these sands include medium to small scale cross bedding, massive and horizontal bedding, carbonaceous styolites, carbonaceous wisps and occasional shale influx zones that are rippled with flaser bedding. The irregular carbonaceous laminations and wisps are more common in the dirtier sand upsection from the cleaner massive and cross stratified sands. Intraformational clay clasts are scattered throughout the sand in the Frank Schafer No. 1 core, with an increase in mottled bedding (bioturbation) toward the top of the Thomas No. 1 genetic unit.

Type 2 quartz dominated channel sands are interpreted as marine influenced channels in the transitional zone seaward of type 1 terrestrial influenced channel sands. The similar characteristics of both type 1 and type 2 quartz dominated channels suggests they may be genetically related. However, the presence of skeletal zones and enhanced glauconite content in type 2 channels suggests these sands may have been deposited seaward of the type 1 terrestrial sands during type 1 deposition. This would explain the stratigraphically higher position of the type 2 sands with respect to the type 1 sands in the Canton area cores (i.e., Frank Schafer No. 1 and Thomas No. 1, Appendix B), presumably caused by Anadarko Basin subsidence and Morrowan sea transgression.

Arenaceous Skeletal Dominated Channel Sands

A second genetic unit type includes skeletal dominated channel sands. An example of this sand type is shown in Figure 8. This genetic type consists of dark-to-light grey arenaceous skeletal medium calcirudite to medium calcarenite grainstones and packstones. This unit shows sharp to erosional basal contacts with sharp, erosional and transitional upper contacts, and is generally thinner (3½ to 12 feet thick) than the quartz dominated channel sands. Cores in the Southwest Canton Field area show the skeletal dominated channel sands most often occur at a higher stratigraphic position than the quartz dominated channel sands; they were never observed as a lowermost Morrow sand. (See Tidball No. 4, Thomas No. 1, Frank Schafer No. 1, Kephart No. 1, and Paul Willis No. A-5 in Appendix B, for example.)

Lithologically, this genetic unit shows an overall decrease in skeletal percentage upsection with a corresponding increase in fine to

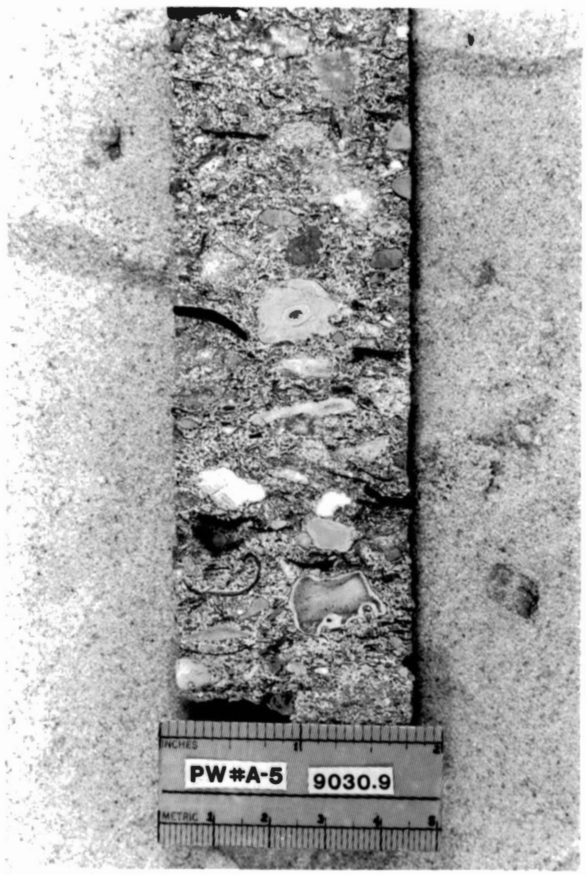

Figure 8. An Arenaceous Skeletal Littoral Channel Sand. (Note the presence of lithic clasts. Photograph is from the basal portion of the genetic unit, Paul Wills A-5.)

medium grained quartz grains. Individual genetic units from different cores show a gradation from very arenaceous skeletal types as in Frank Schafer No. 1) to less arenaceous types (Paul Wills A-5). The skeletal grains are allochtonous and include echinoids, bryzoan, brachiopod, phylloid algae and trilobite fragments (see Chapter V). Lithic pebbles in the form of collophane, siltstone-shale, skeletal limestone and carbonate clasts are most common in the basal portions of this sand type and may be voluminous enough to form a conglomeratic basal zone (as in Figure 8 and in the Kephart No. 1 core). Other clast types include intraformational clay pebbles which are common in the Paul Wills A-5 skeletal channel (Figure 8).

Sedimentologically, this unit is upward fining where it is thick enough to be distinguished (in Paul Wills No. A-5, Frank Schafer No. 1 and Kephart No. 1), with massive basal zones that contain local scour and graded bedding (in Kephart No. 1 and Frank Schafer No. 1). Horizontal bedding and cross bedding occur sequentially upsection from the massive basal zone in Paul Wills No. 5 (Appendix B).

In all cores this genetic unit shows a general increase in shale content upsection, resulting in skeletal packstones with an increase in irregular carbonaceous laminations and observable penecontemporaneous deformation (see Frank Schafer No. 1). The sedimentary features observed in this genetic unit reflect a response to a waning flow regime.

The prominence of skeletal grains and channel-like sedimentary character suggest that the arenaceous skeletal dominated sands were deposited as marine influenced tidal or estuarine channels occurring within a littoral context. The channel types described herein have a similar sedimentary character and show a complete gradation from quartz arenites and wackes to skeletal quartz arenites and wackes to very arenaceous skeletal grainstones and packstones, and finally to less arenaceous skeletal grainstones and packstones. These different lithologic types probably represent a relatively continuous system of channel deposition within a transitional zone context whereby within a chronostratigraphically equivalent time framework the skeletal dominated sands were deposited in marine conditions away from siliclastic influences associated with the quartz dominated fluvial sands landward. The higher stratigraphic position of the skeletal dominated channel sands above the quartz arenitic channel sands in the Thomas No. 1, Frank Schafer No. 1, Tidball No. 4 and Paul Wills No. A-5 cores in the southwest Canton area supports this hypothesis (Figure 7).

Nonarenaceous Skeletal Dominated Buildups and Thin Channels

Nonarenaceous light grey-to-grey-green skeletal fine to medium calcirudite grainstone and packstone buildups constitute the third fundamental genetic unit type observed in cores. A photograph of this genetic unit is shown in Figure 9. These carbonate sands occur stratigraphically above the lower Morrow channel sand zone in shales associated with the Upper Morrow and upper portions of the Lower Morrow. This genetic unit characterizes the bioclastic marker unit correlated on the cross section network (Plates 2-9). This sand is the thinnest of all sand types in the Canton area (generally less than 5 feet), occurs within black glauconitic shales, and is laterally gradational into argillaceous, wackestones, mudstones, and skeletal shales. As mentioned in Chapter III, the lenticular nature of these buildups is most apparent

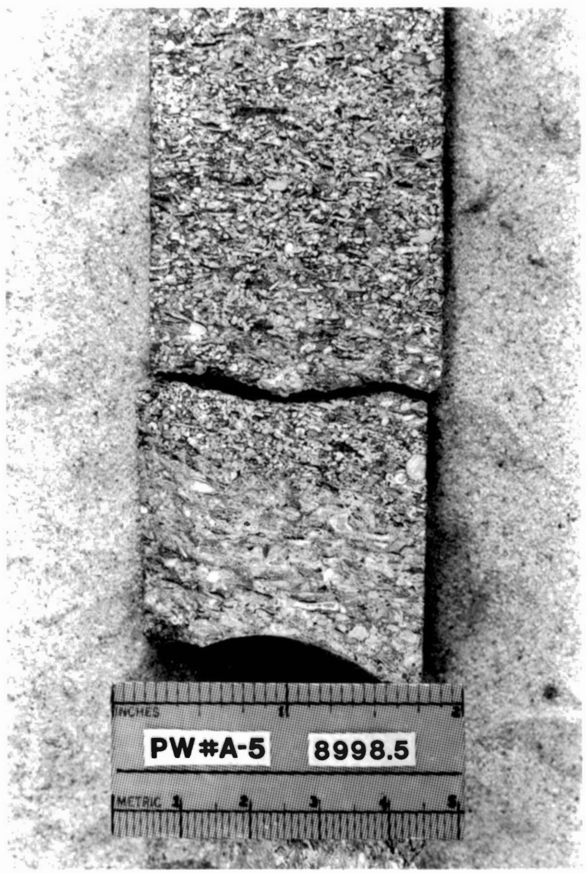

Figure 9. A Nonarenaceous Skeletal Grainstone. (This sand represents a shallow marine shoaling buildup. Note the upward fining character in this example. Example was photographed from the Paul Wills A-5 core.)

along sections perpendicular to strike (compare Plates 2-6 to Plates 7-9, for example).

Lithologically, this unit consists primarily of skeletal fragments, argillaceous matrix, and traces of glauconite. The skeletal grains are allochtonous and include echinoids, gastropods, bryzoans, brachiopods, trilobites and pelcypods (see Chapter V).

This unit shows sharp basal contacts and sharp to transitional upper contacts (based on electric log character) in the cleaner grainstones and packstones (as in Paul Wills A-5). As shown in the Tidball No. 4 core, more transitional contacts characterize the argillaceous types.

Sedimentary structures in this unit include ripples, cross stratification, horizontal bedding, occasional irregular horizontal shale laminations and penecontemporaneous deformation features (see Tidball No. 4; Paul Wills A-5). A slightly larger skeletal grainsize zone occurs in the basal portion of the Paul Wills No. A-5 (Figure 9). This example suggests at least some of the thin nonarenaceous skeletal sands in or near the Upper Morrow have an upward fining character.

This thin nonarenaceous skeletal dominated sand type is interpreted as marine influenced thin channels and shoaling buildups deposited away from quartz sand influence. The fact that this genetic unit type is nonarenaceous, rich in skeletal fragments, relatively thin and occurs with glauconitic shales suggests these sands may be shallow marine shoaling channels and buildups. This genetic unit was probably deposited seaward of the thicker quartz dominated and arenaceous skeletal dominated channel types discussed above.

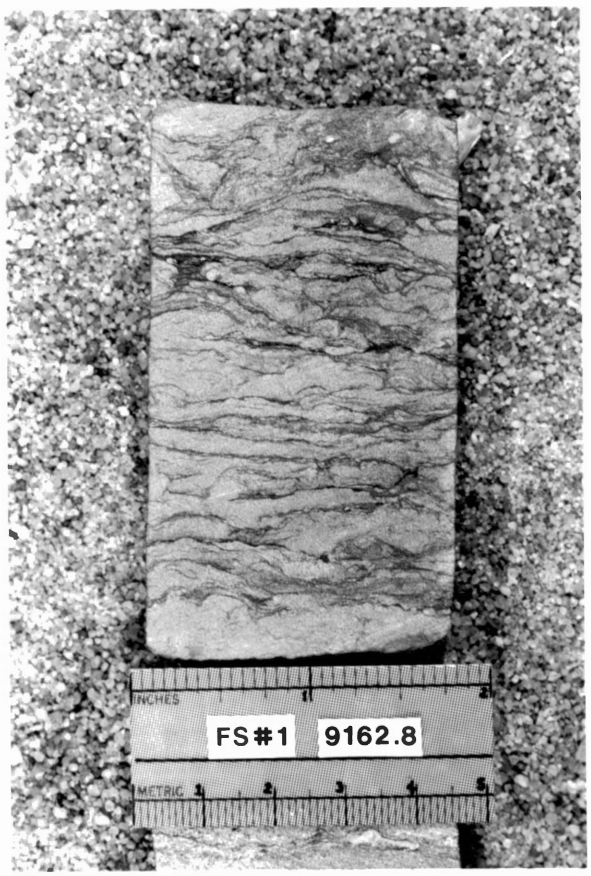

Figure 10. A Bioturbated Quartz Wacke Tidal Flat Sand. (Note the irregular to mottled bedding. Example was photographed from the Frank Schafer No. 1 core.)

Bioturbated Quartz Wacke Tidal Flat Sands

A fourth genetic unit type in the area includes a light to dark grey to green-grey very fine grained bioturbated quartz wacke clayey sandstone. A photograph of this genetic unit is shown in Figure 10. This unit occurs in all cores described within and south of the Southwest Canton Field and is difficult to distinguish on electric logs from the other genetic unit types. Primary characteristics of this genetic unit are relatively sharp to transitional facies unit contacts, trace amounts of glauconite, a consistent very fine grainsize, slightly fossiliferous character and burrowed to extensively bioturbated appearance. This unit consists of intercalated, black shales and sands, with ripples, wavey bedding, penecontemporaneous deformation features and burrows where not extensively bioturbated. Fossil content rarely exceeds 2%, and consists of allochthonous fine to very fine calciarenite size echinoderms, trilobites, brachiopods, gastropods and forams (see Chapter V).

Stratigraphically, this unit occurs near the top of the Lower Morrow sand zone in a similar stratigraphic position as the arenaceous skeletal dominated channel sands. (See Frank Schafer No. 1, Tidball No. 4, Paul Wills No. A-5, Thomas No. 1, and Chain No. 1, Appendix B, for example). In the Southwest Canton Field cores, the thickness of this unit varied from 35 feet in Tidball No. 4 to 10 feet southeastward in Paul Wills No. A-5. The very fine bioturbated quartz wacke clayey sand was absent in cores in the Carlton area, east of the Southwest Canton Field (DeMoss A-1, Kephart No. 1, Winters No. 1, and Wiley No. 1).

This genetic unit is interpreted as a marine reworked littoral sand occurring within a tidal flat context. The fundamental aspects of this sand--its bioturbated nature, slightly fossiliferous character, presence of glauconite, consistent very fine quartz grain size and wavy bedded sedimentary structures where not extensively bioturbated--suggest possible shallow marine reworking of older arenaceous channel sands and shaley interchannel zones following a slight rise in sea level. This presumably resulted in wavy to flaser bedded very fine grained quartz sands and shales that were later burrowed and bioturbated following deposition in a tidal flat regime. The similar stratigraphic position of this genetic unit with the higher energy arenaceous skeletal tidal channels suggest these genetic units were deposited in a similar local environmental context. The bioturbated quartz wacke clayey sands perhaps represent lower energy interchannel zones on the tidal flat.

Morrowan Shales

Two distinct shale types occur in the Lower and Upper Morrow section respectively in the Canton area. Shales in the Lower Morrow are black and contain coal and wood fragments which reflects fluvial environments. In Tidball No. 4, the shales below the lowermost Morrow sand are crumbly and contain brachiopod, gastropod and nonfossiliferous zones with impure siderite and pyrite concretions. Local very thin grained sand to silt influx occurred near the basal Morrow sand in the "Bond" silt zone. Coal was logged in shales on top of the Pre-Pennsylvanian unconformity surface in the Pan American Haigler E-1 well (in a mud and cuttings analysis, unpublished Amoco document). Occasional wood fragments were logged in shales below the lowermost Morrow channel sand in the DeMoss A-1 core. Above the basal Morrow sand within the Lower Morrow sand zone, the shales contain coal horizons, allochtonous wood fragment particles, are crumbly, and are gradational into quartz dominated sands downsection (see Tidball No. 4, Paul Wills A-5, and Frank Schafer No. 1, for example).

Southwest Canton Field cores show Upper Morrow and upper Lower Morrow shales are black, fissile, and contain occasional glauconite and skeletal grains. This reflects a greater marine influence and sapropelic character compared to the Lower Morrow fluvial (or humic) shales.

Presence of Upward Coarsening Bar Sands

No distinct upward coarsening bar-like sand units were observed in the cores studied. However, coarsening upward log curves were sparsely distributed in the study area (see Figure 19). Upward coarsening log curves were also characteristic of three cores examined in the Canton area.

In the Thomas No. 1 core plugs, a very slight upward coarsening grain size occurs in quartz arenites from 9619-9585 feet (Appendix B). In this case, very fine quartz grains nearing silt size grade upsection to very fine quartz grains nearing fine grain size with coarse skeletal fragments. This slight upward coarsening is recorded on the gamma ray log curve (Appendix B).

In the Chain No. 1 plug interval, no distinct increase in quartz grain size occurs upsection. Between 9555 and 9517 feet, this unit is characterized by slightly coarser sands that occur in the middle of the sand body and fine slightly toward the borders of the sand unit. In these core plugs, increased shale content downsection results in an upward coarsening electric-log character (see Figure 11 and Appendix B).

The Winters No. 1 core has an upward coarsening electric-log signature from 8747 to 8715 feet (see Figure 11 and Appendix B). This interval is interpreted as a small deltaic buildup in Appendix B.

The Thomas No. 1 and Chain No. 1 core plug intervals show channel-like sharp basal contacts (with conglomerate in the Chain No. 1), very slight upward coarsening grain sizes, the common occurrence of carbonaceous styolites and transitional upper contacts into shales. Hence, although these sands do show electric-log characters suggestive of upward coarsening marine bars, direct examination of the rocks suggests these units do not display characteristics of marine bars and are more closely related to the type 1 and 2 channel sands identified in the other Canton area cores. The presence of upward coarsening marine bar sands cannot be established in the study area based on log character alone.

Genetic Unit Log Signature and Summary of Morrowan Environmental Context

A summary of the genetic unit types and characteristic electric-log signatures is shown in Figure 11. The different lithologic channel types are not distinguishable based on log character alone, and cores are needed to differentiate the different channel types. Another interesting feature is the log response related to the basal conglomerates in Tidball No. 4, DeMoss A-1 and Humble Kephart No. 1, which show high shale-like gamma ray values.

Core and stratigraphic evidence from the Morrow Formation in the Southwest Canton Field area shows the unit records a marine transgression within a strandline or transitional environmental context. This evidence is summarized as follows:

1. Morrow deposition occurred on top of an eroded Chesterian

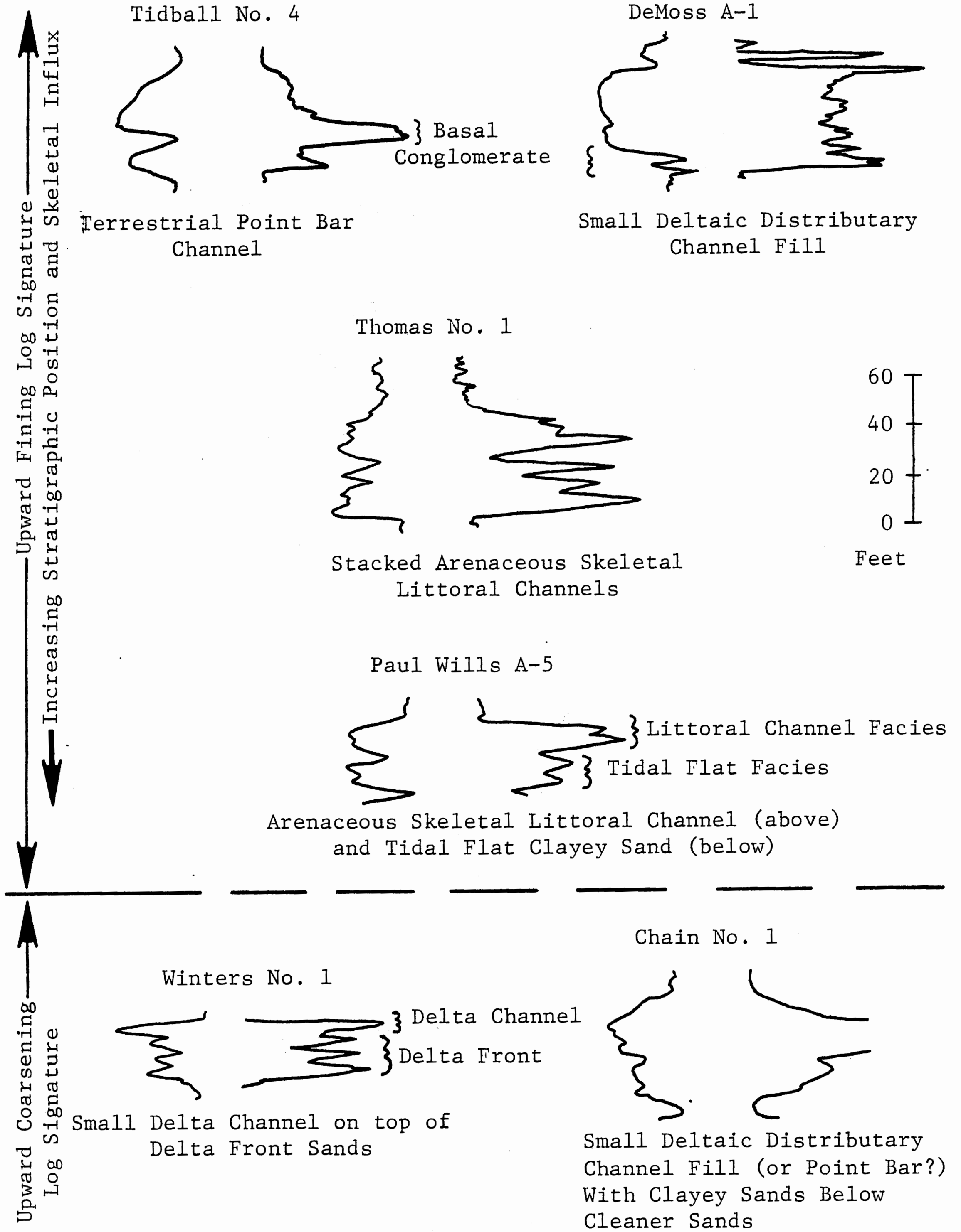

Figure 11. Electric-log Signatures Characteristic of Morrow Formation Sands in the Canton Area

land surface with shales and silts stratigraphically below the lowermost sand in the Lower Morrow sand zone. Cores (Tidball No. 4, DeMoss A-1, and Kephart No. 1) and cuttings (Pan Am Haigler E, NW SE 14-18N-13W) show the shales are nonmarine due to the occurrence of coal, wood fragments, and absence of glauconite. These rocks were probably deposited in quiet water subareal swamps and marshes associated with lagoons or other low energy shallow water bodies near the strandline. The occurrence of gastropods and brachipods in the Tidball No. 4 core may be related to lagoonal or marsh grazing. Occasional thin quartz silts and arenaceous skeletal influx zones may occur locally upsection near the lowermost Morrow sands (as, for example, the "Bond" silt zone) representing storm influx and proximity to siliclastic sediments.

2. The basal portion of the lower Morrow sand zone is often marked by an erosive based polymictic pebble conglomerate derived from several source areas associated with quartz dominated terrestrial point bar or small delta distributary channel sands. This represents a facies change from lagoonal shales to quartz sands within a subareal lowland to deltaic context. No thick coarsening upward sequences were observed in cores, which suggests large deltas did not exist in the Southwest Canton Field area.

3. The Lower Morrow sand zone is marked by a gradation into more skeletal marine influenced tidal channels and bioturbated very fine quartz wacke tidal flat sands that record marine transgression. A complete gradation occurs in the channels from quartz dominated terrestrial types down section to skeletal dominated marine types upsection, suggesting a transitional strandline environmental context with complex interfingering of lenticular sand bodies.

4. The upper Lower Morrow nonarenaceous thin skeletal grainstone channels and shoaling buildups with glauconitic interbuildup shales record continued transgression and waning arenaceous influence. The argillaceous skeletal grainstones may be storm derived deposits.

5. Although a complete Upper Morrow core was not described in the Southwest Canton Field, electric-log curves suggest the section is predominately shale with thin lenticular limestone units. No prominent upward fining sand units occur in this zone.

6. A comparison of the cores in the northern and sourthern portions of the study area shows a greater marine influence basinward. (Compare the DeMoss A-1, Kephart No. 1 and Winters No 1 cores, for example.) This in part may be due to erosional truncation of the Upper Morrow in a shelfward direction.

Figure 12 shows a schematic environmental model for the Morrow Formation in the Canton area. Note that with distance, the bioclastic marker is not chronostratigraphically equivalent. Based on this model, strike oriented correlations (i.e., perpendicular to page along the third dimension) are more likely to be chronostratigraphically consistent than dip oriented correlations within the Morrow interval. Dip oriented correlations with distance are not chronostratigraphically consistent and are a record of sea level changes, not equivalent time. This environmental model may be applicable to the shelfward limits of the Morrow Formation along the entire Watonga trend.

Distribution of the Producing Sands

Of the four sand genetic units--quartz dominated point bar and delta distributary channels, arenaceous skeletal tidal flat channels,

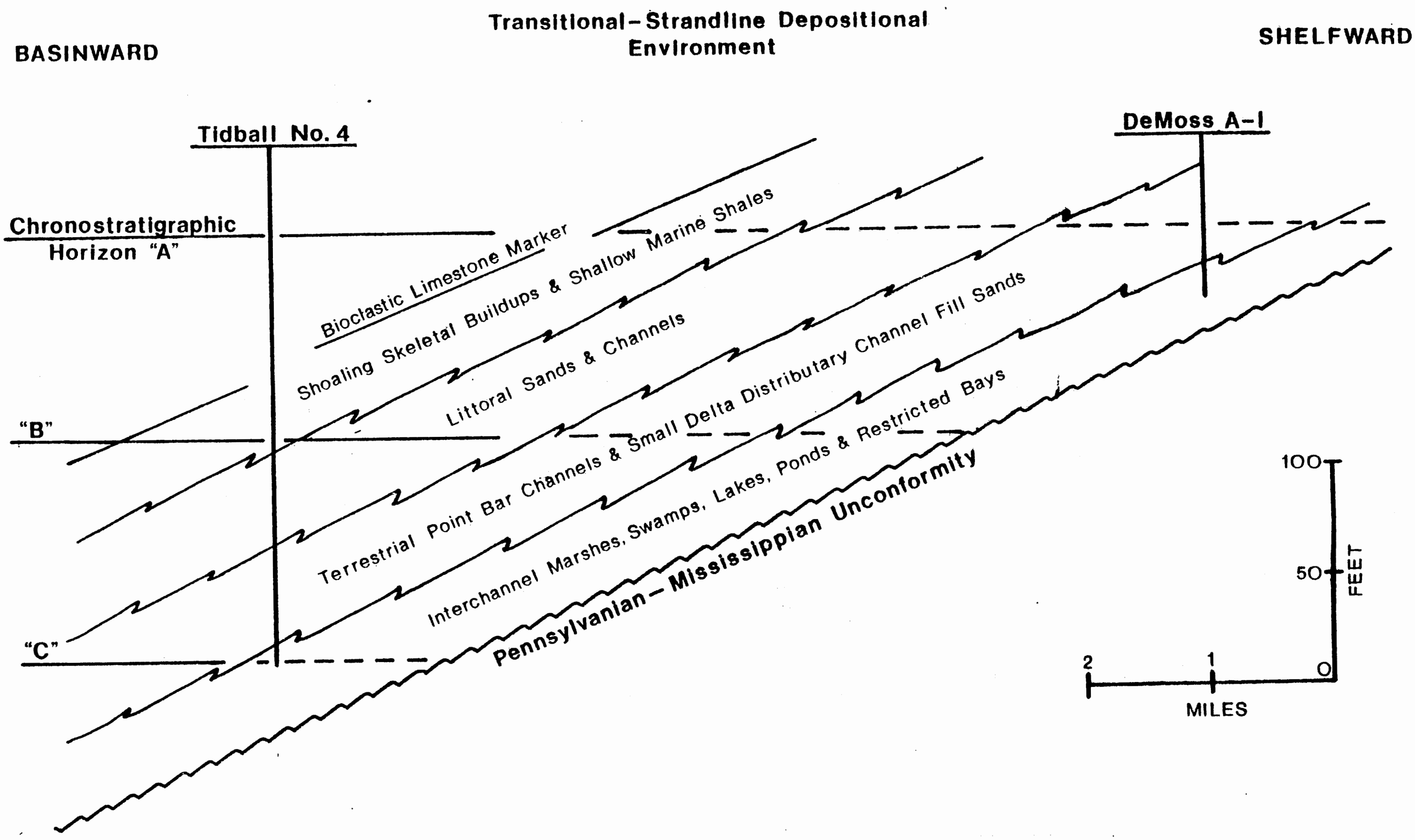

Figure 12. Schematic Environmental Model for the Morrow Formation in the Canton Area. (Note that at any one chronostratigraphic time, terrestrial river sands are deposited shelfward, with littoral and shallow marine deposition basinward. Horizons C-A reflect sea-level and sea transgression.)

nonarenaceous skeletal channels and buildups, and the bioturbated quartz wacke tidal flat clayey sandstones--only the point bar and delta distributary sands produce significant amounts of oil and gas in the Southwest Canton Field area. The carbonate sands were often tightly cemented by carbonate cements and are not productive where observed in the Canton area cores. However, under certain petrologic conditions favorable for the generation of secondary porosity, carbonate sands may contain porosities and permeabilities sufficient for excellent petroleum production in the area (see Chapter VI). The bioturbated tidal flat clayey sands are generally nonproductive in the Canton area because they contain for the most part, too high a detrital matrix content to permit diagenetic fluid circulation and the generation of secondary porosity (see Chapter VI). Hence, the clayey tidal flat sands are generally nonproductive because of a lack of porosity. However, this sand may contain posorities sufficient for marginal production in local clean zones within the genetic unit (see Paul Wills A-5, Appendix B).

A net sand isopach map of the Morrow Formation in the Canton area is shown in Plate 10 (and in Figures 13-14). This map represents only those sands capable of economical petroleum production. This includes point bar channels, delta distributary channels and skeletal tidal channels that are not tight and contain porosities $\geq 8\%$. Clean, bioturbated quartz wacke tidal flat sands account for less than 5% of the accounted sand thickness in this map. Appendix A describes the technique used in constructing Plate 10.

General sand distribution trends appear somewhat irregular and inconsistent in Plate 10. However, certain sand distribution trends are observable. In the Southwest Canton Field, the sand distribution is roughly parallel and perpendicular to structural strike in the central to north-central portion of the field. Northwest of the field, sand distribution is generally northwest-southeast, parallel to strike. South and east of the field the sand distribution is irregular with a few thick zones trending in a northeast-southwest direction, perpendicular to strike (T17N, R14-13W, R13-12W boundaries).

The lenticular nature of the Morrow producing sands is apparent in Plate 10. In the Southwest Canton Field, five-foot thick contour line "holes" occur within ½ - 1 mile of 40-50 foot contour lines (T18N, R14W, for instance), which illustrate the rapid pinchout character of the Morrow sands in the study area.

In Figures 13 and 14, wells with distinct upward fining and upward coarsening electric-log signatures are outlined, respectively. The upward fining channel sands cover the greatest areal extent of the Morrowan genetic sand types in the study area, and are concentrated in the Southwest Canton Field. Upward coarsening sands are sparse in the Canton area.

When comparing the outline of the Southwest Canton Field production (Figure 2) to the distribution and thickness of the channel sands (Figure 13), a good correlation results. This correlation suggests the channel sands are responsible for the production in the Southwest Canton Field.

Observations of Plate 10 (and Figures 13-14) suggest the Southwest Canton Field exists as a field within a continuous lenticular sand trend. The field is not an isolated sand body or structurally controlled (plate 1). The field is bordered by lenticular sand bodies on all sides except to the northeast where the Morrow Formation is truncated shelfward. Hence, petroleum trapping is stratigraphic. Moreover, the

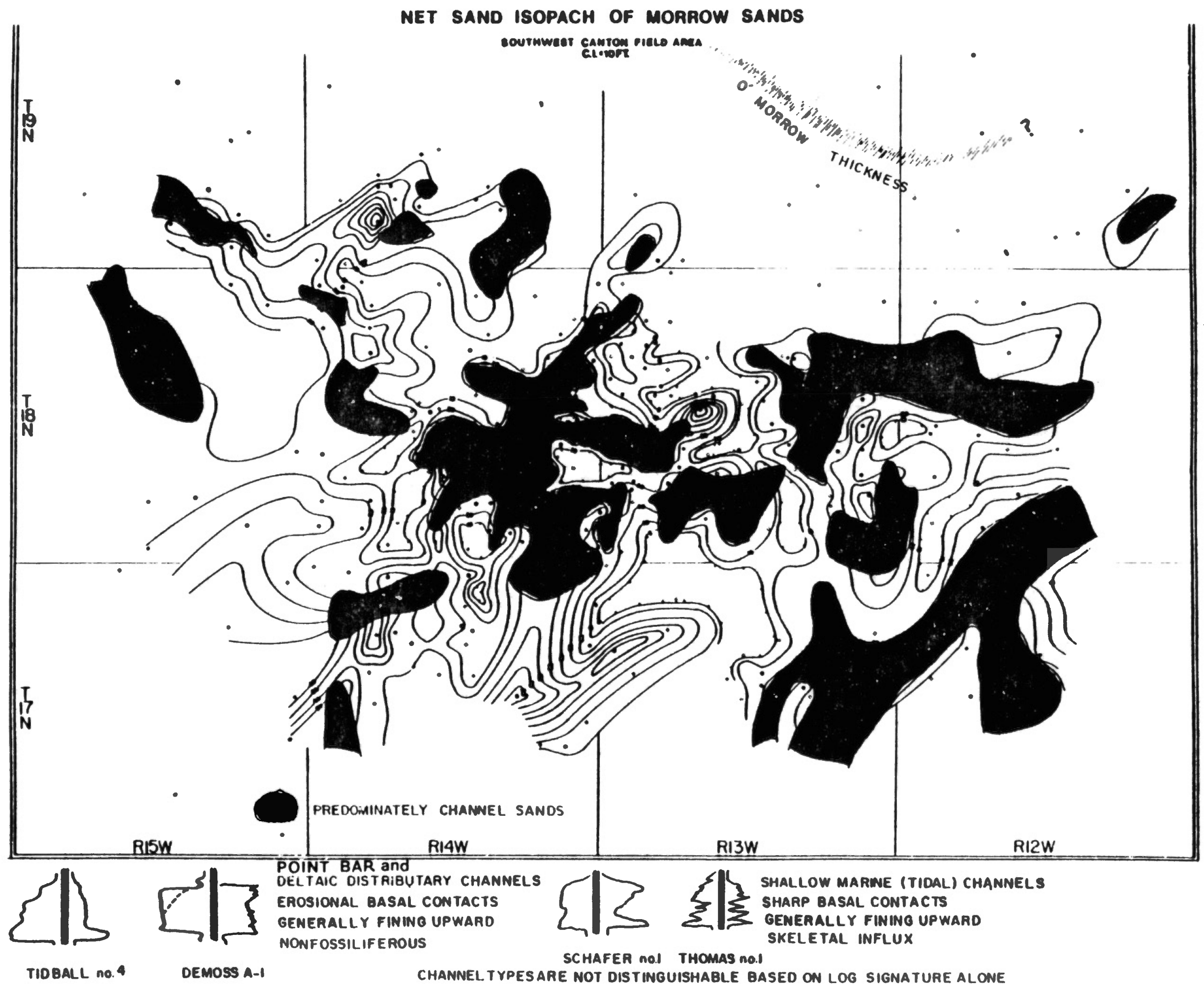

Figure 13. Distribution of Upward Fining Channel Sands in the Canton Area

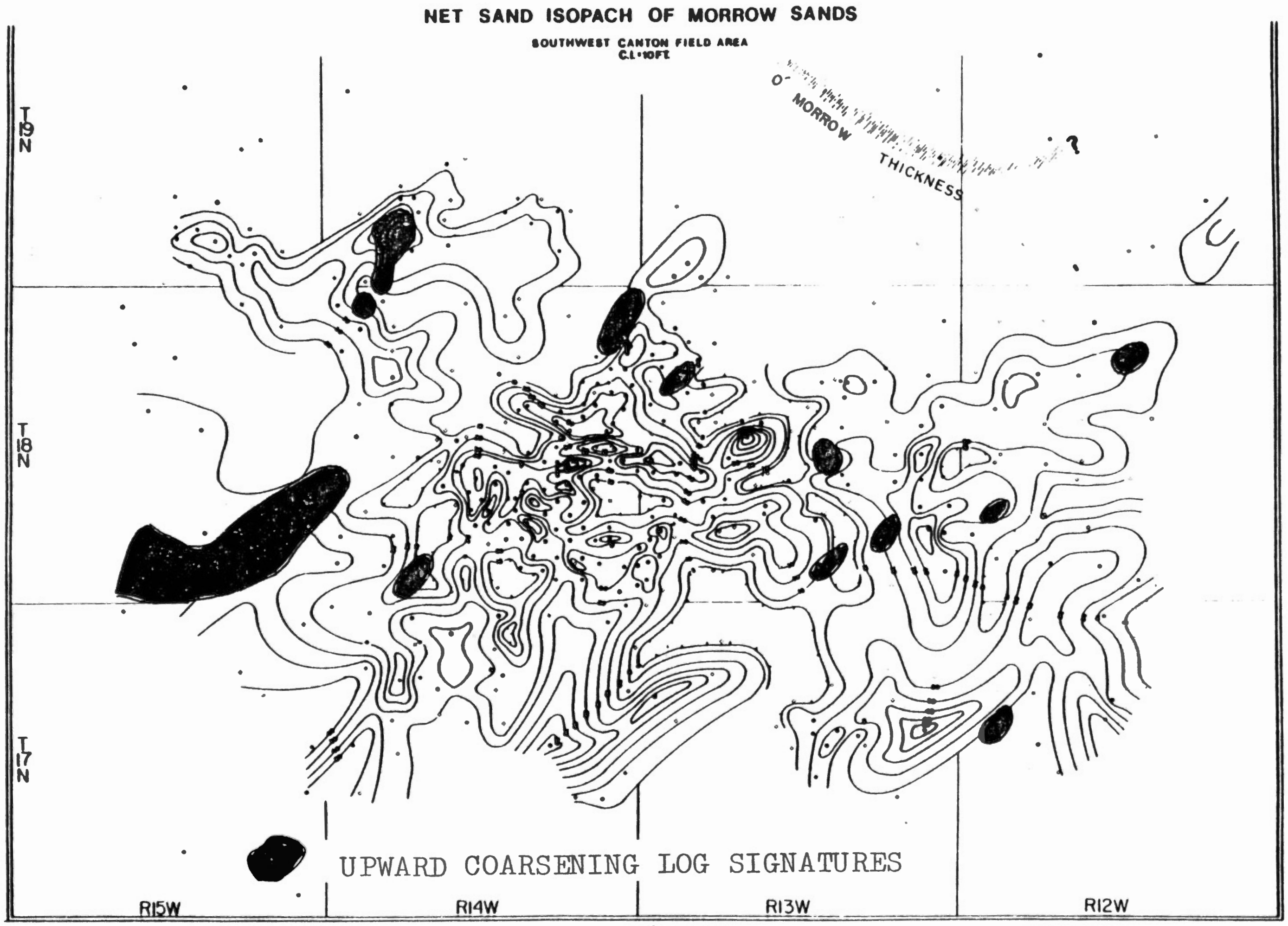

Figure 14. Distribution of Upward Coarsening Sands in the Canton Area. (Note the sparse distribution compared to the channel sands in Figure 13. No upward coarsening marine bars were interpreted in cores from this study.)

Southwest Canton Field is included as part of the greater Watonga trend province, and is not excluded from it. Because excellent production exists on the shelfward limits of the Morrow Formation where Lower Morrow channel sands occur (as in DeMoss A-1, Appendix B), the Morrow Formation is an excellent exploration target up to its shelfward limits in the Canton area.

CHAPTER V

PETROLOGY

Introduction

Seven distinct lithologic sand types were identified in cores and thin sections sampled from the Morrow Formation in the Canton area. Two conglomerate, two skeletal, and three arenaceous quartz sand types were differentiated. Delineation of these different lithologic suites is made on the basis of the major detrital components that characterize the Morrow sands. The primary detrital constituents are quartz grains, skeletal fragments, detrital clay matrix, and rock fragments and clasts. Variations in the percentage of each detrital component results in the distinct Morrow sand lithologies.

Quanternary diagrams graphically distinguish the different lithologic types identified and use the primary detrital components as end-members. Appendix B shows quanternary diagrams for each core sampled in the Canton area. Each diagram is constructed based on quantitative mineralogic analysis from thin sections. The percentage of each primary detrital component was normalized with respect to the four primary detrital components and plotted on the quanternary diagrams shown.

Figure 15 summarizes the results shown in Appendix B by illustrating the location of each Morrow lithologic sand type on a single quanternary diagram. Zones 1-7 in Figure 15 correspond to specific

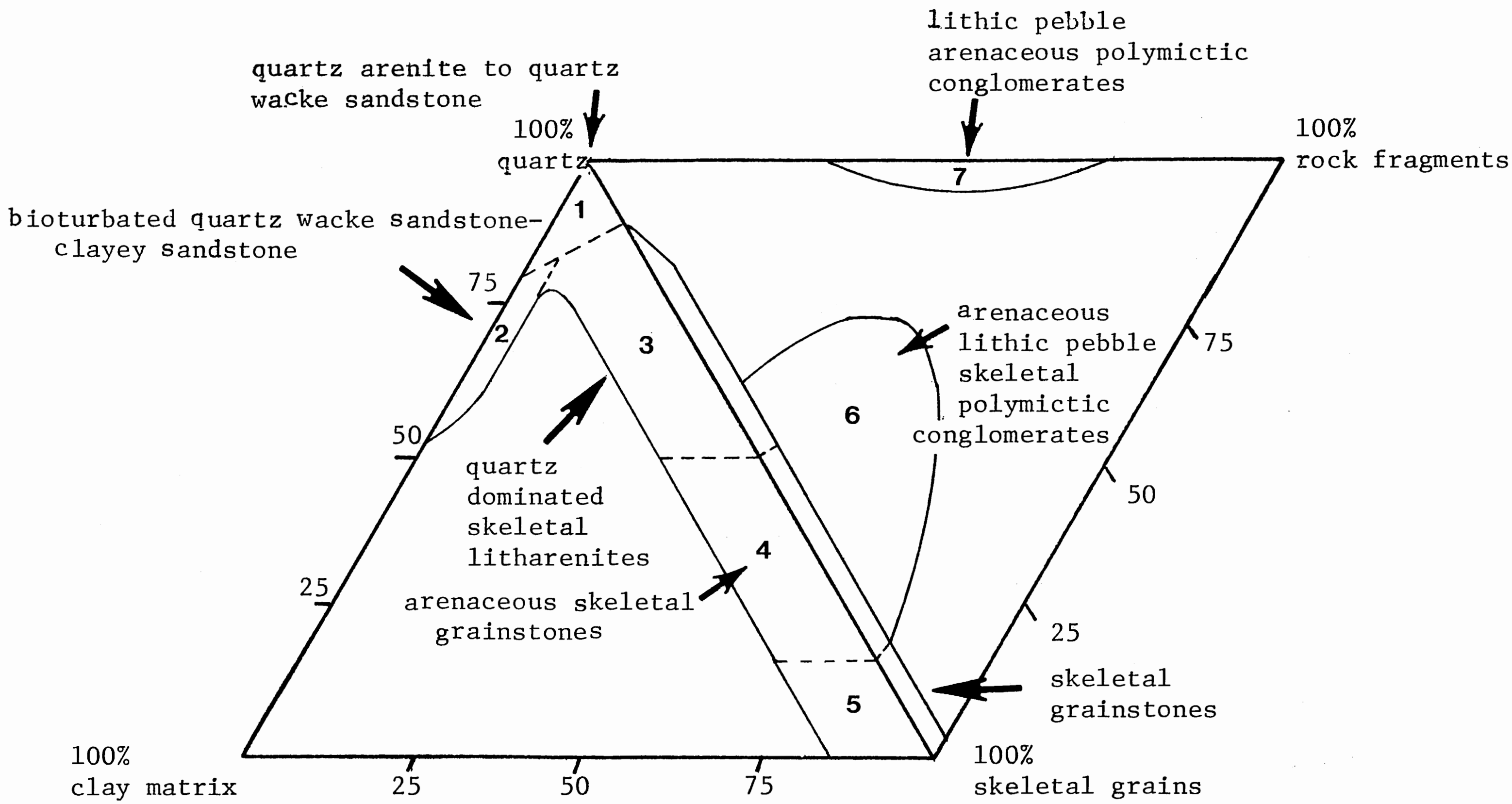

Figure 15. The Morrow Formation Lithologic Sand Types

lithologic types as shown.

The different lithologies in the Morrow reflect the genetic units identified and interpreted in Chapter IV. The quartz arenite to quartz wacke sandstones (zone 1) and lithic pebble arenaceous polymitic conglomerates (zone 7) are characteristic of the terrestrial point bar and deltaic distributary channel sands. The tidal flat channels are characterized by arenaceous skeletal grainstones (zone 4) and arenaceous lithic pebble skeletal polymictic conglomerates (zone 6) with the nonarenaceous skeletal grainstones and packstones (zone 5), interpreted as shoaling littoral buildups. The zone 3 quartz dominated skeletal litharenites occur in transitional settings between terrestrial channels and marine influenced skeletal tidal channels and shoaling littoral buildups. This lithologic type also occurs locally in the zone 1 channel sandstones. The quartz wacke sandstones and clayey sandstones (zone 2) are found in both the terrestrial channel and bioturbated tidal flat deposits.

Oil and gas production in the cores examined is restricted primarily to the quartz dominated lithologic types. With respect to Figure 15, production from zones 2 and 3 sands is not as prolific as in clayey zone 1 sands. The most prolific Morrow production observed occurs in the DeMoss A-1 and Kephart No. 1 cores which produce from clayey quartz arenite to quartz wacke sandstones with excellent porosity. An arenaceous skeletal grainstone also produces in the Kephart No. 1 core. In the Thomas No. 1 and Chain No. 1 wells, plugs indicate production occurs from quartz arenitic sands that contain local skeletal rich zones. Marginal production from the bioturbated quartz wacke sandstones to clayey sandstones occurs in the Paul Wills A-5 core. However, no other core well produced from a similar lithologic (or genetic unit) type. In the cores examined, the skeletal dominated sands and conglomerates (zones 4-7, Figure 15) are nonproductive except in the Kephart No. 1 core. Hence, skeletal grainstones should not be overlooked as potential reservoir sands in the area (see Chapter VI).

Detrital Constituents in the Morrow Formation

The detrital and authigenic constituents characteristic of the Morrow Formation sands are listed in Figure 16.

Monocrystalline quartz is the dominant quartz type in the Morrow Formation. Monocrystalline quartz commonly occurs in medium to silt size, rounded to subrounded grains with advanced to medium stage syntaxial quartz overgrowths. Where the quartz occurs with carbonate cements, the quartz grains and surrounding overgrowths are often corroded by the carbonate. Polycrystalline quartz is rare and occurs in trace amounts.

A variety of fossil types occur as skeletal fragments in the Morrow Formation. The skeletal types observed in relative order of abundance include echinoderm plates and stems, bryzoans, brachiopod shells and spines, trilobites, red and green algae types, ostracods, gastropods, milliolid and fusulinid foraminifera, and stromatoporiods. These fragments ranged from medium calcirudite to medium calcarenite size. Typical skeletal types are illustrated in Figures 26, 27, 28 and 29 in Chapter VI. Although all of the skeletal types above are present in the skeletal dominated sands, only echiniods with occasional bryzoans, brachiopods, trilobites, ostracods and rare foraminifera were observed in the quartz dominated sands.

Lithic pebbles and grains (rock fragments) are common in the Morrow

Detrital Constituents

Quartz
- Monocrystalline
- Polycrystalline

Skeletal Fragments
- Echinoids, Brachiopods, Bryzoans, Trilobites, Ostrocods, Forams, Algea, Gastropods

Lithic Pebbles and Grains
- Siderite
- Collophane
- Skeletal Grainstone
- Clayey SS - Sdy Claystone
- Silty Shale (Intraformational)
- Fossiliferous Shale
- Carbonized Wood Fragments

Clay Matrix
- Often replaced by mixed layer illite-smectite and chlorite. May include glauconitic pseudomatrix

Glauconite

Other Constituents
- Leucoxene, Biotite, Muscovite, Chert, Zircon, Plagioclase, Staurolite

Relative Abundance →

Authigenic Constituents

Silica
- Syntaxial Quartz Overgrowths
- Chalcedony
- Microquartz
- Megaquartz (Drusy)
- Menescus Cement

Carbonate
- Mosaic Calcite and Micritic Calcite Aggregates
- Piokilotopic Calcite
- Siderite
- Dolomite
- Sparry Calcite

Clays
- Chlorite
- Kaolinite
- Mixed layer--illite smectite

Opaque Constituents
- Pyrite
- Carbonaceous Matter

Figure 16. Detrital and Authigenic Constituents in the Morrow Formation Sands, Canton Area

Formation conglomerates. These fragments occur as rounded to subrounded, pebble to granule size clasts with variable sphericity. Very fine to very coarse grained rock fragments were occasionally observed in the skeletal grainstones, but are rare in the quartz dominated sands. Seven different lithic clast types were identified in the Morrow Formation and are described below.

Siderite and skeletal grainstone pebbles are the carbonate clast types characteristic of the Morrow conglomerates in the Canton area. The siderites are finely crystalline to micritic brown-red to grey-brown clasts with iron stained clast rims and/or intragranular fractures. These clasts are occasionally coated with light grey chert, and may show small calcite filled radial fractures spaced two to three millimeters apart. The siderite clasts may be either totally micritic or include corroded silt size quartz, chert and skeletal grains with occasional pyrite crystal traces. The skeletal clasts are light grey to tan-grey in plain light and contain fine calcirudite to medium calcarenite echinoids, bryzoans, foraminifera, brachiopods, gastropods and pellets in a sparry calcite matrix.

Collophane pebbles and granules are common in the Morrow conglomerates with very coarse to fine grained fragments occasionally occurring in the skeletal sands. This clast type is characterized by a brown to orange color in plain light, and an amorphous crystal habit that is isotropic under crossed nicols. Phosphatization is generally restricted to the clast itself, which suggests these clasts were phosphatized before Morrow deposition. The collophane clasts may 1) be completely amorphous without inclusions; 2) contain scattered silt size quartz and occasional skeletal grains; or 3) contain fine to very fine grained subrounded quartz that may comprise up to 45% of the collophanized clast. This third collophane clast type may also contain fine to medium grained chert, coated grains with quartz nuclei, carbonate replaced chert grains and skeletal grains. Occasional elongate apatite crystals and pyrite cubes were observed in all collophane clast types.

Siliclastic pebbles are less common than the carbonate and collophane rock fragments in the Morrow conglomerates. These clasts occur as clayey sandstones to sandy claystones, intraformational silty shales and fossiliferous shales. The clayey sandstones and sandy claystones are black, dark grey or brownish-red in plain light and are often replaced by brown micritic carbonate. Very fine to fine grained subrounded quartz grains occur with silt size carbonaceous and pyritic particles in this clast type. The silty shales were observed as intraformational pebbles in the channel sands, and are often related to silty shale laminations. This clast type is characterized by a dark brown color in plain light, scattered silt size quartz grains, ductilly deformed clast edges and a matrix that is often replaced by finely crystalline to micritic carbonate. The fossiliferous shale clasts were rarely observed (see Table I). This clast type occurs as slightly fossiliferous dark grey to black pebbles that contain no quartz. The fossils may be pyritized and include crinoids, gastropods, sponges, orned corals and coated grains.

Carbonized wood fragments are the last rock fragment type. They occur in pebble to sand size grains, are black, opaque and resemble vitrain particles in hand specimen. The carbonized wood fragments are more common in Lower Morrow shales than sands.

Detrital clay matrix occurs in the skeletal and quartz sands as clay mix that is often replaced by authigenic chlorite and illite-smectite mixed layer clay. The clay matrix is green, green-brown, brown, red-brown to black in plain light. The green tinted matrix types indicate a predominance of authigenic chlorite. The brown types reflect mixed layer clays, or hydrocarbon stained matrix. Brown matrix is also characteristic of glauconite alteration. (See Chapter VII and Figure 34.) The dark types are rich in carbonaceous matter and hydrocarbons.

Glauconite, characterized by its green color, occurs in discrete fine to very fine detrital grains. Although generally not a major constituent in the Canton area, green glauconite occurs in amounts up to 4% in some Morrow sands. The discrete glauconite grains are often replaced by illite-smectite mixed layer clays and chlorite (see Figure 18). Glauconite grains may also be ductilly deformed and occur individually or with a ductilly deformed clay matrix. Ductilly deformed glauconite may be altered to a brown color and difficult to distinguish from the clay matrix. (See Figure 34 in Chapter VII.)

Other constituents include, in order of abundance, leucoxene, biotite, muscovite, zircon, chert, plagioclase, and staurolite. These constituents are usually very fine grained. Leucoxene, an opaque mineral with pearly white luster, is the most common trace constitutent. This mineral is an alteration product of titanium-bearing minerals (Kerr, 1959). Biotite, muscovite, chert and zircon are trace minerals that were occasionally present in the thin section samples, with plagioclase and staurolite the least common trace minerals.

Authigenic Constituents in the Morrow Formation

Authigenic silica occurs as syntaxial quartz overgrowths, meneseus silica cements, chalcedony, microquartz and drusy megaquartz.

Syntaxial quartz overgrowths are a common constituent in the Morrow sands. The overgrowths may or may not be marked by dustlines composed of clay minerals. Where dustlines are not present, the boundary between the overgrowth and quartz grain is not distinguishable petrographically. In this case, overgrowth identification is still possible because Morrow quartz grains are predominantly rounded to subrounded, and overgrowths show euhedral angular edges. Quartz overgrowth cementation is illustrated in Chapters VI and VII, Figures 23, 24, and 32, respectively.

Chalcedony, microquartz, drusy megaquartz and menescus silica cements occur as pore filling authigenic silica cements. Microquartz and chalcedony fill intergranular and intra-skeletal grain voids in both quartz dominated and skeletal dominated sands. Drusy magaquartz, with euhedral interlocking monocrystalline quartz crystals occurs occasionally in the skeletal grainstones filling voids in tubular and elongate skeletal fragments. Menescus silica cements occur only with advanced stage overgrowths in clean quartz arenite sands.

Five different authigenic carbonate types were identified in the Morrow Formation. Piokilotopic calcite and mosaic calcite cements often occur with micritic calcite aggregates. These cements are the dominant carbonate types in the Canton area. Sparry calcite, dolomite and siderite cements are not as common as piokilotopic and mosaic calcite cements.

Piokilotopic calcite is common in the quartz dominated sands but is less common in the skeletal grainstones where mosaic calcite predominates. Piokilotopic calcite is characterized by localized, very large single calcite crystal cements that encase several quartz grains or other detridal grains. This cement type may fill the intergranular space around detrital grains completely, or occur in the detrital clay matrix as isolated, less developed "patchy" calcite cements associated with skeletal fragments. Commonly localized tightly cemented poikilotopic calcite areas occur with other zones that are not cemented similarly. Scholle (1979) recognized similar fabrics in clastic sediments and suggested the distribution and occurrence of piokilotopic calcite cements are a function of the presence of original detrital skeletal fragments upon which single calcite crystal cements grow as a result of calcite nucleation.

Nonpiokilotopic mosaic calcite crystal cements and micritic aggregates are common cement types and occur in a variety of forms. The micritic aggregates consist of small equant crystals that commonly line and cement detrital grains or occur in the intergranular space (or clay matrix) as micritic patches. The mosaic calcite cements occur as larger anhedral crystal clusters often associated with piokilotopic cements in intergranular areas.

Dolomite and siderite authigenic carbonates occur as isolated euhedral rhombs, void filling cements, and aggregates. Isolated dolomite rhombs were occasionally observed partially replacing detrital skeletal grains and calcite cements in the skeletal sands and conglomerates. Void filling dolomite cements were also observed in the skeletal sands. Small dolomite and siderite rhombic rrystals and aggregates occur as gain lining cements or matrix aggregates in both the quartz and skeletal Morrow sand types. Brown siderite aggregates often replaced skeletal grains in skeletal quartz arenites. Siderite and domomite are distinguishable on the basis of color in plain light. Siderite is brown to brown-red with dolomite colorless to grey.

Dolomite cements show euhedral rhombic edges compared to generally anhedral calcite.

The final authigenic carbonate type is sparry calcite, which occurs as a void filler in intergranular pockets or intra-skeletal grain voids. Drusy calcite spar also occurs in association with phylliod algae, a common fossil type in the skeletal grainstones. Sparry calcite is common only in the skeletal grainstones and packstones, and was not observed in the quartz dominated sands.

<u>Authigenic clays</u> observed in the Morrow Formation sands include chlorite, kaolinite and mixed layer illite-smectite. Authigenic clays are most common in the Morrow quartz sands and are not often significant in the skeletal dominated sands that are dominated by carbonate matrix types.

Chlorite is a common Morrow authigenic clay that is responsible for the green tinted plain light character of the clay matrix in quartz dominated sands. Chlorite occurs as a pore filling, pore lining and replacement mineral characterized by its green color and grey-blue first order "ultrablue" birifringance. Chlorite replaces detrital clay matrix and glauconite in the Morrow sands. SEM analysis shows edge-to-face chlorite is the most common morphologic type (see Figure 32 in Chapter VII, for example). However, slightly vermicular crystal habits were observed in some pore filling chlorites. The chlorite observed in this study is of the iron-rich variety (Al Shaieb, 1982, personal communication).

Kaolinite occurs as a pore filling authigenic clay that is characterized by vermicular booklet-shaped particles and chert-like birifringance. This mineral is a common authigenic constituent in the quartz sands. A SEM/EDXA view of kaolinite and its typical morphology is shown in Figure 17.

Illite-smectite mixed layer clay replaces glauconite and the clay matrix. Pure illite is a common associate of illite-smectite mixed layer clay, and is characterized by small fibrous "lathlike" crystals that are often dispersed throughout glauconite and the clay matrix. Figure 18 shows a SEM/EDXA photograph of replacive iron rich illitic mixed layer clay. Illite-smectite mixed layer clays may also occur as pore lining minerals.

Authigenic carbonaceous matter is common in the Morrow quartz dominated sands and occurs in a variety of forms. Carbonaceous matter in the clayey quartz arenites and quartz wacke sands commonly occurs in irregular styolitic laminea that is often associated with shale lamination zones. The styolites are often vitrainized. Carbonaceous matter also occurs sparsely in isolated elongate to spherical "patches" between quartz grains in the intergranular space. In the producing sands, pore filling hydrocarbons often stained the intergranular space (and clay matrix) a dark red-brown to black color in plain light (as in the DeMoss A-1 core, Appendix B).

Authigenic pyrite is common in both quartz and skeletal dominated sands and often occurs in association with carbonaceous matter and detrital grains. Pyrite observed in association with carbonaceous matter occurs along styolites as impure to pure particles and patches. Intergranular pyrite is commonly associated with hydrocarbon matter and often rims pores or carbonate filled voids. More rare frambiodal spheres associated with the clay matrix and local pyrite cementing of quartz was also observed in the intergranular space. In the Canton area samples,

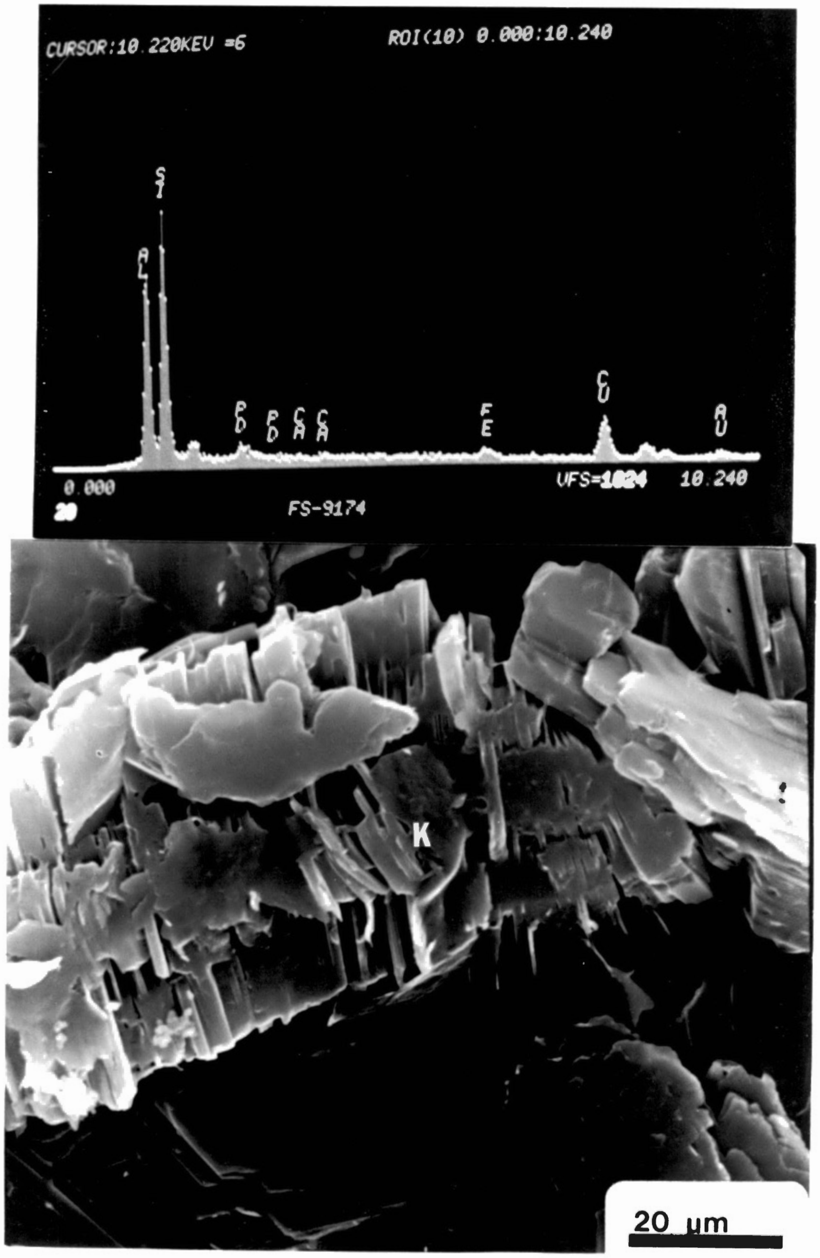

Figure 17. SEM Photograph of Void Filling Kaolinite (K), Showing Typical Vermicular Morphology. (EDXA analysis in upper photograph shows kaolinite is not an iron-rich mineral. The copper is from sample preparation.)

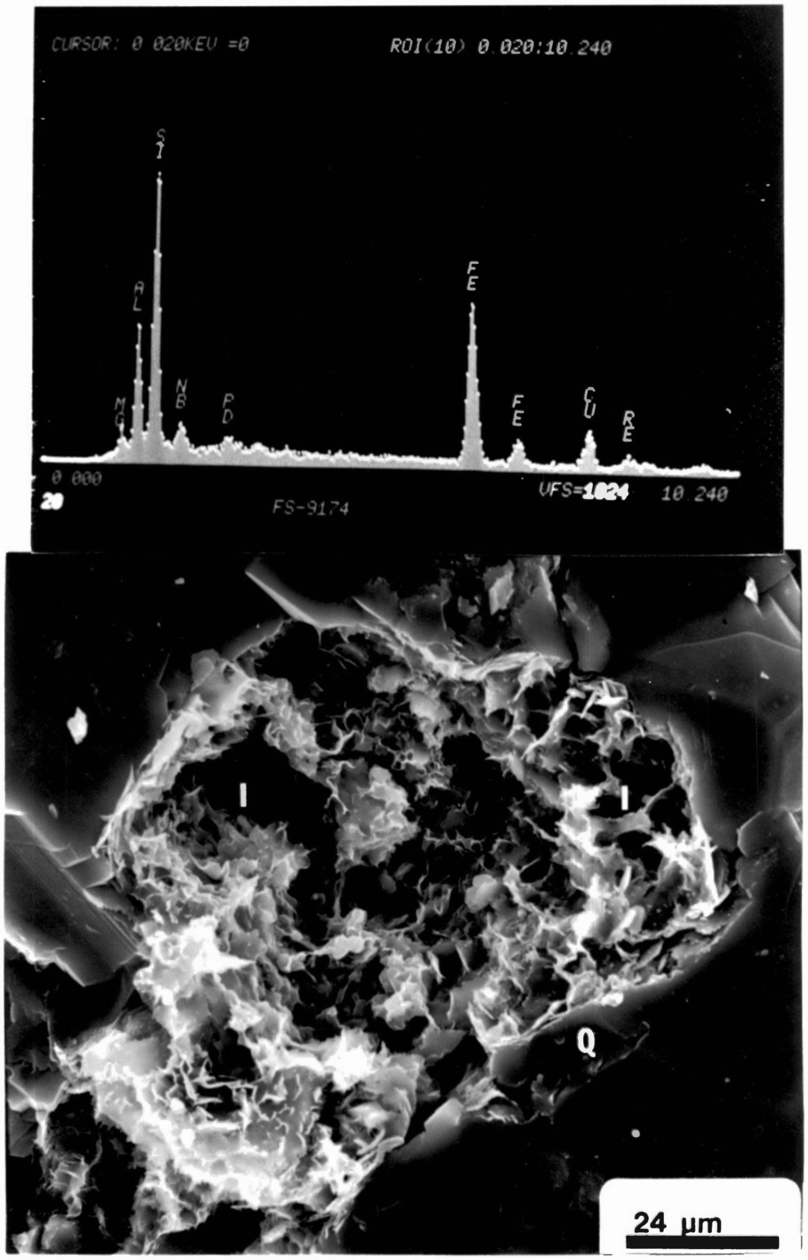

Figure 18. SEM/EDXA Analysis of Iron-Rich Illitic Mixed Layer Clay in a Glauconitic Quartz Sand. (The corroded quartz [Q] grains reflect earlier partial dissolution. Pore bridging illite laths [I] and delicate clay morphologies imply later recrystallization. The original detrital material may have been glauconite.)

the most common detrital grains replaced by pyrite are skeletal and collophane fragments which show varying degrees of pyrite replacement, from complete to incipient. Incipient replacement is characterized by isolated pyrite crystals of micritic size that appear dustlike. Incipient pyrite cubes are often observed in collophane clasts.

Morrow Lithologic Types and Constituent Percentage

The mineral and rock constituents that characterize each lithologic type are summarized in Tables I-VI. This data reflects thin sections sampled from the three Southwest Canton Field cores, Tidball No. 4 (TB), Frank Schafer No. 1 (FS), Paul Wills A-5 (PW), and the DeMoss No. 1-A (DM) core east of the field. These cores and samples are representative of the Canton study area.

The Morrow Formation conglomerates are a nonproductive lithologic type that show two endmember units differentiated on the basis of skeletal grain percentage (Figure 15). Arenaceous lithic pebble polymitic conglomerates to sandy conglomerates are the first endmember type. This conglomerate type is associated with terrestrial point bar and small deltaic distributary channel fill sands. The conglomerates may be slightly skeletal (as in TB 9191 and TB 9188, Table I) to nonskeletal (as in DeMoss A-1, Appendix B). Arenaceous lithic pebble skeletal polymitic conglomerates are the second endmember type, which occur in association with littoral channels and often grade into arenaceous skeletal grainstones. (See TB 9146, FS 9176, and FS 9185 in Table I, and Kephart No. 1, Chain No. 1 and Thomas No. 1 in Appendix B for examples.)

Table I lists the constituent types and percentages from

TABLE I

CONSTITUENT TYPE AND PERCENTAGE FROM REPRESENTATIVE CONGLOMERATES
SAMPLED IN THE SOUTHWEST CANTON FIELD

Detrital Fragments and Grains*										Authigenic Constituents^Δ				
Siderite Clasts %	Collophane Clasts %	Skeletal Grainstone Clasts %	Clayey Sandstone Clasts %	Silty Shale Clasts %	Skeletal Shale Clasts %	Carbonized Wood Fragments %	Quartz %	Skeletal Fragments %	Clay Matrix %	Carbonate Matrix %	Microquartz Chalcedony %	Carbonaceous Matter %	Pyrite %	Sample Well/feet
25	10	0	0	2	1	Tr	32	2	0	24	2	2	Tr	TB 9191
5	8	20	5	0	0	1	35	2	0	21	3	1	Tr	TB 9188
7	7	0	5	0	0	0	21	44	0	13	0	0	3	TB 9146
16	4	0	3	0	0	0	31	20	2	24	Tr	Tr	Tr	FS 9176
3	2	0	0	4	0	0	45	29	4	13	1	1	1	FS 9185
8-25	2-10	0-20	0-5	0-4	0-1	0-1	21-45	2-44	0-4	13-24	0-3	0-2	Tr-3	Range
8	6	4	3	1	Tr	Tr	33	19	1	19	1	Tr	1	Average

*Includes trace amounts of chert and leucoxene grains. Clay matrix includes authigenic clays.

ΔSyntaxial quartz overgrowths not well developed except in local quartz-rich zones.

representative conglomerates sampled in the Southwest Canton Field. Note the variance in skeletal fragment percent (from 2-44%) and the common occurrence of siderite and collophane pebbles. Detrital matrix constituents consist of rounded to subrounded, coarse to very fine grained quartz, fine calcirudite to fine calcarenite skeletal fragments and localized sparse amounts of mixed detrital clay. Carbonate authigenic constituents comprise an average of 19% of the conglomerate in Table I. These include all of the carbonate cements listed in Figure 16. Authigenic silica includes syntaxial quartz overgrowths, microquartz, chalcedony, and occasional drusy quartz. Authigenic pyrite and carbonaceous styolites also occur in the Morrow conglomerates.

The skeletal dominated sands in the Morrow Formation occur in arenaceous to nonarenaceous medium calcirudite to medium calcarenite grainstones. Based on the cores observed, the arenaceous grainstones may grade into lithic pebble skeletal polymitic conglomerates or quartz dominated skeletal lithic arenites. The arenaceous grainstones are poorly sorted due to medium grained and coarse silt size quartz grains, and are submature to immature sands with variable skeletal grain sphericity that is dependent on fossil type. The nonarenaceous grainstones are generally well sorted.

Table II lists the constituent types and percentage from representative skeletal grainstones sampled in the Southwest Canton Field. Note the variance in skeletal grain percent from 10 to 80%, which is reflective of arenaceous and nonarenaceous skeletal litharenite types, respectively. The lower skeletal percentages (FS 9180, FS 9166, and PW 9031) generally occur with above average quartz percentages, and are rich in piokilotopic calcite cement. The higher skeletal percentages

TABLE II

ARENACEOUS TO NONARENACEOUS SKELETAL GRAINSTONES IN THE SOUTHWEST CANTON FIELD

Detrital Constituents[1]				Authigenic Constituents[2]						
Quartz %	Skeletal Fragments %	Rock Fragments %	Clay Matrix %	Carbonate Matrix %	Quartz Overgrowths	Chalcedony %	Drusy Megaquartz %	Pyrite	Carbonaceous Matter %	Sample well/feet
15	72	4	0	9	NOT WELL DEVELOPED	0	0	Tr	Tr	TB 9145
1	72	Tr	0	23		Tr	4	0	Tr	TB 9103
19	49	1	0	31		0	0	Tr	0	FS 9183
16	61	2	0	20		1	Tr	Tr	0	FS 9182
25	30	6	0	39		Tr	0	Tr	0	FS 9180
27	70	0	0	2		0	0	Tr	1	FS 9172
10	74	Tr	0	15		0	0	Tr	Tr	FS 9171
33	40	0	0	25		0	0	2	Tr	FS 9166
19	44	12	5	19		1	Tr	Tr	Tr	PW 9031
10	69	2	13	5		0	0	Tr	1	PW 9021
Tr	80	2		17		0	0	Tr	0	PW 8997
Tr-33	30-80	6-12	0-13	2-39		0-1	0-4	0-Tr	0-1	Range
16	60	3	2	19		Tr	Tr	Tr	Tr	Average

[1] Includes trace amounts of glauconite, leuconxene and polycrystalling quartz. Clay matrix includes authigenic clays.

[2] Includes trace amounts of void filling microquartz.

may contain lower quartz percentages and/or lower carbonate cement and rock fragment percentages (PW 8997, TB 9103, and TB 9145, respectively).

As shown in Table II, the detrital constituents in the skeletal sands are primarily skeletal fragments and quartz with minor rock fragments, and mixed clay matrix. Trace amounts of glauconite, leucoxene, biotite, zircon and polycrystalline quartz were also observed. These detrital constituents comprise an average of 81% of the skeletal sands in Table II. Authigenic constituents, which comprise an average of 19% of the skeletal grainstones in Table II consist primarily of the authigenic carbonate cement types with minor amounts of pyrite, carbonaceous matter, syntaxial quartz overgrowths, microquartz, void filling drusy megaquartz, and chalcedony.

The quartz arenite to quartz wacke sandstones are generally fine grained well sorted sands. Medium and very fine grained types also occur. The quartz grains are rounded to subrounded, and show a high to low spericity. The maturity of this lithologic type is primarily a function of clay matrix percentage. Supermarine to immature sands exist in this lithologic type.

Tables III-V list the constituent types and percentages from representative quartz arenite sands sampled in the Canton area. Table III lists a nonproductive Tidball No. 4 channel that consists of clayey quartz arenite to quartz wacke sandstone. Somewhat cleaner samples from the Frank Schafer No. 1 core are listed in Table IV. Here, two sampled genetic units are listed consisting of clean and clayey quartz arenite sandstone types. Table V shows the DeMoss A-1 samples that were taken from a clayey quartz arenite to quartz wacke distributary channel sandstone. This genetic unit has produced over 4.1 billion

TABLE III

THE TIDBALL NO. 4 QUARTZ ARENITE TO QUARTZ WACKE CHANNEL SANDSTONE

Detrital Constituents*			Authigenic Constituents						
Quartz %	Clay Matrix %	Leucoxene %	Carbonate Matrix %	Quartz Overgrowths	Microquartz Chalcedony %	Pyrite %	Carbonaceous Matter %	Porosity %	Sample well /feet
70	11	0	11		3	Tr	1	1	TB 9188
83	9	0	2		1	0	5	Tr	TB 9186
95	2	0	1	INTERMEDIATE TO ADVANCED STAGE	Tr	Tr	Tr	2	TB 9185
83	13	0	1		Tr	Tr	3	Tr	TB 9183
83	11	0	3		Tr	Tr	3	Tr	TB 9181
75	13	0	0		0	Tr	1	1	TB 9179
41	28	Tr	30		0	0	1	0	TB 9176
74	25	Tr	Tr		0	0	1	0	TB 9715
70	27	1	0		0	Tr	2	Tr	TB 9171
74	24	1	Tr		0	Tr	1	Tr	TB 9169
41-95	2-27	0-1	0-30		0-3	0-Tr	Tr-5	0-2	Range
75	17	Tr	5		Tr	Tr	2	Tr	Average

*Includes trace amounts of zircon, muscovite, biotite, chert, plagioclase and coaly wood fragments. Clay matrix includes authigenic clays.

TABLE IV

THE FRANK SCHAFER NO. 1 SLIGHTLY SKELETAL QUARTZ ARENITE CHANNEL SANDSTONES

Detrital Constituents[*]					Authigenic Constituents						
Quartz %	Clay Matrix %	Skeletal Frags %	Rock Frags %	Glauconite %	Carbonate Matrix %	Quartz Overgrowths	Microquartz Chalcedony %	Pyrite %	Carbonaceous Matter %	Porosity %	Sample well/feet
89	4	2		1	0	ADVANCED STAGE OVERGROWTHS		Tr	1	2	FS 9204[+]
92	1	2		Tr	2		Tr	Tr	0	3	FS 9202[+]
92	Tr	3		Tr	Tr			Tr		3	FS 9200.5[+]
79	9	1			1			Tr	8	Tr	FS 9200[+]
94	1	1		Tr				Tr	Tr	3	FS 9195[+]
95	Tr	Tr	Tr	Tr	1			Tr	Tr	3	FS 9190[+]
92	1	3	Tr	1	2			0		1	FS 9176
89	1	Tr		1	2			Tr	Tr	6	FS 9175
79-94	Tr-9	Tr-3	0-Tr	Tr-1	0-2		0-Tr	0-Tr	0-8	Tr-6	Range
90	2	2	Tr	Tr	1		Tr	Tr	1	3	Average

[*]Includes trace amounts of leucoxene, zircon, biotite, chert, plagioclase, and staurolite. Clay matrix includes authigenic clays.

[+]Produces oil and gas.

TABLE V

THE DeMOSS A-1 QUARTZ ARENITE TO QUARTZ WACKE CHANNEL SANDSTONE

Detrital Constituents*		Authigenic Constituents					
Quartz %	Clay Matrix %	Carbonate Matrix %	Quartz Overgrowths %	Pyrite %	Hydrocarbons %	Porosity %	Sample well/feet
89	Tr	1	NOT WELL DEVELOPED	Tr	3	7	DM 8452+
84	Tr	Tr			3	13	DM 8446+
85	2	0			4	9	DM 8437+
84	1	Tr		Tr	2	13	DM 8432+
85	Tr	Tr			1	13	DM 8428+
84-89	Tr-2	0-1		0-Tr	2-4	7-13	Range
85	1	Tr		Tr	3	11	Average

*Includes trace amounts of leucoxene, zircon, biotite and chert. Clay matrix includes authigenic clays.

+Produces oil and gas.

cubic feet of gas and 1/4 million barrels of oil since production started in December, 1966. This sand is the most prolific producing cored interval observed in the Canton study area.

As shown in Tables III-V, detrital constituents in the quartz arenites and quartz wacke sandstones are primarily quartz and mixed clay matrix with occasional skeletal fragments and glauconite. Trace minerals include leucoxene, chert, biotite, muscovite, zircon, plagioclase, staurolite, and polycrystalling quartz. Occasional trace amounts of carbonitized wood fragments were observed in Tidball No. 4. Authigenic components include syntaxial quartz overgrowths, microquartz, chalcedony, authigenic clays, kaolinite, chlorite, illite, carbonate matrix (commonly piokilotopic and moxaic calcite), pyrite, brown glauconite and carbonaceous matter. Hydrocarbon stains are prominent in the DeMoss A-1 sand.

Quartz dominated skeletal litharenite sandstones are identical to the quartz arenite and quartz wacke sandstones, except in skeletal grain percentage. This lithologic type contains between 10 and 50% skeletal fragments relative to the total quartz amount. Examples occur in the Thomas No. 1 and Chain No. 1 core wells (Appendix B).

Table VI lists the constituent types and percentage from representative bioturbated quartz wacke sandstones to clayey sandstones in the Southwest Canton Field. This lithologic type contains very fine grained quartz that has high to low sphericity. Some local moderate to well sorted zones were observed in the sand, but for the most part, this lithologic type is poorly sorted and immature. This sand type differs from the quartz arenite to quartz wacke channel sands becuase it shows a slightly lower quartz content, contains more mixed clay matrix, often

TABLE VI

THE BIOTURBATED QUARTZ WACKE SANDSTONE TO CLAYEY SANDSTONES IN THE SOUTHWEST CANTON FIELD

Detrital Constituents*				Authigenic Constituents						
Quartz %	Clay Matrix %	Skeletal Fragments %	Glauconite %	Authigenic Carbonate %	Quartz Overgrowths	Microquartz Chalcedony %	Pyrite %	Carbonaceous Matter %	Porosity %	Sample well/feet
65	10	2	1	20	INTERMEDIATE TO ADVANCED STAGE OVERGROWTHS	–	Tr	1	1	TB 9137
50	0	1	1	47		–	Tr	Tr	Tr	TB 9127
65	21	2	2	1		–	1	3	1	TB 9123
60	25	1	2	8		–	3	1	Tr	TB 9113
58	21	1	2	17		–	Tr	Tr	Tr	TB 9110
75	22	Tr	1	1		–	Tr	Tr	0	FS 9164
72	22	1	4	Tr		–	Tr	Tr	Tr	FS 9159
74	11	0	0	13		Tr	Tr	2	Tr	PW 9044+
67	30	0	0	Tr		Tr	2	1	Tr	PW 9041+
73	22	Tr	0	1		Tr	1	1	2	PW 9039+
88	10	0	0	Tr		Tr	Tr	2	0	PW 9036+
50-88	0-30	0-2	0-4	Tr-47		Tr	Tr-3	Tr-3	0-2	Range
68	18	1	1	10		Tr	1	1	Tr	Average

*Includes trace amounts of leucoxene, zircon, biotite, muscovite, chert, polycrystalline quartz and plagioclase. Clay matrix includes authigenic clays.

+Produced marginal amounts of oil.

contains skeletal grains and commonly is tight. Marginal production from this lithologic type occurs in the Paul Wills A-5 core, but does not occur in the other cores examined.

The detrital constituents in the bioturbated quartz wacke sandstones to clayey sandstones include quartz, clay matrix, skeletal fragments, and glauconite with trace amounts of leucoxene, zircon, biotite, chert, polycrystalline quartz and plagioclase. Authigenic carbonates averaged 10% in this lithologic type. Piokilotopic calcite, micritic calcite aggregates in association with the clay matrix and occasional dolomite rhombs were observed. As a whole, the carbonates are more abundant in the cleaner quartz-rich zones than the clay-rich zones, perhaps as a result of bioturbation. The carbonate cements often corrode and replace quartz and clay matrix. Pyrite, carbonaceous matter, syntaxial quartz overgrowths, microquartz and chalcedony are additional authigenic components that occur in this lithologic type.

Clay Extraction

Figure 19 illustrates the x-ray diffraction results for clays extracted from the PW 9039 sample (Table VI). This sample is representative of the bioturbated quartz wacke sandstone to clayey sandstone lithologic type. Raw data for the clay extractions in this lithologic type are summarized in Table VII. The authigenic minerals kaolinite and chlorite are identifiable by a sharper peak relative to the more rounded mixed layer illite-smectite clay peaks. Within this lithologic type, the relative percentages of each clay type, mixed layer illite-smectite, chlorite and kaolinite average 7%, 6%, and 6%, respectively.

Figure 20 shows the x-ray diffraction results for clays extracted

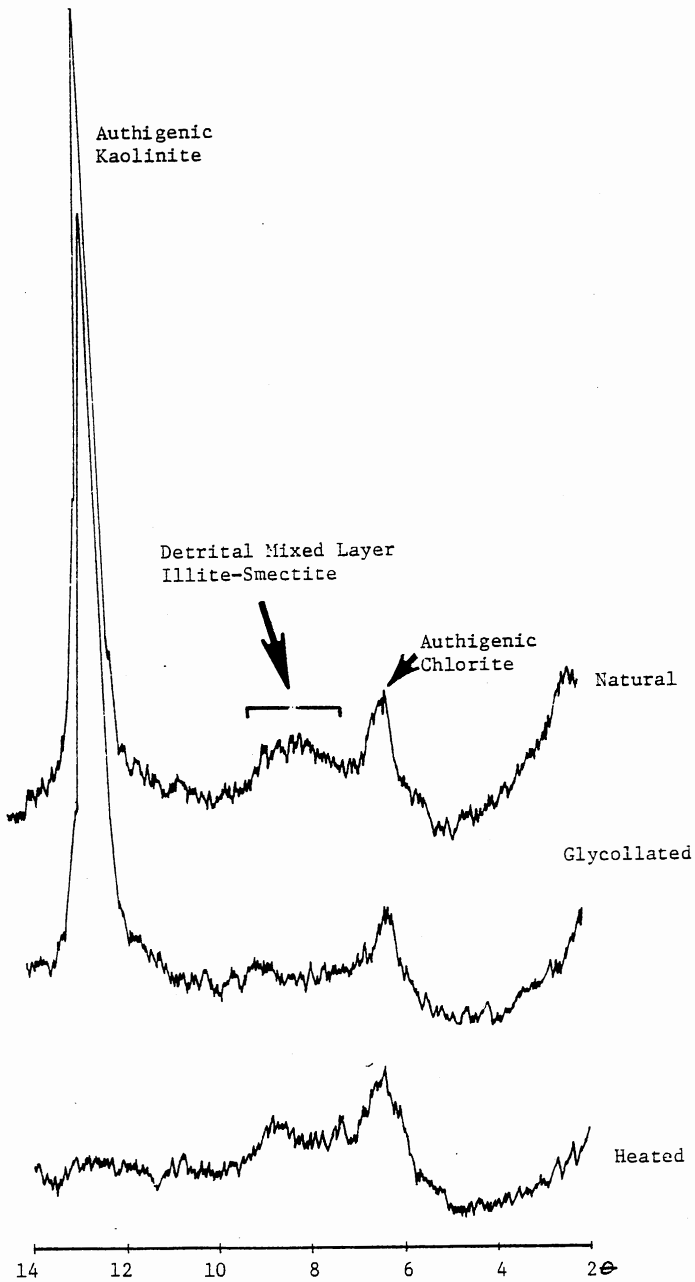

Figure 19. X-ray Diffraction Results for a Clay Extracted Bioturbated Quartz Wacke Tidal Flat Sandstone. (Sample from the Paul Wills A-5 core at 9039 feet.)

TABLE VII

RAW DATA SUMMARY OF CLAY EXTRACTION/X-RAY DIFFRACTION RESULTS IN THE BIOTURBATED QUARTZ WACKE SANDSTONE TO CLAYEY SANDSTONE LITHOLOGIC TYPE

% Clay Matrix	Clay Fractions: Illite-Smeltite	Clay Fractions: Chlorite	Clay Fractions: Kaolinite	% Mixed Layer Illite-Smeltite	% Chlorite	% Kaolinite	Sample
10	.70	.24	.06	7	2.4	0.6	TB 9137
25	.46	.42	.12	11.5	10.5	3	TB 9113
22	.46	.16	.38	10.1	3.5	8.4	FS 9164
11	.14	.39	.47	1.5	4.3	5.2	PW 9044
22	.15	.31	.54	3.3	6.8	11.9	PW 9039
10-22	0.14-0.70	0.16-0.42	0.06-0.52	1.5-11.5	2.4-10.5	0.6-11.9	Range
18	0.38	0.30	0.31	6.7	5.5	5.8	Average

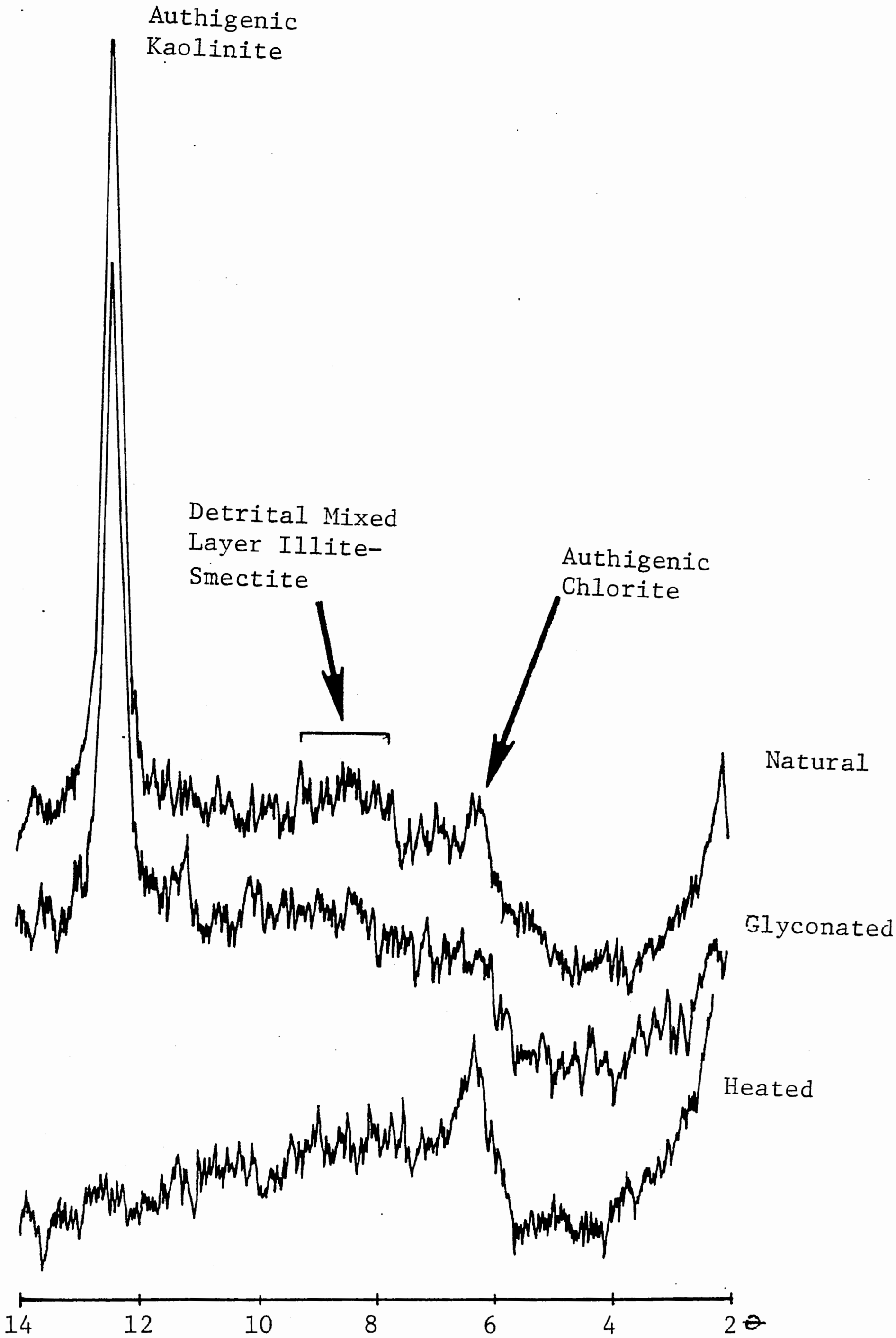

Figure 20. X-ray Diffraction Results for a Clay Extracted Producing Quartz Arenite Channel Sand. (Sample From the Frank Schafer No. 1 Core at 9200 Feet.)

from the FS 9200 sample (Table IV), a typical producing quartz arenite to quartz wacke channel sand. Table VIII summarizes the raw data for the clay extracted samples in this lithologic type. Within this lithologic type, the relative percentages of each clay type, mixed layer illite-smectite, chlorite and kaolinite average 1.1%, 1.3%, and 2.5%, respectively.

TABLE VIII

RAW DATA SUMMARY OF CLAY EXTRACTION/X-RAY DIFFRACTION RESULTS IN THE QUARTZ ARENITE TO QUARTZ WACKE CHANNEL SANDSTONE LITHOLOGIC TYPE

% Clay Matrix	Clay Fractions: Illite-Smeltite	Clay Fractions: Chlorite	Clay Fractions: Kaolinite	% Mixed Layer Illite-Smeltite	% Chlorite	% Kaolinite	Sample
2	.32	.36	.32	0.6	0.7	0.6	TB 9185
23	.21	.23	.56	4.8	5.3	12.9	TB 9179
9	25	30	.45	2.3	2.7	4.0	FS 9200
1	.38	.20	.34	0.4	0.3	0.3	FS 9195
1	.24	.27	.49	0.2	0.3	0.5	FS 9175
1	.13	.41	.46	0.1	0.4	0.5	PW 9066
Tr	.14	.27	.57	Tr	Tr	Tr	PW 9055
Tr	.44	.28	.28	Tr	Tr	Tr	DM 8452
Tr-23	0.13-0.44	0.23-0.41	0.28-0.49	Tr-4.8	Tr-5.3	Tr-12.9	Range
5	0.26	0.3	0.43	1.1	1.3	2.5	Average

CHAPTER VI

POROSITY

Introduction

Several independent workers have defined and distinguished similar specific porosity types in clastic rocks (Schmidt and McDonald, 1979; Scholle, 1979). The porosity types in clastic rocks are defined with respect to primary or secondary porosity.

The fundamental primary porosity types include 1) interparticle, 2) intraparticle, and 3) intercrystal porosity. Interparticle or intergranular porosity is the most common primary porosity type. Intraparticle primary porosity occurs within skeletal grains or rock fragments that contain voids of primary origin. Intercrystal primary porosity may occur within pore filling clay cements (i.e., kaolinite). The latter two primary porosity types are commonly rare compared to primary intergranular porosity.

Secondary porosity occurs as a result of a variety of diagenetic processes. The genetic classification of secondary porosity types by Schmidt and McDonald (1979) reflects these processes. The fundamental secondary porosity types include 1) dissolution of detrital components (i.e., grains and matrix); 2) dissolution of authigenic pore filling cements; 3) dissolution of authigenic replacive minerals; 4) fracture porosity, and 5) shrinkage porosity.

The terms preserved, enlarged, reduced, and filled are often used as genetic terms associated with primary or secondary porosity types. Composite, complex, or hybrid porosity are terms used to describe pores resulting from several different secondary porosity types or coexisting primary and secondary porosity, respectively.

Porosity Types in the Morrow Formation

Primary porosity in the Morrow Formation is not significant. The primary interparticle space is often filled by authigenic silica and/or carbonate cements. In the producing Morrow sands examined, the primary interparticle space is obliterated by pore enlarging secondary porosity. Where primary porosity was observed, it occurs as reduced interparticle porosity characterized by uncorroded pore rimming euhedral quartz overgrowths (Figure 21). This porosity type occurs where interparticle cementation did not completely fill the interparticle pore space in the quartz dominated sandstones. Primary porosity was not observed in the skeletal sands or conglomerates. Primary porosity in the Morrow Formation was not observed in amounts greater than 2% in the Canton area.

Secondary porosity accounts for almost all of the porosity observed in the Morrow Formation within the Canton area. It occurs in percentages up to 22% in Morrow cores examined from the Carlton area (i.e., DeMoss A-1 and Kephart No. 1). Secondary porosity occurs in all Morrow sand types, but is most abundant in the quartz dominated sandstones.

All of the genetic classes of secondary porosity defined by Schmidt and McDonald (1979) were observed in the Morrow Formation. Dissolution of the detrital clay matrix is the dominate genetic type. This porosity

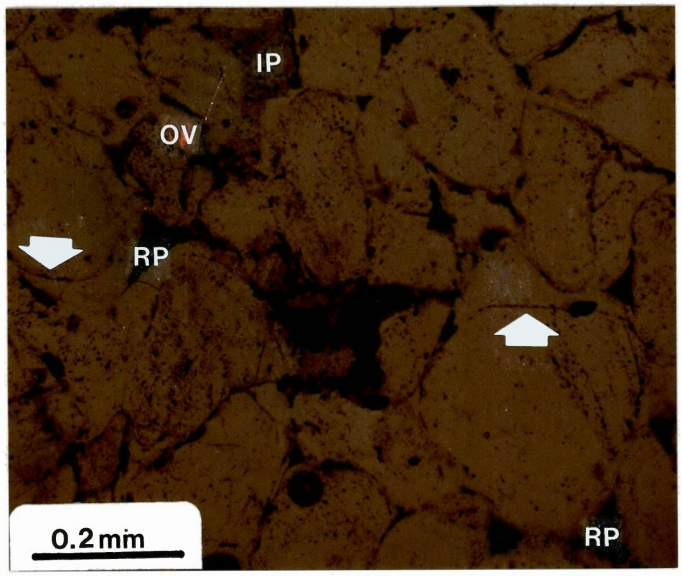

Figure 21. Reduced Intergranular Porosity (RP) and Intercrystalline Kaolinite Porosity (IP). (Note the dustlines and advanced to intermediate stage euhedral quartz overgrowths [OV]). FS 9200

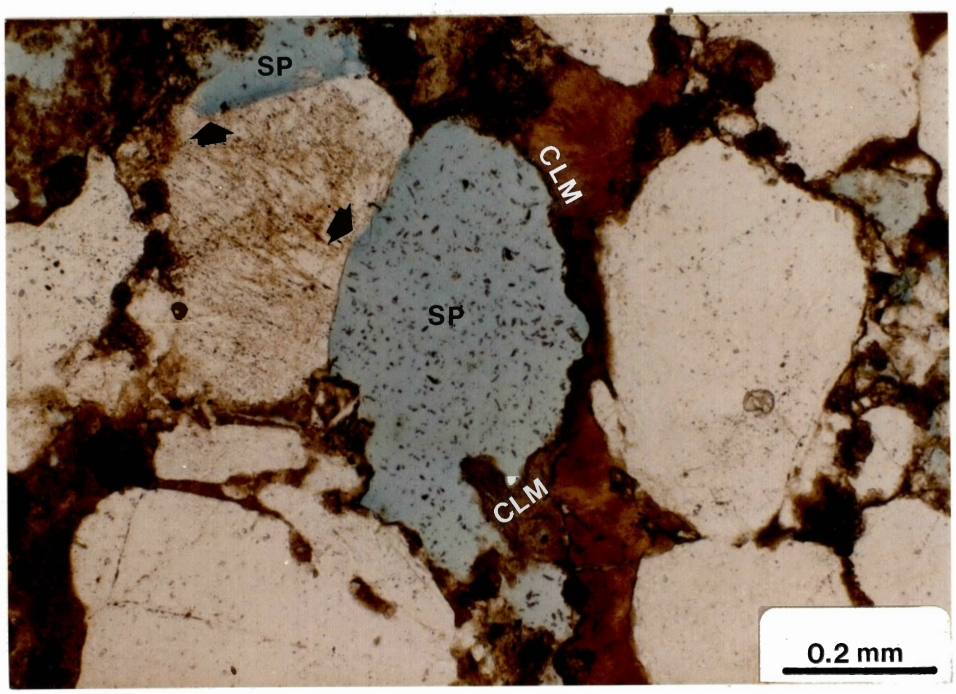

Figure 22. Secondary Porosity (SP) Generated by Dissolution of the Clay Matrix (CLM). (Arrows highlight the partially corroded quartz rims.) HK 8504

type accounts for the high porosities observed in the Canton area. All other genetic types generally account for a smaller percentage of the total secondary porosity in the Morrow sands within the study area.

Petrographic evidence for dissolution of detrital clay matrix is excellent. Clay matrix rimmed pores and floating clay matrix patches in oversized or elongate interparticle pores of secondary origin are common. These features are suggestive of partial dissolution of the clay matrix. Corroded and welded quartz grains and quartz overgrowths rimming oversized and elongate secondary pores were observed where dissolution of the detrital matrix is complete. This was common in the quartz dominated sands. Skeletal fragments in the Morrow sandstones were often preserved and unaffected by dissolution effects. Figures 22 and 23 illustrate characteristic features of clay matrix derived porosity.

Selective dissolution of glauconite was a common feature observed in the glauconitic Morrow sands. Characteristically, the glauconite grains are partially dissolved and corroded or leave glauconite grain shaped porosity molds when completely dissolved. This porosity type is generally not significant in the Canton area where glauconite percentage is commonly less than 1% in the Morrow sands. However, increased glauconite concentrations could generate significant porosities. One Frank Schafer No. 1 thin section (FS 9174) showed porosities in excess of 6% that were primarily derived from the dissolution of glauconite (Figure 24).

Selective dissolution of the other detrital grain types occurs but is not significant. Partial dissolution of detrital quartz is reflected by corroded and welded grains along oversized or elongate secondary

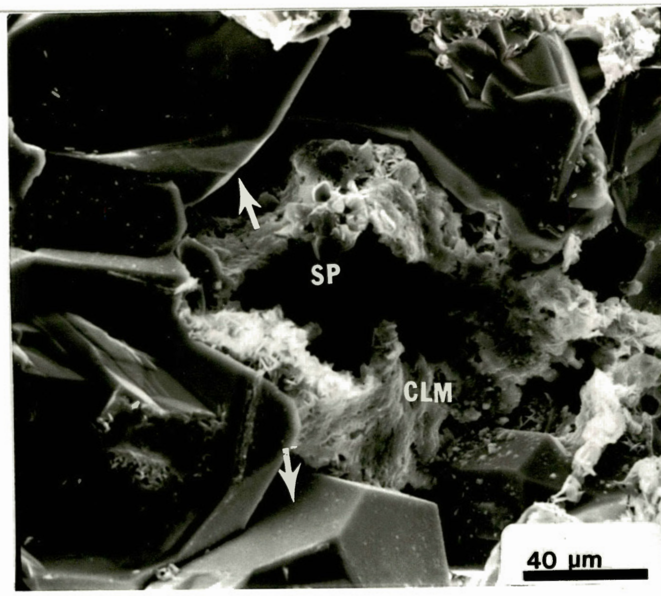

Figure 23. SEM View of Secondary Porosity (SP) Generated From Clay Matrix (CLM) Dissolution. (Arrows point to euhedral quartz overgrowths.) DM 8454

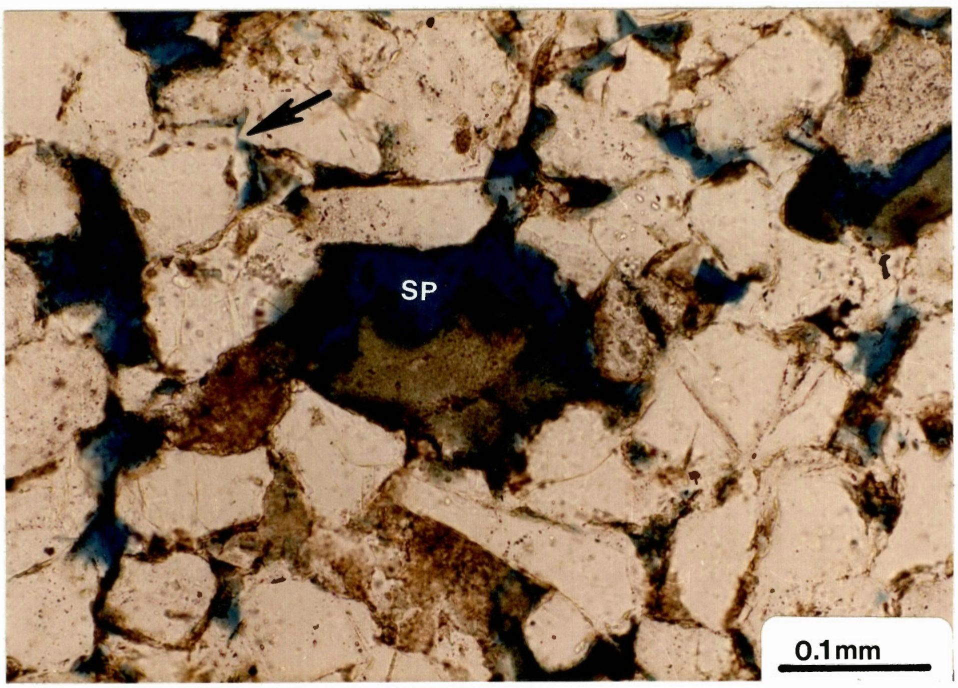

Figure 24. Secondary Porosity (SP) Created as a Result of Glauconite Dissolution. (Arrow shows euhedral quartz overgrowth edge.) FS 9174

pore rims (Figure 22). Occasional floating quartz grains were also observed. Significant partial dissolution of quartz occurs only where porosities are high in association with relatively complete dissolution of the detrital matrix. Occasional moldic porosity associated with detrital skeletal grains also occurs. This is generally a minor porosity type that was not commonly observed in the Morrow sands. Often, skeletal shaped molds are rimmed by pyrite. This implies pyritic skeletal grain replacement followed by dissolution of pyrite. In this case, care must be taken to differentiate between secondary porosity derived from skeletal grain or pyrite dissolution (see Figure 26).

The dissolution of pore filling authigenic silica cements was commonly observed. Partial dissolution of quartz overgrowths frequently occurs along oversized or elongate secondary pores. Here, the syntaxial quartz overgrowths show corroded edges. Porosity generated from the partial dissolution of quartz overgrowths commonly occurs in association with the dissolution of detrital clay matrix and partial dissolution of quartz grains (as in Figure 22).

Dissolution of void filling microquartz was observed in the quartz dominated sands. In most observed sands, microquartz occurs in trace amounts less than 1%, and dissolution of microquartz is not observed. However, in the Kephart No. 1 producing sand, porosity derived from the partial dissolution of authigenic microquartz was consistently observed. Figure 25 shows typical pore features characteristic of this sand. This porosity type appeared to contribute significantly to the total percentage of secondary porosity in this well. Porosities in the Kephart No. 1 producing sand are high (up to 20%) and are dominated by the dissolution of clay matrix.

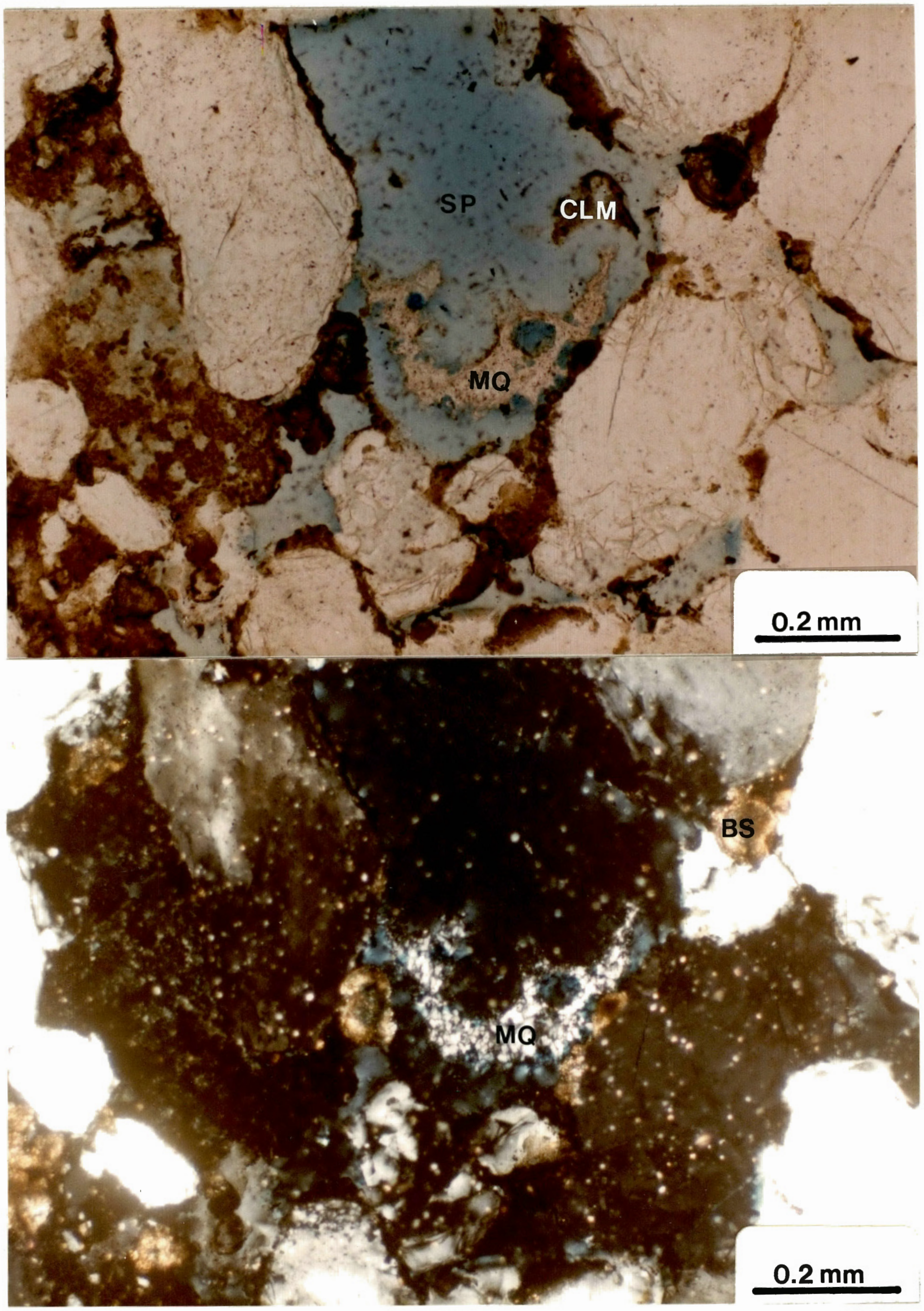

Figure 25. Plane Light and Crossed Nichol Views of Secondary Porosity (SP) Derived From Dissolution of Microquartz (MQ) and Clay Matrix (CLM). (Note floating microquartz and clay matrix character with corroded edges and intraconstituent voids. Braciopod spines (BS) are not affected by dissolution.) HK 8504

Partial dissolution of authigenic microquartz is characterized by corroded microquartz edges and floating microquartz patches in the secondary pore space (Figure 25). Intraconstituent pores were also common in the Kephart No. 1 core (as shown in Figure 25). Complete dissolution of microquartz is probable because of its observed association with oversized pores and porosity derived from the dissolution of detrital matrix.

Partial dissolution of carbonate cements occurs but is not common. Carbonate cements, as with skeletal grains, are often not affected by dissolution in the Canton area (see Figures 26 and 28).

Dissolution of pyritic replaced skeletal grains was observed as previously mentioned. This porosity type is characterized by fossil shaped molds with pyritic rims. Figure 26 illustrates typical examples. Rarer, partial dissolution of pyritic replaced collophane grains was also observed.

The dissolution of clay minerals that replace the detrial matrix may be significant. Commonly, chloritic linings on pore rims (as in Figure 28) and floating chloritic patches in pores are observed. In such cases, it is difficult to prove whether clay matrix dissolution occurred before or after chlorite recrystallization.

Fractured quartz and skeletal grains were occasionally observed in the Morrow sands. Where observed, fracturing is generally local and is restricted to individual grains. Figure 27 illustrates fracture porosity in a skeletal grain. In a few instances, microfractures that cut several grains were observed. However, the microfractures may be a result of coring and sample cutting rather than natural geologic processes. Shrinkage porosity associated with glauconite grains is the final secondary porosity type observed in the Morrow Formation sands.

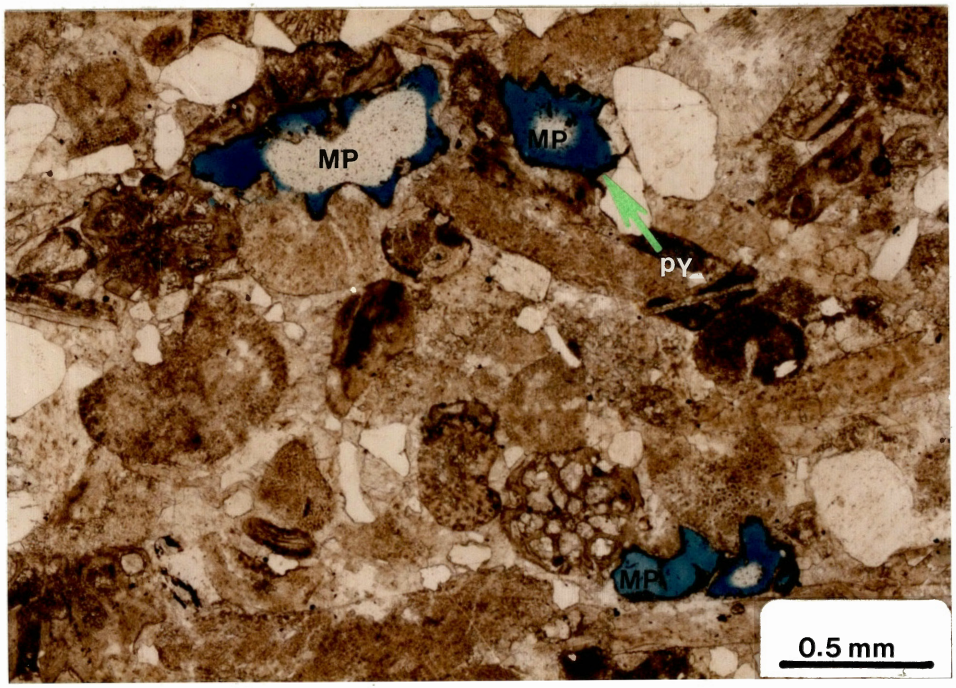

Figure 26. Moldic Porosity (MP) Generated by Selective Pyritic Replacement of Skeletal Grains Followed by Pyrite Dissolution. (The thin opaque pore rims are impure pyrite (PY). Rock type is an arenaceous skeletal grainstone.) FS 9171

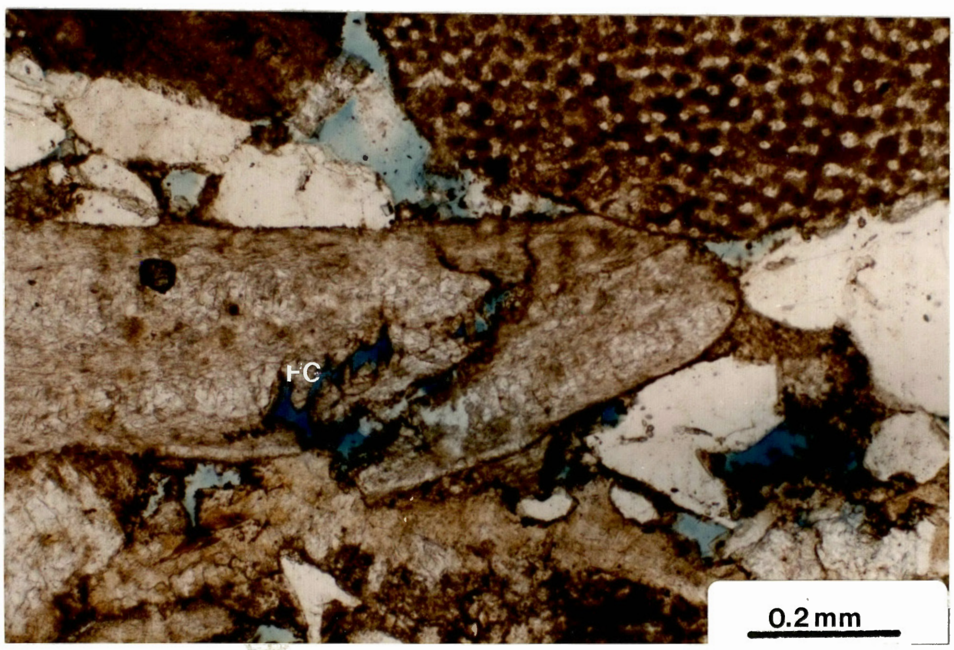

Figure 27. Fracture Porosity in an Elongate Skeletal Grain. (Note euhedral fibrous calcite (FC) on pore edge.) HK 8508

Both fracture and shrinkage derived porosities generally contribute less than 1% to the effective secondary pore space in most thin sections examined. However, fracture porosity of individual grains becomes more common in sands with high porosities (>20%). This may be a consequence of increased rock stress following the creation of secondary pore voids.

Porosity Trends in the Canton Area

Plate 11 is a porosity map of the Morrow sands. The total footage of porosity ($\geq$8%) for each well was calculated from bulk density and sonic logs. These values were subsequently contoured with porosity zones greater than 14% outlined. The methodology used for the construction of this map is summarized in Appendix A.

As reflected in the core observation, the higher porosities ($\geq$14%) occur east and southeast of the Southwest Canton Field. Elsewhere in the area, porosity zones ($\geq$14%) are localized and spotty. The Southwest Canton Field contains porosities generally between 8 and 12%.

The overall character of the porosity map is reflective of porosity development in the channel sands. Contoured porosity trends are similar to contoured sand trends shown on the net sand isopach map (Plate 10). Thick contoured porosity lenses coalesce with thick sand lenses along the periphery of the Southwest Canton Field, and in the northwest, northeast, and southeast extremes of the mapped area. Moreover, the outline of the Southwest Canton Field production correlates nicely with the contoured porosity. The extremely variable contoured porosity thicknesses in the Southwest Canton Field (from >5 feet to <50 feet over short distances) reflects the lenticular channel sand distribution characteristic of the Morrow Formation.

Most of the contoured porosities greater than 20 feet trend subparallel to structural strike. The porosity trends appear channel-like in the northeastern, northwestern, and southeastern mapped areas. The thick porosity trends compare nicely with the channel-like upward fining log characteristics distributed in Figure 13, but do not correlate consistently with the upward coarsening log signatures outlined in Figure 14. This relation simply reflects the good porosity development in the channel sands.

Porosity and Lithologic Type

The skeletal grainstones observed from Morrow Formation cores contain, for the most part, low porosities. Thin section observed porosities are commonly in trace amounts. This is true of all of the observed Canton area cores except for the Kephart No. 1 core (in Appendix B). Typically, the skeletal sands are tightly cemented by authigenic carbonate cements. Occasional moldic porosity may occur as a result of the dissolution of skeletal grains in pyritic replaced skeletal grains (as in Figure 2 6). Additional trace amounts of porosity may result from the dissolution of glauconite.

However, an arenaceous skeletal grainstone in the Kephart No. 1 core (Appendix B) shows intergranular porosity in amounts up to 13%. Here, the intergranular porosity is secondary and is apparently derived from the dissolution of detrital clay matrix. Evidence for this porosity type is based largely on petrographic results. As shown in Figure 28, a thin veneer of recrystallized detrital clay matrix rims an oversized secondary pore. Oversized pores are common in the Kephart No. 1

skeletal grainstone, with rarer, but observable, detrital clay matrix pore rims. Euhedral carbonate cements and preserved skeletal grains may also rim the pore spaces, as illustrated in Figure 29. This suggests the carbonates are relatively insoluble and the secondary porosity was generated from noncarbonate constituents.

The Kephart No. 1 example shows porosities sufficient for oil and gas production may occur in slightly argillaceous skeletal grainstones. The percentage of original detrital clay matrix in this example is approximately 14-15% (assuming a 1:1 replacement of porosity for clay matrix). This lithologic type should not be overlooked as a potential reservoir in the area. Clean skeletal grainstones, whether arenaceous or nonarenaceous, were always tightly cemented by carbonate cements and nonproductive in the cores observed. Skeletal dominated sands containing greater than 15% detrital clay matrix also showed extremely low porosities.

The best porosities in the Morrow Formation occur in the quartz dominated sands. Observed porosities between 15 and 20% are common in quartz channel sands east of the Southwest Canton Field in the Carlton area (i.e., the DeMoss A-1 and Kephart No. 1 cores). Lower porosities, between 8 and 12%, characterize the Southwest Canton Field (Plate 11).

Clean quartz arenite and skeletal grainstone sands (<5% detrital clay matrix) were almost always tightly cemented by advanced stage quartz overgrowths and authigenic carbonate cements in the thin sections observed, respectively. Conversely, the bioturbated quartz wacke sandstones to clayey sandstone lithologic type contains detrital clay matrix in excess of 15%. This tidal flat sand generally contains relatively low porosities, often in amounts less than 1%. Presumably,

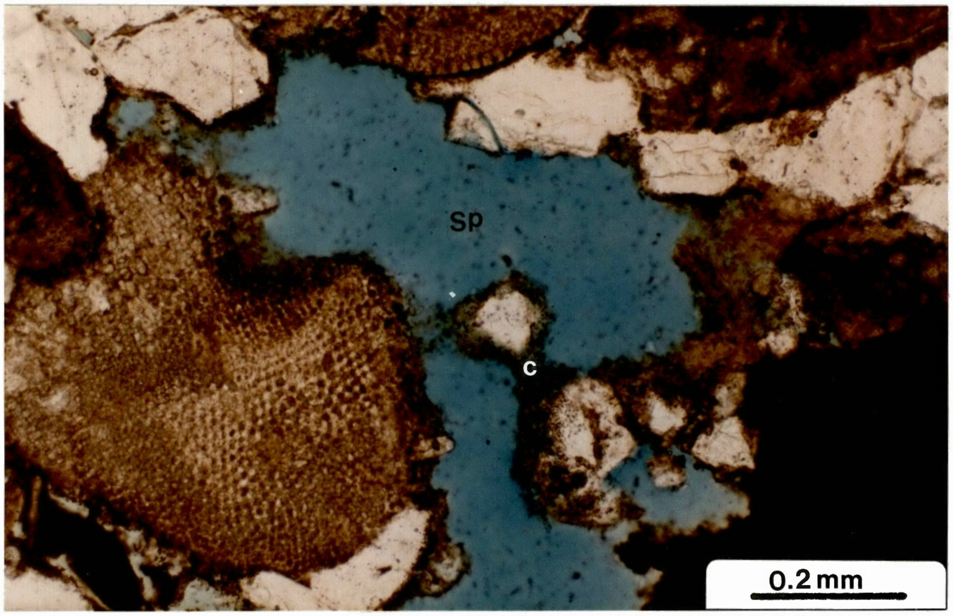

Figure 28. Secondary Porosity (SP) in a Skeletal Grainstone Created as a Probable Result of Clay Matrix Dissolution. (Note the pore rimming clay matrix that is partially recrystallized by chlorite (C). Sample is from the Kephart No. 1 core HK 8508.)

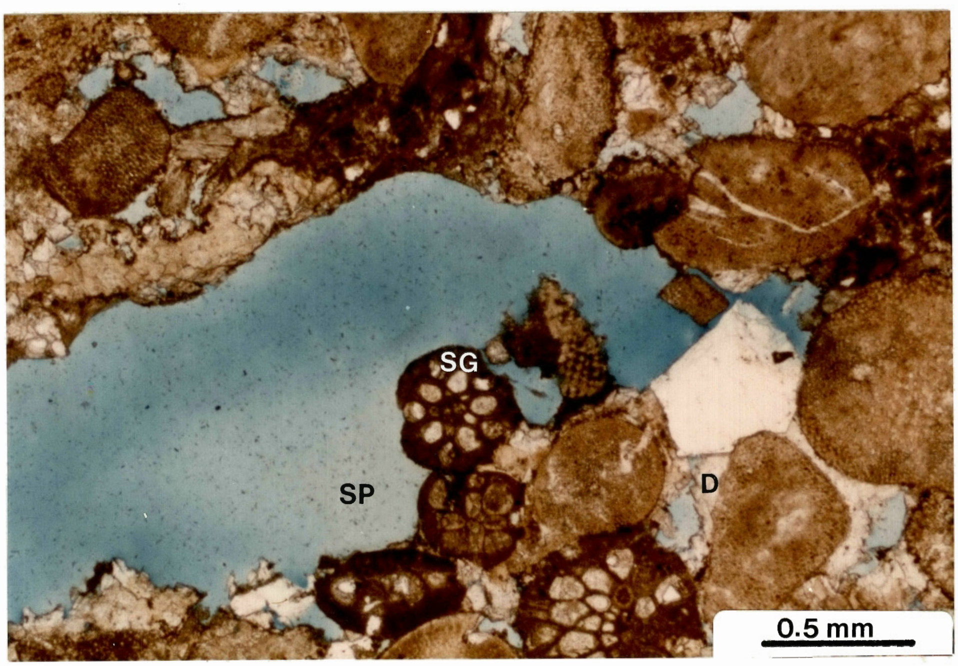

Figure 29. Oversized Secondary Porosity (SP) in a Skeletal Grainstone. (Note the uncorroded pore rimming skeletal grains (SG) and euhedral pore filling dolomite cement (D). Sample is from the Kephart No. 1 core HK 8508.)

sands with higher detrital clay percentages (>15%) are impermeable to the flow of diagenetic fluids that are responsible for dissolution and the creation of secondary porosity.

The amount of porosity in a particular genetic unit appears to primaily be a function of the amount of original detrital clay matrix and glauconite deposited with the Morrow sands in the Canton area. As previously mentioned, dissolution of the detrital clay matrix is the most prominent porosity type in both the quartz and skeletal dominated sands. Glauconite in the examined core is commonly not a major constituent. However, where it does occur in amounts >5%, dissolution of glauconite contributes significantly to the generation of secondary porosity.

The optimum percentage of original detrital clay matrix for the generation of secondary porosity is between approximately 5 and 15% (dirty quartz arenite to quartz wacke sandstone). This is based on the 102 thin sections and eight Morrow cores examined in the study area. It is conceivable that a Canton area sand containing 5% detrital clay matrix could generate 8% effective porosity in combination with the other secondary porosity types (i.e., dissolution quartz overgrowths, quartz grains, authigenic silica cements, glauconite, etc.).

CHAPTER VII

MORROW SAND DIAGENESIS

Introduction

Several distinct diagenetic processes affected the Morrow Formation in the Canton area. These processes are inferred from mineralogic and textural features identified in thin sections, SEM/EDXA examination and x-ray diffraction analysis of clay extracted samples. Wilson and Pittman (1977) outline the petrographic criteria for the recognition of authigenic clays in sandstones. The recognition of secondary pores in sandstones is reviewed by Schmidt and McDonald (1979). Several additional workers have discussed diagenetic processes and their recognition in sandstones (Scholle, 1979; Scholle and Schluger, 1979).

Recognition of the diagenetic processes responsible for modifying the Morrow sandstones is important. As discussed in Chapter VI (Porosity), secondary porosity is the prominent porosity type in the Morrow reservoir in the Canton area. With respect to petroleum exploration, understanding of the processes responsible for the generation of secondary porosity and knowledge of the paragenetic sequence is useful. This knowledge may be applicable to other clastic reservoirs in different areas.

Figure 30 summarizes the diagenetic features observed in the Canton area Morrow sands. Typical examples are listed with effects on porosity.

MECHANICAL DEFORMATION FEATURES

Ductile deformation of soft detrital components
Examples: glauconite, detrital clay matrix, micas
Generally reduces porosity

Fracture of brittle detrital grains
Examples: quartz, elongate skeletal grains; Results in enhanced porosity

DISSOLUTION FEATURES

Dissolution of detrital grains, clay matrix, authigenic cements and replacing minerals
Examples: glauconite, detrital clay matrix, authigenic silica cements, pyrite
Dissolution is partial to complete; results in secondary porosity

PRECIPITATES

Authigenic void filling minerals and cements
Examples: kaolinite, microquartz, chalcedony, carbonate cements, quartz overgrowths, drusy calcite and silica spar; Reduces porosity

ALTERATION AND REPLACEMENT FEATURES

Alteration/replacement of detrital grains and matrix
Examples: chlorite, illite, calcite, dolomite, siderite, pyrite
Products may be selectively dissolved resulting in enhanced porosity

PRESSURE SOLUTION FEATURES

Sutured quartz overgrowth contacts
Stylolitic skeletal grain contacts
Carbonaceous styolites

SHRINKAGE OF GLAUCONITE

Enhances porosity

Figure 30. Diagenetic Features Observed in the Morrow Sands, Canton Area

Morrow Sand Components and Diagenesis

The primary Morrow Formation mineral and mineraloid components influenced by diagenetic processes are: 1) the silica mineral group (void filling silica cements and detrital quartz); 2) detrital and authigenic clays; 3) glauconite; 4) carbonates; 5) pyrite, and 6) carbonaceous matter (styolites and hydrocarbon influx). These components were consistently recognized as diagenetic products or related to dissolution and the creation of secondary porosity. The relative timing of each component with respect to secondary porosity generation and hydrocarbon migration is listed in Figure 31.

Silica Mineral Group

A variety of diagenetic processes affect the silica components. These include:

1. precipitation of authigenic cements
2. partial to complete dissolution of silica mineral components
3. pressure solution of quartz overgrowth contacts
4. mechanical fracture of detrital quartz grains

Early silica diagenesis is marked by the precipitation of syntaxial quartz overgrowth cements. Advanced and intermediate stage quartz overgrowths were observed. Advanced stage syntaxial quartz overgrowths completely encase the original quartz grains, show sutured overgrowth contacts where the overgrowths interfere with each other and often seal the intergranular pore space. Figure 32 illustrates typical advanced stage overgrowth cementation. Advanced stage overgrowths occur only in the cleaner quartz arenite sands or in local clean quartz zones in

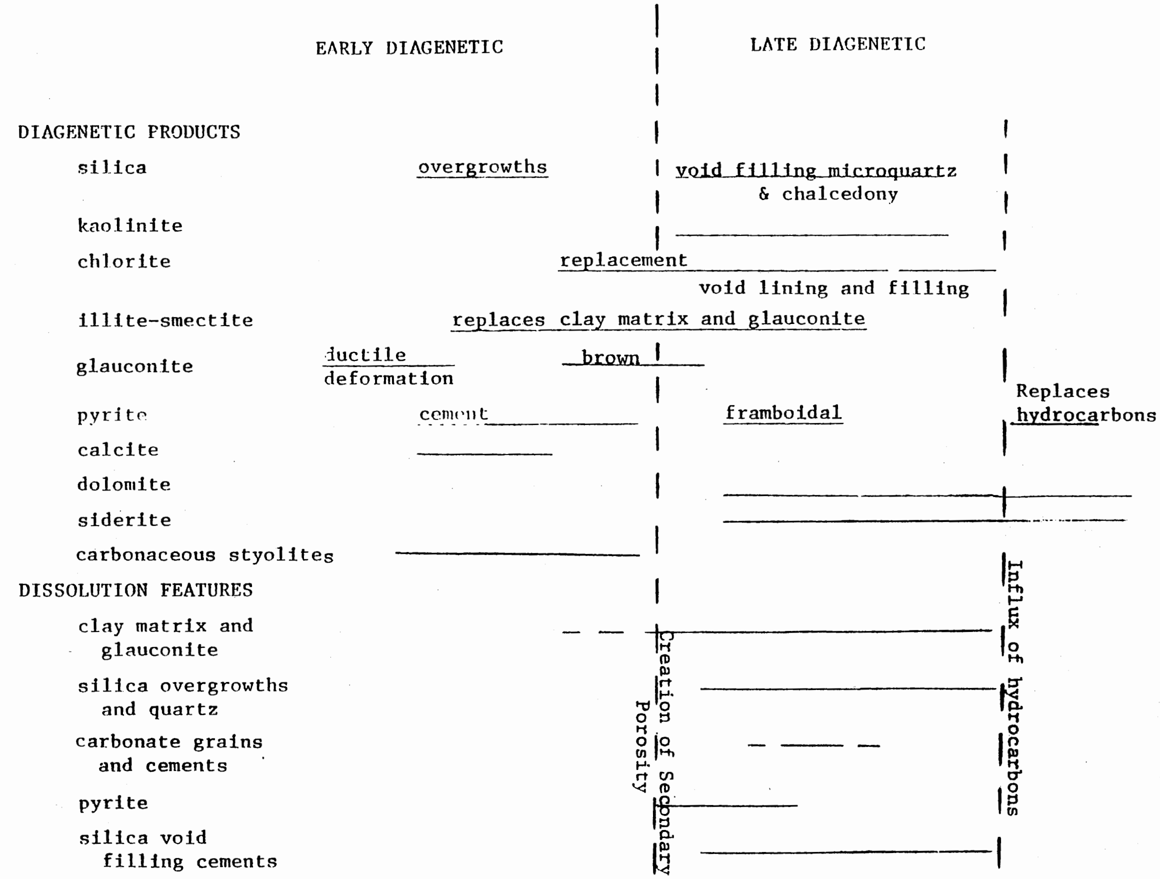

Figure 31. Relative Timing of Precipitation and Dissolution Features in Morrow Sandstones, Canton Area. (Timing is with respect to secondary porosity development and hydrocarbon influx into the secondary pore space.)

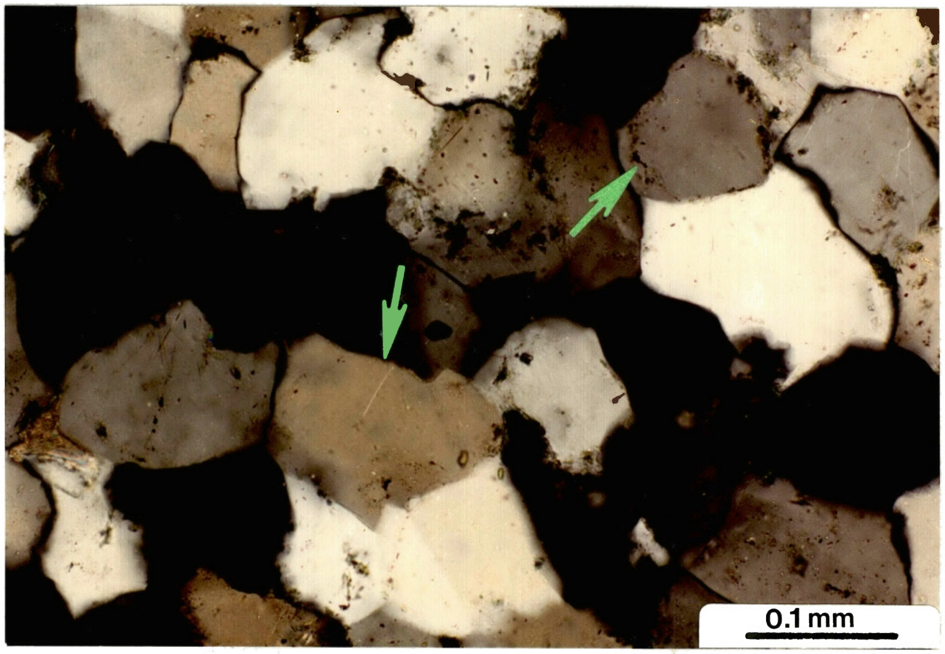

Figure 32. Advanced Stage Quartz Overgrowth Cementation. (Note presence or absence of dustlines and interlocking overgrowth contacts indicated by arrows; TB9185.)

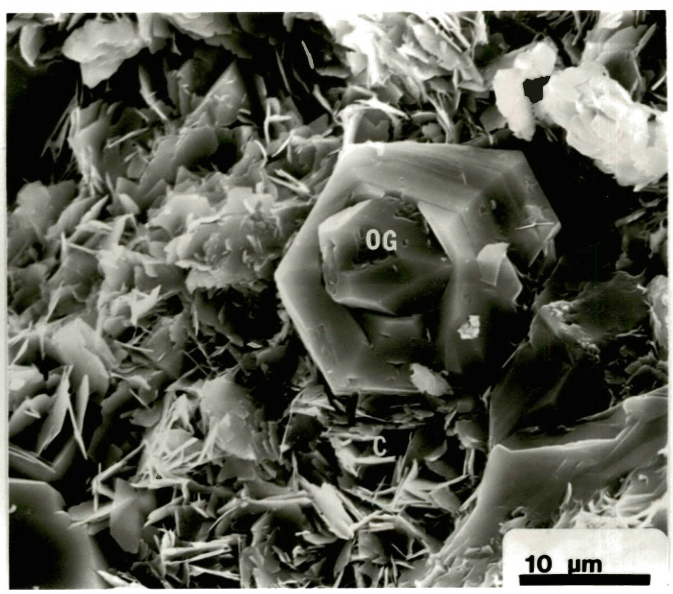

Figure 33. Quartz Overgrowth Surrounded to Edge-to Face Chlorite (C). (The prismatic inner overgrowth (OG) preceded precipitation of the outer overgrowth. Note growth lines on upper right face of outer overgrowth.)

dirtier or skeletal dominated Morrow sands. This overgrowth type is not characteristic of the dirtier quartz wacke or skeletal Morrow sand types. Intermediate stage overgrowths occur in all Morrow lithologic types containing quartz except the cleanest quartz arenite sandstones. Intermediate stage overgrowths often occur with intergranular clay or carbonate matrix, do not seal the intergranular space, and show euhedral crystal faces where the overgrowths do not interfere with each other (see Figure 24). Figure 33 shows a grain coating overgrowth that records two distinct phases of growth. The quartz overgrowths predate the generation of secondary porosity because they are often corroded or welded by secondary pore rims.

Workers examining the Pennsylvanian Strawn (Land and Dutton, 1978) and Eocene Wilcox (Boles and Franks, 1979) sandstones in Texas estimated temperatures of 60°C for the formation of quartz overgrowths. Compared to today's geothermal gradient in the Canton area (0.0105°F), this corresponds to a depth of approximately 6500 feet.

Several workers have suggested alteration of shales adjacent to sands as possible sources of early silica (Hower, et al. 1976; Powell et al. 1977; Boles and Franks, 1979). No preferental overgrowth cementation was observed in sands adjacent to shales in cores examined in the Canton area.

The later authigenic silica cements, microquartz and chalcedony, fill secondary pores. These cements may be common in enlarged intergranular zones associated with clay matrix (see Figure 25 in Chapter VI). Drusy quartz spar was most often observed filling secondary voids in the carbonate sands. Later carbonate cement corrosion of the drusy quartz spar is common. Al Shaieb (1983 personal communication) suggests the alteration of clay matrix and glauconite in the Morrow Formation releases silica that may induce the precipitation of these cement types.

Partial to complete dissolution of detrital quartz and authigenic silica cements is most common in producing sands with high porosities. The dissolution of silica is associated with the dissolution of the clay matrix. Silica corrosion is common along or within secondary pores generated from clay matrix dissolution (see Figure 22, Chapter VI).

Pressure solution of quartz overgrowth contacts was observed occasionally in advanced stage overgrowths. Pressure solution is identifiable by sutured contacts. Pressure solution of quartz grains was not observed. Fracture of detrital quartz and skeletal grains is rare, but relatively more common in sands with high porosities. This was discussed in Chapter VI.

Detrital and Authigenic Clays

All clay types in the Morrow Formation are affected by diagenesis. Diagenesis of the clay minerals includes the following processes:

1. ductile deformation of the original detrital clay matrix
2. alteration and replacement of the clay matrix by chlorite and illite-smectite mixed layer clay
3. dissolution of the clay matrix (detrital and recrystallized detrital)
4. precipitation of void filling kaolinite and chlorite

Ductile deformation of the clay matrix is an early diagenetic feature in response to compaction during burial. Here, the soft clay matrix flows between rigid detrital particles. Often, replacement of the clay matrix by chlorite and illite-smectite mixed layer clay obliterates any flow texture imprinted during deformation. Ductilly deformed glauconite is a common feature observed in glauconitic sands which is related to the mechanical flow of clay matrix.

Replacement of detrital clay matrix by authigenic clays probably preceded the last imprint of hydrocarbon matter. The presence of unstained recrystallized clay matrix is lacking in hydrocarbon stained areas. This suggests hydrocarbon influx post dated detrital clay matrix recrystallization. It is conceivable that clay matrix replacement occurred both before and after clay matrix dissolution and secondary porosity generation. This is difficult to verify by classical petrographic techniques; however, pore filling and lining chlorite, mixed layer illite-smectite and kaolinite clays are late diagenetic minerals because they are precipitated in secondary pore space following the creation of secondary porosity.

Glauconite

Four diagenetic processes were observed that affect glauconite in the Canton area Morrow Formation. These are:

1. selective, partial to complete dissolution of glauconite pellets (discussed in Chapter VI)

2. shrinkage of glauconite (discussed in Chapter VI)

3. ductile deformation of glauconite and transformation to brown glauconitic pseudomatrix

4. alteration of glauconite by chlorite and/or iron rich illite-smectite (discussed in Chapter V)

Ductile glauconite deformation is an early diagenetic feature associated with compaction and the ductile flowage of clay matrix. Glauconite deformation is characterized by a modification of the original spherical to ellipsoidal grain shape. This results in a ductilly-derived glauconitic "pseudomatrix" that may be significant in glauconite rich sands. As in undeformed glauconite, the deformed glauconite may be unaltered or completely recrystallized by chlorite an/or mixed layer illite-smectite clays. This makes recognition of the original ductile fabric difficult.

Figure 34 shows an example of ductilly deformed glauconite pseudomatrix. In this case, the original green glauconite is partially altered to brown glauconitic pseudomatrix. This type of alteration was observed only in glauconites that were ductilly deformed. Brown glauconite alteration never affected undeformed green glauconite in the examined samples. Al Shaieb (1983), personal communication) also recognized green to brown glauconite alteration associated with mechanical deformation in Morrow Formation sands elsewhere in the Anadarko Basin. Where brown glauconitic pseudomatrix alteration is complete, it is difficult to petrographically distinguish from clay matrix. Because glauconite deformation occurs with the ductile flow of detrital clay matrix, the resultant pseudomatrix in glauconitic sands is a detrital clay-glauconite mix.

Carbonates

The carbonate components include skeletal grains and carbonate cements. These components are described in Chapter V. Diagenesis of the carbonates includes the following processes:

1. pore filling carbonate cementation

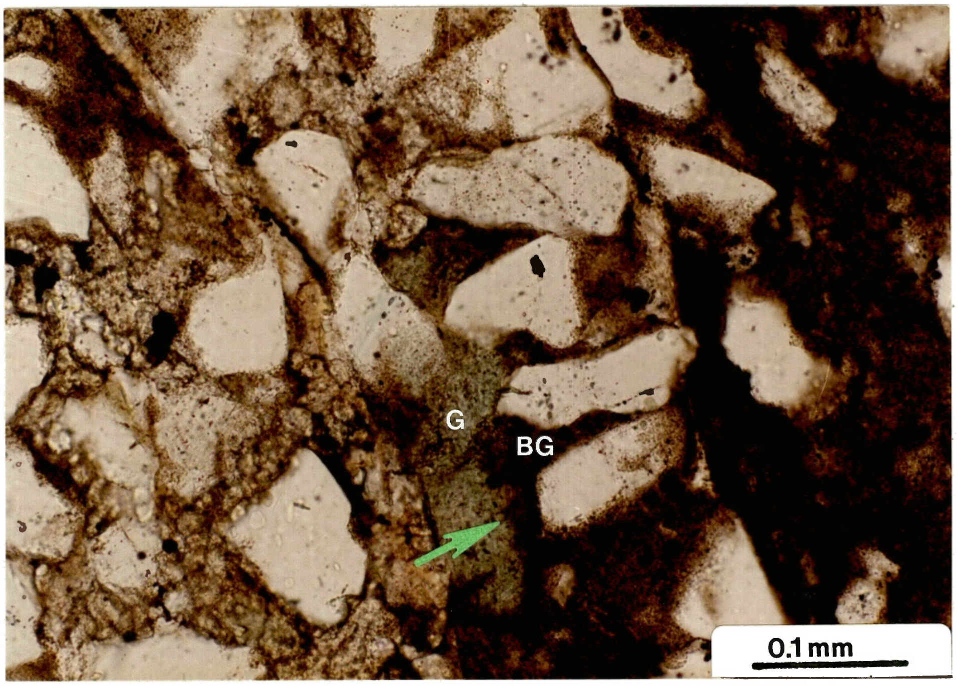

Figure 34. Ductilly Deformed Green Glauconite (G) Forming a Brown Glauconite (BG) "Pseudomatrix." (Green to brown glauconite transformation is shown by arrow; TB 9113.)

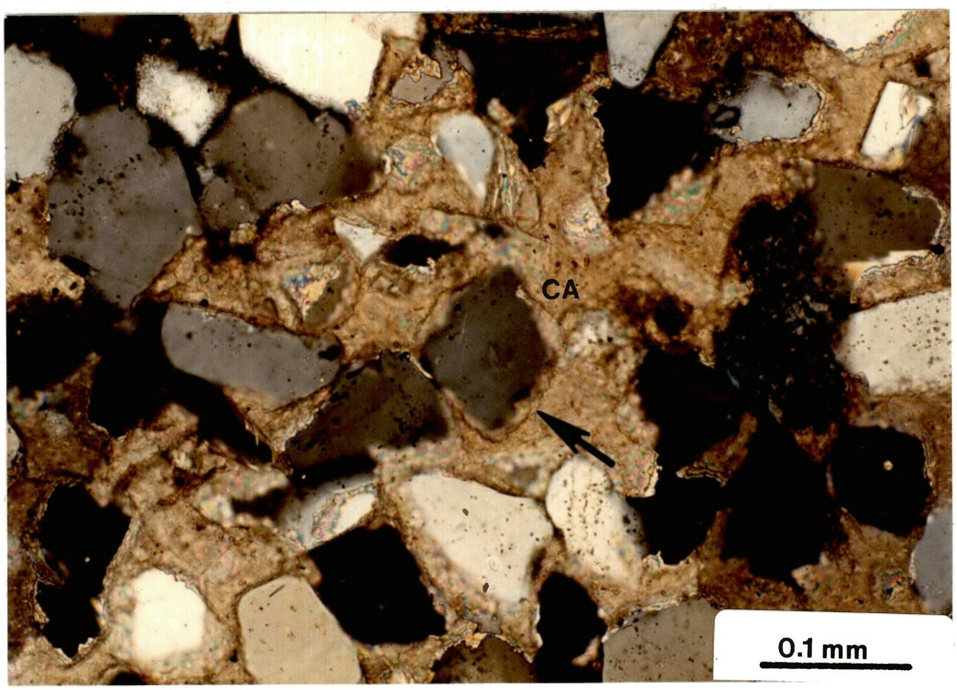

Figure 35. Intragranular Piokilotopic Calcite Cement (CA) in a Quartz Dominated Sand. (Quartz corrosion is shown by arrow; TB 9113.)

2. corrosion of quartz grains and silica cements by carbonate cements
3. dissolution of skeletal grains and carbonate cements
4. brittle fracture of elongate skeletal grains (discussed in Chapter VI)
5. Pressure solution of skeletal grain contacts

Intergranular mosaic calcite and piokilotopic calcite cementing agents in the Morrow sands are early diagenetic features. These cements often corrode quartz grains and silica overgrowths. A typical example of piokilotopic calcite cementation is shown in Figure 35. Calcite cementation occurred before secondary porosity, as commonly observed from calcite cements outlining moldic porosity and occasional partial dissolution of calcite cements. Rarer sparry calcite is also an early diagenetic feature because it fills primary void space within fossil grains (i.e., phylloid algae) and intergranular pockets of primary character. Late diagenetic calcite cement diagenesis (post-dating secondary porosity development) was not consistently observed in the Morrow sands and is not a prominent feature in the Canton area.

Less common siderite and dolomite cements, where observed, occur as late stage cements. Late siderite aggregates were occasionally observed altering void filling microquartz and megaquartz. Isolated euhedral dolomite rhombs were observed replacing detrital grains and early calcite cements in skeletal sands and conglomerates. Occasional dolomite cements with euhedral rhombic edges were observed growing along pore edges in the skeletal sands (Figure 28, Chapter VI). Both dolomite types are late diagenetic features. Pressure solution along skeletal grain boundaries was often observed in skeletal grainstones.

Pressure solution affecting quartz grains and other silica components is not a common phenomenon except in association with organic matter. Pressure solution of skeletal grains is probably an important source of calcium carbonate in the Canton area Morrow sands. Larese (1983) mentioned pressure solution of carbonate skeletal grains has been recognized as an important source for carbonate cements in sandstones.

Pyrite

Although pyrite occurred in relatively minor amounts in the Canton area, it is an important constituent because of its relationship to the generation of secondary porosity (Chapter VI). Early pyrite diagenesis is illustrated by moldic porosity generated as a result of pyritization of skeletal grains and subsequent dissolution (Figure 26, Chapter VI). This is discussed in Chapter VI. As mentioned in Chapter V, pyritization also occurs along carbonaceous styolites and hydrocarbon matter. Occasionally, pyrite may also be a cementing agent of detrital grains. The rare framboidal spheres observed in intergranular areas associated with clay matrix may be a late diagenetic feature.

Carbonaceous Matter

Carbonaceous matter in the Morrow Formation is a significant diagenetic component. Carbonaceous styolites are common in the Morrow quartz dominated channel sands. The styolites are a product of pressure solutionof organic rich clay laminations. Presumably, organic matter is a catalytic agent that induces pressure solution in quartz sands (Larese, 1983).

The Morrow Formation Diagenetic Sequence

The major diagenetic events affecting Morrow sands in the Canton area are listed below in chronologic order:

1. compaction with ductile deformation of clay matrix and glauconite. Includes some possible early fracturing of elongate detrital grains. This diagenetic phase generally reduces porosity.

2. early quartz overgrowth diagenesis. This stage reduces and fills the primary intergranular space. Possible authigenic clay replacement of the detrital matrix may be associated with this phase.

3. early piokilotopic and mosaic calcite diagenesis. This stage further reduces the interparticle pore space. Pyritization of skeletal grains is probably associated with this stage.

4. the creation of secondary porosity through dissolution of the clay matrix. In glauconitic sands, the dissolution of glauconite contributes significantly to the generation of secondary porosity. However, observed Canton area cores generally show relatively low amounts of glauconite (commonly <1%). Dissolution of pyritic replaced detrital grains, quartz overgrowths and quartz grains contribute to the development of secondary porosity. Minor dissolution of the carbonate components occurs, but it is not significant. Quartz grain fracturing may be related to the completion of this phase.

5. Secondary pore filling processes include void filling kaolinite, chlorite and silica cements microquartz, megaquartz, chalcedony and drusy silica spar. Hydrocarbon migration occurred during and after this stage.

6. Late carbonate diagenesis is marked by siderite and dolomite cements. This stage may have occurred before and after hydrocarbon

migration.

One characteristic of the above diagenetic sequence is the alternating silica and carbonate precipitation. Carbonate precipitation follows silica precipitation before and after the generation of secondary porosity. This may reflect fluctuations in the pH of the subsurface brines. Krauskopf (1979) reviews the chemical behavior of carbonate and silica in brines with variable pHs.

The chronologic order of the diagenetic events above is generally consistent in all of the Morrow lithologic sand types observed. Variations in this scheme do occur as a natural byproduct of the complex diagenetic character of the Morrow sands. For example, evidence for multiple stages of secondary porosity generation is common. Secondary pore filling microquartz and chalcedony may be partially dissolved by a second stage of secondary porosity. Moreover, portions of the above diagenetic sequence may be missing in different Morrow sands. Late diagenetic carbonates, dissolution of the detrital matrix, and secondary porosity diagenetic features are not always present. The sequence listed above is accurate, however, with respect to the timing of each diagenetic feature. Whether a particular diagenetic feature occurs in a rock or not is often a function of inherent mineralogy.

Diagenetic Minerals and Formation Damage

The Morrow Formation sands in the Canton area contain several authigenic products that are sensitive to well drilling, completion and stimulation techniques. These minerals include all of the authigenic clays--kaolinite, mixed layer illite-smectite and chlorite--and the iron-rich diagenetic carbonates siderite and ankerite.

Almon and Davies (1978) reviewed well stimulation techniques and their effect on sensitive authigenic components. Other papers by Almon and Davies (1977, 1979) and Pittman (1979) have also mentioned the importance of understanding diagenetic zones with respect to potential formation damage.

Based on the diagenetic constituents observed in the Canton area, three primary formation damage problems are possible. These include 1) the migration of clays during fluid flow; 2) clay swelling as a by-product of freshwater stimulation, and 3) the precipitation of relatively insoluble $Fe(OH)_3$ as an acid treatment side effect.

Void filling kaolinite booklets may, during turbulent flow, migrate through the pore system. This will reduce the overall permeability of the reservoir, because the clay booklets clog and stack up within pore throats. Authigenic illite crystals related to mixed-layer clay may also contribute to the problem by clogging pore throats. The use of a clay stabilizing agent (i.e., polyhydroxy aluminum) early in history of the well will alleviate this problem (Almon and Davies, 1978).

Several problems may occur due to the presence of mixed-layer illite-smectite clays. Clay swelling in the smectitic portion of mixed-layer illite-smectite clays will seal pore throats and result in lower permeabilities. Secondly, it is possible that illitic diagenetic films that cover smectite may break loose and migrate in response to swelling smectite. Moreover, pore lining smectite-illite mixed-layer clays may also break loose and migrate as a result of clay swelling. These latter two features could reduce permeabilities by the migration of clay into pore throats. A common method used to prevent this problem is the use of oil base or potassium chloride (KCl) drilling, completion and stimulation systems (Almon and Davies, 1978).

The iron-rich minerals, chlorite, iron-rich illitic mixed-layer clay, siderite, and iron dolomite (ankerite) are extremely sensitive to acids and oxygenated waters. Severe completion problems may occur as a result of improper acid treatments. These minerals are soluble in hydrochloric acid, and release iron to the system during solution. This liberated iron will precipitate as gelatinous ferric hydroxite $[Fe(OH)_3]$ which seals pore throats. Permeability is therefore greatly reduced. Prevention of this problem involves the addition of oxygen scavengers and iron chelating agents to the well acidation program (Almon and Davies, 1978). A weak (5%) HCL solution with the proper iron chelating and oxygen scavenger agents is a recommended corrective procedure (Almon and Davies 1978).

Hydroflouric acids should not be used in the Canton area without the complete removal of $CaCO_3$ from the system. Otherwise, relatively insoluble CaF_2 may precipitate near the borehole (Almon and Davies, 1983). This could be a problem in potentially productive skeletal sands.

CHAPTER VIII

PETROLEUM MATURATION

Introduction

Vitronite reflectance is a useful indicator of temperature histories in sedmimentary units containing organic material. Its use as an indicator of coalification stage and degree of petroleum maturation is well established and documented (Hood et al., 1975; Selley, 1976; Barker, 1979; Waples, 1980). Essentially, the amount of light reflected from coaly material (vitronite) is proportional to the degree of maturity of the organic matter. Because this maturity is irreversible, vitronite reflectance records the maximum thermal imprint a sedimentary unit has undergone.

The effect and importance of temperature and the effective heating time as dominant controls on organic matter maturation is well established (Barker, 1979). Because formation temperature is primarily a function of depth of burial in stable cratonic areas, depth of burial is an important parameter with respect to the degree of organic matter maturation in the Canton area.

Shales and carbonaceous laminations from three cores--Paul Wills A-5, DeMoss A-1, and Winters No. 1--were sampled for vitronite reflectance in the Canton area. The sample location on each core is shown in Appendix B, and the reflectance values are listed in Table IX. These reflectance values are indicators of (1) the maximum depth of burial of the Morrow sediments in the Canton area, and (2) the maximum effective formation temperature. Hence, in conjunction with additional geologic data, inferences can be drawn about the thermal history of the Morrow Formation and its relation to petroleum maturation in the Canton area.

Maximum Formation Temperature

Hood, Gutjahr and Heacock (1975) and Hood (1983) related vitronite reflectance to maximum formation temperature (T_{max}) and effective heating time (T_{eff}), and applied this relationship to examples from the Piceance Creek (Western Colorado) and Anadarko Basins. Figure 36 illustrates the Canton area vitronite reflectance values with respect to Hood's (1983) relation of average vitronite reflectance (VR/E), T_{max} and T_{eff}.

Hood, Gutjahr and Heacock (1975) defined T_{eff} as the time during which a specific rock unit has been within 15°C (27°F) of its maximum temperature. With respect to the Morrow Formation in the Canton area, an effective heating time of 260 million years is used (Figure 36). This figure is based on the following geologic features:

1. The thick Pennsylvanian section in the Anadarko Basin is a record of relatively high subsidence rates throughout Pennsylvanian time. Brewer (1982) recently suggested subsidence of the Anadarko Basin is related to overthrusting of the Wichita Uplift, a positive physiographic feature and sediment source area from Morrowan to Lower Permian time.

2. Subsidence of the Anadarko Basin continued into Permian time with isostatic equilibrium occurring in the Upper Permian. Permian

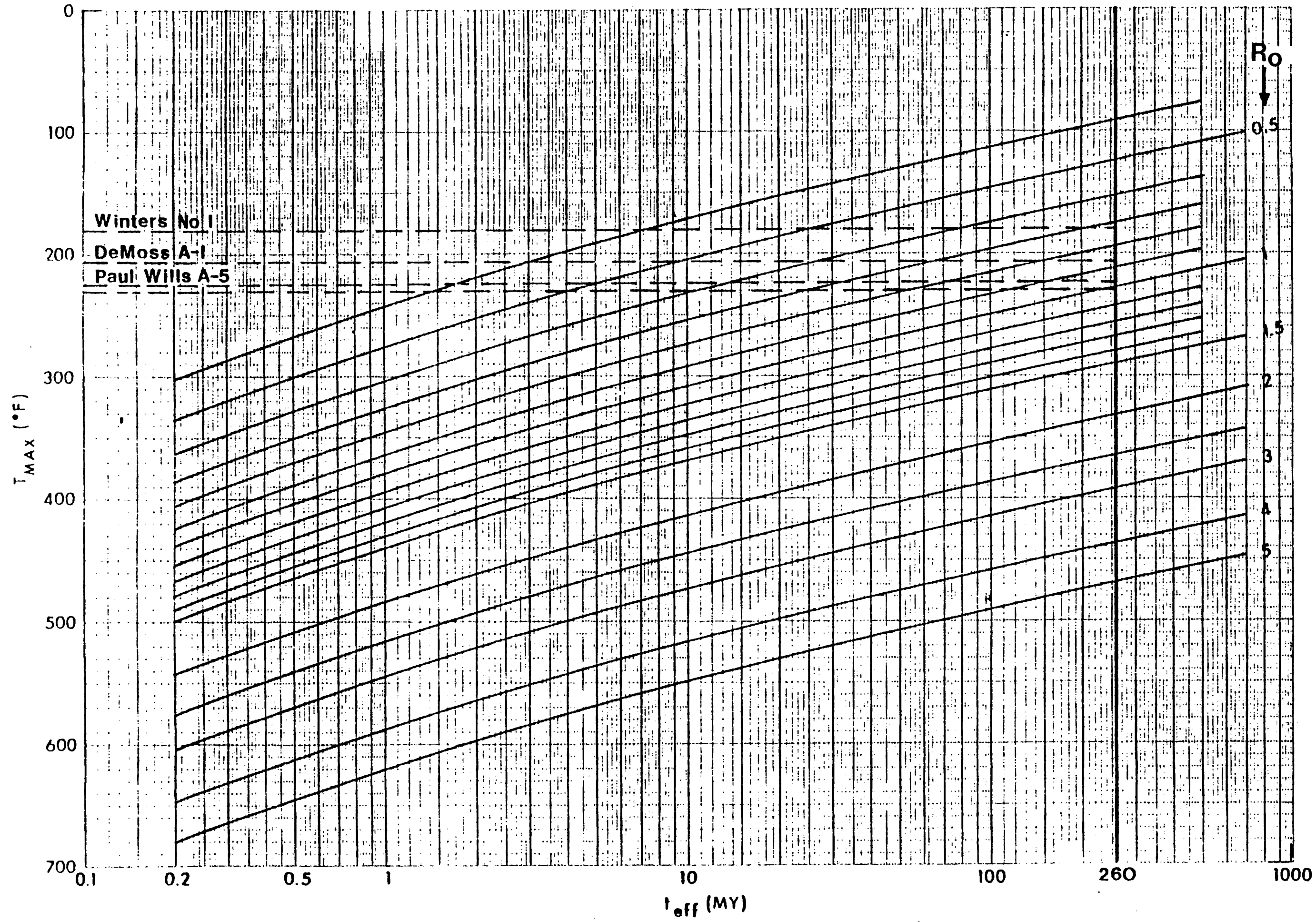

Figure 36. Relation of Average Vitronite Reflectance (R_O) to Maximum Temperature (T_{max}) and Effective Heating Time (T_{eff} in Millions of Years). (After Hood and others, 1975.)

sedimentation was dominated by arkosic alluvial fan sediments shed from the topographically high Wichita Uplift. Al Shaieb and others (1977) mapped the distribution of the Permian alluvial fan deposits and found clastic sedimentation was prolific in Upper Wolfcampian time but waned significantly in Leonardian time. By Guadalupian time (Upper Permian), the Wichita Uplift was not a major sedimentary source area or topographic feature.

3. No major orogenic or depositional events have affected the Anadarko Basin since Lower Permian time (Al Shaieb, 1983; Donovan, 1983). Therefore, the present depth of the Morrow Formation in the Anadarko Basin is probably very similar to its depth 260 million years ago at the end of Lower Permian time.

Hood (1983) also used 260 million years for the effective heating time in studies including the Morrow Formation in the Anadarko Basin. As mentioned above, 260 million years corresponds to the Upper and Lower Permian system boundary. Although somewhat arbitrary, the sedimentary record in the Anadarko Basin implies 260 million years is a geologically reasonable estimate for effective heating time in the Canton area Morrow sediments.

Table IX compares T_{max} values generated from Figure 36 to present formation temperatures. A sampling of bottom hole temperatures from eleven different wells throughout the Canton area resulted in an average temperature gradient of 1.05^{o}F per 100 feet. An assumed average surface temperature of 70^{o}F was used in all temperature gradient calculations (method used followed Asquith, 1982, p. 5). In Table IX, all present formation temperatures ($T_{present}$) were calculated based on computed average temperature gradient of 1.05^{o}F per 100 feet.

TABLE IX

COMPARISON OF PRESENT FORMATION TEMPERATURES ($T_{present}$) WITH T_{max}

DeMoss A-1	Sampled Interval	
Depth	8471 ft	
T_{max}	207°F	
$T_{present}$	159°F	
Average R_o	0.87	
Range	0.71-1.11	
Winters No. 1		
Depth	8627 ft	
T_{max}	180°F	
$T_{present}$	161°F	
Average R_o	0.72	
Range	0.58-0.92	
Paul Wills A-5	**Interval 1**	**Interval 2**
Depth	9000 ft	9079 ft
T_{max}	225°F	230°F
$T_{present}$	164°F	165°F
Average R_o	0.97	1.05
Range	0.82-1.03	0.78-1.20

In the three sampled core wells, T_{max} is greater than $T_{present}$ in every case. If today's depth of the Morrow formation is similar to its depth 260 million years ago, today's temperature gradient is approximately 30 percent lower than the paleogradient responsible for T_{max}. If lower geothermal gradients resulted in lower effecting heating times (T_{eff}), then T_{max} values on Figure 36 would be significantly increased. In this case, an even greater disparancy between the present and paleothermal gradients would occur.

In any case, this evidence suggests a paleogeothermal gradient higher than the present temperature gradient affected Morrow sediments in the Canton area. The present status of organic matter maturation in the Morrow Formation is a product of this higher geothermal gradient and not of the present temperature gradient. This area is an example of the disparity between modern and ancient temperature gradients. Modern gradients should not be considered as accurate approximations of ancient gradients in the Anadarko Basin.

Vitronite Reflectance and Oil Maturation

Figure 37 shows average reflectance values from the Canton area plotted with respect to the principal stages of petroleum maturation and T_{max}. The calibration of vitronite reflectance to stages of petroleum maturation and the extension of T_{max}/R_o gradient in Figure 36 is after Hood, Gutjahr and Heacock (1975). Several additional workers have calibrated vitronite reflectance to oil maturation similarly (Barker, 1979; Waples, 1980).

The core samples in Figure 36 occur within the zone of oil generation. Therefore, based on these data alone, oil should be the dominant

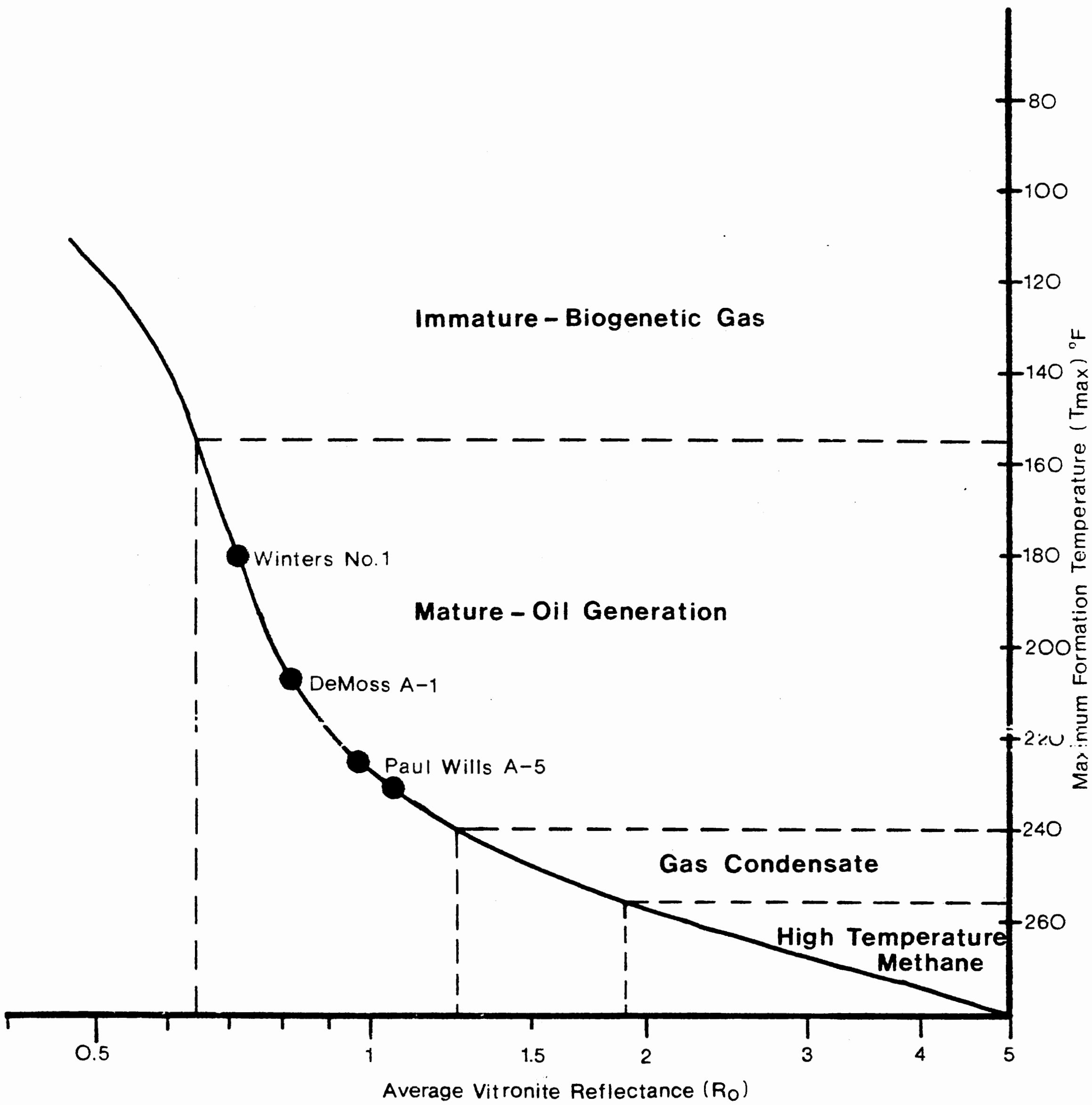

Figure 37. Canton Area Reflectance Values and Stages of Petroleum Generation. (Modified from Hood and others, 1975.)

petroleum product generated in the Canton area. Although oil production is significant in the Southwest Canton Field and surrounding area, major quantities of gas have also been produced in the area. The sampled DeMoss A-1 and Winters No. 1 wells in the Carlton area (Figure 2, Chapter I) showed initial gas potentials of 11,329 MCFD and 2817 MCFD, respectively. Total cumulative gas production in the Southwest Canton Field alone has been 4.1 BCF though 1981.

The presence of gas in the Southwest Canton Field may reflect the original character of the petroleum source rocks. It is well known that humic shales can generate prolific gas deposits but are not sources for oil (Barker, 1979). Sapropelic shales may generate both oil and gas (Barker, 1979).

As discussed in Chapter IV, humic shales containing wood fragments are the dominant shale type in the Lower Morrow section within the Southwest Canton Field. Conversely, the shales in the Uppor Morrow section lack humic derived wood fragments, contain shallow marine fossils, and show a more sapropelic character. Cores and cross sections show the ratio of humic to sapropelic shales is approximately 1:1 in the Southwest Canton Field Morrow Formation.

It is probable that the Morrow Formation shales are the source rocks for the petroleum generated in the Canton area sands. If this assumption is correct, the gas generated in the Canton area may be a result of thermal maturation of the humic shales within the temperature conditions defining the oil window in Figure 37. The sapropelic shales were probably the source rocks for the oil in the Morrow producing sands. This interpretation explains the apparent disparity between the theoretical placement of the vitronite reflectance values within the oil window and the prolific gas production in the area. Moreover, this also illustrates the important role environment of deposition plays with respect to the type of petroleum generated.

CHAPTER IX

SUMMARY AND CONCLUSIONS

A summary with conclusions concerning the major results determined in this study is listed below. All conclusions listed were formulated with respect to the Morrow Formation within the Southwest Canton field. Unless specifically noted, these inferences are applicable to the area surrounding the field (shown in Plates 10 and 11) as well.

Conclusion

1. The Canton area exists within a relatively stable "shelf" structural context. Structure is dominated by gentle basinward warping. No significant structural closures were contoured. The magnitude of basinward warping increases in the southeastern extreme of the study area (T17N, R15W), which may reflect the structual hingeline of the Anadarko Basin.

2. Stratigraphic and sedimentologic evidence suggests the structural and average depositional strikes coincide in the area.

3. In the Canton area, the Thirteen Finger Limestone unconformably overlays Morrow strata. This unconformity is angular and reflects a gap in the sedimentary record during basinward structural warping. A marine transgression deposited Atokan limestones and shales on eroded and tilted Morrow strata. The unconformity is not a chronostratigraphically consistent horizon because progressively younger Atokan rocks onlap Morrow

strata in a shelfward direction.

4. The Morrow Formation thins shelfward and is truncated by the Atokan-Morrowan unconformity northeast of the Southwest Canton Field. Morrow Formation thicknesses range from approximately 85 to 360 feet from the northern to southern extremes of the Southwest Canton Field.

5. The existence of a Pennsylvanian-Mississippian uncomformity in the Canton area is verifiable. Dip oriented cross sections show erosional basinward thinning of Upper Chester Limestones. Regionally, the Chesterian unit thickens basinwards. Additional indicators include Lower Morrow ("Bond" zone) silts that onlap the Upper Chesterian surface and the difference in lithology between Chesterian and Morrowan strata.

6. The position of the Pennsylvanian-Mississippian unconformity exists at the top of the Upper Chester argillaceous carbonates where they exist. This is defined by the onlapping "Bond" silts. Basinward of the Upper Chester Limestone truncation, the unconformity occurs in shales between the Lower Chester Limestone and Lower Morrow sands. In this case, the unconformity is picked at the base of a low conductivity zone which may be accompanied by a subtle gamma ray increase on electric logs. This pick is questionable because the unconformity may vary its stratigraphic position and not be recorded by mechanical logs. Palynologic and paleontologic data are necessary to verify the unconformity's stratigraphic position where it occurs in shales in the southern (basinward) portion of the Southwest Canton Field.

7. Correlatable units within the Morrow Formation include the "Bond" silt zone and a bioclastic limestone above the Lower Morrow quartz sands. The producing Lower Morrow sands are lenticular. The

"Bond" silt zone has a limited subsurface areal extent in the area. This unit is absent shelfward of its onlap on the Upper Chesterian surface (in the southern portion of the Southwest Canton Field) and pinches out along strike near the western boundary of the Southwest Canton Field. Hence, the use of this unit as a mappable horizon is limited. The bioclastic marker correlates relatively well along strike oriented cross sections, but is difficult to correlate consistently along dip oriented sections. Here, the limestone unit commonly pinches out laterally into shales and segregates into a series of thin but distinct limestone units. This unit is not a reliable chronostratigraphic horizon in the area.

8. The top of the Thirteen Finger Limestone is an excellent chronostratigraphic horizon in the area.

9. The lower and upper portions of the Morrow Formation in the Southwest Canton Field show different lithologic characters. The Lower Morrow consists of quartz sands, arenaceous skeletal sands and shales; the Upper Morrow is predominately shale with thin nonarenaceous skeletal sands. Oil and gas production is restricted to the Lower Morrow sands. These sands are thicker and better developed than the Upper Morrow sands.

10. Four distinct genetic sand types occur in the Morrow Formation. Quartz dominated sands, arenaceous skeletal dominated sands, nonarenaceous skeletal sands, and bioturbated quartz wacke sands to clayey sands are the fundamental sand types. Quartz dominated sands occur as terrestrial point bars and small delta distributary channel fill sandstones. Arenaceous skeletal dominated sands reflect transitional marine settings. These sands are interpreted as tidal or estuarine channel sands. The bioturbated sands are interpreted as

tidal flat sands. They occur in a similar stratigraphic position as the tidal and estuary channel sands. Nonarenaceous skeletal sands are interpreted as shoaling marine buildups and channels.

11. The genetic sand types reflect a transition from terrestrial to shallow marine conditions within a transitional depositional context. The depositional sequence is recorded stratigraphically from lowest to highest as follows: a) quartz dominated terrestrial point bars and distributary channel fill sands; b) littoral arenaceous skeletal channels and quartz wacke tidal flat sands, and c) nonarenaceous skeletal buildups and channels. Genetic types a) and b) constitute the basal and upper portions of the Lower Morrow sand zone, respectively. Type c) occurs in the Upper Morrow shales. The stratigraphic position of the genetic types records a Morrowan transgression whereby the strandline migrated northeastward (shelfward).

12. Quartz dominated channel sands are producing sands in the Canton area. Oil and gas production reflects the distribution of these sands.

13. Productive sand lenses trending parallel and perpendicular to strike occur in the central and north-central portions of the Southwest Canton Field. Sand trends oriented similarly also occur to the south and east of the field (Plate 10). Elsewhere, the producing sand distribution is irregular.

14. Reservoir sands in the Southwest Canton Field occur as a part of a lenticular sand trend associated with the Watonga trend. This field is bordered by lenticular sand bodies and is not an isolated feature. Trapping in the area is stratigraphic.

15. Seven distinct lithologic sand types were identified in the

Morrow Formation. Channel sands consist of three types: quartz arenite to quartz wacke sandstone, quartz dominated skeletal litharenites and arenaceous skeletal grainstones. Basal conglomerates include lithic pebble arenaceous polymictic conglomerates and arenaceous lithic pebble skeletal polymictic conglomerates. These conglomerates occur in association with the quartz and skeletal dominated channel sand types, respectively. Skeletal grainstones and bioturbated quartz wacke sandstone to clayey sandstone are the last two lithologic types. These types reflect the skeletal buildup and tidal flat genetic units, respectively.

16. Secondary porosity is the dominant porosity type in the Morrow reservoir sands. Primary porosity is not a significant porosity type.

17. Dissolution of the clay matrix is the major mechanism responsible for the generation of secondary porosity in the reservoir sands. Glauconite dissolution is significant in sands containing relatively high glauconite percentages. Dissolution of silica cements and quartz grains occurs in association with clay matrix dissolution. Dissolution of pyrite and fracture porosity occurs but is minor. Carbonate dissolution is infrequent and is not significant.

18. Original detrital clay matrix percentage, between 5 and 15 percent is optimum for the creation of secondary porosity. Sands containing greater than 15 percent detrital clay matrix generally contain low porosities (<6 percent) because they are relatively impermeable to diagenetic fluid circulation. Sands containing less than five percent original clay matrix are tightly cemented by advanced stage quartz overgrowths (in quartz sands) or carbonate cements (in skeletal sands).

19. The areal distribution of porosity in the Canton area reflects

the distribution of the channel sands. Porosities in the Southwest Canton Field generally range between 8 and 12 percent. Higher porosities occur east of the field (Plate 11).

20. Highest porosities occur in the quartz arenite to quartz wacke channel sands. In this lithologic type, porosities were observed up to 22 percent. Skeletal channel sands (quartz dominated skeletal litharenites and arenaceous skeletal grainstones) where observed, are often tight. However, porosities up to 14 percent were observed in one arenaceous skeletal grainstone unit. The potential of slightly argillaceous skeletal sands as a reservoir in the area should not be overlooked. The bioturbated quartz wacke tidal flat sands generally contain detrital clay matrix percentages above 20 percent, which is too high for good reservoir quality sands in the area. However, local clean zones within this clayey sand may be of economic interest. Where observed, the skeletal grainstone buildups and conglomerates were tightly cemented.

21. Diagenetic processes responsible for porosity reduction include ductile deformation of clay matrix and glauconite, and the precipitation of authigenic void filling cements. Common precipitates include a) quartz overgrowths; b) void filling silica cements microquartz, chalcedony, and drusy megaquartz; c) void filling kaolinite, chorite, and grain lining chlorite, and d) calcite, dolomite and siderite cements.

22. The diagenetic sequence of the Morrow Formation sands can be classified with respect to the creation of secondary porosity. Early and late diagenetic processes occurred before and after secondary porosity generation, respectively. Early diagenetic processes include a) ductile deformation of clay matrix and glauconite; b) quartz

overgrowth cementation; c) calcite cementation; d) pyrite cementation and pyritic replacement of detrital grains; e) replacement of clay matrix by authigenic clays; f) transformation of green glauconite to brown glauconite; g) pressure solution of skeletal grain contacts, and h) the formation of carbonaceous styolites by pressure solution. Late diagenetic features include a) dolomite and siderite cementation; b) precipitation of void filling silica; c) precipitation of pore filling and lining authigenic clays, and d) pyritic replacement of hydrocarbon matter and rarer precipitation of framboidal pyrite.

23. X-ray diffraction and SEM analysis show chlorite, kaolinite, and mixed-layer illite-smectite clays as the major authigenic clay types.

24. All of the authigenic clays and later diagenetic carbonate cements are sensitive to well stimulation, completion and drilling techniques. EDXA analysis shows chlorite, illitic mixed-layer clay and dolomite/siderite cements are iron rich. Improper acid treatments could reduce permeability. Kaolinite and smectitic mixed-layer clays seal pore throats by clay migration and swelling. Proper drilling and well completion techniques should be used to protect against formation damage.

25. The generation of gas and oil in the Soutwest Canton Field is a function of the original Morrowan shale character. Geothermal gradients that were at least 30 percent hotter than present-day temperature gradients in the Canton area baked hydrocarbons from Morrowan shales. The generation and migration of hydrocarbons into the Morrow reservoir sands occurred some time between late Permian and Holocene time.

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APPENDIX A

METHODOLOGY USED FOR CONSTRUCTING NET SAND AND POROSITY ISOPACH MAPS

1. Net Sand Isopach Map (Plate 10)

Determination of Morrow sand thickness involved the following procedure:

a. Drew shale line on gamma ray curve.

b. Sandstones of reservoir quality occur four division units to left of shale line. This is equivalent to 60 API units less than shale line on logs calibrated at 15 API units per division unit. Sandstones occurring less than four division units to left of shale line are shaley and contained porosity less than 5%. This calibration resulted from comparing the gamma ray log response to the reservoir and nonreservoir quality sands in each examined core.

c. Limestone sands containing no porosity were subtracted from the total sand footage.

2. Porosity Map (Plate 11)

Porosities were determined from bulk density and sonic logs. In the porosity map (Plate 11), approximately 70% of the spotted data were derived from bulk density logs. Where bulk density logs were not available, sonic logs were used.

The procedure for constructing the porosity map involved summing the total footage of porosity $\geq$ 8% in each well. This summed amount was then spotted and contoured. Average porosity percentages were also calculated for the summed intervals $\geq$8%. Wells containing average porosity $\geq$ 14% are highlighted on the porosity map (Plate 11).

Determination of the 8% porosity line on bulk density logs involves the following relation:

A. $$\phi_{den} = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f}$$

where

ϕ_{den} = density derived porosity = .08(for 8% porosity)

ρm_{na} = matrix density = 2.66 (measured directly and averaged from examined cores

ρ_f = density of fluid in pores = 1.0 (assumed)

ρ_b = formation bulk density = 2.53 (at 8% porosity)

(from Merkel, 1979, and Asquith, 1982)

A vertical line at ρ_b = 2.53 was drawn on each bulk density log. Footage of $\phi_{den} \geq$ 8% was then summed. Average porosity percentages were calculated by determining the average ρ_b in intervals with 8% porosity, and then substituting and solving for ϕ_{den} in the above relation, A.

Determination of the 8% porosity line on sonic logs involves the following relation:

b. $$\phi_s = \frac{\Delta T - \Delta T_{ma}}{\Delta T_f - \Delta T_{ma}}$$, where

ϕ_s = sonic derived porosity = .08 (for 8% porosity)

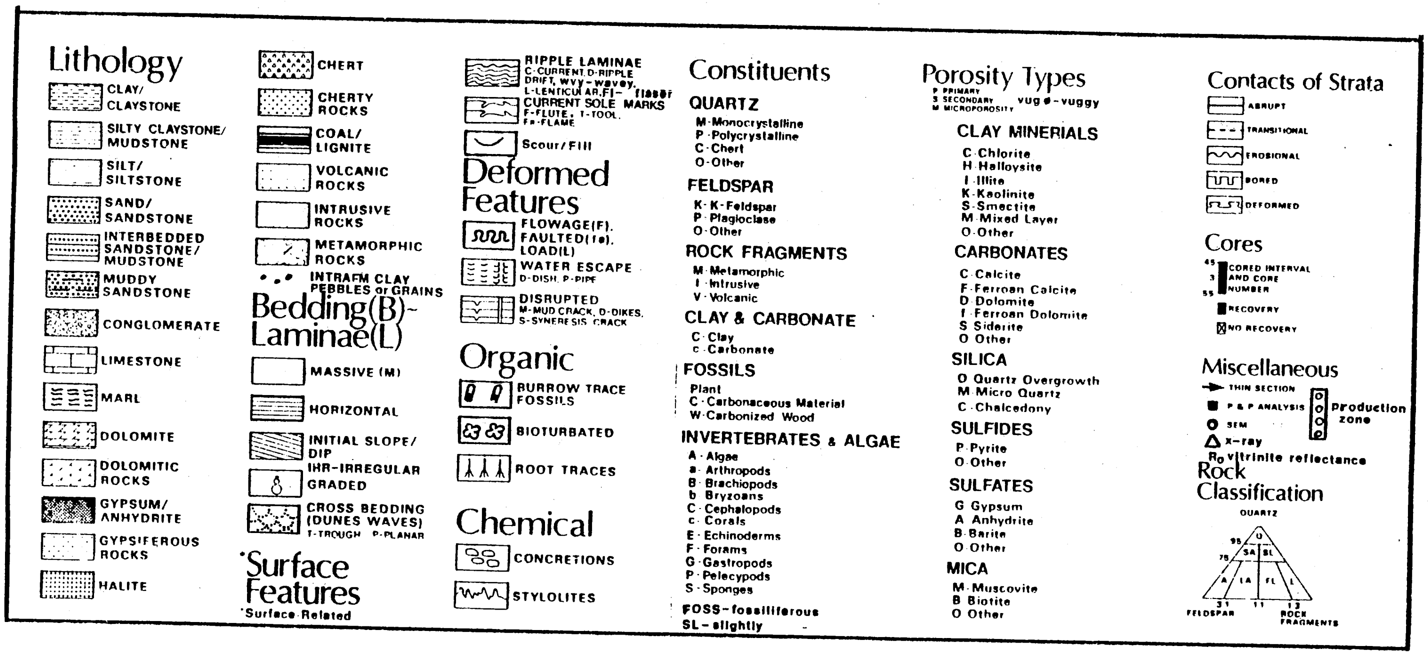
ΔT_F = interval transit time of fluid in well bore = 200 (fresh water). T_F derived from R_m and T^{o}F values on log headings with subsequent comparison to mud salinity. Resultant salinities were fresh (Merkel, 1979, p. 28)

ΔT_{ma} = interval transit time of matrix = 53.8. Calculated by averaging 55 and 52.6, which correspond to interval transit times of consolidated sandstone with clay and consolidated sandstone, respectively (Markel, 1979)

ΔT = interval transit time of formation at 8% porosity = 65.5. A vertical line at ΔT = 65.5 was drawn on each sonic log. Footage of $\phi_s \geq$ 8% was then summed. Average porosity percentages were calculated by determining the average ΔT in intervals with $\geq$ 8% porosity, and then substituting and solving for ϕ_s in the above relation B.

APPENDIX B

CORE SUMMARIES AND ENVIRONMENTAL INTERPRETATIONS



Key for Symbols and Abbreviations Used on Core Logs

WELL:	Texas Pacific - Tidball No. 4
LOCATION:	NE SW NE NW 22-18N-14W, Dewey County
CORE INTERVAL: (Stratigraphic Position)	9070-9213 (Lower and Upper Morrow)
WELL STATUS:	Dry and abandoned, 8/77

The core interval consists of quartz arenites, quartz wackes, conglomerates, skeletal grainstones, skeletal packestones, and shales. The overall character of the core grades from terrestrial or transitional (quartz sands and coaly shales) to shallow marine (skeletal sands and shales) upsection.

An upward coarsening black claystone to clayey siltstone unit occurs at the base of the core (9213-9192). The claystone contains gastropods, brachiopods, and carbonaceous vitrain particles. Upsection, this unit shows interstratified clayey silts to massive siltstones. Characteristic features include horizontal and ripple laminations, occasional echinoids, and burrowing, which increases upsection. These sediments probably represent restricted interchannel (or lagoonal ?) clays and silty clay buildups.

An upward fining quartz arenite to quartz wacke sandstone occurs at 9192-9168. This unit is interpreted as a meandering point bar channel sand. Characteristic features include 1) an erosional basal contact; 2) a basal lithic pebble conglomerate; 3) fining upwards medium to fine quartz arenite sandstones and very fine quartz wacke clayey sandstones; 4) local scour zones; 5) coal laminations and carbonaceous styolites; 6) penecontemporaneous deformation features, and 7) burrows. Sedimentary structures include horizontal bedding and trough cross stratification. The sands grade upsection into bioturbated coaly clayey siltstones (9168-9163) and coaly woodfragmented black shales (9163-9147). These units are interpreted as interchannel floodplain, marsh, swamp or lagoonal claystones.

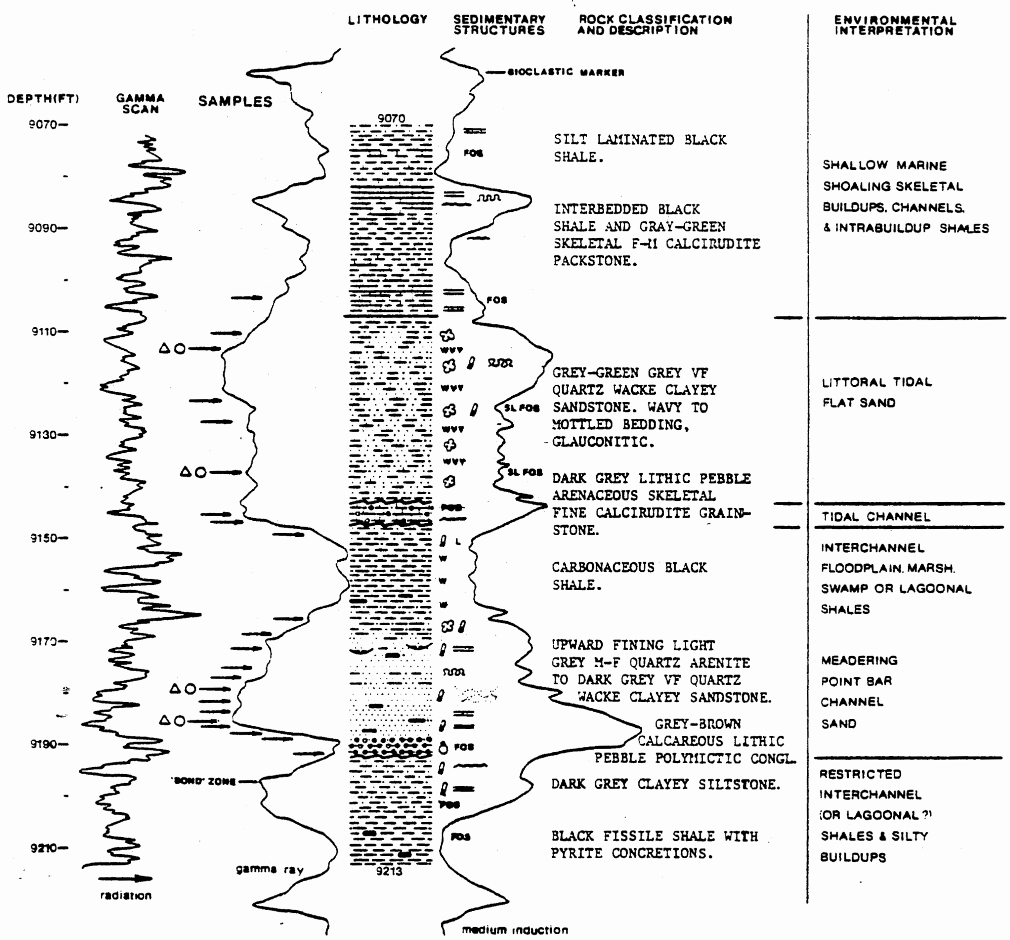
A thin lithic pebble arenaceous skeletal fine calcirudite grainstone occurs at 9147-9143. This sand is interpreted as a shallow marine tidal channel. The erosive basal contact, lithic pebbles and skeletal lithology are suggestive of channeling within a shallow marine context.

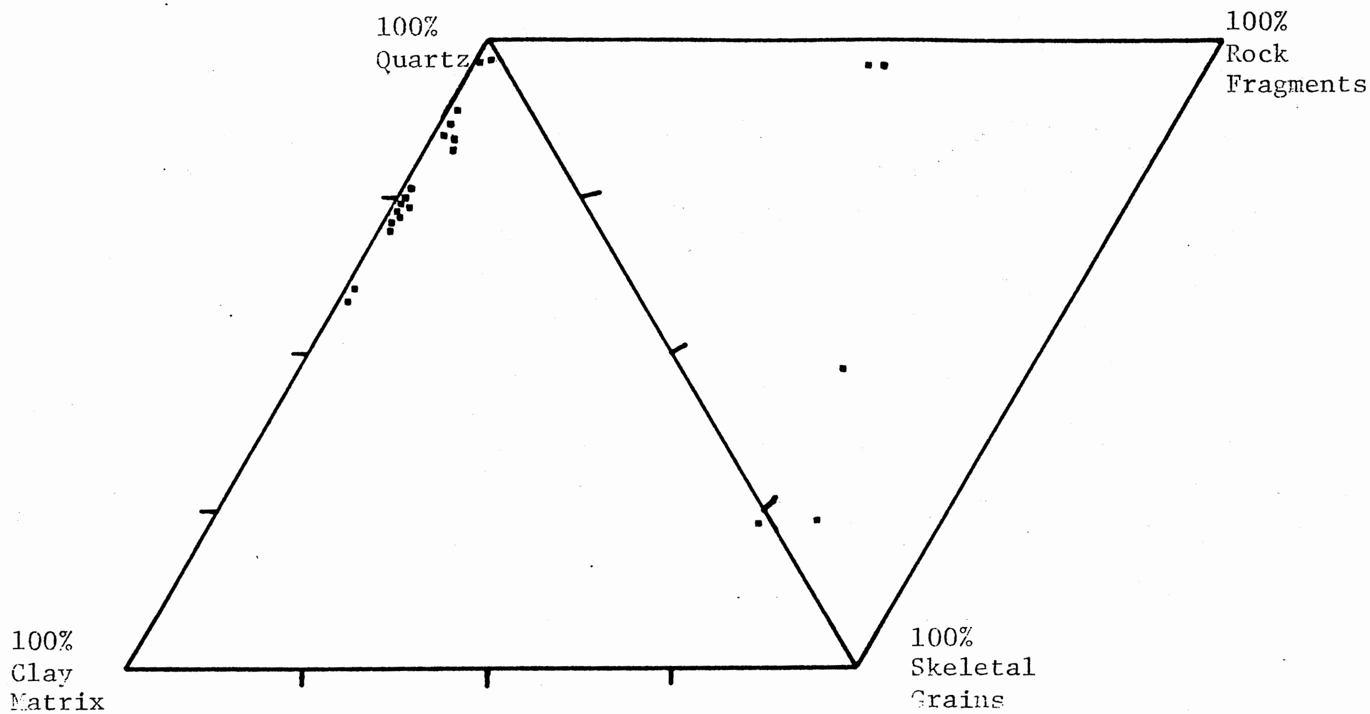
A bioturbated quartz wacke sandstone and clayey sandstone occurs at 9143-9107. These sands show a consistent very fine quartz grain size, have sharp upper and lower contacts and are slightly fossiliferous (1-2%). Observed skeletal types include echinoids, trilobites, gastropods, brachiopods, and rarer foraminifera. Burrows, penecontemporaneous deformation features, ripples and wavey bedded interstratified shale and sandstones occur where the sands are not extensively bioturbated. This occurrence of preserved wavey bedding and ripples increases upsection. This unit is interpreted as a littoral tidal flat sand.

The upper core interval is interpreted as shallow marine skeletal shoaling buildups, channels and interbuildup shales (9107-9070). Lithologic types include nonarenaceous (1% quartz) skeletal fine to medium calcirudite wackestones, packstones and glauconitic, fossiliferous black shales. Buildup and/or channel skeletal types observed include echinoids, trilobites, gastropods, bryzoans, and brachiopods. These sediments were probably deposited within an upper neritic to littoral context seaward of the tidal flat quartz wacke sands.

TEXAS PACIFIC-TIDBALL NO. 4

D/A





TEXAS PACIFIC -- TIDBALL NO. 4

Lithologic Plot of Thin Section Samples With Respect to the Primary Detrital Components

WELL:	Texas Pacific - Frank Schafer No. 1
LOCATION:	NE NE SW 22-18N-14W, Dewey County
CORE INTERVAL: (Stratigraphic Position)	9156-9205 on core, 9166-9215 on e-logs (Lower Morrow)
CUMULATIVE PRODUCTION: (Time Interval)	347,905 MCFG (1/77-7/79); IPF: 208 BOPD (completed 4/76)
PRODUCING INTERVAL:	9191-9208, 9226-9038 on core; 9201-9218, 9236-9258 on electric logs

The core interval shows five distinct sand types: quartz arenites, skeletal quartz arenites, skeletal grainstones, conglomerates, and quartz wacke clayey sands. The interval gets richer in glauconite and skeletal fragments upsection.

A quartz arenite to slightly skeletal quartz arenite sandstone occurs at 9205-9190. Characteristic features in this sand are 1) A fining upward, fine to very fine grain size; 2) a sharp (erosional?) basal contact (based on electric log signature); 3) the presence of intraformational clay clasts, carbonaceous styolites and occasional coaly horizontal shale laminations: 4) trace amounts of glauconite, and 5) a skeletal grain percentage, generally $\leq$ 3% but locally up to 10%. Sedimentary structures include massive bedding, small and medium scale crossbedding, and graded bedding associated with skeletal zones. Ripples are associated with the horizontal shale laminations and the carbonaceous styolites are more abundant upsection.

This unit is interpreted as a small delta distributary channel fill sand or a transitional meandering point bar channel sand. Deposition may have occurred seaward of unfossiliferous upward fining point bar channel types (as in Tidball No. 4, 9192-9168).

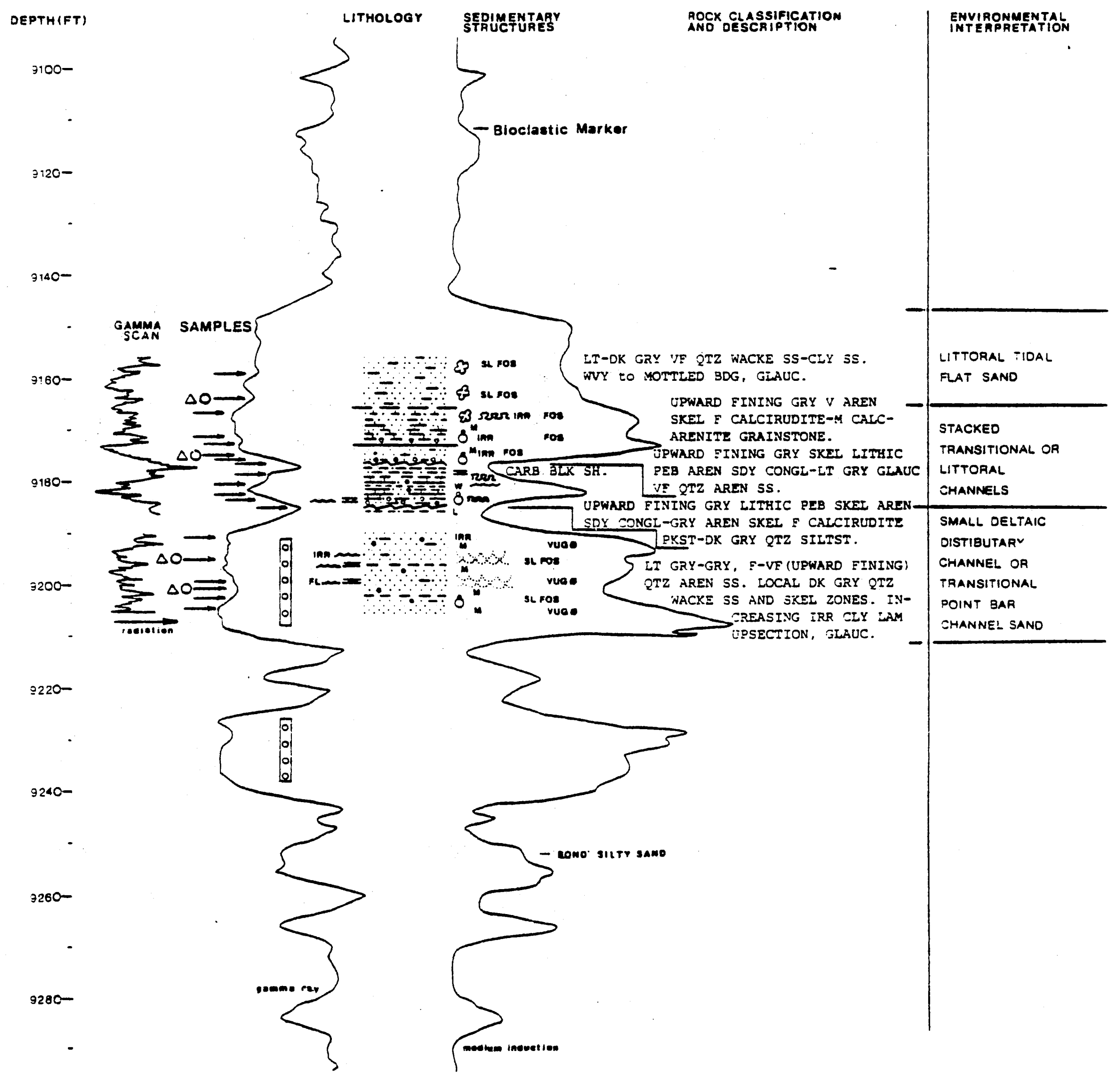
A series of thin (3-7 ft) sands and shales occur at 9185-9166. Within this zone, the individual sand types are as follows: 1) A lithic pebble skeletal quartz sand conglomerate grades upsection to arenaceous skeletal fine calcirudite packstones and dark grey quartz siltstone at 9185-9177. This erosive based upward fining unit contains graded bedding, penecontemporaneous deformation features, thin, horizontal bedded wood fragmented shales and ripples. 2) A skeletal lithic pebble quartz sand conglomerate overlays the above units. This conglomerate grades upsection to glauconitic fine and very fine skeletal quartz arenite sandstones at 9177-9173. This unit has an erosive basal contact and is upward fining. 3) An upward fining arenaceous skeletal fine calcirudite to medium calcarenite grainstone occurs at 9173-9166. This unit has a sharp basal contact and is transitional upsection into very fine grained quartz wacke clayey sands. Characteristic features include penecontemporaneous deformation features, irregular carbonaceous shale laminations, graded bedding, and bioturbation at the top of the unit.

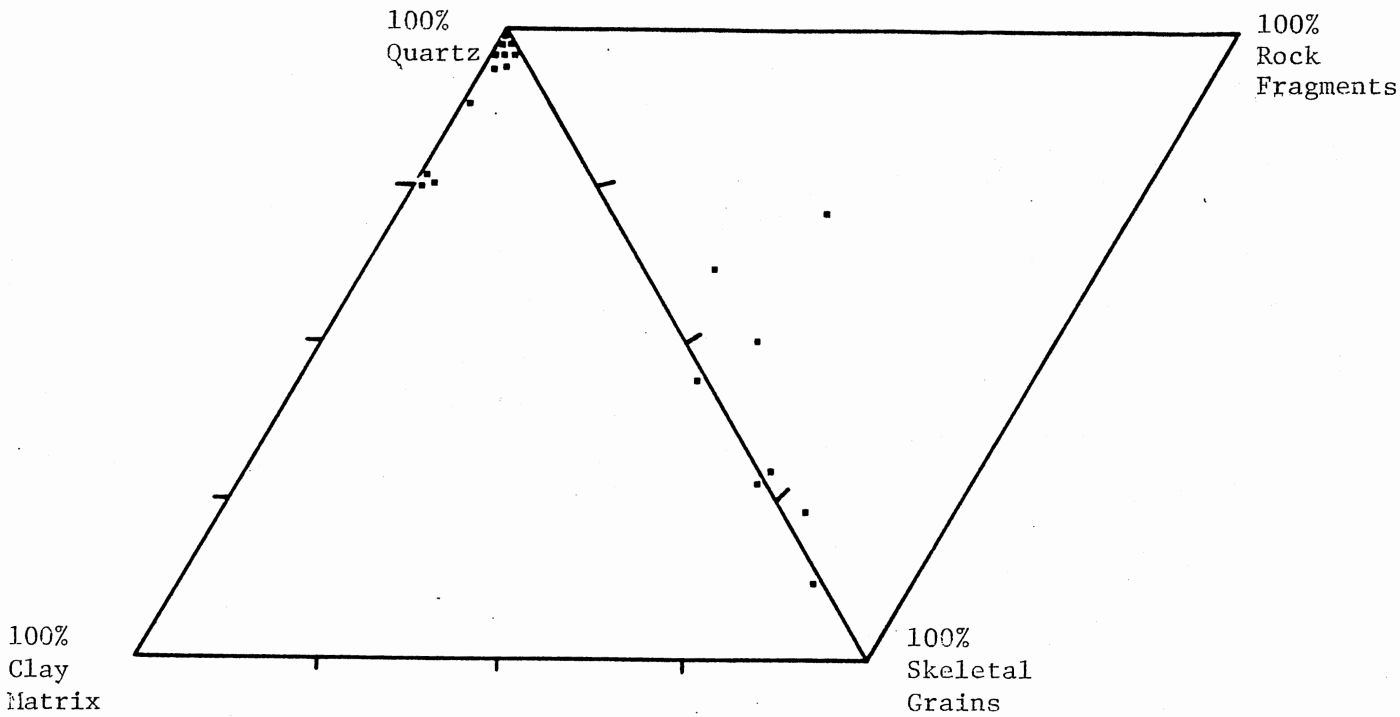
These rocks are interpreted as a series of stacked transitional marine influenced channels. This interpretation is based on the channel-like characteristics of each unit and the stacked character. The skeletal sands may represent littoral tidal or esturine channels.

A bioturbated very fine grained sandstone to clayey sandstone occurs at the top of the core interval (9166-9156). This unit is slightly fossiliferous (Tr-2%), glauconitic (Tr-4%), contains a consistent very fine grain size, and has a transitional basal contact with the underlaying skeletal littoral channels. Penecontemporaneous deformation features, ripples and crude horizontal shale laminations occur where the unit is not bioturbated. This unit is interpreted as a littoral tidal flat sand.

TEXAS PACIFIC-FRANK SCHAFER NO.1

IP: 208 BOPD + 196 MCFD





TEXAS PACIFIC - FRANK SCHAFER NO. 1

Lithologic Plot of Thin Section Samples With Respect to the Primary Detrital Components

WELL:	Ladd - Paul Wills No. A-5
LOCATION:	NE SW 25-18N-14W, Dewey County
CORE INTERVAL: (Stratigraphic Position)	8995-9086 on core; 9017-9108 on e-logs (Lower and Upper Morrow)
CUMULATIVE PRODUCTION: (Time Interval)	1,246 BO (10/78-11/81)
PRODUCING INTERVAL:	9030-9040, 9046-9062 on cores; 9052-9062, 9068-9084 on e-logs

Sediments on the lower half (9030-9086) of the core interval include quartz sands and coaly wood fragmented humic shales. Skeletal sands occur upsection (8945-9030) with sapropelic shales that contain glauconite and skeletal fragments.

Quartz Sands and Humic Shales

Sediments at the base of the core (9067-9085) include thin quartz wacke clayey very fine grained sands and silts interbedded with burrowed coaly wood fragmented shales. The silty sands show transitional contacts with shales, penecontemporaneous deformation features, horizontal bedding, ripples, and are bioturbated. These rocks overlay a thin shaley crinoidal-brachiopod packstone that contains crude shale laminations and graded bedding. This thin skeletal horizon coarsens upward from black organic-rich shales. These sediments are interpreted as nonmarine to transitional interchannel sands and clays.

An overlaying quartz arenite sandstone unit occurs at 9067-9046. This unit is characterized by an abrupt basal contact, a consistent fine grain size, and is transitional upsection into bioturbated silts and wood fragmented coaly shales. This sand contains rootlets at the top of the unit, intraformational clay pebbles, penecontemporaneous deformation features, burrows, and carbonaceous styolites. Trace amounts of glauconite and irregular graded quartz silt microlaminations also occur. Sedimentary structures include massive bedding which occurs below medium to small scale trough crossbedding and ripples. These features suggest a nonmarine channel or a small deltaic distributary channel may have deposited these sands. Point bar sands often show distinct upward fining quartz grain sizes and basal conglomerates which are not characteristic of this sand unit.

At 9035-9048 a quartz wacke sandstone to clayey sandstone transitionally overlays coaly shales. Characteristic features include a consistent very fine quartz grain size, bioturbation, penecontemporaneous deformation features and trace amounts of glauconite. This sand contains approximately 1% skeletal fragments. Where the original sand fabric is not destroyed by bioturbation, the unit contains interlaminated horizontal to gently dipping silty shales and very fine-grained quartz sands. This sand unit occurs below a lithic pebble sandy conglomerate (9035-9032) containing a sharp basal contact, graded pebble sizes, intraformational shale pebbles, ripples and skeletal grains. These features suggest the quartz wacke unit probably represents a transitional sand deposited seaward of lagoonal or interchannel marsh claystones. The quartz wacke unit is interpreted as a tidal flat sand with the conglomeratic sands representing transitional channels.

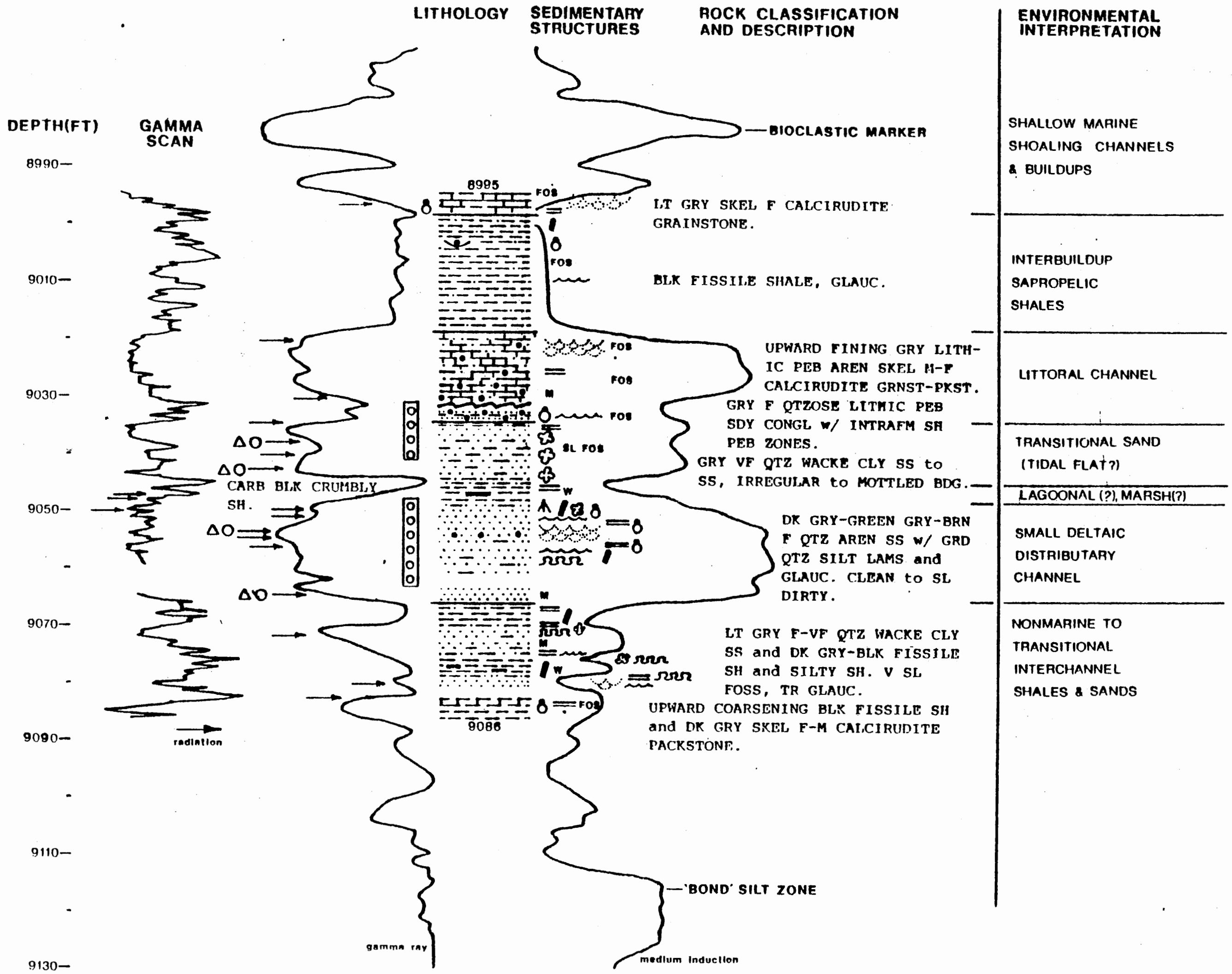
Skeletal Sands and Sapropelic Shales

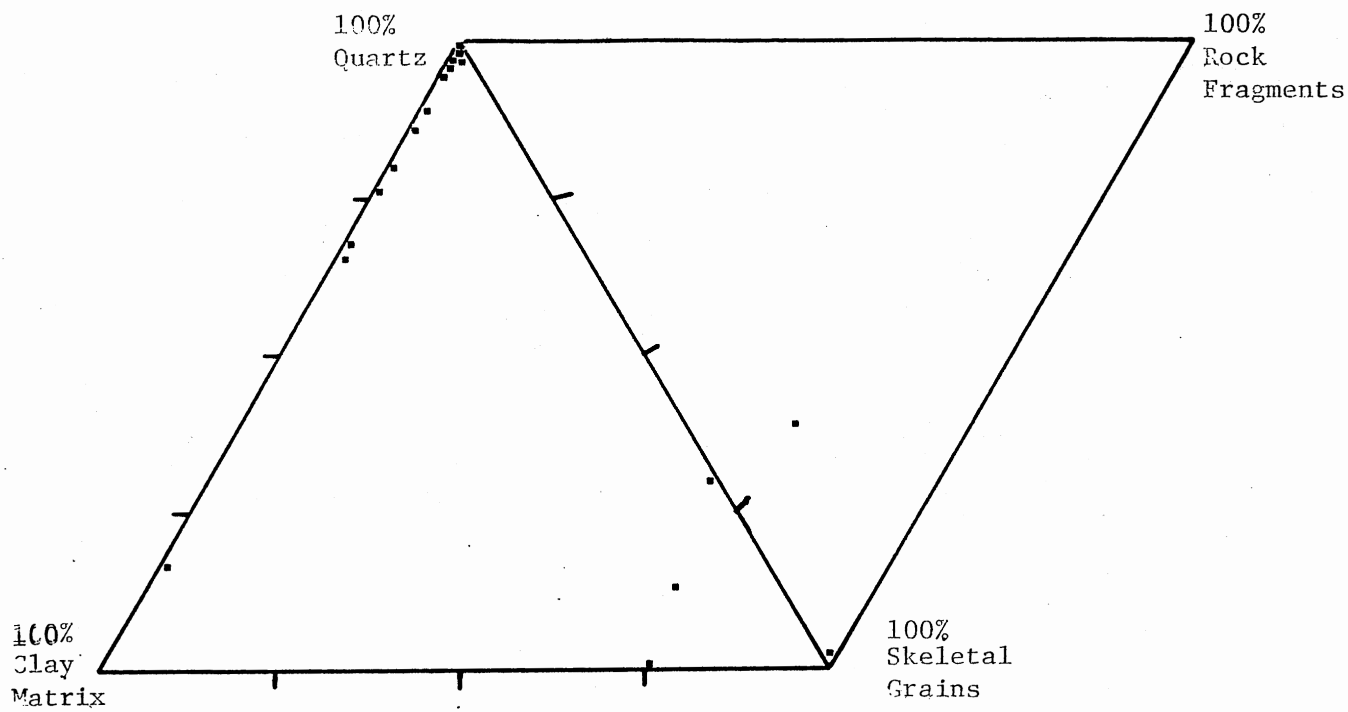
A lithic pebble arenaceous skeletal medium to fine calcirudite grainstone-packstone (9032-9020) erosionally overlays transitional quartz sand conglomerates. This skeletal sand is upwind fining and contains intraformational clay pebbles and irregular shale laminea. Sedimentary structures grade from massive to horizontal bedding upsection with medium scale low angle cross-bedding near the top of the unit. The lithic collophane and carbonate clasts decrease in size and amount upsection. Common skeletal types include echinoids, bryzonans, and brachiopods. This unit is interpreted as a littoral channel sand, perhaps a tidal or esturine channel deposit.

A nonarenaceous skeletal fine calcirudite grainstone (8995-8999) occurs at the top of the core interval. This sand is separated from the arenaceous skeletal channel sand downsection by 21 feet of black glauconitic slightly fossiliferous sapropelic shale. The nonarenaceous sand is characterized by a sharp basal contact, a thin, slightly coarser grained basal lag, and irregular shale laminations. Common skeletal types include echinoids, brachiopods and bryzoans. This sand is interpreted as a shallow marine shoaling channel and/or buildup.

LADD PETROLEUM-PAUL WILLS A-NO. 5

IP: 10 BOPD, Trace Water





LADD - PAUL WILLS NO. A-5

Lithologic Plot of Thin Section Samples With Respect to the Primary Detrital Components

WELL:	Texaco - G. I. Thomas No. 1
LOCATION:	SW NE 16-17N, 14W, Dewey County
CORE PLUG INTERVAL: (Stratigraphic Position)	9614-9567, 9562-9539, 9520-9509, 9495-9491 (Lower Morrow)
INITIAL POTENTIAL: (Completion Date)	IP 27BOPD + 119BWPD (5/60)
PRODUCING INTERVAL	9574-9594

In this well, core plugs at one-foot intervals were examined from 74 feet of sand. Quartz arenites, skeletal quartz arenites, quartz wacke clayey siltstones, and arenaceous skeletal packstones and wackestones were identified. These sands increase in skeletal content upsection and generally represent a series of stacked channels separated by shales.

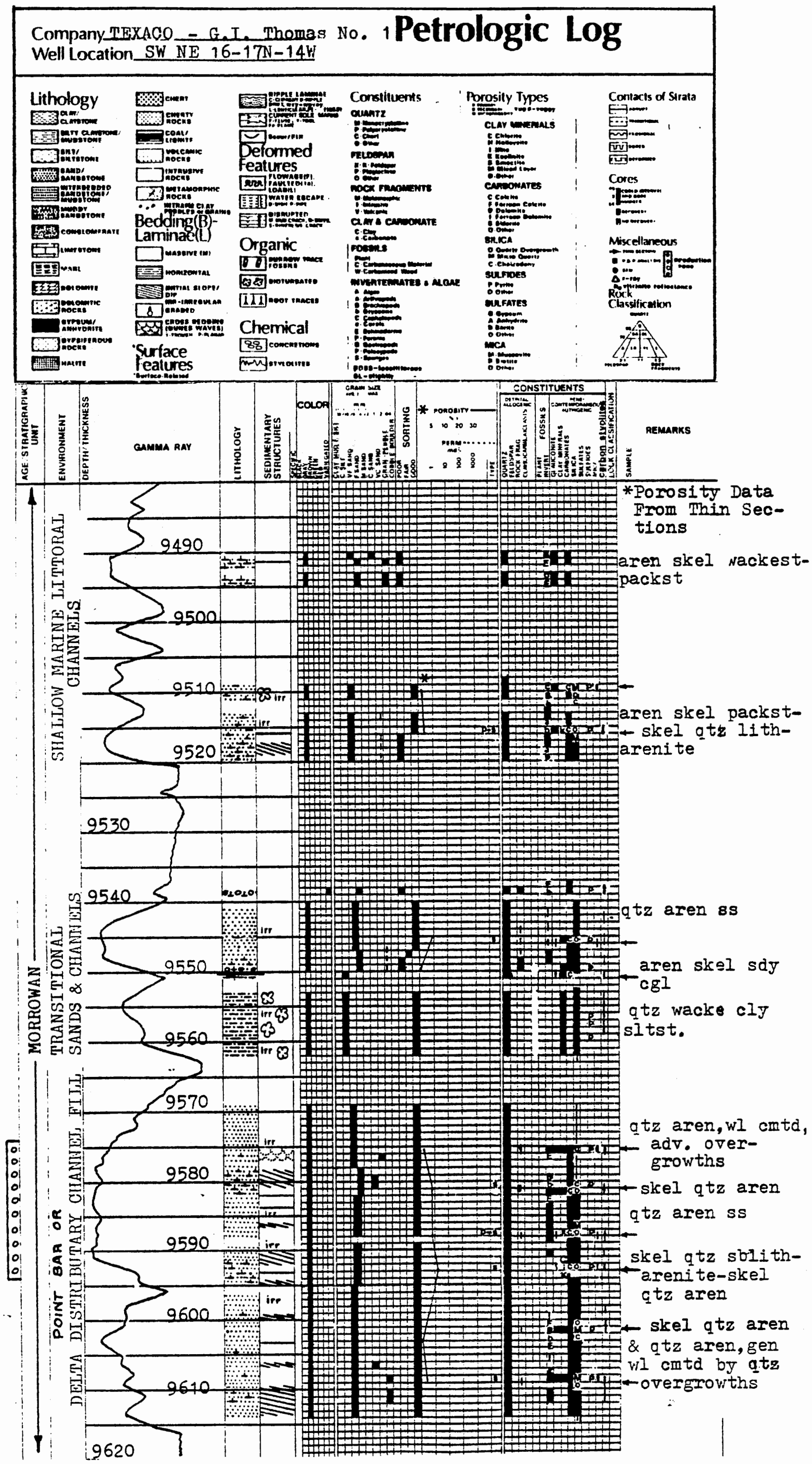
The sands in the lower interval (9614-9569) consist of cross stratified fine to very fine quartz arenite sandstones with occasional skeletal influx zones. These sands contain carbonaceous styolites, minor amounts of glauconite, and are generally well cemented by quartz overgrowths and calcite. The sand grainsize increases slightly in skeletal zones and decreases toward the top of the sand unit (8578-8569). Elsewhere, the sand shows a relatively consistent grain size. The gamma ray curve shows relatively sharp basal contacts for this unit.

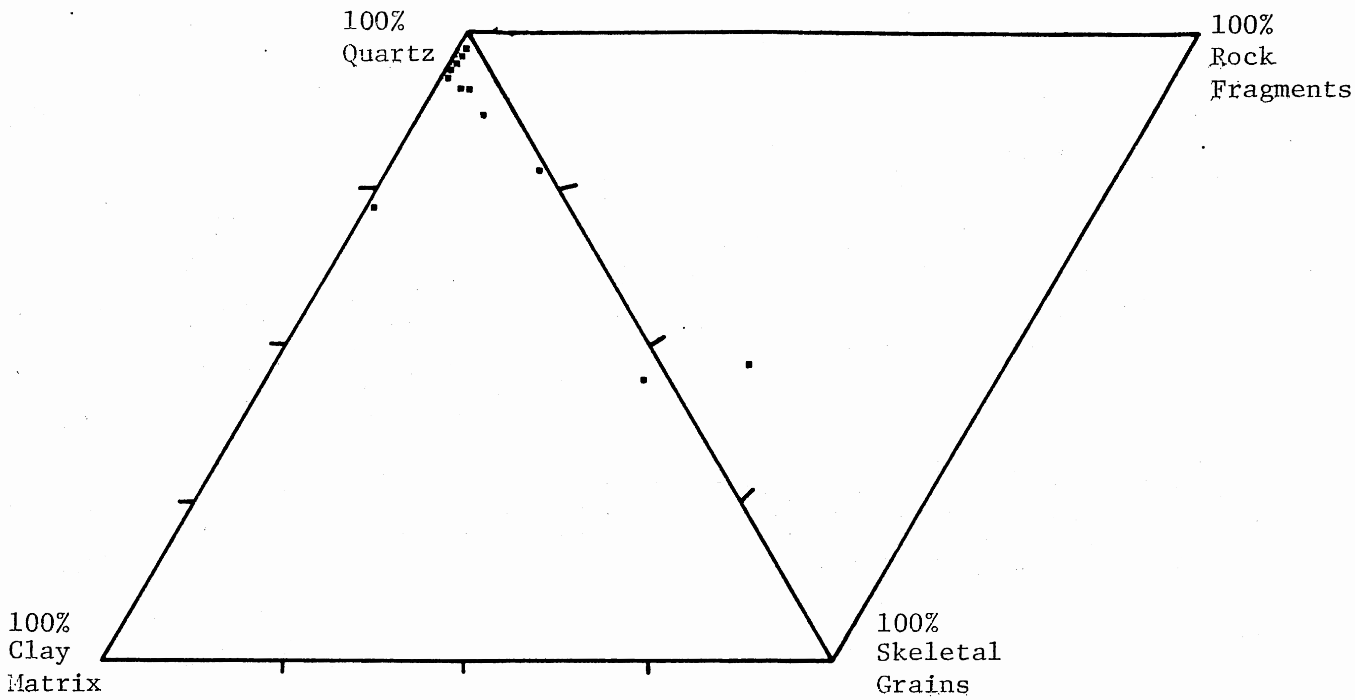
This sand is interpreted as a deltaic distributary channel fill or a point bar deposit. The consistent to upward fining grainsize, sharp basal contacts, cross stratification and carbonaceous styolites are characteristic of distributary channels and point bars. The skeletal zones may reflect storm influx and/or intrachannel downcutting and erosion.

A quartz wacke clayey siltstone is overlain by a conglomeratic basal quartz arenite sandstone upsection (9562-9539). The siltstones are extensively bioturbated, unfossiliferous, contain carbonaceous styolites, trace amounts of glauconite, and show a consistent coarse silt grain size. Upsection, the sand becomes slightly cleaner, and bioturbation is enhanced. The gamma ray curve shows a sharp basal contact for this unit. The overlaying sandstone also has a sharp basal contact, and is upward fining from a skeletal lithic pebble conglomerate to a fine and very fine grained slightly skeletal to fossiliferous quartz arenite sandstone. The sand is generally massive, and contains carbonaceous styolites and glauconite.

These sands are interpreted as transitional sands and channels. The bioturbated clayey siltstones may be marine reworked terrestrial clayey sands and/or tidal flat sands. The sharp basal contact, carbonaceous styolites and lack of fossils suggests this unit may be related to terrestrial channel development. The presence of glauconite and bioturbation imply possible later shallow marine (litteral) modification. The quartz arenite sandstone is interpreted as a marine influenced transitional channel because it contains glauconite, skeletal fragments and is upward fining with a basal conglomerate and sharp basal contact.

The arenaceous skeletal packstones (9520-9509, 9495-9491) are interpreted as shallow marine littoral channels. These rocks show sharp basal contacts, fine upwards and contain interbedded shales and silts. The sands contain glauconite, initial dip bedding (cross-bedding) and are bioturbated. These sands probably represent tidal or esturine channels deposited seaward of the underlaying sedimentary types.


Company TEXACO - G.I. Thomas No. 1
Petrologic Log
Well Location SW NE 16-17N-14W
Lithology
Constituents
Porosity Types
Contacts of Strata
Cores
Miscellaneous
Rock Classification
Deformed Features
Bedding(B)-Laminae(L)
Organic
Chemical
Surface Features
AGE: STRATIGRAPHIC UNIT
ENVIRONMENT
DEPTH/THICKNESS
GAMMA RAY
LITHOLOGY
SEDIMENTARY STRUCTURES
COLOR
SORTING
CONSTITUENTS
REMARKS
*Porosity Data From Thin Sections
SHALLOW MARINE LITTORAL CHANNELS
MORROWAN
TRANSITIONAL SANDS & CHANNELS
POINT BAR OR DELTA DISTRIBUTARY CHANNEL FILL
9490
9500
9510
9520
9530
9540
9550
9560
9570
9580
9590
9600
9610
9620
aren skel wackest-packst
aren skel packst-
skel qtz lith-arenite
qtz aren ss
aren skel sdy cgl
qtz wacke cly sltst.
qtz aren, wl cmtd, adv. over-growths
skel qtz aren
qtz aren ss
skel qtz sblith-arenite-skel qtz aren
skel qtz aren & qtz aren, gen wl cmtd by qtz overgrowths



TEXACO G. I. THOMAS NO. 1

Lithologic Plot of Thin Section Samples With Respect to the Primary Detrital Components

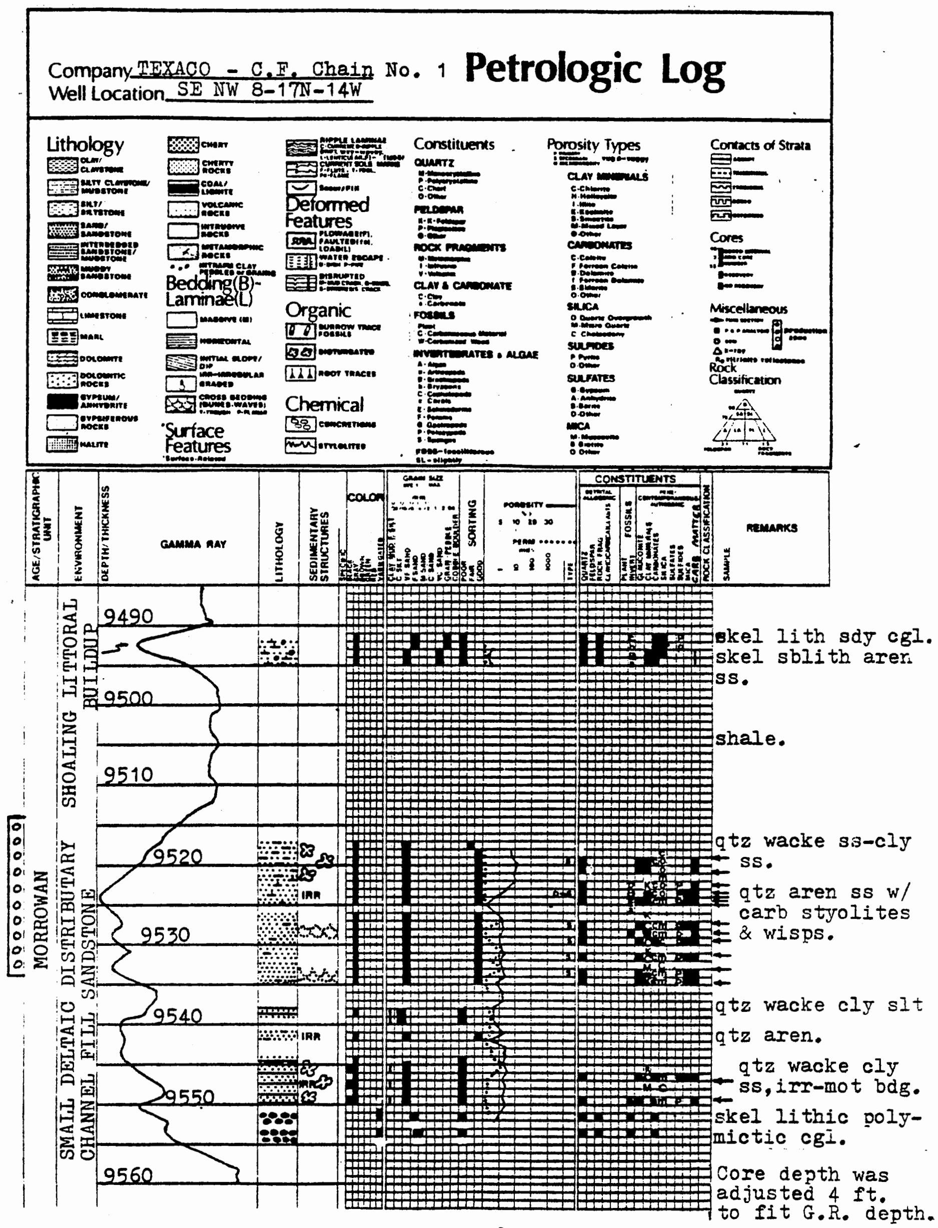
WELL:	Texaco - C. F. Chain No. 1
LOCATION:	SE NW 8-17N-14W, Dewey County
CORE PLUG INTERVAL: (Stratigraphic Position)	9554-9518, 9495-9483 (Lower Morrow)
CUMULATIVE PRODUCTION: (Time Interval)	234,547 MCF (5/62 - 5/70); 60,336 BO (8/71-10/81)
PRODUCING INTERVAL:	9514-9534

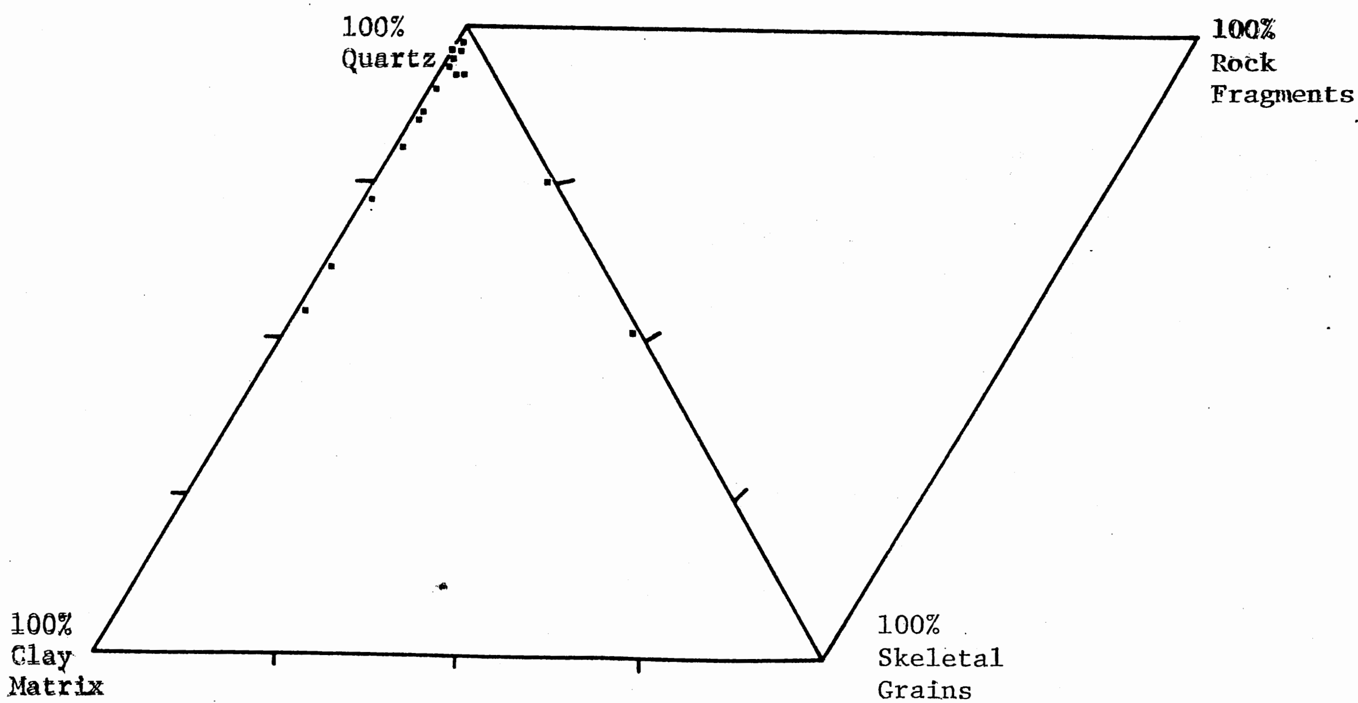
In this well, core plugs at one foot intervals were examined from 30 feet of sand. Quartz wacke clayey sands and quartz arenite sands characterize a lower sand unit (9554-9518) with skeletal sands and conglomerates occurring upsection (9495-9493).

The lower sand unit contains an irregular bedded, very fine grained bioturbated quartz wacke clayey sandstone (9550-9544) that occurs above basal lithic pebble conglomerates. Electric logs suggest the basal contact below the conglomerates is sharp. Very fine quartz arenite sands occur above the quartz wacke clayey sands. These clean sands are massive and cross stratified. In turn, the quartz arenites grade upsection to bioturbated, slightly fossiliferous very fine quartz wacke sandstones and clayey sandstones. All of the above sands contain carbonaceous styolites and trace amounts of glauconite.

This sand unit is interpreted as a small deltaic distriburary channel fill sandstone. This interpretation is based on the following criteria: 1) the sharp basal contact; 2) the conglomerate base; 3) the consistent very fine quartz grain size; 4) the occurrence of carbonaceous styolites, and 5) the presence of cross bedding. Point bar channels often show distinct upwardfining quartz grain sizes. The clayey sands above the basal conglomerate gives the gamma ray log an upward coarsening character.

The upper sand (9494-9495) is a four foot thick skeletal sublithic arenite sandstone to skeletal lithic pebble arenaceous conglomerate. This unit coarsens upwards and occurs in shales. Thick sand is interpreted as a shallow marine littoral shoaling buildup.


Company TEXACO - C.F. Chain No. 1
Well Location SE NW 8-17N-14W
Petrologic Log
Lithology
Bedding(B)-Laminae(L)
Deformed Features
Organic
Chemical
Surface Features
Constituents
Porosity Types
Contacts of Strata
Cores
Miscellaneous
Rock Classification
AGE/STRATIGRAPHIC UNIT
ENVIRONMENT
DEPTH/THICKNESS
GAMMA RAY
LITHOLOGY
SEDIMENTARY STRUCTURES
COLOR
SORTING
POROSITY
CONSTITUENTS
FOSSILS
ROCK CLASSIFICATION
SAMPLE
REMARKS
MORROWAN
SHOALING LITTORAL BUILDUP
SMALL DELTAIC DISTRIBUTARY CHANNEL FILL SANDSTONE
9490
9500
9510
9520
9530
9540
9550
9560
IRR
skel lith sdy cgl.
skel sblith aren ss.
shale.
qtz wacke ss-cly ss.
qtz aren ss w/ carb styolites & wisps.
qtz wacke cly slt
qtz aren.
qtz wacke cly ss,irr-mot bdg.
skel lithic polymictic cgl.
Core depth was adjusted 4 ft. to fit G.R. depth.



TEXACO - C. F. CHAIN NO. 1

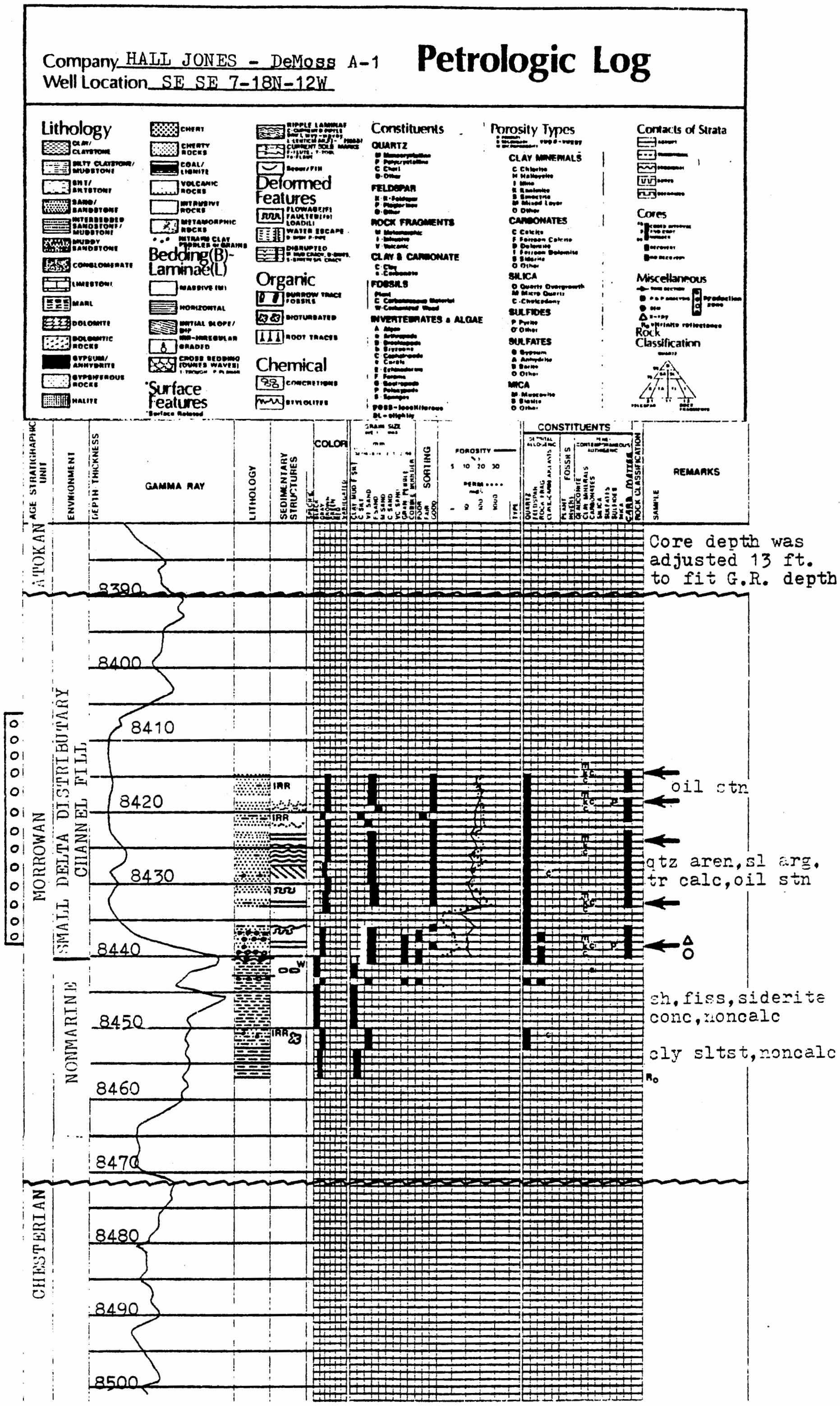
Lithologic Plot of Thin Section Samples With Respect to the Primary Detrital Components

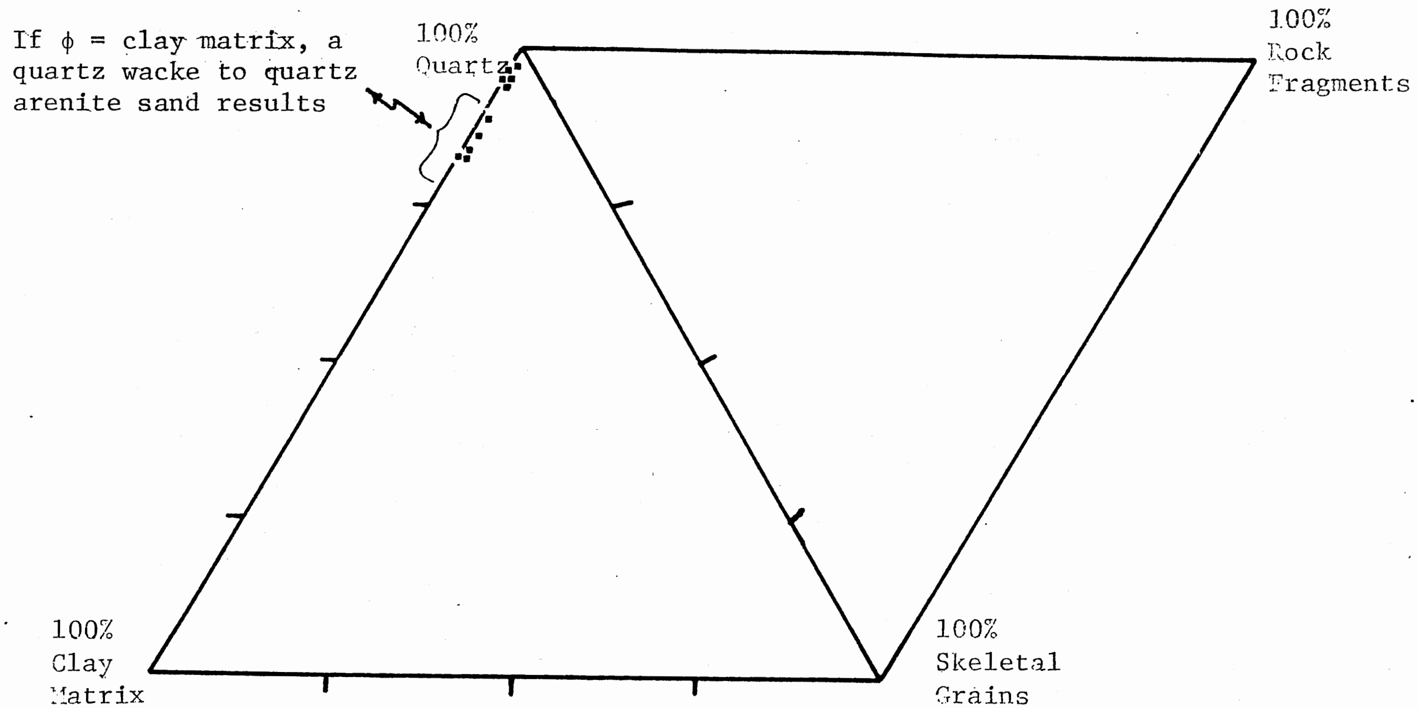
WELL:	Hall Jones Oil - DeMoss A-1
LOCATION:	SE SE 7-18N-12W, Blaine County
CORE INTERVAL: (Stratigraphic Position)	8415-8457 (Lower Morrow)
CUMULATIVE PRODUCTION: (Time Interval)	4,140,863 MCFG + 243,671 BO (12/66-12/81)
PRODUCING INTERVAL:	8406-8438 ft

The core interval consists of a conglomeratic based unfossiliferous fine to very fine quartz arenitic sandstone (8415-8440) which erosionally overlays shales, clayey siltstones and very fine quartz wacke clayey sandstones (8440-8457). The quartz arenite unit is oil stained and is an excellent reservoir sand.

The quartz arenite sandstone unit is interpreted as a small delta distributary channel fill sand. The absence of fossils and glauconite, coupled with the presence of carbonaceous styolites, intraformational clay pebbles, and stratigraphic position above wood fragmented sideritic shales suggests a nonmarine depositional context. The sandstone thickness, erosive basal contact, presence of a basal conglomerate, and types of sedimentary structures found in this unit are characteristic of modern terrestrial point bar and deltaic distributary channel fill sands. Point bar channels often show upward fining quartz grain sizes. More consistent grain sizes (as in this sand unit) are characteristic of deltaic distributionary channel fill sands.

The black shales below the channel sand contain wood fragments, siderite concretions and are noncalcareous. These features are characteristic of restricted interchannel freshwater bays, floodplains, marshes, swamps, or lagoonal settings. The local conglomerate influx may be storm derived. The quartz wacke clayey sandstones and clayey siltstones at the base of the core interval may be related to channel development.


Company HALL JONES - DeMoss A-1
Well Location SE SE 7-18N-12W
Petrologic Log
Lithology
Bedding(B)-Laminae(L)
Deformed Features
Organic
Chemical
Surface Features
Constituents
Porosity Types
Contacts of Strata
Cores
Miscellaneous
Rock Classification
AGE STRATIGRAPHIC UNIT
ENVIRONMENT
DEPTH THICKNESS
GAMMA RAY
LITHOLOGY
SEDIMENTARY STRUCTURES
COLOR
SORTING
POROSITY
CONSTITUENTS
FOSSILS
ROCK CLASSIFICATION
SAMPLE
REMARKS
ATOKAN
MORROWAN
CHESTERIAN
SMALL DELTA DISTRIBUTARY CHANNEL FILL
NONMARINE
8390
8400
8410
8420
8430
8440
8450
8460
8470
8480
8490
8500
IRR
Core depth was adjusted 13 ft. to fit G.R. depth
oil stn
qtz aren,sl arg, tr calc,oil stn
sh,fiss,siderite conc,noncalc
cly sltst,noncalc



HALL JONES - DeMOSS A-1

Lithologic Plot of Thin Section Samples With Respect to the Primary Detrital Components

WELL:	Humble Oil - Kephart No. 1
LOCATION:	SW SE 20-18N-12W, Blaine County
CORE INTERVAL: (Stratigraphic Position)	8470-8547 (Lower Morrow)
CUMULATIVE PRODUCTION: (Time Interval)	2,187,760 MCFG (5/67-12/81) + 127,691 BO (1/67-9/81)
PRODUCING INTERVAL:	8493-8507

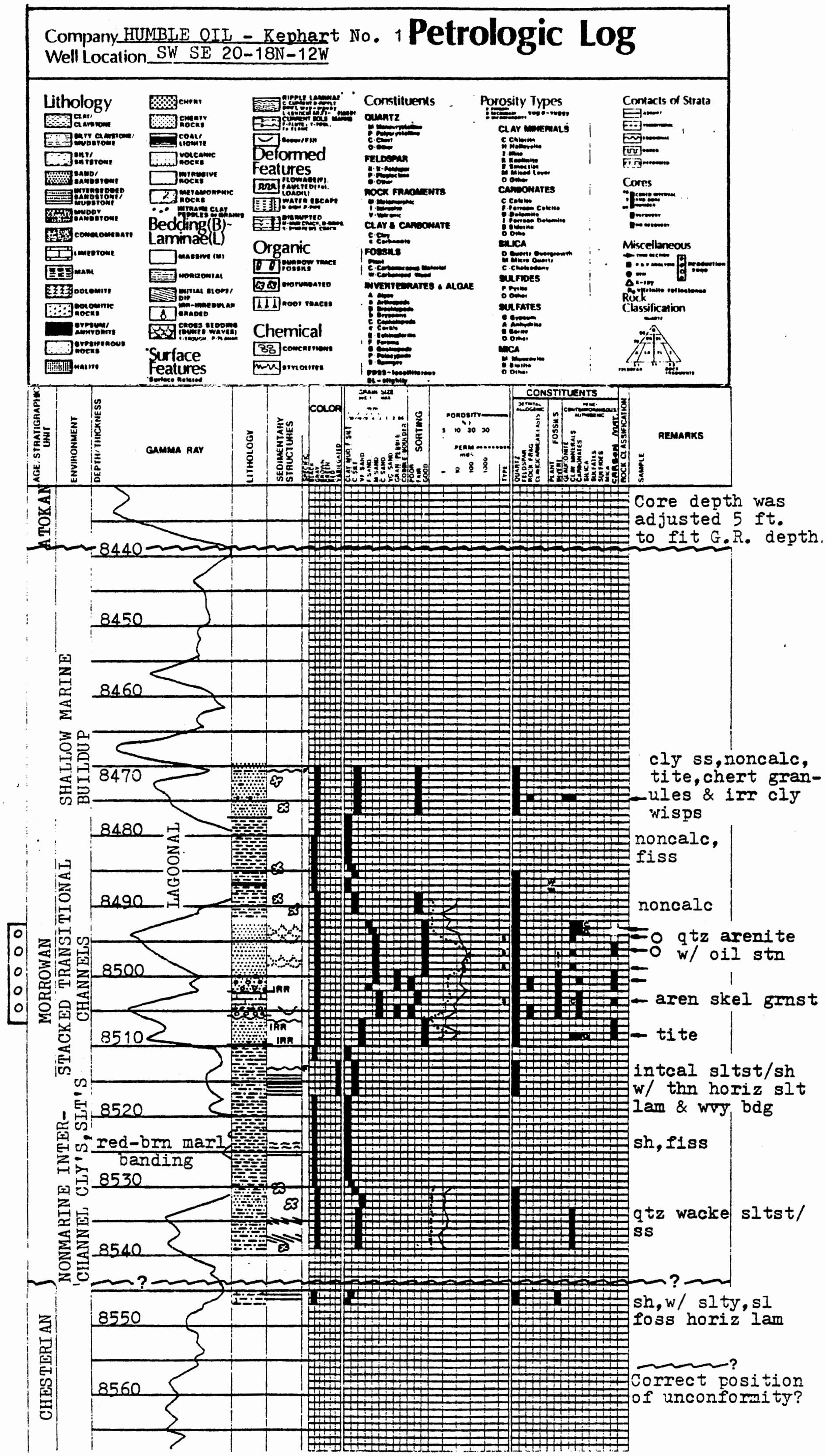
The core interval consists of a producing sand sequence composed of quartz arenite sandstones (8506-8510; 8493-8500) and arenaceous skeletal grainstone (8502-8506). These sands are in sharp contact above shales, intercalated clayey silts and silty sandstones. The producing sands are gradational upsection into bioturbated silts and coaly shales. At the top of the core interval, a glauconitic clayey sandstone (8470-8477) sharply overlays the carbonaceous shales.

Three distinct sand types comprise the producing sand zone as follows: 1) The basal sand is a very fine grained quartz arenite sandstone (8506-8510). This sand is generally massive and contains ripples, irregular shale laminea and carbonaceous styolites. This sand is non-productive because it is tightly cemented by quartz overgrowths with less common carbonate and clay cements. 2) The arenaceous skeletal grainstone (8502-8506) erosionally overlays the very fine quartz arenite sandstone. This unit is an upward fining, conglomeratic based channel sand that contains scour zones and irregular shale laminea. This sand is gradational to arenaceous conglomerates upsection. Oversized secondary pores, a result of clay matrix dissolution, characterize this skeletal sand unit. 3) An oil-stained medium grained quartz arenite sandstone (8493-8500) occurs at the top of the producing sand. This upward fining unit is characterized by transitional contacts and a basal lithic pebble conglomerate. Upsection, this unit grades to bioturbated silts and coaly shales, and decreases in skeletal fragment percentage. The sand also contains carbonaceous styolites. Characteristic sedimentary structures include massive and cross stratified bedding.

The producing sand zone is interpreted as a sequence of stacked transitional and littoral channels. The sharp and erosive basal contacts, scoured surfaces, repetitive upward fining grainsizes, basal conglomerates and cross bedding are characteristic features of channel sands. The quartz arenitic sands may be terrestrial influenced strandline channels (point bars or small deltaic distributary channels) because they lack fossils, grade upsection to coaly shales, and contain carbonaceous styolites. The skeletal sands are marine influenced and may be tidal or esturine channel deposits. The coaly shales above the producing sands are interpreted as lagoonal deposits because of their stratigraphic association with both marine and transitional nonmarine sands.

A tight bioturbated clayey sand/siltstone (8470-8477) sharply overlays carbonaceous shales at the top of the core interval. This unit contains a glauconitic clay matrix, chert granules, intraformational clay granules, irregular clay wisps and occasional horizontal and rippled shale laminations. This sand is noncalcareous. Because this unit shows both marine and nonmarine characteristics, it is difficult to interpret. The presence of glauconite and bioturbation suggests this unit may represent a shallow marine clayey sand buildup of originally terrestrial influenced sand.

The shales, intercalated clayey siltstones and silty sandstones below the producing sand zone are interpreted as quiet water nonmarine deposits. The shales which contain sideritic marls may represent restricted interchannel freshwater bays, lakes, or ponds with the silty sands derived from channel sand influx. Possible Chesterian strata may occur in the slightly fossiliferous, silty shales at the base of the core. Additional palynotologic and paleontologic evidence is needed to verify the position of the Missippian-Pennsylvanian unconformity (it may occur at 8556 feet).


Company HUMBLE OIL - Kephart No. 1
Petrologic Log
Well Location SW SE 20-18N-12W
Lithology
Deformed Features
Bedding(B)-Laminae(L)
Organic
Chemical
Surface Features
Constituents
Porosity Types
Contacts of Strata
Cores
Miscellaneous
Rock Classification
AGE, STRATIGRAPHIC UNIT
ENVIRONMENT
DEPTH/THICKNESS
GAMMA RAY
LITHOLOGY
SEDIMENTARY STRUCTURES
COLOR
SORTING
CONSTITUENTS
ROCK CLASSIFICATION
SAMPLE
REMARKS
ATOKAN
MORROWAN
CHESTERIAN
SHALLOW MARINE BUILDUP
LAGOONAL
STACKED TRANSITIONAL CHANNELS
NONMARINE INTER-CHANNEL CLY'S, SLT'S
red-brn marl banding
8440
8450
8460
8470
8480
8490
8500
8510
8520
8530
8540
8550
8560
Core depth was adjusted 5 ft. to fit G.R. depth.
cly ss, noncalc, tite, chert granules & irr cly wisps
noncalc, fiss
noncalc
qtz arenite w/ oil stn
aren skel grnst
tite
intcal sltst/sh w/ thn horiz slt lam & wvy bdg
sh, fiss
qtz wacke sltst/ss
sh, w/ slty, sl foss horiz lam
Correct position of unconformity?

WELL:	Winters No. 1
LOCATION:	NE 4-17N-12W, Blaine County
CORE INTERVAL: (Stratigraphic Position)	8628-8662, 8672-8694, 8723-8755 (Upper and Lower Morrow)
INITIAL POTENTIAL: (Completion Date)	IP 2,575 MCFGD + 15 BC/2 hours 12/66)
PRODUCTION INTERVAL	8717-8720

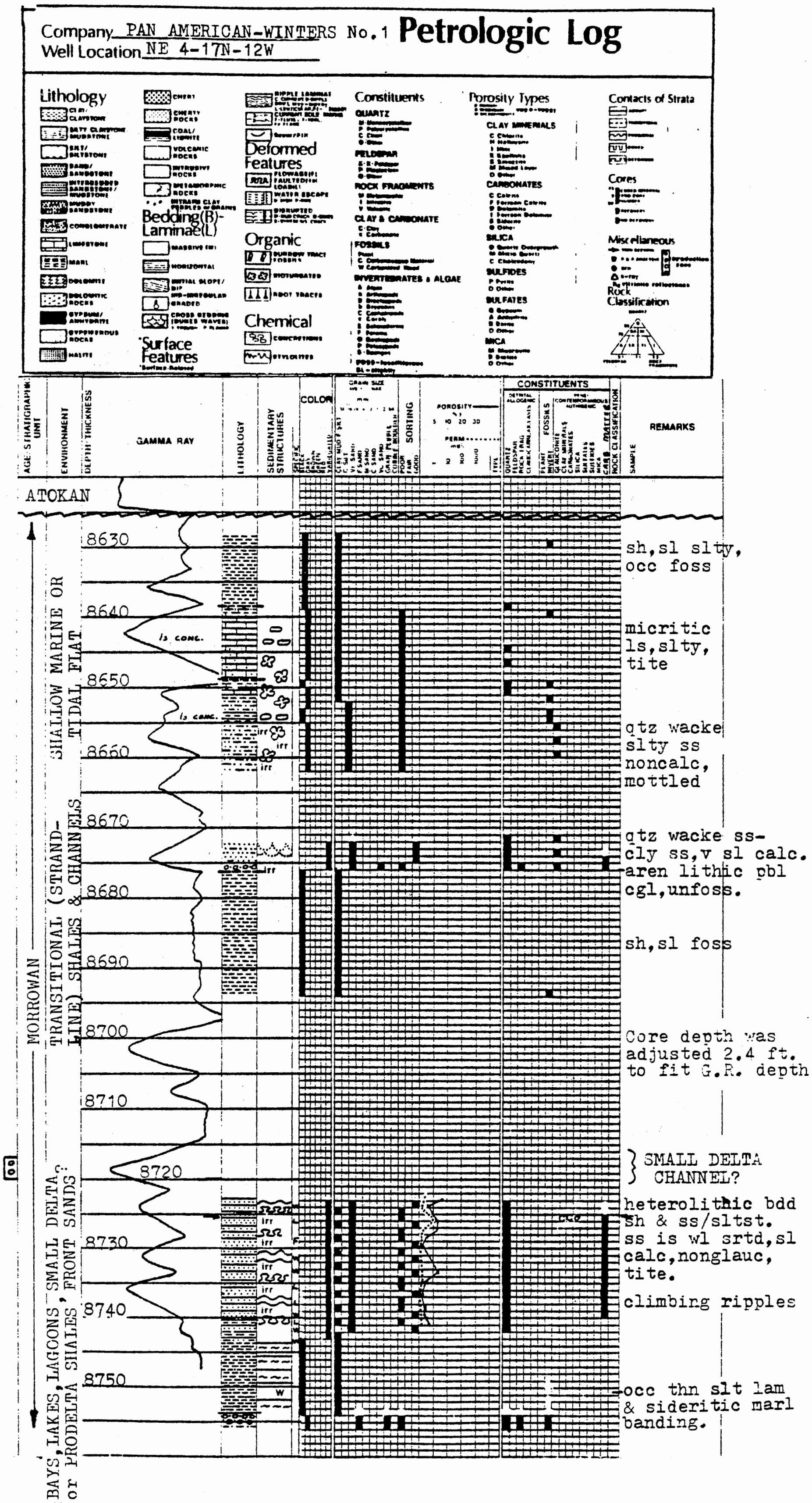
Three core intervals occur: 1) shales that coarsen upward to heterolithic bedded tight sands and shales in the Lower Morrow (8755-8723); 2) a slightly fossiliferous shale unit capped by a conglomeratic based sandstone unit (8694-8672) , and 3) siltstones, limestones, and shales in the Upper Morrow (8662-8628). Production occurs from a sand unit above the heterolithic bedded shales and sands. Sands in the heterolithic deposits were also perforated, but are not productive because they are tightly cemented by quartz overgrowths, mosaic calcite and chloritic clay.

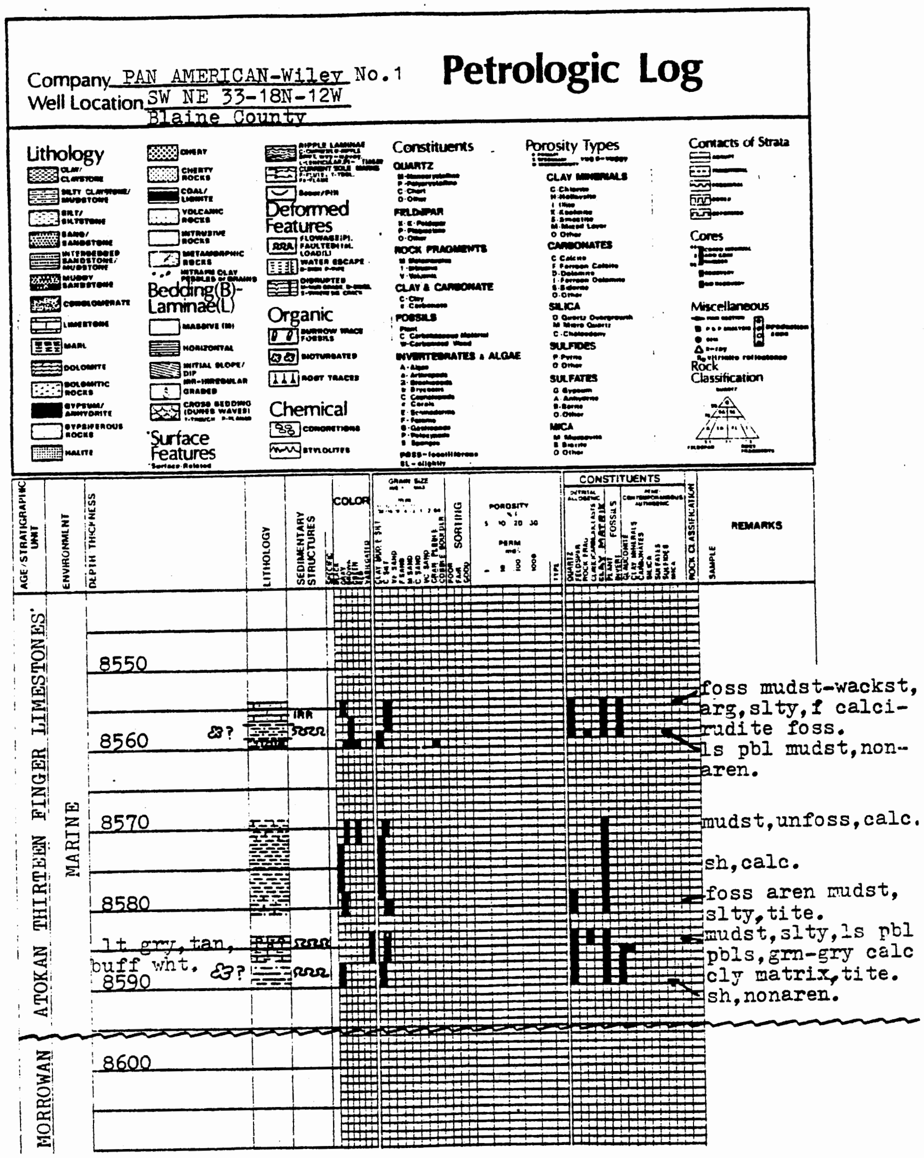
The shales below the heterolithic deposits contain occasional horizontal silt laminea, sideritic marl banding, wood fragments, and are fossiliferous. These deposits probably represent restricted environments such as interchannel bays, lakes, and lagoons, or perhaps are prodelta shales.

The heterolithic bedded shales and sands are rippled with wavey, lenticular and flaser bedding. The unit also shows penecontemperaneous deformation features and irregular bedding. The sands are very fine grained, well sorted, nonglauconitic, and contain irregular clay wisps, shale laminea and carbonaceous styolites. The sands reflect a non-marine character and may represent small delta front sands (i.e., small delta buildups on prodelta?). Production occurs from a possible deltaic channel sand that rests atop the heterolithic sands and shales.

The middle core interval (8694-8672) consists of a thin upward fining conglomeratic based sand unit which rests atop slightly fossiliferous black shale. The sand is a very fine grained quartz wacke sandstone to clayey sandstone. The sand contains glauconite, occasional subhorizontal irregular clay laminations, cross bedding, and is slightly calcareous. This sand was probably deposited in a marine influenced transitional channel atop transitional (strandline) shales. Deposition probably occurred seaward of time equivalent, more terrestrial sediments (as described above).

The upper Morrow core section (8662-8628) consists of three lithologic types separated by transitional contacts. The basal unit consists of glauconitic, bioturbated quartz wacke silty sandstone. Upsection, these units grade to buff white bioturbated silty micritic limestones and light grey mudstones, followed by dark grey to black fossilferous shales. These rocks are interpreted as tidal flat deposits or may represent marine conditions further offshore. Glauconite, bioturbation, arenaceous micritic limestones, and fossiliferous limestones could occur in either environment.


Company PAN AMERICAN-WINTERS No. 1
Well Location NE 4-17N-12W
Petrologic Log
Lithology
Deformed Features
Bedding(B)-Laminae(L)
Organic
Chemical
Surface Features
Constituents
Porosity Types
Contacts of Strata
Cores
Miscellaneous
Rock Classification
AGE STRATIGRAPHIC UNIT
ENVIRONMENT
DEPTH THICKNESS
GAMMA RAY
LITHOLOGY
SEDIMENTARY STRUCTURES
COLOR
SORTING
CONSTITUENTS
REMARKS
ATOKAN
MORROWAN
SHALLOW MARINE OR TIDAL FLAT
TRANSITIONAL (STRAND-LINE) SHALES & CHANNELS
BAYS, LAKES, LAGOONS, SMALL DELTA, or PRODELTA SHALES, FRONT SANDS?
8630
8640
8650
8660
8670
8680
8690
8700
8710
8720
8730
8740
8750
ls conc.
ls conc.
sh, sl slty, occ foss
micritic ls, slty, tite
qtz wacke slty ss noncalc, mottled
qtz wacke ss-cly ss, v sl calc.
aren lithic pbl cgl, unfoss.
sh, sl foss
Core depth was adjusted 2.4 ft. to fit G.R. depth.
} SMALL DELTA CHANNEL?
heterolithic bdd sh & ss/sltst.
ss is wl srtd, sl calc, nonglauc, tite.
climbing ripples
occ thn slt lam & sideritic marl banding.



(This core was examined to characterize the Atokan Thirteen Finger lithology in the study area. A written description of this unit occurs in Chapter III.)

VITA

Mark Veeder South

Candidate for the Degree of

Master of Science

Thesis: STRATIGRAPHY, DEPOSITIONAL ENVIRONMENT, PETROLOGY AND DIAGENETIC CHARACTER OF THE MORROW RESERVOIR SANDS, SOUTHWEST CANTON FIELD, BLAINE AND DEWEY COUNTIES, OKLAHOMA

Major Field: Geology

Biographical:

Personal Data: Born in Minneapolis, Minnesota, December 7, 1954, the son of Mr. and Mrs. W. A. South.

Education: Graduated from Littleton High School, Littleton, Colorado, in January, 1973; received Bachelor of Science degree in Geology from Fort Lewis College, Durango, Colorado, in 1978; enrolled as a special student at the Colorado School of Mines in 1979; completed requirements for the Master of Science degree at Oklahoma State University, Stillwater, in July, 1983.

Professional Experience: Field Geologist, Copper and Molybdenum Exploration, Placid Oil Company, 1978; Roughneck, Parker Drilling Company, 1979; Mud Logger on Data Units, Dresser-Magcobar, 1979; Summer Geologist, Amoco Production Company, 1980, 1981; Graduate Teaching Assistant, Geology Department, Oklahoma State University, 1980-1982.