# DEPOSITIONAL ENVIRONMENT, PETROLOGY, DIAGENESIS, AND PETROLEUM GEOLOGY OF THE COTTAGE GROVE SANDSTONE, NORTH CONCHO FIELD, CANADIAN COUNTY, OKLAHOMA

By

R. BRYAN WALLER

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DEPOSITIONAL ENVIRONMENT, PETROLOGY, DIAGENESIS

AND PETROLEUM GEOLOGY OF THE COTTAGE GROVE

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Thesis Approved:

Arthur W. Cleaves, II
Thesis Advisor

Zuhair al-Shaieb

Gary F. Stewart

Norman N. Durham
Dean of the Graduate College

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# CHAPTER I

# INTRODUCTION

The present recession has resulted in a 20% net decrease in the price of oil. This price reduction has had a tremendous effect on the oil and gas business. Drilling contractors, service companies, equipment dealers, and vendors have had to reduce their prices to remain competitive. Therefore, the decrease in the price of oil was directly offset by the reduction in well costs. These factors combine to make the development of shallow reservoirs economically very attractive.

As the hunt for shallow reservoirs emerges, an understanding of the nature of the depositional environment and diagenetic alterations of shallow sandstone reservoirs is critical for a successful exploration strategy. A reevaluation of many shallow sandstones has proved them to be prolific reservoirs with interesting diagenetic histories.

## Location and General Characteristics

The Pennsylvanian Cottage Grove Sandstone produces oil and gas from a stratigraphic trap in the North Concho Field (the East Calumet Field is another name applied to the same area). The field is located in Canadian County, east of Calumet, Oklahoma, T12N-T14N, R8W and R9W (Figure 1). The field trends north-south and is approximately 3 miles wide and 15 miles long. For the purpose of this study the entire trend of Cottage Grove production will be referred to as the North Concho

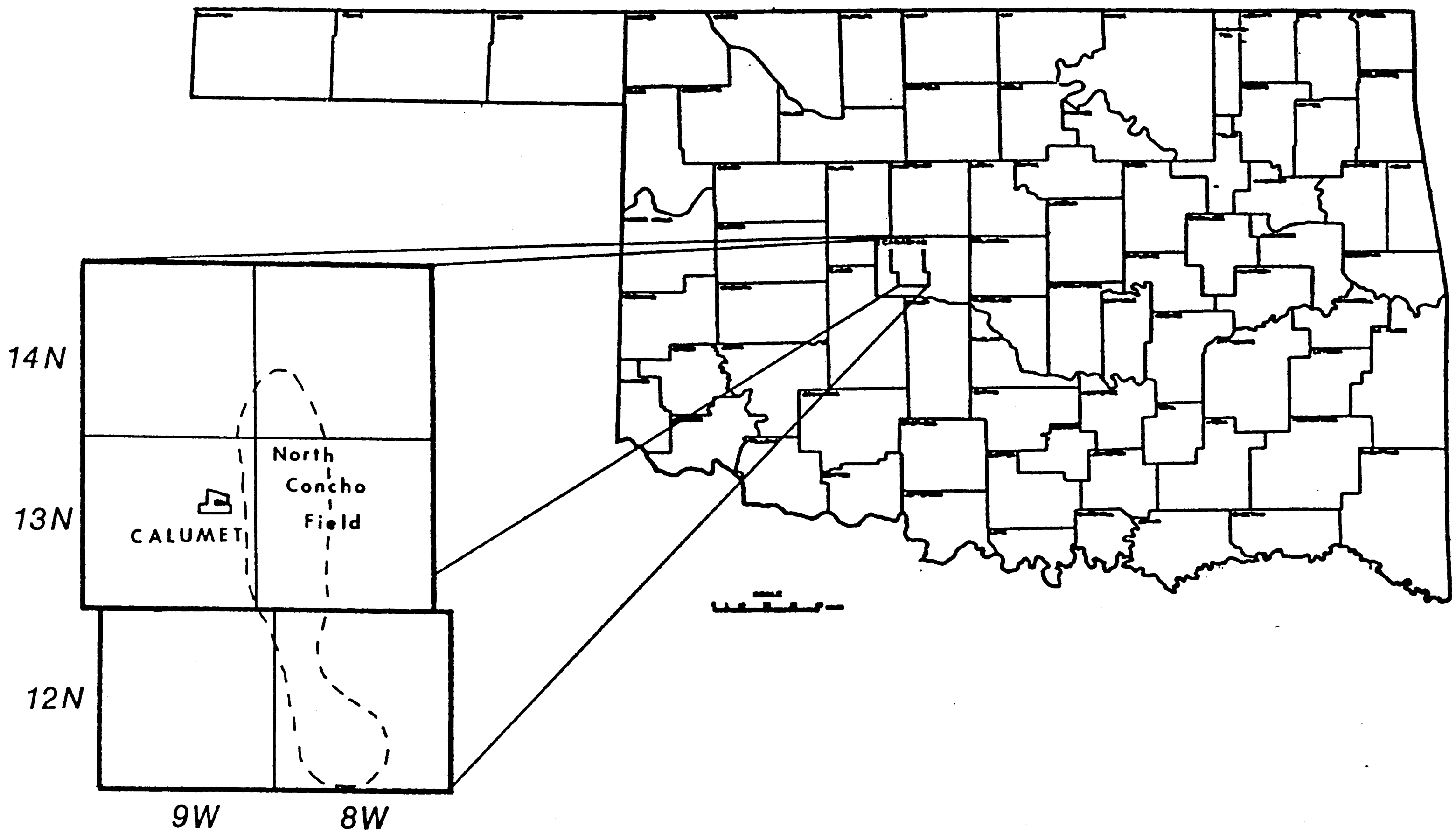



Figure 1. Location of the Study Area

Field. Several other field names have be used for the production in the southern part of the study area. The North Concho Field lies in the Watonga-Chickasha Trend. Subsea elevations to the top of the Cottage Grove Sandstone range from 6050 feet in the northeastern part of the area to 7250 in the southwest. The field had produced approximately 3.5 million bbls of oil and over 2 Bcf of casing head gas at the end of 1985 (Petroleum Information, 1985).

## Objectives and Methods

The principal objective of this study is to evaluate all aspects of the Cottage Grove Sandstone in the North Concho Field as they apply to reservoir characteristics and develop exploration strategies applicable to similar reservoir units in Oklahoma. Characterization of the Cottage Grove Sandstone was accomplished by electric log correlation sections, isolith maps, structural maps, and a log signature map. These subsurface data provided useful information concerning structural and stratigraphic relationships responsible for the reservoir trap. Net sand maps were constructed to illustrate the geometry of the Cottage Grove sands. A porosity map was constructed to compare with net sand maps and to relate porosity trends to the upper sandstone body. Eight cores were examined to determine the internal organization, structure, petrology, and diagenetic character of the sand. Cored intervals were calibrated with their corresponding gamma ray log signatures to correct core depths and to compare lithologies with log signatures. This helped to identify lithologies in wells that were not cored in the area. An evaluation of the spatial arrangement of all internal features and their relationship to bounding lithologies and to external sandbody geometry helped define an internal organization which lead to a depositional environment reconstruction. Recognition of ancient depositional environments is crucially important in the exploration and development of future oil and gas reserves. Understanding the depositional environment of a prolific sandstone can assure that wells may be better positioned resulting in a higher probability of success.

## Previous Investigations

The Cottage Grove Sandstone has not received much attention in the geologic literature. Most writing on the Cottage Grove is found in articles and publications concerning related topics.

The Cottage Grove Sandstone was named by Newell from Cottage Grove Township in the southern part of Allen County, Kansas (Moore, 1932). Capps (1959) described the Cottage Grove lithologically from subsurface samples in a stratigraphic analysis of Missourian and lower Virgilian rocks in northwestern Oklahoma. He suggested that the Cottage Grove was deposited on a low-energy, neritic shelf and had a southerly source. Oakes (1940) described the Cottage Grove as a buff colored, fine-grained, massive to thin bedded sandstone. This was based on an outcrop examination in Washington County, Oklahoma. Pate (1959) analyzed stratigraphic traps in northwestern Oklahoma and included the Cottage Grove in his discussion of future exploration targets. The Cottage Grove Sandstone was also described from subsurface samples by Gibbons (1960). He suggested the Cottage Grove was a western extension of an equivalent unit east of the Nemaha uplift. Rascoe (1962), in a regional stratigraphic analysis of Pennsylvanian and Permian rocks of the western Midcontinent, suggested that the distribution of the Cottage Grove was related to the formation of an east-west sedimentary trough across Oklahoma. Later, Rascoe (1978) indicated that the major source of the Cottage Grove Sandstone was the Ouachita Mountains. He concluded this by suggesting a fluvial-deltaic origin for the unit in central Oklahoma and by noting its progressive change to marginal-marine environments in the west. Rascoe and Adler (1983) concluded that the overall sandstone content of the terrigenous clastic facies of the Missourian Series increases in an easterly direction, as numerous lenticular sandstones appear in the section in central Oklahoma. Swanson (1967) discussed oil and gas accumulations occurring in areas of marked facies changes. He noted that the Cottage Grove exhibits this type of stratigraphic trap in the northern hinge zone of the Anadarko basin.

More specific studies dealing with the Cottage Grove Sandstone were done by Calvin (1965), Holmes (1966), Lalla (1975), and Towns (1978). Calvin (1965) discussed the incidence of oil and gas in the Cottage Grove Sandstone in Southeastern Kansas. He determined that the production was not confined to higher porosities and permeabilities but to the extreme northern Cottage Grove pinchout. Holmes (1966) described the Cottage Grove Sandstone as a series of bars trending northeast-southwest in the Cedardale Field, Woodward and Major Counties, Oklahoma. Towns (1978) interpreted the Cottage Grove Sandstone as an offshore shallow-marine bar in the South Gage Field in Ellis County, Oklahoma. Lalla (1975) determined the Cottage Grove Sandstone to be of deltaic origin in northern Oklahoma, east of the Nemaha ridge. He also hypothesized a sediment source from the southeast.

# CHAPTER II

## STRUCTURAL FRAMEWORK

### Introduction

The North Concho Field is located on the northeastern edge of the asymmetric, west-northwest trending Anadarko basin. Figure 2 shows the location of the study area within the surrounding structural setting. The axis of the basin is found on its southern margin, parallel and adjacent to the Amarillo-Wichita Mountain front. The basin is bounded on the north by a broad cratonic shelf. The Nemaha uplift separates the basin from the Central Oklahoma platform to the east. The western border of the Anadarko basin is defined by the Cimarron Arch-Keyes Dome, which trends north across the Oklahoma Panhandle (Huffman, 1959).

In depth and volume the Anadarko Basin is one of North America's major crustal features. Sediments in the heart of the basin exceed 40,000 feet in thickness, thus constituting one of the thickest and most complete Paleozoic sections in the Mid-Continent structural province (Adler, et al., 1971).

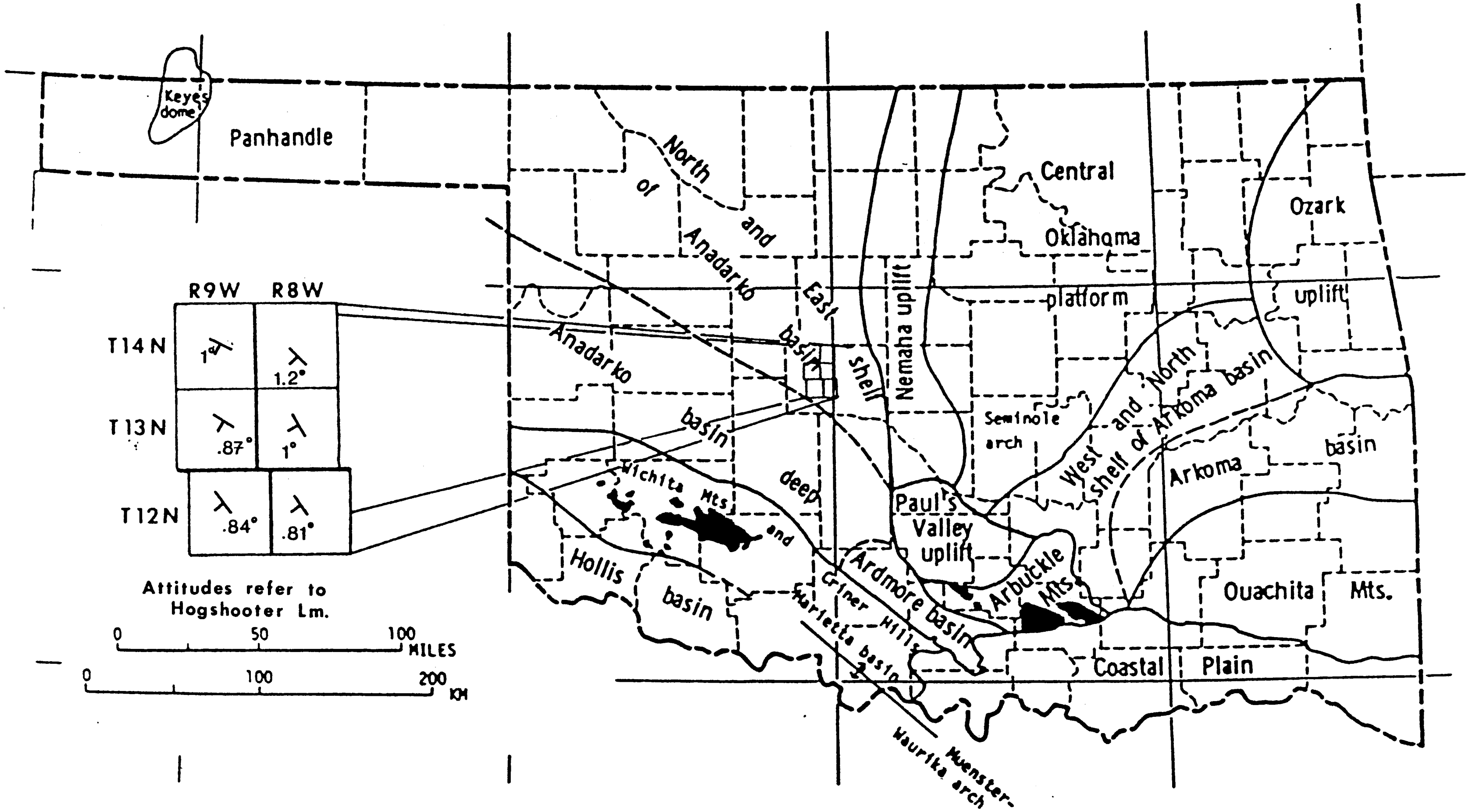



Figure 2. Location of the Study Area in the Surrounding Structural Setting (Evans, 1979)

# Regional Geologic History

The geologic history of the Anadarko basin began in early Cambrian time when a "hot spot" in the earth's crust caused thermal crust expansion, uplift, and eventually ruptured to form three rifts oriented at approximately 120 degree angles to each other (Figure 3a). Oklahoma rifting involved the formation of uplifts and grabens contemporaneous with the deposition of more than 20,000 feet of graywacke, layered chert, spilitic basalt, and rhyolite in the grabens (Rascoe and Adler, 1983).

Two arms of the triple-rift junction continued spreading to form a young ocean basin (Figure 3b). The evolution of the Anadarko basin is directly related to the opening and closing of this Paleozoic ocean basin known as the "Proto-Atlantic". Following this rift opening, the southern edge of North America developed into an Atlantic-type margin, accumulating a prism of sediments ranging in age from Ordovician to Mississippian. The landmass drifting away from the North American Plate has been termed Llanoria. The present day Ouachita orogenic belt approximates the ancient continental margin of North America. The third arm, trending west-northwest across southern Oklahoma, failed to continue spreading and activity ceased. This caused crustal cooling and thus initiated thermal subsidence. This lithospheric densificaton, caused by the crustal cooling, created a long term isostatic imbalance in southern Oklahoma, resulting in an aulocogen (Rascoe and Adler, 1983). This aulocogen acted as a strongly negative tectonic feature (with the exception of its stabilized southwestern margin) and

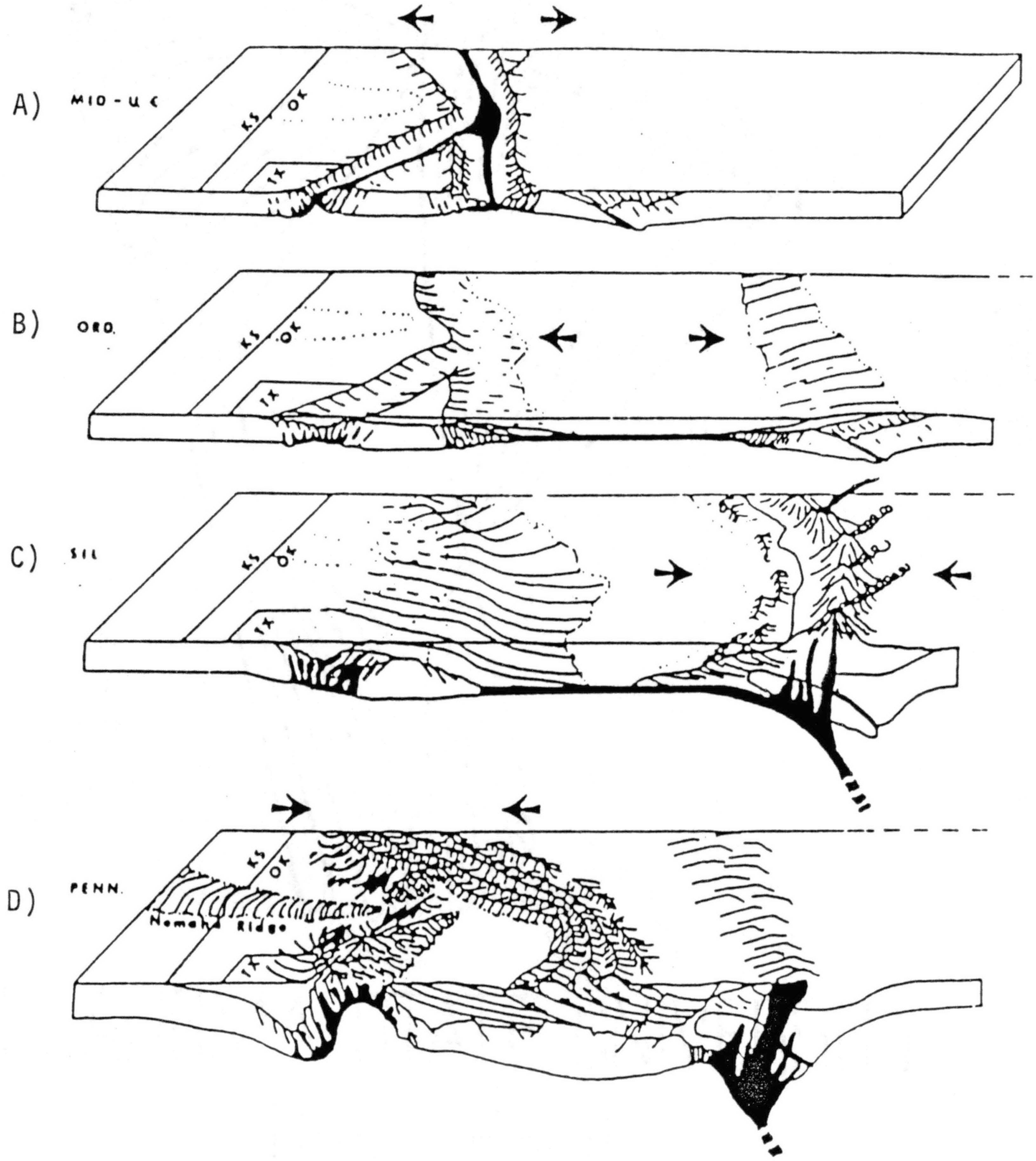



Figure 3. Generalized Sketch of the Tectonic Evolution of Oklahoma (Greatly modified from Briggs and Roeder, 1975)

accumulated sediments for the remainder of the Paleozoic Era (Rascoe and Adler, 1983).

During the Devonian or Early Mississippian, the Proto-Atlantic ocean basin began to close (Figure 3c), accommodated by southward subduction beneath "Llanoria". Convergence culminated during the Atokan, when the subduction complex ran aground upon the rifted continental margin. Eventually the collision of these two plates, which were once united, created left-lateral compressive stresses that were transmitted far into the continental interior. The most likely paths of stress transmission would tend to be in ancient pre-existing faults (basement weaknesses). The ancient aulacogen, with its numerous dormant normal faults striking somewhat parallel to this new compressive force, seemed to be the likely choice.

The paleo-basement faults in the area to the north of the aulacogen are not well documented due to the thick sedimentary cover. Burke and Dewey (1973) stated that the Nemaha ridge could possibly overlie an incipient rift which failed to spread beyond the stage of axial dike injection. This would make the Oklahoma aulacogen part of a four-armed rift structure: a structure described by Burke and Dewey (1973) which was noted to form in other areas. A petrographic examination of basement rocks in Oklahoma by Denison (1978) concluded that the occurrence of more deeply emplaced rocks at the basement surface near the Nemaha ridge area indicates that the Nemaha uplift had a precursor in Pre-Cambrian time. Detailed mapping of the Nemaha ridge by Grammill and Wheeler (1968) reveals the structure is not a ridge or anticlinal axis, but is composed of a number of differentially warped fault blocks. In several places Grammill and Wheeler noticed that these blocks were displaced by high angle reverse faults which pivoted locally (scissor-faulting). Major episodes of Nemaha ridge uplift and truncation closely correlate with major episodes of left-lateral megashearing in the Mid-continent. This suggests that the Nemaha ridge is an area of basement weakness that was strongly affected by tectonic forces transmitted through the Oklahoma area.

During the Pennsylvanian geosuture the compressional forces reactivated the dormant southern Oklahoma aulocogen and segmented it into strongly negative basins and strongly positive uplifts (Rascoe and Adler, 1983). Uplifts and down-warping were controlled by the pre-existing basement weaknesses (faults) and stress fields set up in the crust by the oblique continental collision. Structural readjustments of the Nemaha ridge resulted in an uplift trending north to south. The rejuvenation of normal faults into combination strike-slip, thrust faults displaced portions of the segmented aulacogen horizontally and vertically onto the adjacent Anadarko basin. This weight, along with alluvium shed from the uplift (granite wash), further controlled subsidence of the Anadarko basin. Compressive forces resulting from the geosuture also caused the thrusting of flysch-type sediments onto the Arkoma foreland basin area in southeastern Oklahoma. This area remained a site of molasse deposition throughout the Desmoinesian (Figure 3d). This structural deformation is known as the Ouachita Mountains. Crustal loading resulting from this thrusting assisted in further subsidence of the Arkoma foreland basin. The Arkoma basin area was previously subsiding as the result of crustal thinning caused by the Cambrian rifting. The uplift of this large sedimentary pile of recycled continental margin sediments provided a major source of clastic material for Oklahoma basins (Krumme, 1975).

## Basin Subsidence Rates

The curves in Figure 4 illustrate variations in the rate of sediment entrapment for the Anadarko and Arkoma basins, and the Ouachita geosyncline. There are various inaccuracies resulting from the generation of these curves, but these do not detract from the overall significance and value of the curves (Donovan et al., 1983). Specifically, there are inaccuracies in the absolute time scale itself, uncertainties in the relationship of local sequences to this time scale, and variations in the estimates of thickness used (Donovan et al., 1983). All three curves record accelerated sediment entrapment rates in Cambro-Ordovician times, and relatively slow entrapment rates in Silurian, Devonian, and Early Mississippian times. Maximum entrapment rates started during the Late Mississippian and continued into the Pennsylvannian Period. The dynamic interplay of rapid subsidence and the influx of sediments from multiple sources resulted in the distribution of complex depositional facies throughout the Anadarko basin (Moore, 1979). The progressively deepening Anadarko and Arkoma basins received an influx of clastic debris from the Amarillo-Wichita and Ouachita uplifts, respectively. Because the rate of subsidence exceeded deposition, coarse sediments eroded from the uplifts were deposited close to the source, and associated finer grained detritus was distributed slightly further into the basins. The uplifted sedimentary pile of the Ouachita overthrust area provided a prolific source that was capable of constructing shallow marine and terrestrial environments

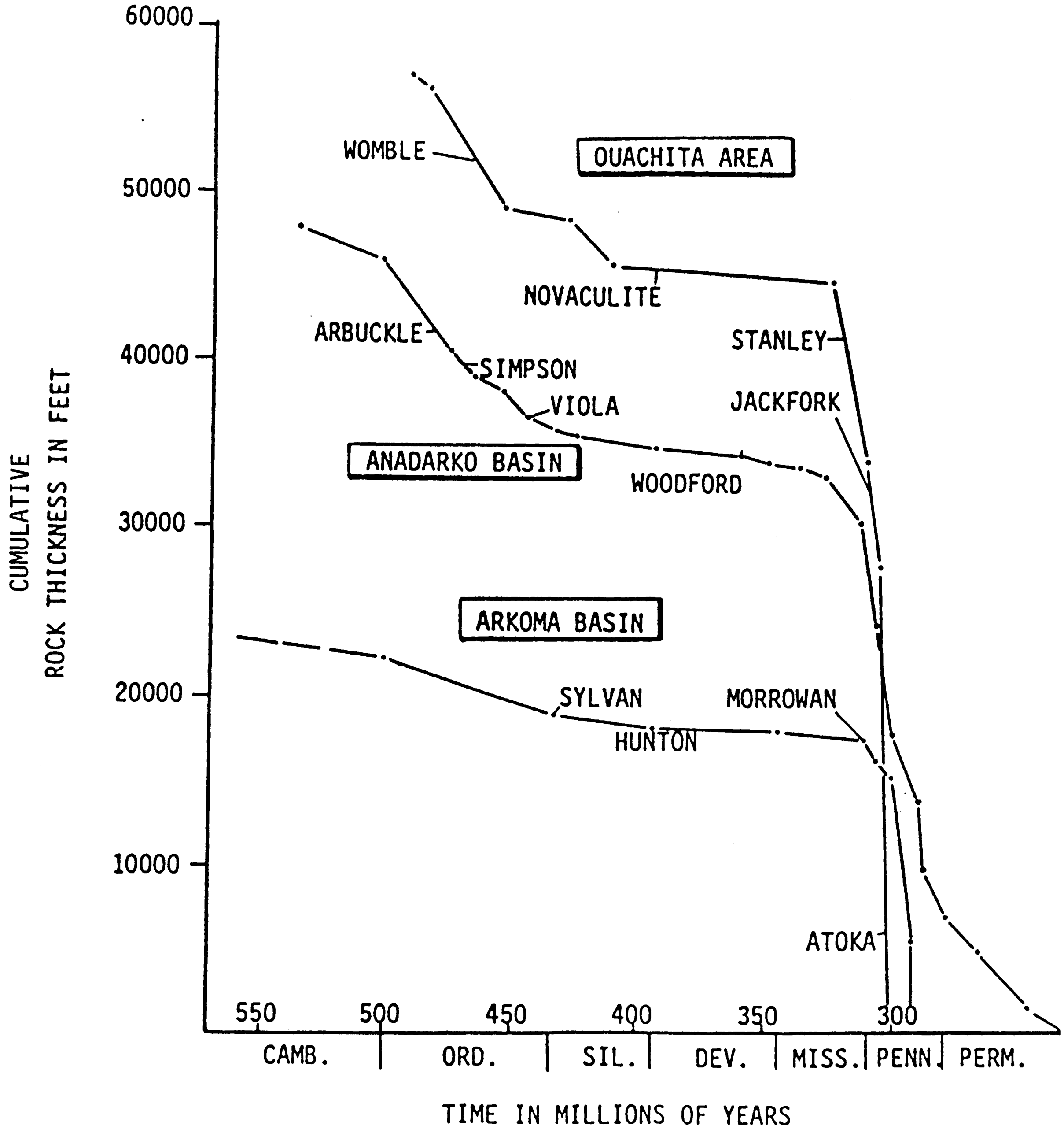



Figure 4. Rock Thickness as a Function of Geologic Time

(paralic) within the subsiding Arkoma basin. The sources contributing to the Anadarko basin were not as plentiful. South of the Anadarko shelf edge during this time, the basin was sediment-starved and waters were deep (Moore, 1979). The positive north-south trending Nemaha ridge controlled source distribution and the large supply of clastics shed from the Ouachita uplift was restricted to the Arkoma basin. Northern, cratonic, sources contributed minor amounts of sediment to both basins. Figure 5 is a generalized sketch of the structural controls on source influence during Late Desmoinesian time.

Figure 4 also illustrates approximate basin filling times in each of the basins. Although some of the sedimentary pile of Oklahoma has been removed by recent erosion, the approximate time interval between basin closings should remain unaffected. The Arkoma basin seems to have stopped subsiding sometime before Missourian time while the Anadarko was still strongly subsiding. In the early Missourian, clastics from the Ouachitas had filled the Arkoma basin and spilled westward across the positive Nemaha axis and northeastern shelf of the Anadarko basin into the deeper portions of the Anadarko basin (Moore, 1979). The progradation of widespread clastic wedges from northeastern and southeastern Oklahoma from the distant Ouachita uplift thus became the predominant source for the Anadarko basin (Moore, 1979).

## Paleotopography

Figure 6 is a generalized sketch of the paleogeography of the Oklahoma area during Late Missourian deposition (Combined from Moore, 1979; Rascoe and Adler, 1983; Rascoe, 1962). During Missourian deposition, the North Concho area sediments were deposited in a shallow

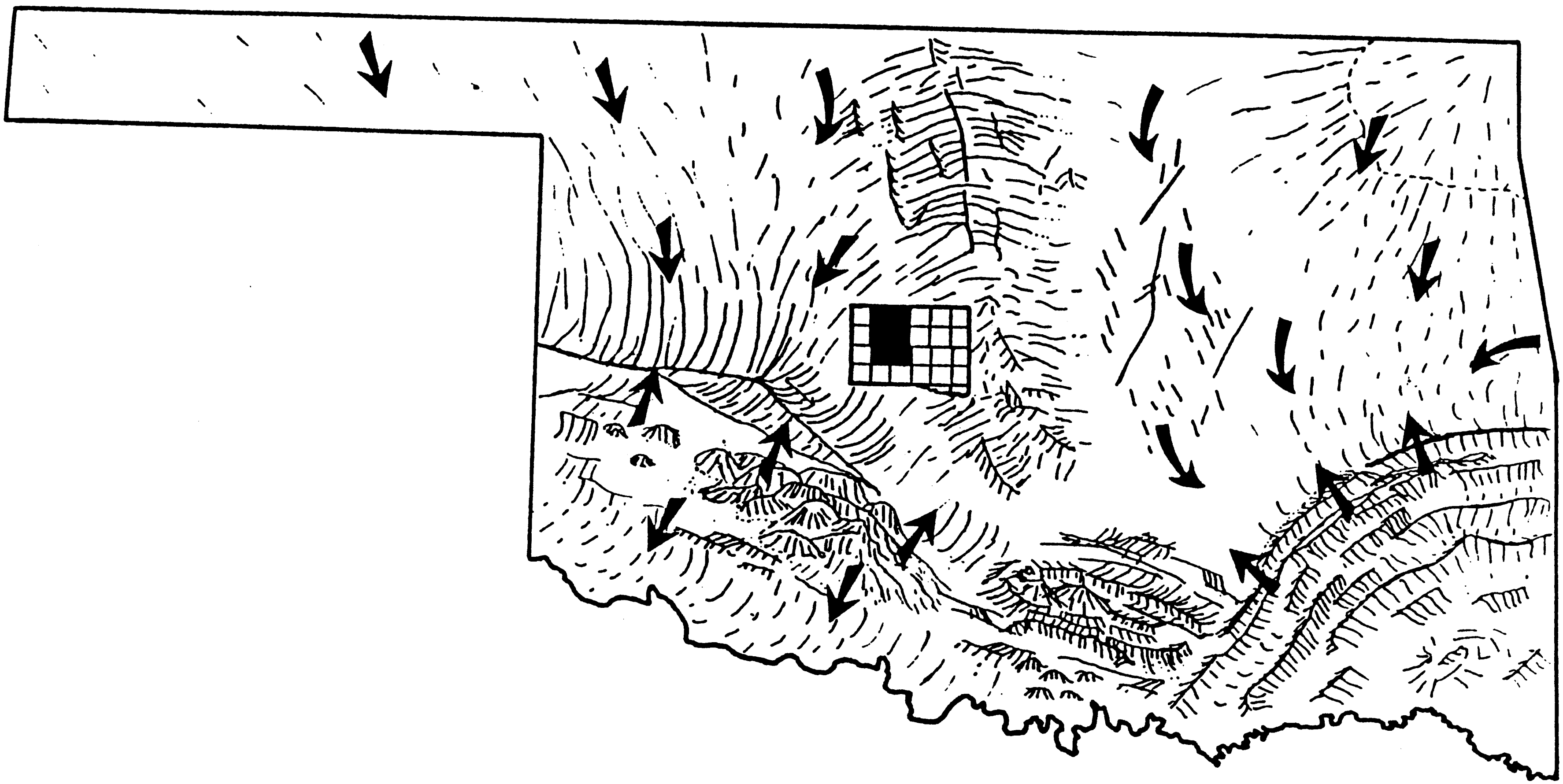


Figure 5. Structural Controls on Source Influence During Late Des-Moinesian (Combined from Moore, 1979; Rascoe and Adler, 1983; and Rascoe, 1962)

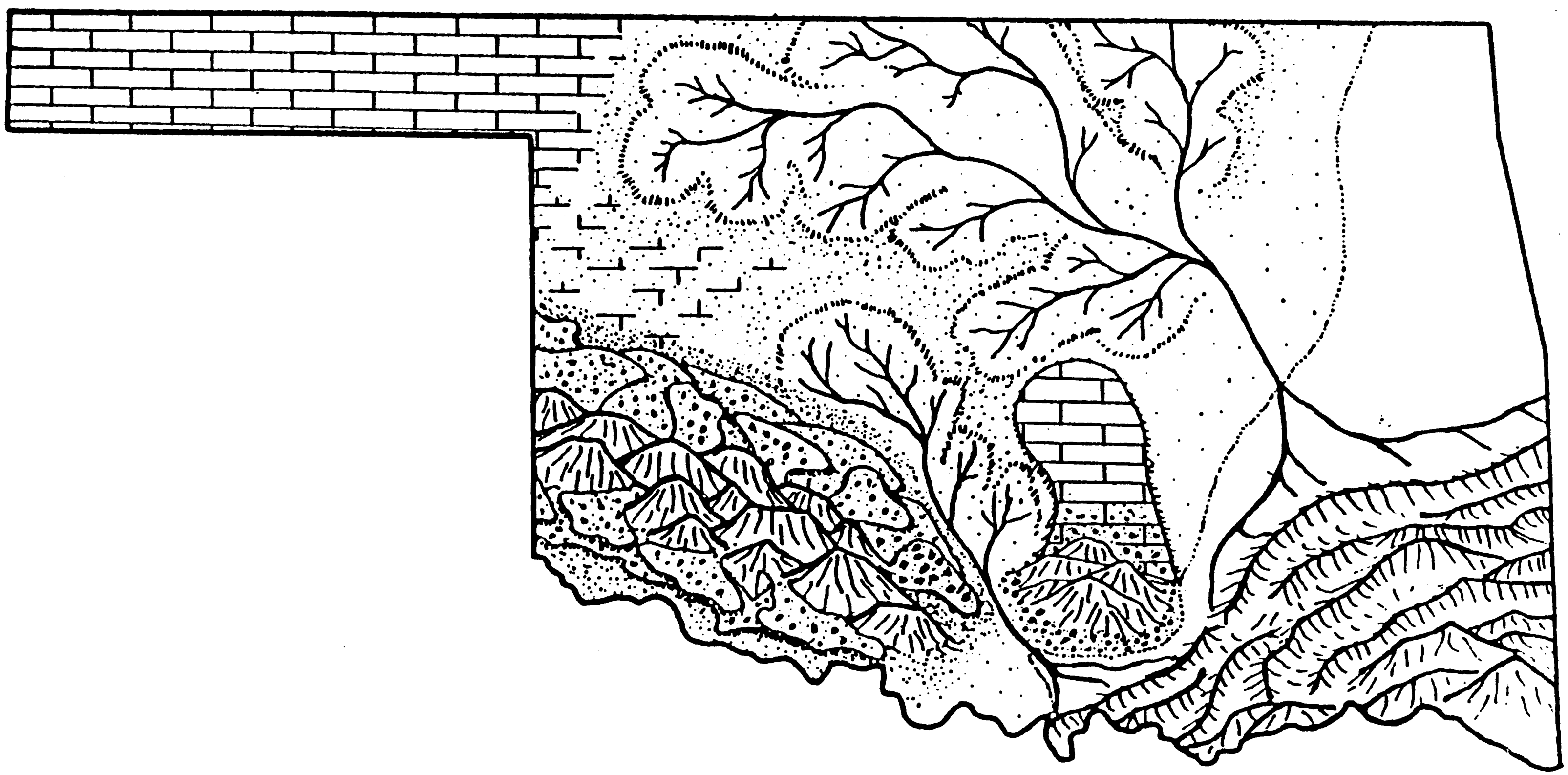


Figure 6. Interpretation of Missourian Paleogeography and Depositional Environment (Combined from Moore, 1979; Rascoe and Adler, 1983; and Rascoe, 1962)

marine, fluvial-deltaic environment on a relatively stable cratonic shelf. Clastic wedge sediments of the Amarillo-Wichita uplift are generally proximal to the southern basin edge, but could have contributed to distal sedimentation during times of slow subsidence. During periods of low supply of clastic material from the Ouachitas, carbonates were deposited in areas of shallow water (Moore, 1979). To the north across Kansas, carbonates were far more abundant, clastics were sparse, and a broad, carbonate shelf developed (Moore, 1979). The southern margin of this carbonate shelf forms the northern shelf edge of the Anadarko basin that crosses southern Kansas, northwestern Oklahoma, and the Oklahoma and Texas panhandles (Moore, 1979). Transition of these massive carbonates to a terrigenous clastic facies is abrupt and occurs within a zone generally a few miles in width (Rascoe and Adler, 1983).

The Arbuckle orogeny in Late Missourian time profoundly affected southern Oklahoma (Huffman, 1959). The Arbuckle Mountain system was formed and parts of the Wichita-Amarillo trend were refolded and refaulted. Post-orogenic sediments in the Arbuckle region include various conglomerates shed from the uplifted areas over younger Missourian sediments (Huffman, 1959). In south-central Oklahoma the Seminole uplift area consists of Missourian carbonate sediments deposited on a platform of older Missourian clastics (Rascoe and Adler, 1983).

## Local Structure

Structure maps of the North Concho area are shown in Plates 2 and 3. Plate 2 is a map contoured on the top of the Hogshooter Limestone.

The Hogshooter Limestone is a significant marker of regional extent deposited during a maximum transgression (Rascoe and Adler, 1983). No major tectonic features were recognized in the North Concho study area. Regional warping seems to be the only structural control. Faulting in the study area was not detected. Structural strike is to the northwest at 320-325 degrees. The average structural dip in the area averages about 90 feet per mile to the southwest across the North Concho Field. Gentle folds present in the study area are probably the result of differential compaction and regional warping of the thick sedimentary pile.

Plate 3 is a structural map contoured on the top of the Cottage Grove Sandstone. The contour values are on the top of the uppermost sand present in the Cottage Grove interval (whether upper or lower sand unit). There appears to be no consistent relationship between both structure maps and Cottage Grove Sandstone thickness. This suggests that regional warping occurred after Cottage Grove deposition and that any structural relief or closure is a compactional phenomenon resulting from the dewatering and warping of the basin.

# CHAPTER III

## STRATIGRAPHIC FRAMEWORK

### Introduction

The Cottage Grove Formation is a formal stratigraphic unit present in the Missourian Series equivalent to the Late Pennsylvanian Epoch. The Missourian Series has been divided into the Ochelata and the Skiatook Groups by Lukert (1949). The Cottage Grove Formation is in the lower part of the Ochelata Group. The Hoxbar Group is a rock stratigraphic term roughly equivalent to the Missourian Series. Some Cottage Grove production in the study area has been referred to as "Hoxbar" production. The Hoxbar Group is composed of marine carbonates, sandstones and shales exhibiting complex intertonguing relationships (Jordan, 1957). Figure 7 shows the stratigraphic relationships of the Cottage Grove to other formations of the North Concho area. All formation contacts within the Hoxbar Group in the study area are conformable.

Regionally, the Cottage Grove Sandstones are thought to be stratigraphically equivalent to parastratigraphic rock units such as the Osage-Layton sand, Musselem sand, the Broyles-Layton sand, and the Peoples sand. To the north the sand is equivalent to the carbonates of the lower part of the Kansas City Group. The main emphasis of this study is on the Cottage Grove interval, herein defined for purposes of this

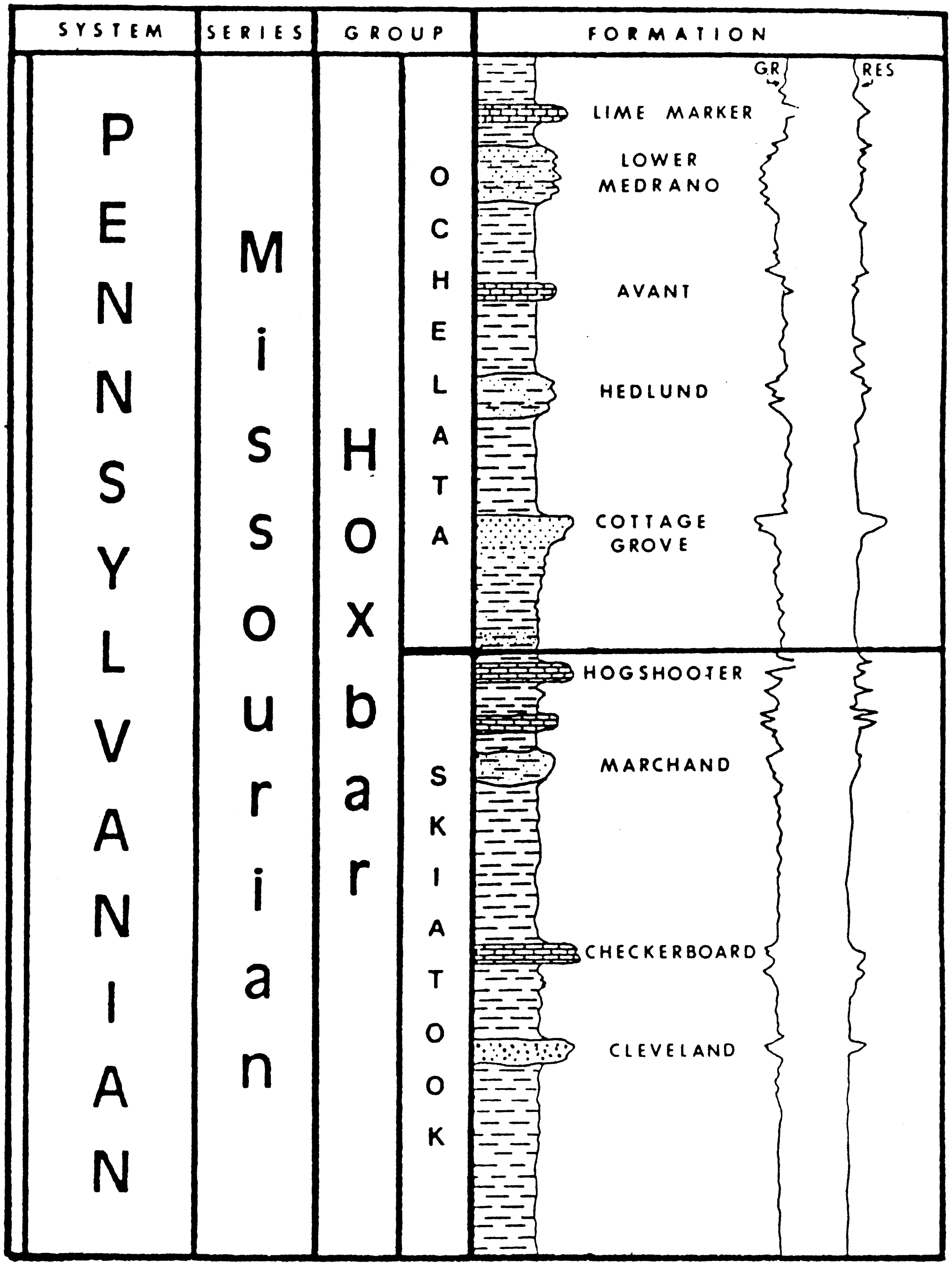



Figure 7. Stratigraphic Column at North Concho Field

study as the section of rock from the top of the Hogshooter "hot shale" marker to the top of the first sand present below the Hedlund zone.

## Correlation

Characteristics of the Cottage Grove Formation and its relationships with adjacent units were determined by several stratigraphic cross sections. The cross section network is illustrated in Plate 1. The Cottage Grove interval cross sections were oriented both perpendicular and parallel to the present strike in the North Concho area in order to compare depositional dip orientations to present dip orientations (Plates 4 and 5). This comparison should enable the prediction of stratigraphic traps if the depositional environment has been recognized. Markers used for the Cottage Grove interval sections include a sharp, "hot" gamma ray deflection defining the top of the Hogshooter limestone. The datum chosen for the Cottage Grove interval sections was the top of the Upper sand. When the Upper sand was not developed, the cross sections were hung on resistivity kicks characterizing the undeveloped Upper sand.

A north-south trending cross section (Plate 6) dissecting the North Concho Field was constructed to characterize the genetic interval between the Avant Limestone and the Hogshooter Limestone. This cross section helps to provide an understanding of the relationships of the rock record between the Avant and Hogshooter Limestones.

## Cottage Grove Interval

Seven cross sections (Plates 4 and 5) were constructed in order to define the Cottage Grove interval, gain an understanding of the relationships between the different facies present, and attempt to reconstruct the paleogeomorphic setting for the area. The choice of the datum for the interval cross sections was critical to recreate the paleogeomorphic situations that existed during deposition. A consistent marker bed lying beneath or above the Cottage Grove could have been structurally readjusted by differential compaction during basin subsidence. Thus, a reconstruction of the section by adjusting the deformed limestone markers to horizontal could result in an erroneous paleogeomorphic reconstruction. Since the Cottage Grove Sandstone was deposited on a flat, relatively stable continental shelf it can be safe to assume the top of the sand was more near horizontal after deposition than a limestone marker deposited earlier or later. Therefore, the top of the upper sand was chosen for a datum, because sections appear to closely resemble a paleogeomorphic situation that existed immediately after Cottage Grove deposition.

The cross sections reveal three distinctive correlative log signatures within the Cottage Grove interval. Each of these log signatures characterizes a certain facies. Figure 8 illustrates the log signatures for the facies present. A lower sand facies represented by blocky, fining upwards log signature is found in the south to southwestern part of the study area. It is absent throughout the rest of the North Concho Field. Above this lower facies, a "ratty" log signature commonly representing an alternating sand and shale sequence covers the entire area. An overall upward coarsening log signature characterizes this sand/shale sequence. The boundary between the lower and middle facies is most commonly gradational but in some places is abrupt. The third distinctive log signature defines the top of the Cottage Grove interval

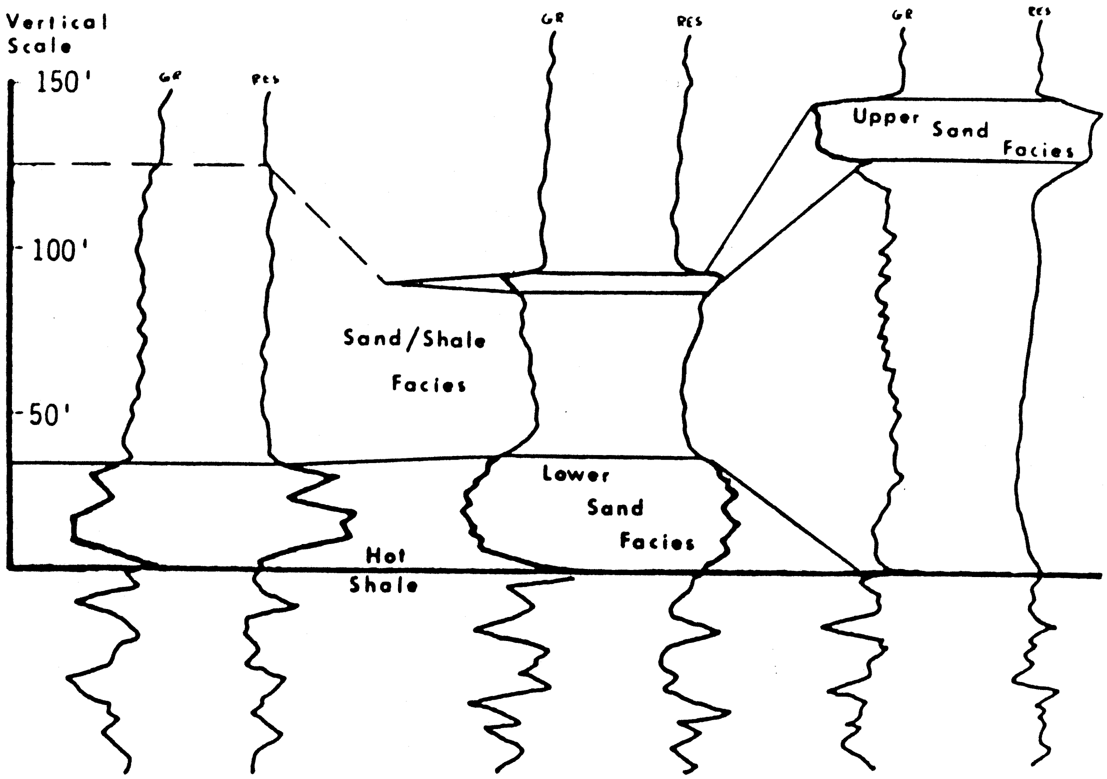



Figure 8. Local Correlation Section of the Cottage Interval of North Concho Field

and this unit is responsible for the North Concho oil production. The boundary between the sand/shale facies and the upper sand facies is either gradational or abrupt. All three facies seem to be related in such a way that they all rarely exist in one well where each facies is fully developed.

Cottage Grove interval thickness in the North Concho Field range from 70 feet in the extreme northern end to approximately 200 feet in the south. The upper producing facies ranges from approximately 40 feet in the southern part of the field to 0 feet in the north. The sand averages a thickness of 17 feet in the productive trend. This up-dip sand pinch out appears to be the trapping mechanism in the North Concho Field. The lower facies varies in thickness where it is present. The middle facies, which is always present, thins consistently to the north with the rest of the interval.

## Avant to Hogshooter Interval

The reference datum for the north-south genetic interval cross section is the Avant Limestone, a significant marker of regional extent (Rascoe and Adler, 1983). Two formations are present in the interval between the Avant and Hogshooter limestones within the study area. The formations in descending order from the Avant limestone are the Hedlund zone and the Cottage Grove Formation. Above the Avant Limestone is the Lower Medrano and a locally correlatable limestone marker. There is some discrepancy as to the names of two intervals above the Cottage Grove Formation. Jordan (1957) states that the Hedlund zone is above the Medrano zone. Oil and gas records in the study area pertaining to the stratigraphic positions of various formations do not coincide with

Jordan (1957). The Cottage Grove Formation is thought to be the only formation existing between the Avant and Hogshooter Limestones in the area (Jordan, 1957). For the purpose of this study the stratigraphic names and their positions will correspond with the oil and gas records, which are geologists' most valuable source of information.

The north-south trending cross section (Plate 6) clearly illustrates a thinning of the Cottage Grove interval to the north without any apparent signs of erosional truncation. This suggests that within the study area the Cottage Grove sediment source was from the south. Local paleodip direction during Cottage Grove deposition appears to have been to the north. Evidence supporting this conclusion is the fact that there is an absence of sand in the extreme north end of the study area, and the net sandstone and total interval thickness increase to the south-southeast. The Hedlund zone thins from approximately 90 feet in the southern part of the area to 50 feet in the north. Above the Avant Limestone, there is an overall thinning of the Lower Medrano from 140 feet in the north to 90 feet in the south. This relationship indicates a paleodip direction reversal between Cottage Grove deposition and Lower Medrano depostion. This could be the result of either variable local subsidence or multiple source directions through time.

# CHAPTER IV

## SANDSTONE BODY GEOMETRY

External geometric sandstone features such as length, trend, and thickness were determined from the cross sections, net sandstone isolith maps, and a log signature map. Using cross sections the two sand bodies in the North Concho area were easily identified, allowing their individual geometries to be easily recognizable. A log signature map (Plate 7) was constructed to illustrate the geometry of the sandstones. Each log on the map was placed on the hot shale datum to show total interval thickness. The log signature map was a useful tool in delineating the relationships of the different Cottage Grove interval facies.

Before an isolith map could be constructed, there had to be a cutoff line determining what was to be called sand. This cutoff was determined by log-core correlations. For the purpose of this study, the gamma ray curve defined sand when a deflection of 45 API units (three divisions) left of the shale base line occurred. When a gamma ray log was not available the sand was determined by an SP deflection distinctive from the adjacent shales. Four isolith maps were constructed on various subjects of interest to gain a better understanding of the Cottage Grove interval (Plates 8-11). The most useful isolith maps to help determine geometry were the individual upper and lower sand isolith maps (Plate 8 and 9).

## Lower Cottage Grove Sandstone Geometry

The Lower Cottage Grove Sandstone displays a dominant south-southeast to northwest trend (Plate 8). The length of the trend is unknown because this sand body enters and exits the study area. The width of this sand body ranges from one mile to approximately four miles. The sandstone bifurcates near the western border of the study area. Thickness of the Lower Cottage Grove Sandstone ranges from 0 to approximately 65 feet. Log signatures defined the thicker sands to be stacked (multistoried) sand bodies. The sand body is elongate and lenticular and exhibits sharp lateral and basal contacts. The locally correlatible hot shale marker is absent in some areas, most likely due to erosion during the deposition of the lower sand body. The upper contact with the sand/shale facies is generally gradational.

The fact that the sand thickens at the expense of the underlying hot shale, as well as the length, width, and trend of the unit all combine to demonstrate classical criteria for delineating a channel deposit.

## Upper Cottage Grove Sandstone Geometry

The north-south trending Upper Cottage Grove Sandstone ranges in thickness from approximately 0 to 40 feet (Plate 9). The width of the sand body ranges from 3 miles in the south to approximately 10 miles to the north. The sand pinches out in the north but continues out of the study area to the south. Thickening to the south increases as sand body width decreases. Basal contacts with the underlying sand/shale facies are abrupt to gradational. The contact with the overlying black shale is abrupt throughout the study area. Sharp basal contacts are generally found in the thicker parts of the sand body. The lateral boundaries grade from abrupt in the south to transitional in the north. The log signature map and the correlation sections clearly exhibit the total interval thinning to the north. All geometrical information indicates that the Upper Cottage Grove Sandstone has the characteristics of a deltaic crevasse splay deposit.

## Depositional Controls

The Cottage Grove interval cross sections and the log signature map illustrate that the presence of the lower sand had a major control on the deposition of the upper sand. The presence of this lower sand seems to have governed the thickness and distribution of the sand/shale facies and the upper sand. Less of the sand/shale facies is present above the lower sand in the southwestern part of the study area. Areas unaffected by lower sand depostion recieved larger amounts of the sand/shale facies. The deposition of the upper sand body seems to have been controlled by the existence and the relationship of the other two facies.

Burst (1969) stated that shortly after settling, clay sediments contain approximately 70-80 percent water by volume. He also states that initial compaction reduces the water content to approximately 30 percent. It is safe to assume that initial compaction was greater in the sand/shale facies because of the higher percentage of clay. Figure 9 is a generalized sketch to demonstrate the effects of early compaction after the sand/shale facies deposition. Early compaction over the entire area resulted in a minor topographic high existing where the lower sand was present. This possibly acted as some sort of levee

Effects of Initial Compaction

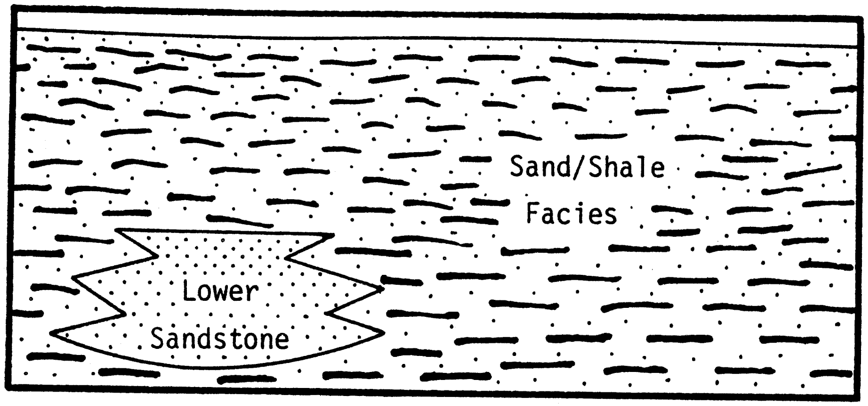



Figure 9a. Relative Cottage Grove Thickness Before Upper Sand Deposition and Initial Compaction

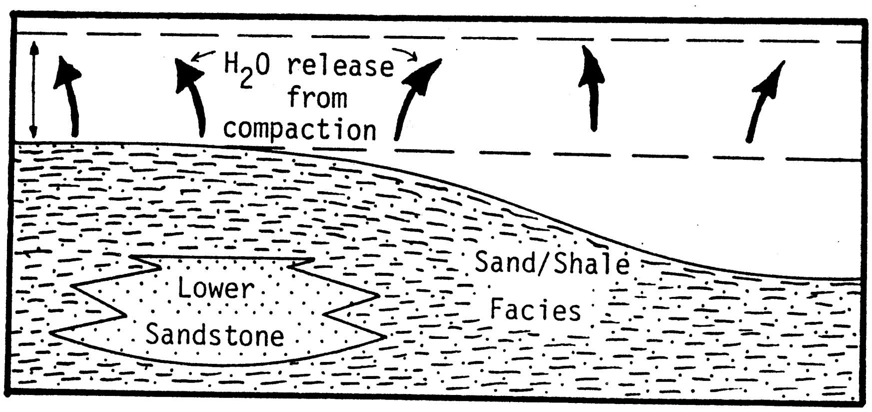



Figure 9b. Effects of Initial Compaction on Thickness Over the Lower Sandstone (After Burst, 1969)

controlling later sediment distribution. Evidence for this is found where the upper sand thins over the thickening lower sand (Figure 10). Comparison of the upper and lower sand isolith maps illustrates the influence the lower sand body had on the distribution of the upper sand. The western boundary of the upper sand parallels and thins out over the eastern boundary of the lower sand body. Figure 11 is a diagram outlining the two sand body boundaries and approximates the position of the levee which governed upper sand distribution. When the upper sand thins and the lower sand is not present, the interval from the top of the upper sand to the hot shale is considerably thinner. This area could represent an area of high paleotopography which resulted in the thinning of sediments over it. Thus, the thinning of the upper sand appears to be the result of the presence of the lower sand, a paleotopographic high, and distal deltaic deposition.

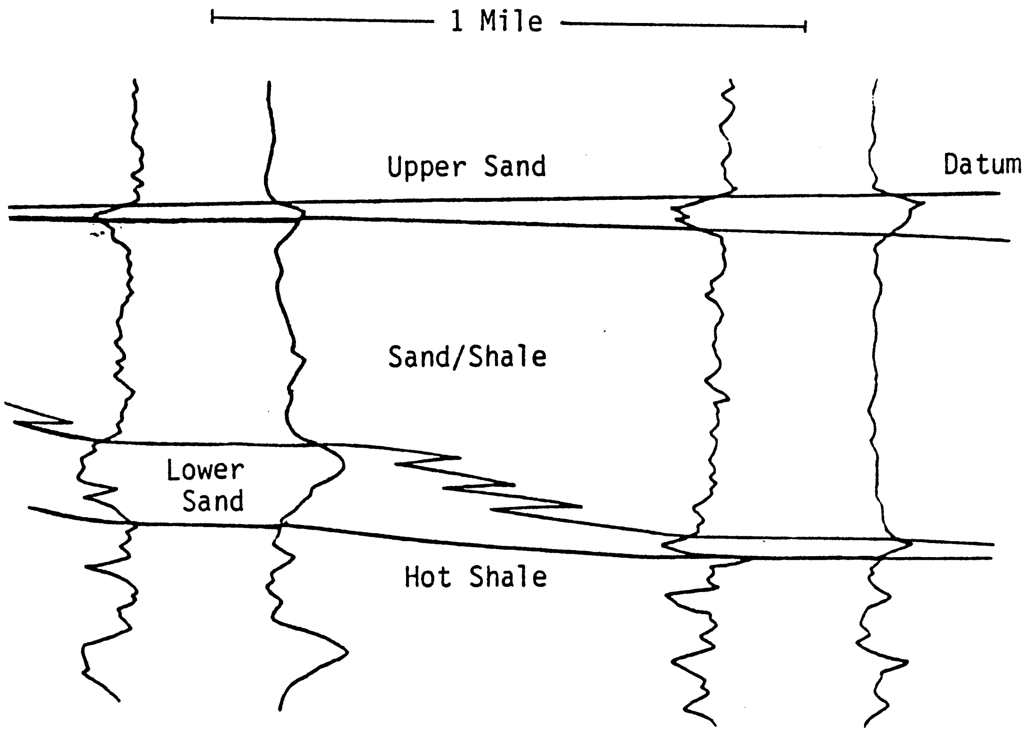



Figure 10. Cross Section Illustrating Upper Sand Thinning Over the Lower Sand

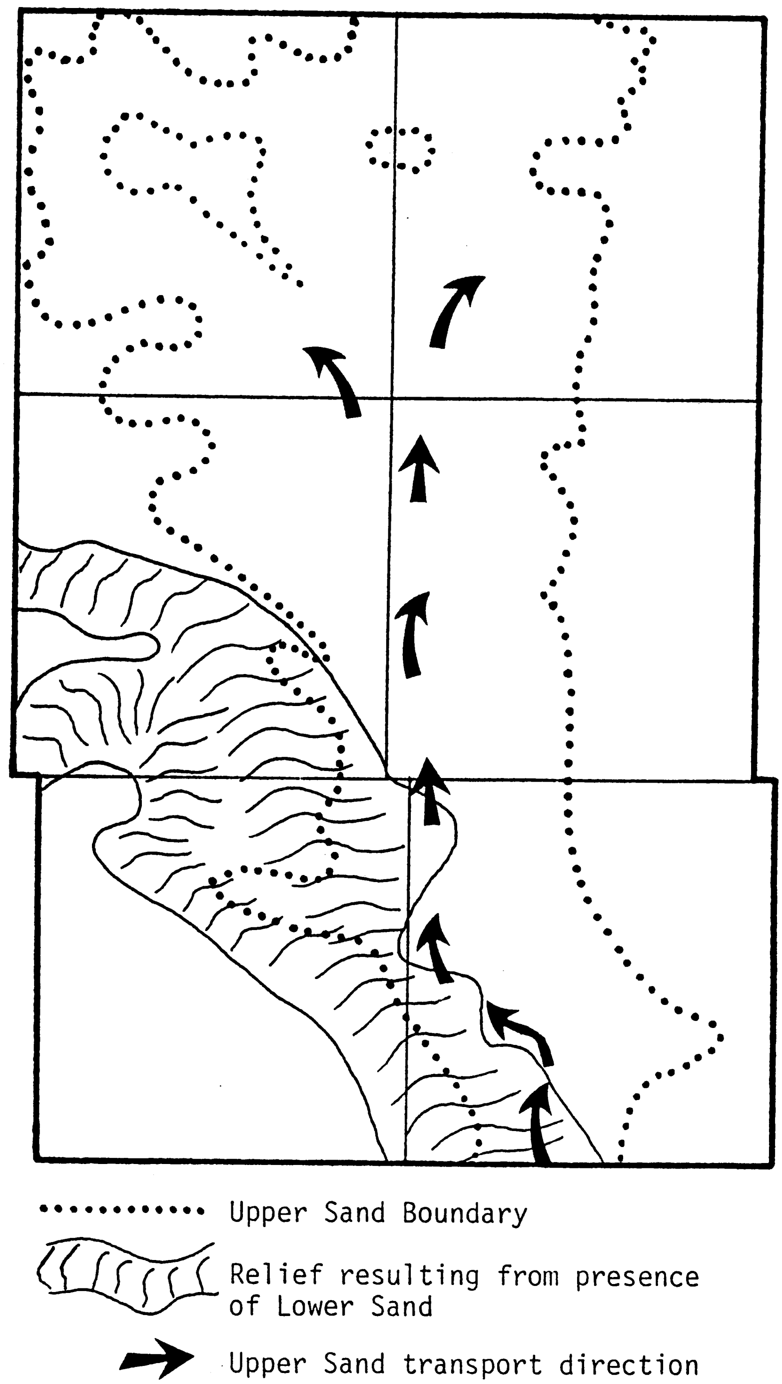



Figure 11. Effects on Upper Sand Distribution resulting from the presence of the Lower Sand

# CHAPTER V

# INTERNAL ORGANIZATION AND DEPOSITIONAL ENVIRONMENT

## Sedimentary Structures

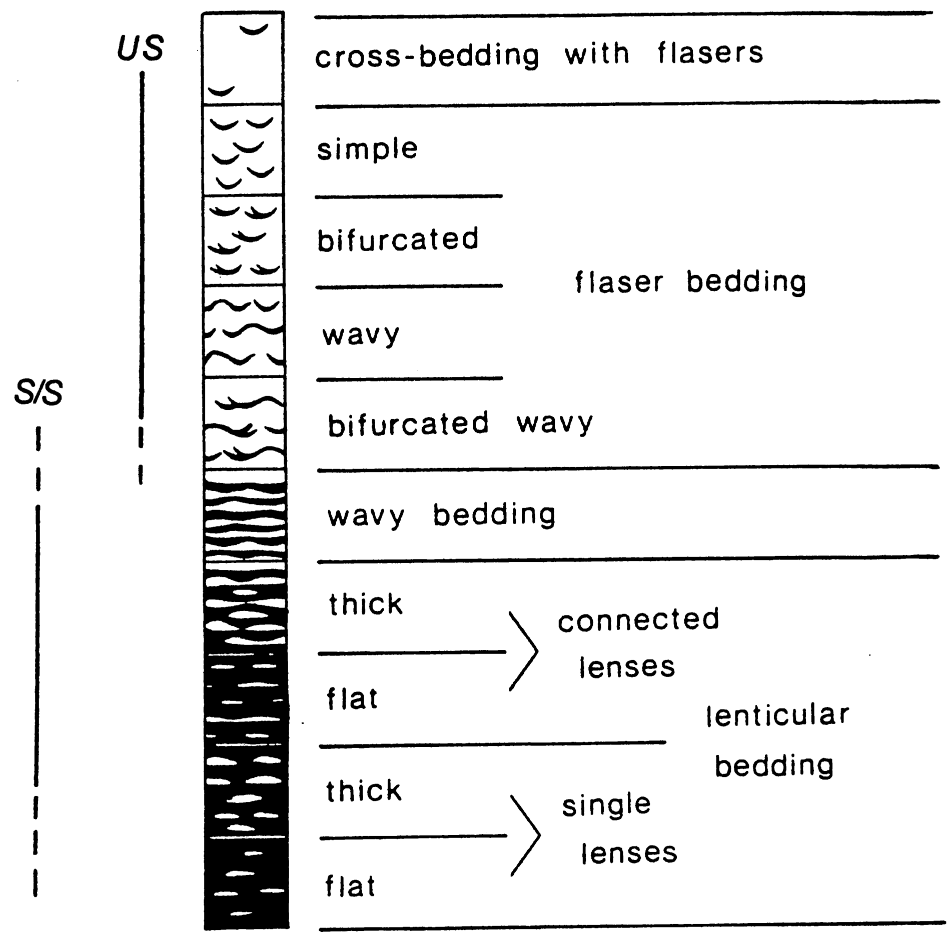
Sediment in transport is accompanied by the organization of grains into various morphological features. Recognition of these features and an understanding of the mechanics of their formation can give clues as to the dynamics of the grain-fluid system in which they were developed. Most sedimentary structures are formed by physical processes operating at or shortly after sediment accumulation. Sedimentary structures aid the geologist in interpreting the environmental conditions that persisted during the accumulation of the sediments. A detailed analysis of eight cores in the North Concho Field revealed the sedimentary structures present in the Cottage Grove Sandstone and their vertical sequences. It is logical to suggest that facies occurring in a conformable vertical sequence were formed in laterally adjacent environments and that facies in vertical contact must be the product of geographically neighboring environments (Reading, 1978). Descriptions of the cores are furnished in the Appendix.

## Lower Channel Sandstone

Only one core in the North Concho Field penetrated the lower channel sandstone (McCann No. 1). The interpretation of the lower sandstone as a channel deposit is based entirely from the core, geometry, and log signature characteristics. Reasons for the low amounts of core is the dominant interest in the upper sandstone as an oil productive zone and the fact that the lower sandstone is rarely present below the productive upper sand.

## Sand and Shale Facies

All cores penetrated the interstratified sand and shale sequence that is present above the lower sandstone. Cores of this sequence show an upward increase of sand content and grain size as a transitional interval to the overlying sand body. Silt-sized particles were seen at the base of this unit and graded upward into very fine-grained sand. Very few cores penetrated this unit deep enough to enable a detailed study of the lower section. Contact with the upper sandstone is generally transitional, but some abrupt contacts resulting from channel-like basal erosion were seen. The contact with the lower sandstone grades from a fining upward sequence up into the coarsening upward sand and shale. Flaser bedding, parallel interstratification, lenticular bedding, and cross-bedding with flasers are present in this zone. Minor amounts of herringbone cross-stratification were found near the top of this sequence. Figure 12 illustrates a relationship of sand and shale as seen with small-scale physical sedimentary structures. Structures found in the sand/shale sequence are shown on the diagram. Flowage-type




US = Upper Sand Facies
S/S = Sand/Shale Facies

Figure 12. Continuum of Flaser, Wavy, and Lenticular Bedding. Figure Illustrates the Relationship of Sand (white) and Mud (black) Found as Small-Scale Physical Sedimentary Structures in Tidal Flat deposits (After Reineck and Wunderlich, 1968)

structures and micro-faulting are also common. Bioturbation also occurs in this sequence and is associated with the shale laminae. These organic-rich muds were a food source for worms and other burrowing organisms which reworked the mud. The abundance and preservation of the burrows indicate that a low-energy environment existed during deposition. Burrow abundance decreases towards the contact with the overlying sandstone as the sand content increases. This suggests that the influx of sediment initiated a decrease in their food supply and drove the burrowing organisms away as the energy of the depositional system increased. Skeletal debris is found in minor amounts throughout the sequence.

Based upon the information obtained from the cores, this sand/shale sequence is interpreted as a marine reworked, littoral facies. The vertical sequence suggests a regressive transition from a shelf siltstone to a tidal flat facies (Reineck, 1972; Weimer, 1976; and Klein, 1977). Photographs of core from this facies can be seen in Figure 13.

## Upper Splay Sandstone

Seven cores studied contained the upper sand. The common vertical sequence of sedimentary structures from the basal contact with the underlying sand/shale sequence is as follows: rip-up clasts, small-scale cross-stratification, herringbone cross-stratification, inter-stratification, small-scale cross-stratification, and bioturbation. Penecontemporaneous deformation occurs with all of these structures and is most common in the thicker accumulations of sand. A photograph of soft sediment flowage is shown in Figure 14. This flowage often masks the original sedimentary structures, making them difficult to dis-

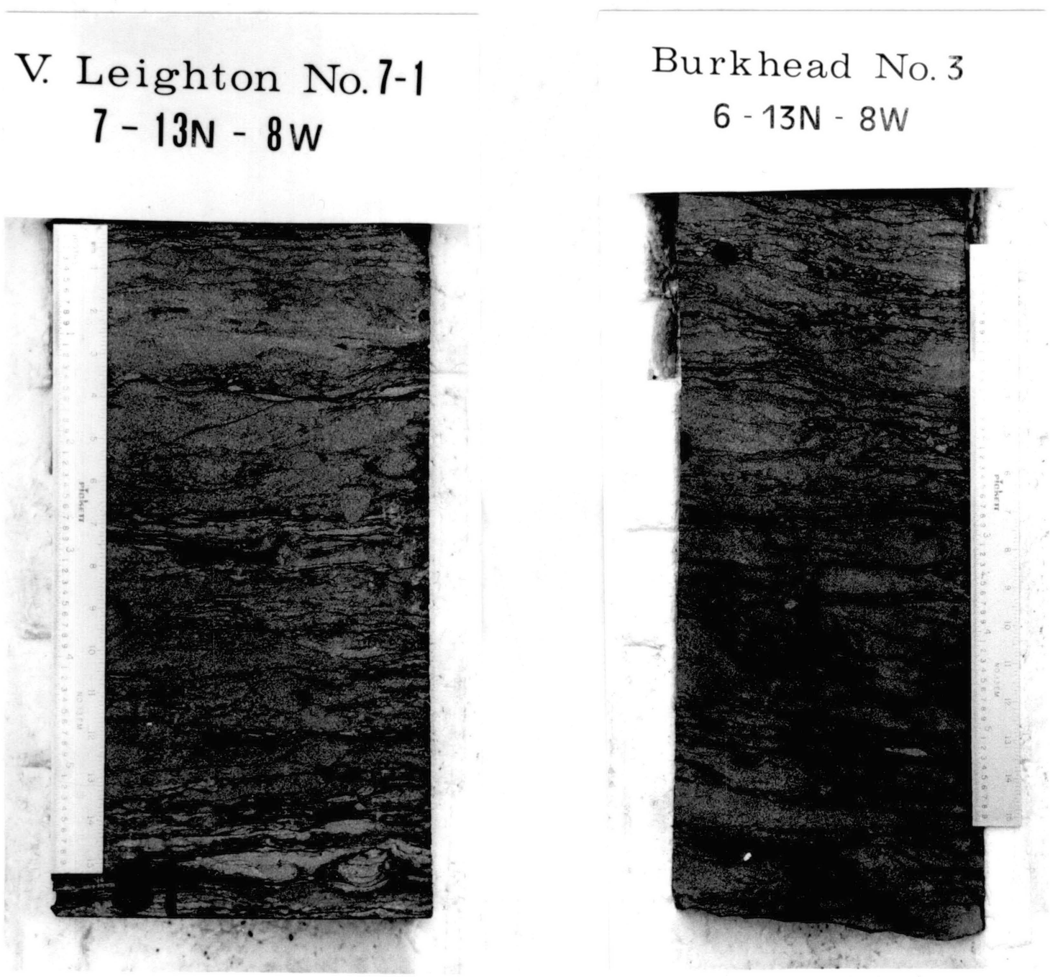



Figure 13. Interbedded Sand and Mud Characteristic of the Tidal Flat Facies

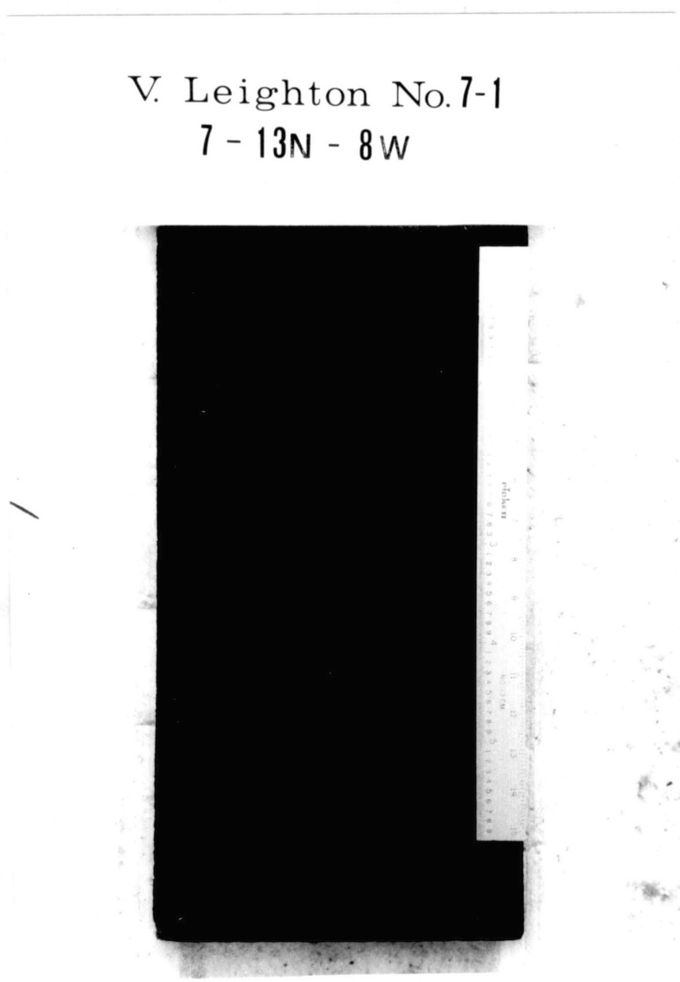



Figure 14. Flowage Features Found in the Upper Sand (Verna Leighton No. 7-1)

tinguish. Types of small-scale cross-stratification include complex ripple bedding, climbing ripples, and ripple bedding with shale flasers. Figure 15 is a photograph of flaser bedding in which mud lenses were deposited in ripple troughs. Rip-up clasts are only found in the thicker sands having abrupt contacts with underlying rock. Core from the south end of the study area (Elmenhorst 29-2 and McCann No. 1) contain more herringbone cross-stratification and interstratification within the sand than the cores toward the north. Core from the Elmenhorst 29-2 well indicate the sand to be a series of stacked tidal channels separated by interstratified rock. Rip-up clasts are common at the bases of these channels. Not all of the sedimentary structures are always present and the order of them may vary slightly depending upon the location of the core within the upper sand.

Approximately the top two feet of the sandstone contain an abundant amount of burrows and fossil debris, both of which increase in abundance toward the abrupt contact with the overlying black shale. The top few inches generally contain at least 12 percent broken fossil debris (Figure 16). This sequence of rock at the top of the sand suggests significant marine reworking of the sand after the cut off of the sediment supply. Photographs of common types of burrows in the North Concho Field are shown in Figures 17 and 18.

The vertical sequence of sedimentary structures and the geometry of the upper sandstone indicate that it is a marine reworked sandstone splay (Heckel, 1972; Shelton, 1973; and Shelton and Rowland, 1974). Sedimentary structures that are common within a sand splay consistently occurred in their anticipated position with respect to core location within the upper sand. The channel of this splay is characterized by

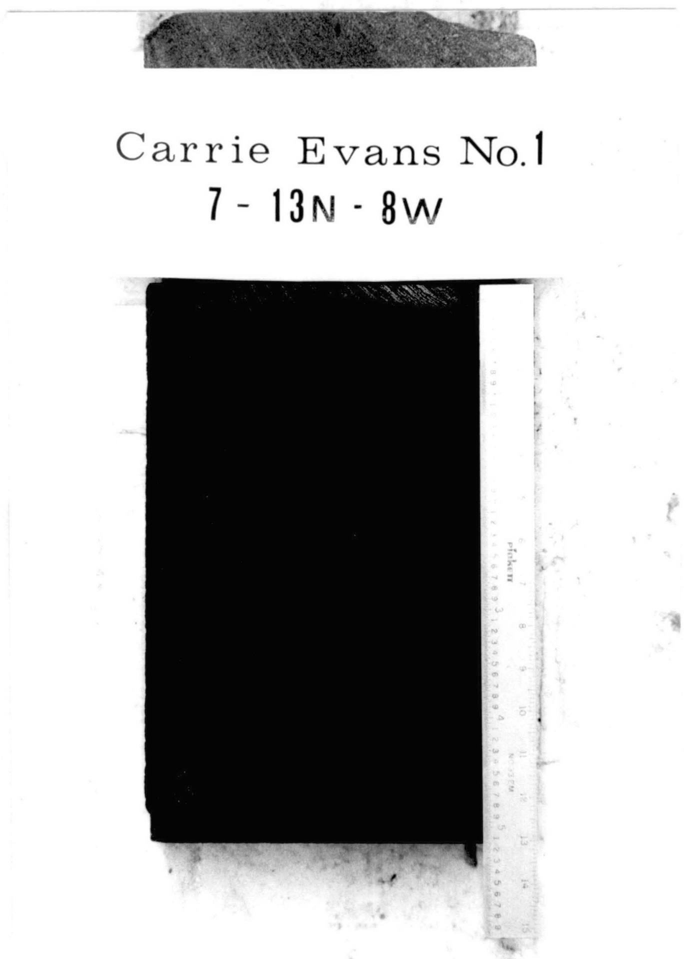



Figure 15. Flaser Bedding in which Mud Lenses were Deposited in Ripple Troughs (Carrie Evans No. 1)

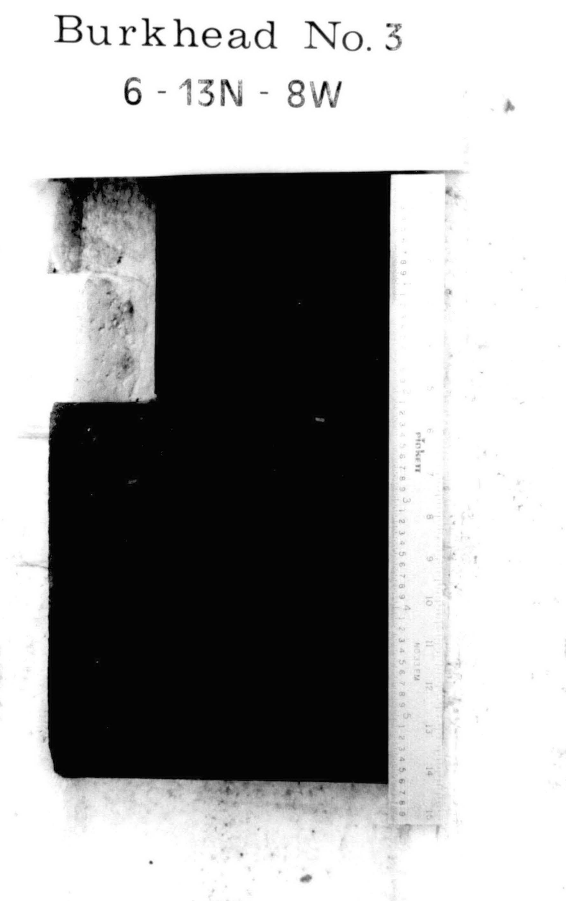



Figure 16. Abandonment Facies Containing Abundant Skeletal Debris and Burrows (Burkhead No. 3)

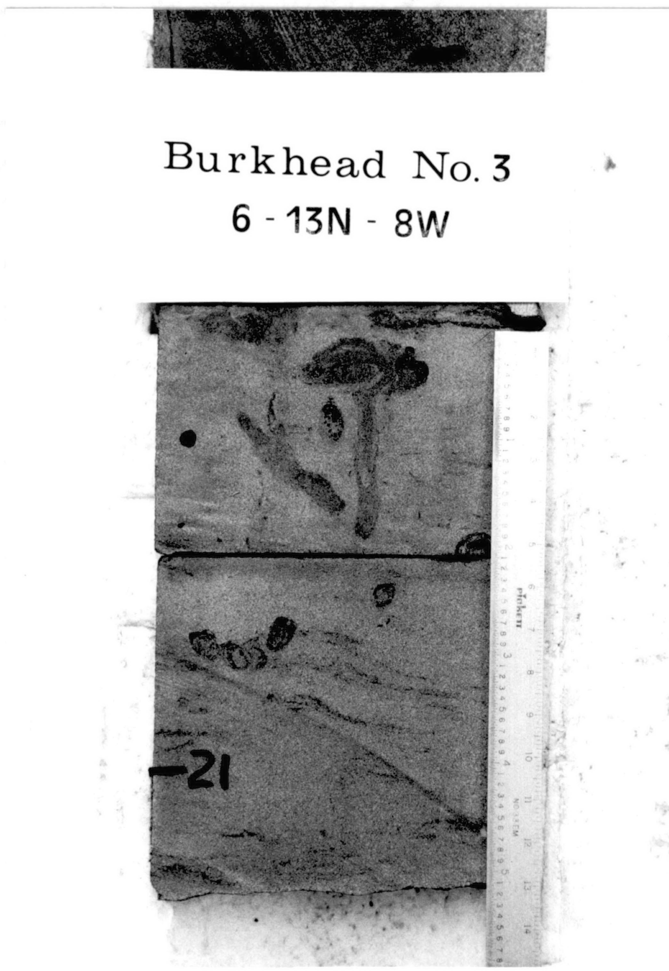



Figure 17. Burrows Common in Core from the Center of the Field (Burkhead No. 3)

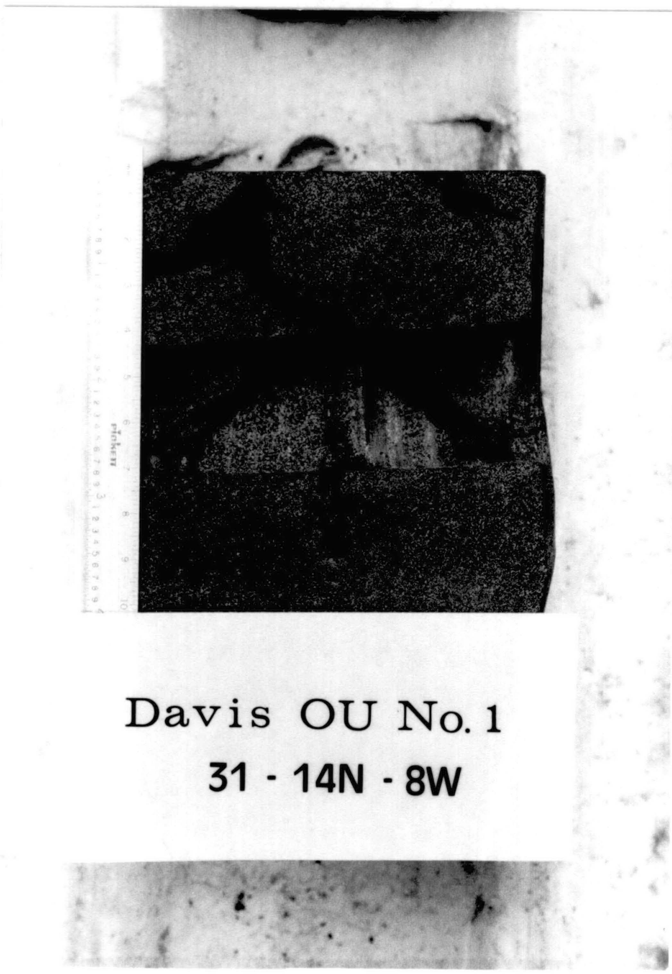



Figure 18. Burrows Characteristic of Core from the Northern End of the Field (Davis OU No. 1)

the thicker sand accumulations that show an abrupt contact with the underlying sand/shale sequence. Gamma ray log signatures defined this channel-like basal erosion and helped to recognize channels in wells that were not cored. Reworking is evident by the upper two feet being extensively burrowed and the high percentage of fossil debris.

## Depositional Environment

All available data have been combined in order to develop a depositional model for the Cottage Grove Sandstone in the North Concho Field. Lower Sandstone information was scarce, therefore, a depositional environment analysis for it was not attempted. The fact that it is channel-like and its existence controlled upper sandstone deposition (Chapter IV) is all that was concluded.

The Cottage Grove Sandstone was deposited during a regressive phase of the cyclic deposition characteristic of the epicontinental seas which existed in the Mid-Continent region during Pennsylvanian (Brown, 1979). Mack and Suttner (1977) estimated a latitude of approximately 10 degrees south for the study area during the Missourian Epoch. This would place the study area in a tropical climate during Cottage Grove deposition.

During the earliest stages of regression, deltaic complexes were prograding westward into the Anadarko basin from the Ouachita uplift. The lower sandstone was deposited within the study area sometime during early regression across the top of the transgressive Hogshooter Limestone. After lower sandstone deposition, local detrital influx decreased and very fine grained sands, silts, and muds were deposited in distal delta-front environments and interlobe areas under low-energy conditions. The presence of a few scattered marine fossils and bioturbation in the sand/shale unit indicate that deposition was slow enough to allow the organisms to live under these depositional conditions.

Subsidence, possibly combined with eustatic regression, enabled distal-deltaic environments to prograde into the study area from the south-southeast. Progradation of the delta into the area allowed distributary channels to cut into the previously deposited sands and muds. Cores from the north end of the study area did not contain sedimentary structures indicative of basal erosion. However, evidence of basal erosion increases towards the south. Soft sediment deformation was more common in the cores to the north. The northern end of the field showed no evidence of having been exposed subaerially. This information, and the fact that herringbone cross-stratification is found in the southern part of the study area and not in the north, suggest the existence of a paleoshoreline in the area during upper sand deposition.

All available data indicate that the Upper Cottage Grove Sandstone was deposited in a shallow marine environment with water depths increasing locally to the north. The occurence of marine organisms, abundance of burrows, herringbone cross-stratification, and eogenetic carbonate, support a marine environment of deposition. Evidence also indicates a minor transgression immediately followed Upper Cottage Grove deposition.

Marine deltas were classified by Fisher (1969) on the basis of the relative effects of marine processes such as waves, currents and long-shore drift versus the progradational and aggradational processes of rivers. High-constructive deltas are made up largely of fluvially-influenced facies. The terms "elongate" and "lobate" refer to the geomorphic configuration of the delta front as reflected by the net sandstone isolith (Cleaves, 1982). A bayhead delta model was considered for the upper sandstone splay but the overall thickness of the North Concho deposit is too great for this type of depositional model (Cleaves, 1982). Therefore, the deltaic splay deposit of the North Concho Field was determined to be derived from a High-constructive, elongate delta (Fisher, 1969). The basis for classifying this deltaic deposit was the dominant fluvial control on deposition and the thick prodelta mudstones (sand/shale facies).

The Elmenhorst 29-2 core contained herringbone cross-stratification within the channel sand immediately above some small-scale cross-stratification. This suggests a unimodal transport system existed before the effects of bimodal transport in the southern part of the study area. The transition of unimodal transport to a bimodal transport marks the onset of transgression in the area. Herringbone cross-stratification was also seen in the upper sand in the McCann No. 1 well. The southward developing channel of the upper sandstone probably acted as a tidal inlet as the transgressing ocean encroached upon the area. The ebb and flow of the tide along with the drainage from the channel helped to distribute the sediments into the shallow marine environment. Abandonment resulted from overextension of the splay, loss of gradient advantage, and avulsion to form a new channel elsewhere. Compaction of the underlying sediments caused subsidence and encouraged wave reworking of the abandoned deltaic splay. This process led to the production of the characteristic abandonment facies at the top of the sand. Figure 19 is a conceptual model of the depositional environment which existed in Oklahoma during Cottage Grove deposition.

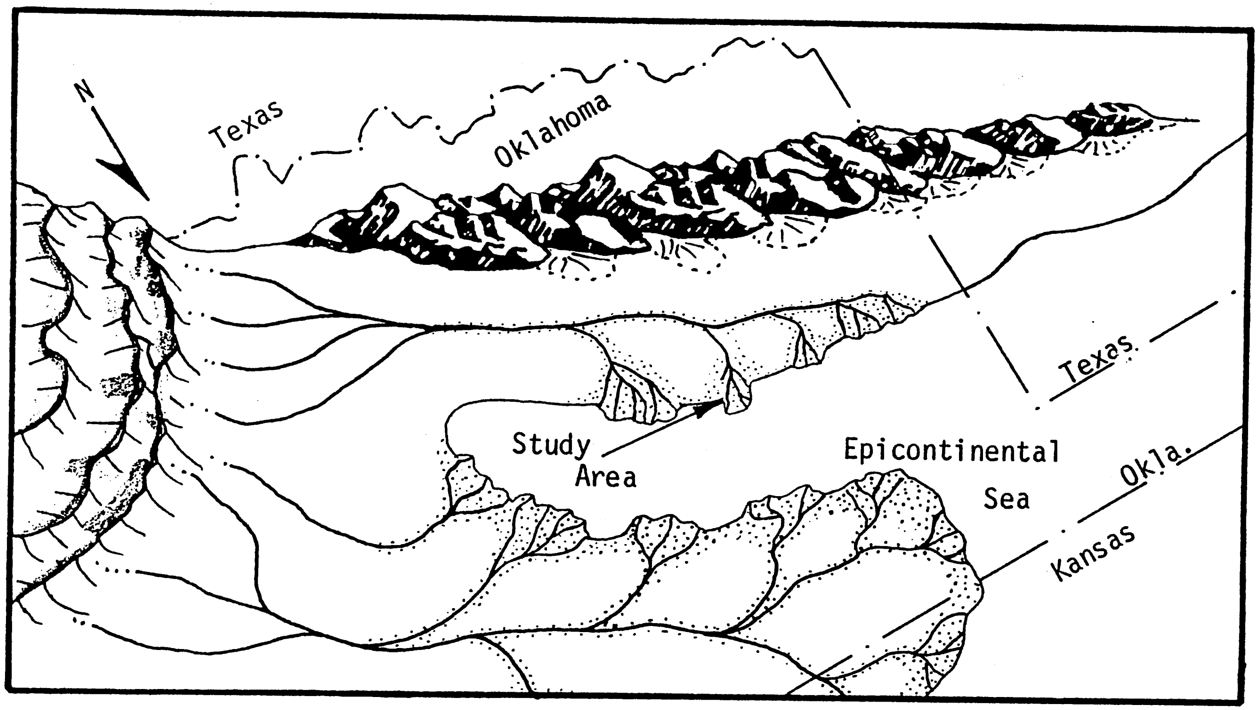



Figure 19. Conceptual Model of the Depositional Environment in Oklahoma During Cottage Grove Deposition

# CHAPTER VI

# PETROLOGY

## Introduction

The petrology of the Cottage Grove Sandstone was determined by thin section analysis from eight cores. The classification of rock types was made on the basis of the major detrital components characterizing the Cottage Grove Sandstone. A ternary diagram (Folk, 1968), with quartz, feldspars, and rock fragments being the apexes, was constructed to provide a sandstone classification for the facies present. The diagram is constructed based on the quantitative mineralogical analysis from the thin sections. Percentages of each of the three detrital components were normalized with respect to each other and then plotted on the ternary diagram. Important differences in the percentage of each of the three detrital components characterize the distinct Cottage Grove facies.

## Methods of Investigation

Mineralogical identification and porosity evolution were determined by the use of petrographic and scanning electron microscopy and x-ray diffraction analysis on selected samples. Thin sections from each core were taken at one foot intervals and at other points of interest. Clay sized minerals were identified by the x-ray analysis of extracted clays derived from each thin section sample. All thin sections were prepared from rocks impregnated with blue epoxy that preserved authigenic clays during preparation and highlighted the porosity. Samples for x-ray analysis were prepared by mix-ball crushing, followed by calcium carbonate, organic material, and iron oxide removal to release the clays for proper analysis (Kittrick and Hope, 1963). The amount of detrital muscovite, biotite, and chlorite that was ground to clay size by the mix-ball mill process is unknown. Diffraction patterns were analyzed for mineral identification. Relative abundance of the clay fraction was determined by a computer which calculated areas under the individual clay peaks. The following equations were used to determine the approximate percentage of each clay type:

1. Two clay minerals present (i.e. illite and kaolinite)

$$I_I(0.29) + I_K(0.16) = I_{total}$$

2. Three clay minerals present:

$$I_I(0.29) + I_K(0.16) + I_C(0.55) = I_{total}$$

3. Example of illite percentage:

$$\frac{I_I(0.29)}{I_{total}} \text{ X } 100 = \text{Illite percentage}$$

where

$I_I$ = area under illite curve

$I_K$ = area under kaolinite curve

$I_C$ = area under chlorite curve

(0.29), (0.16), (0.55), = absorbtion coefficients for correction factors of illite, kaolinite, and chlorite respectively (personal communication, Al-Shaieb, 1984). An example of a representative clay peak analysis can be seen in Figure 20.

## Detrital Constituents

### Quartz

The average quartz content of the Cottage Grove Sandstone ranges from 45% - 78%, making it by far the most abundant mineral constituent. Five types of quartz were distinguished on the basis of internal morphology. The types are: (1) normal, (2) mosaic, (3) composite, (4) strained, and (5) chert. Although these are all types of quartz, the classification of the rocks was done by origin of the constituents. Further subdivision on the basis of inclusions for provenance significance seemed insignificant and was not pursued, because similar types of inclusions occur in quartz from intrusive, volcanic, and metamorphic rocks.

Normal Quartz - This variety makes up an average of 43 - 67% of the total quartz grains. It consists of single, non-undulatory extinction unicrystalline quartz grains.

Mosaic Quartz - Mosaic quartz consists of polycrystalline grains with straight to undulatory extinction that can grade from one component grain into the adjacent grain or remain in its own grain boundary. Each grain is composed of a large number of individual grains with gradational to sharp boundaries and varying extinction positions. Mosaic quartz resembles chert but was differentiated from it by its exceedingly

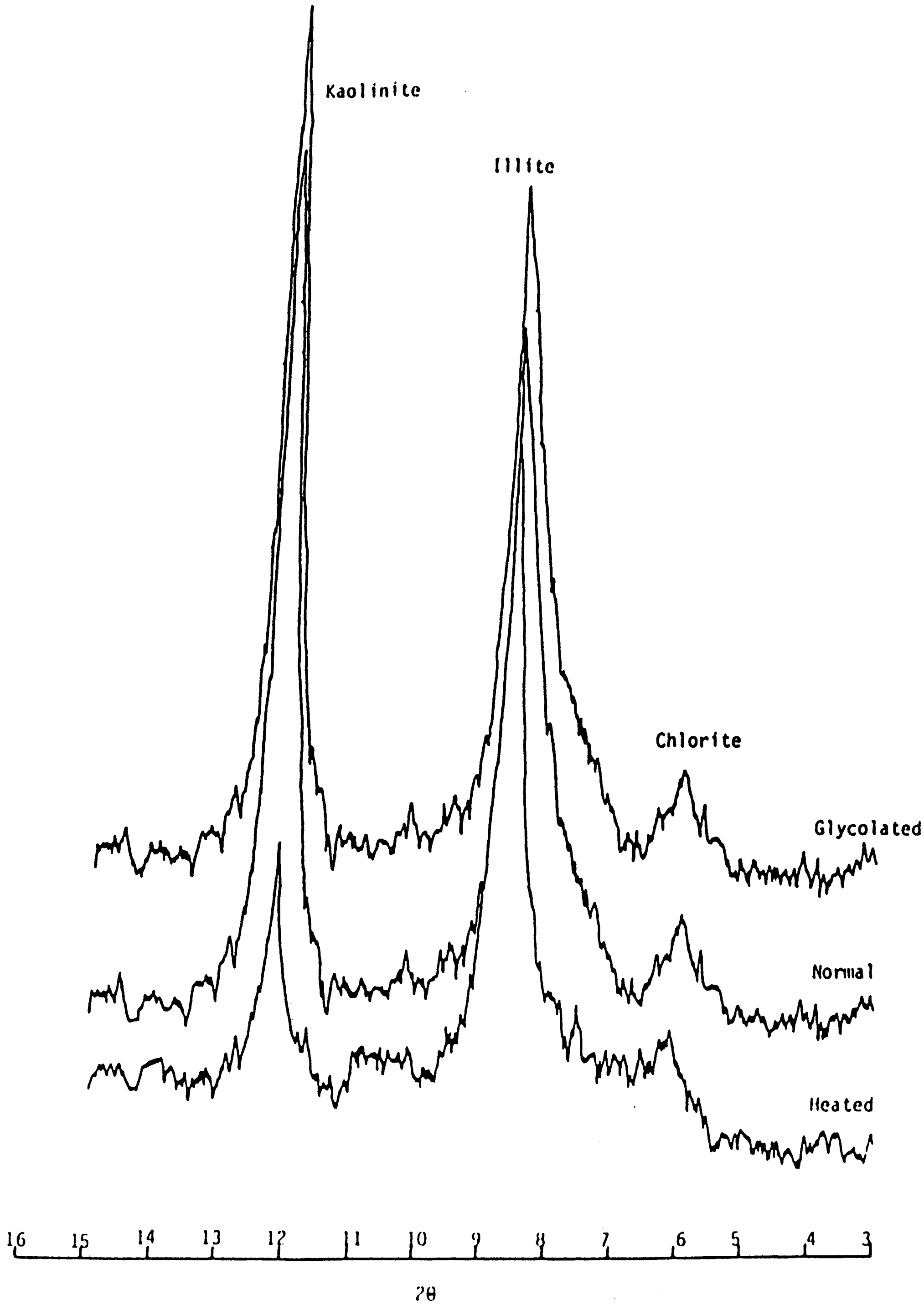



Figure 20. Representative Sample of Clays Present in the Cottage Grove Sandstone

coarse-grained texture. The mosaic quartz is rare and only averages approximately 0.25% of the total silica content.

Strained Quartz - This quartz species is a single quartz crystal with slight to strong undulose extinction (Scholle, 1979). The undulosity of a quartz crystal is a function of the orientation of the grain under the microscope. A universal 3-D microscope stage would be needed to correctly estimate the percentage of strained quartz. Approximately 0.25% strained quartz was detected in the Cottage Grove Sandstone, indicating a lack of strained quartz from the source area or, there has been sufficient time since removed from the source for the disintegration of this unstable variety of quartz.

Chert - Chert is composed of microcrystalline and cryptocrystalline silica crystals giving a very fine grained mosaic and pin-point extinction. There is a total of 0.65% chert present.

## Feldspars

The feldspars in the Cottage Grove Sandstone vary from fresh to completely altered. Many feldspar grains are partially to almost completely replaced by calcite. The common alteration products are sericite and occasionally kaolinite (Figure 21). About 2-3% plagioclase feldspar was found and when unaltered generally exhibited well developed albite twinning. The remaining feldspar (approx. 1%) is untwinned and could be potassium feldspar and minor plagioclase. Microcline often coexists in sandstone with partially dissolved feldspars and it is usually clear and lacks any sign of dissolution. Presumably, this is explainable through the relative temperature of formation stability series of the potash feldspar group. Microcline forms at lower tem-

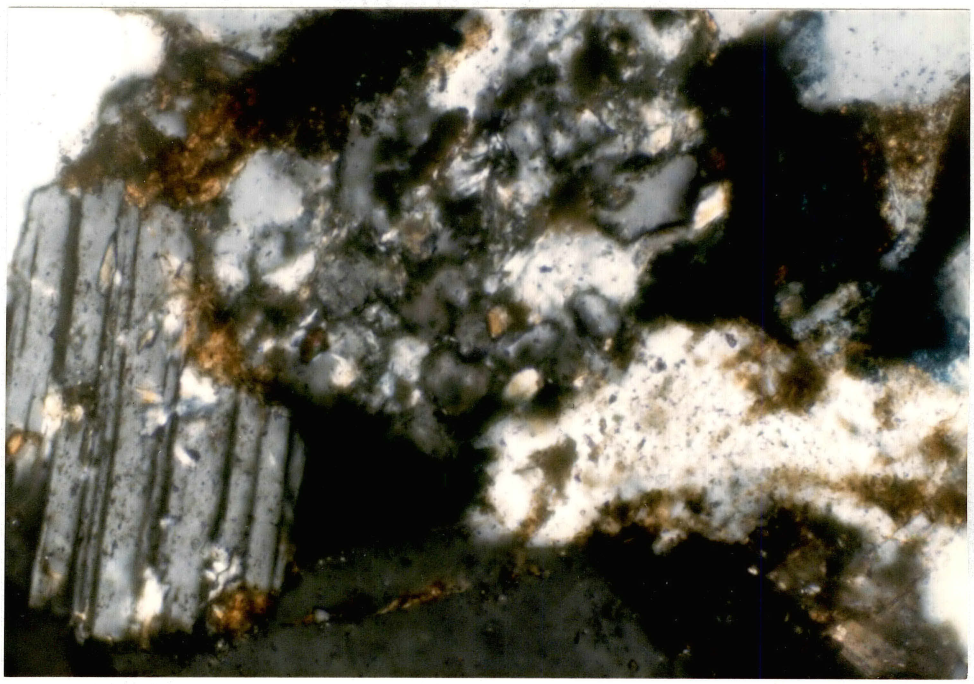


Figure 21. ~~Plane~~ C.N Light View of Feldspar Altering to Sericite (Note Illitic Dust Rim and Authigenic Illite) 400X

peratures and possesses a more ordered structure than both orthoclase and plagioclase, both of which form at higher temperatures and have disordered structures (Pittman, 1979). Therefore, the absence or very minor traces of the more stable microcline could suggest the absence of the low temperature mineral from the source.

### Rock Fragments

Total rock fragments in the Cottage Grove Sandstone averaged approximately 7%. Identifiable rock fragments consisted of metamorphic rock fragments, sedimentary rock fragments, igneous rock fragments, and a very minor amount of unidentifiable rock fragments. Rock fragments frequently exhibited partial authigenic recrystallization.

The most common types of sedimentary rock fragments are shale chips and argillaceous siltstone fragments. Ductile deformation of small shale clasts resulted in detrital matrix. Some shale clasts were derived from erosion of the underlying sand/shale sequence.

Metamorphic rock fragments consisted of mica schists, quartz mica schists, phyllites, and slates. Metamorphic fragments in the Cottage Grove Sandstone appear to be low grade and were probably derived from the metamorphism of argillaceous rocks.

Igneous rock fragments are composed of granophyres and interlocking crystals of quartz and feldspars. These occur in very minor traces and are insignificant.

Skeletal Fragments

A variety of fossil types occur in the Cottage Grove Sandstone. They are most common in the top of the upper sand facies and less common in the lower sand/shale sequence. Crinoid stems, other echinoderm debris, and bryozoans are the dominant constituents. Very minor traces of pelecypods, brachiopods and gastropods are also present. Fossil content in the Cottage Grove Sandstone varies, but occurs at the top of the upper sand in abundances up to 12%.

Glauconite

Characterized by its green color, glauconite occurs in traces in the Cottage Grove interval. Glauconite grains are generally ductilly deformed and occur individually between other sand-sized grains or with clay matrix. Some grains were altered to brown making them difficult to distinguish from other clay matrix.

Detrital Matrix

Detrital matrix is distinguished from rock fragments by its size. Detrital matrix was that portion of the detrital constituents smaller than 0.03 mm in size. It is commonly ductilly deformed between larger framework grains. Detrital matrix varies in color depending on authigenic replacement, oxidation or reduction, or hydrocarbon staining. Brown matrix could be hydrocarbon staining or altered glauconite. Percentages of detrital matrix vary from a maximum of 9% in the upper sand body facies, increasing to much higher percentages into the underlying sand/shale sequence.

Minor Constituents

Other detrital constituents occurred in trace amounts. In order of abundance these constituents are muscovite, biotite-chlorite, zircon, and rutile. Muscovite commonly occurred in lath shaped masses that were ductilly deformed between framework grains. When biotite was seen it was either partially or almost completely altered to chlorite. Biotite was found in subrounded masses, some of which exhibited subhedral crystal faces. Zircon and rutile were the least common detrital constituent and their grains were extremely rounded.

## Diagenetic Constituents

Minerals forming within the Cottage Grove Sandstone after burial include: authigenic silica, carbonate minerals, clay minerals, pyrite, and leucoxene. These authigenic minerals were precipitated in an environment unlike that of their framework host rock. Texturally, they occur as pore filling, pore lining, replacive, and fracture filling minerals.

Silica

Authigenic silica is characterized by quartz overgrowths. Most overgrowths are syntaxial making them difficult to distinguish petrographically. Illitic dust rims and euhedral crystal faces aid in the recognition of the overgrowths (Figure 22). Detectable authigenic silica averages 3%.

Figure 22. Illitic Dust Rims Viewed in C.N Light
(Note Biotite) 200X

## Carbonate

Authigenic carbonate is the major pore filling and replacive diagenetic mineral in the Cottage Grove Sandstone. Three types of carbonate occur in the sand: calcite, siderite, and dolomite. All three types of carbonate were found in higher percentages in the top of the sand. Calcite was the most common type of carbonate in the interval. Siderite and dolomite were only recognized in the top of the upper sand facies. Figure 23 illustrates the average carbonate content in the Cottage Grove Sandstone.

## Clays

Authigenic clays present are illite, chlorite, and kaolinite. Illite is the most common clay and occurs in abundances up to 5%. This percentage increases into the underlying sand/shale sequence. Illite is characterized by small fibrous "lathlike" crystals that often form as pore linings and replace detrital matrix (Figure 24). Minor amounts of illite-smectite mixed layer clay were detected.

Chlorite is the second most common authigenic clay and often replaces detrital matrix. Chlorite also occurs as pore linings with a characteristic edge-to-face morphology (Figure 25). Chlorite is detected by its green color in plain light and averages 2% in the sand.

Kaolinite is the least common authigenic clay in the North Concho area. It occurs as pore filling clay that is characterized by vermicular booklet-shaped masses (Wilson and Pittman, 1977). Kaolinite occurs in percentages up to 1%. Mixed layer clays were present but occurred in very minor traces.

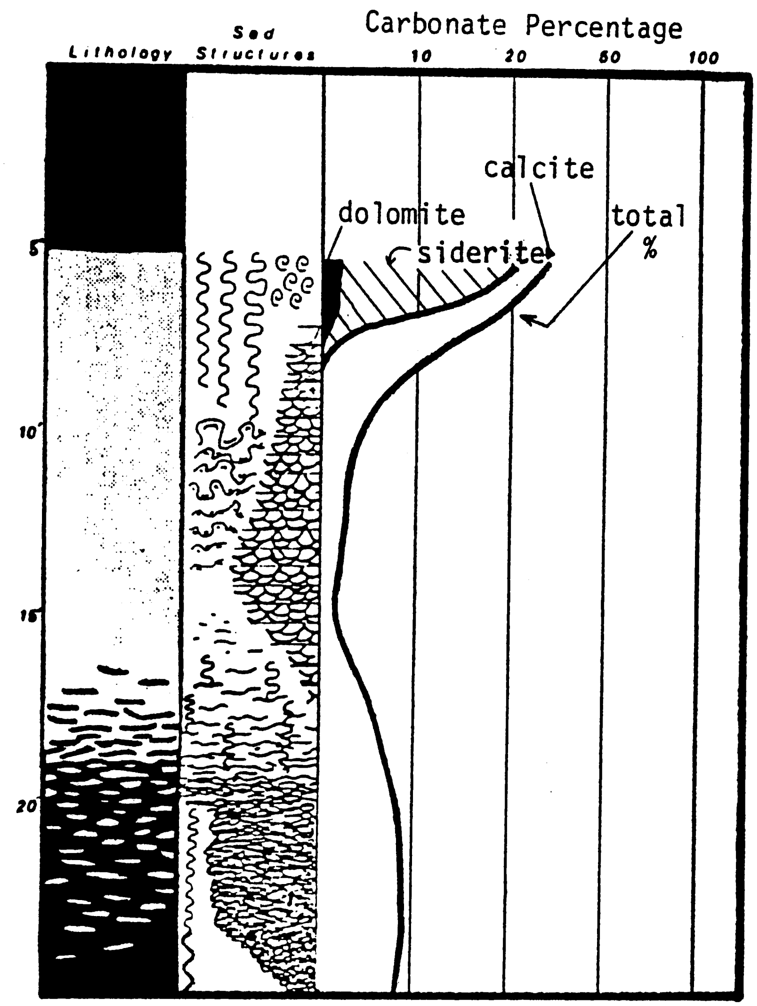



Figure 23. Average Carbonate Cement Content
in the Cores Examined

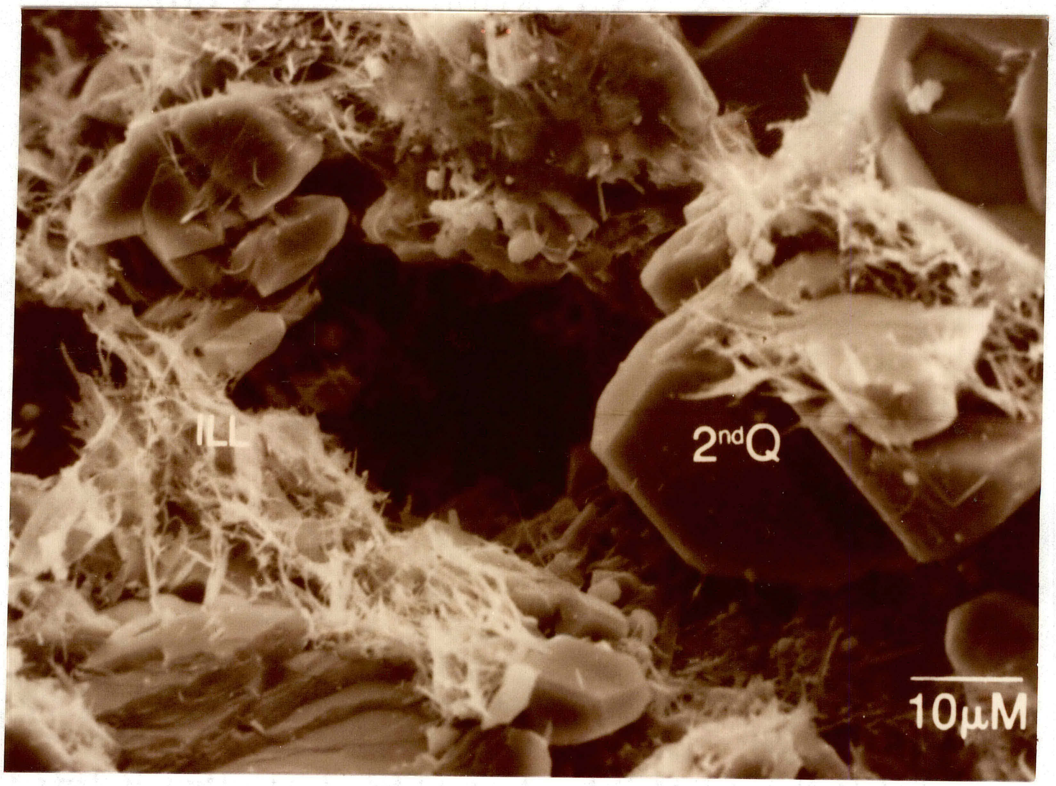



Figure 24. SEM Photograph of "Lathlike" Illite Lining Secondary Quartz and Pores

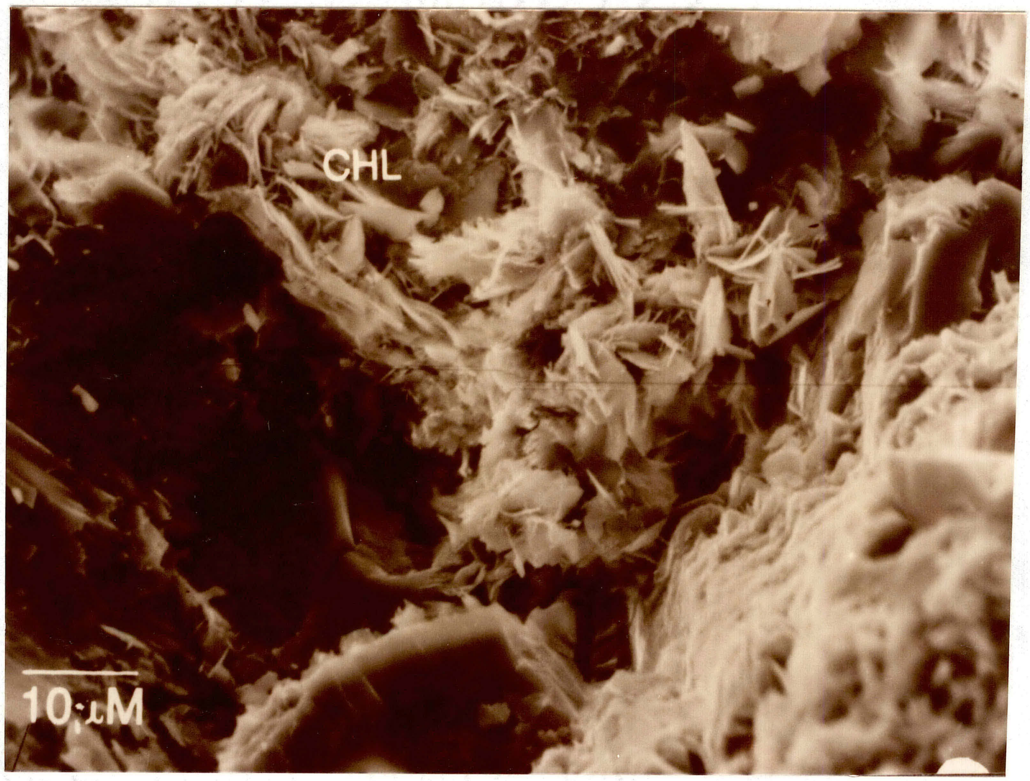



Figure 25. SEM Photograph of "Edge-to-Face" Chlorite

### Pyrite

Authigenic pyrite is found in minor amounts and generally is associated with carbonaceous matter and hydrocarbon residue. When associated with hyrocarbon residue pyrite commonly lines pores. Pyrite replacement is rare but occurs in skeletal fragments. Pyrite is also found in association with hydrocarbon stained detrital matrix. Pyrite commonly occurs as small disseminated euhedral clusters and larger single crystals.

### Minor Authigenic Constituents

Minor authigenic constituents in the Cottage Grove include leucoxene and carbonaceous matter. Leucoxene is an alteration product of titanium-bearing minerals and is distinguished by its white luster. Carbonaceous material occurs as stylolitic laminae and are often vitrainized. Some isolated coal macerals were seen in the sandstone.

## Texture

The Cottage Grove sandstones are uniformily very fine to fine grained throughout the study area. Average framework grain size of the sand, excluding skeletal fragments, varies from 0.08 mm (lower very fine sand) near the base of the interval to 0.17 mm (fine sand) at the top (Pettijohn, 1975). Maximum size of skeletal fragments is 5-6 mm. Overgrowths were not included in individual grain measurements. Although minor variations in grain size exist laterally, a general coarsening-upward sequence characterizes the Cottage Grove interval. Overall, the Cottage Grove Sandstone is well to very well sorted.

Moderate sorting, which is characteristic of the underlying sand/shale sequence, is mainly due to the presence of increasing amounts of detrital matrix. This suggests deposition in an environment of minimum energy.

Because of the abundance of overgrowths and the tendency of the matrix to corrode or obscure grain boundaries, grain roundness was not confined to one category. Many of the angular grains could have been derived from fragmentation of rounded grains or from corrosion associated with diagenetic processes. Sand grain roundness in the Cottage Grove is subangular to subrounded. Probably the most important aspect of grain roundness is the extreme sphericity of the heavy accessory minerals. This indicates that most of the heavy minerals have passed through one or more previous sedimentary cycles. Figures 26 and 27 are photographs displaying the texture of the Cottage Grove Sandstone.

## Classification

Based on petrographic examination, the Cottage Grove interval can be mineralogically divided into two distinct facies adjacent to a gradational boundary. Normalized mineralogical results from thin section data plotted on the Folk (1968) ternary diagrams classify the lower sand/shale facies as a litharenite to sublitharenite and the upper sand body as a sublitharenite. Figure 28 illustrates the classification diagram with all of the thin section data plotted and the separate facies distinguished.

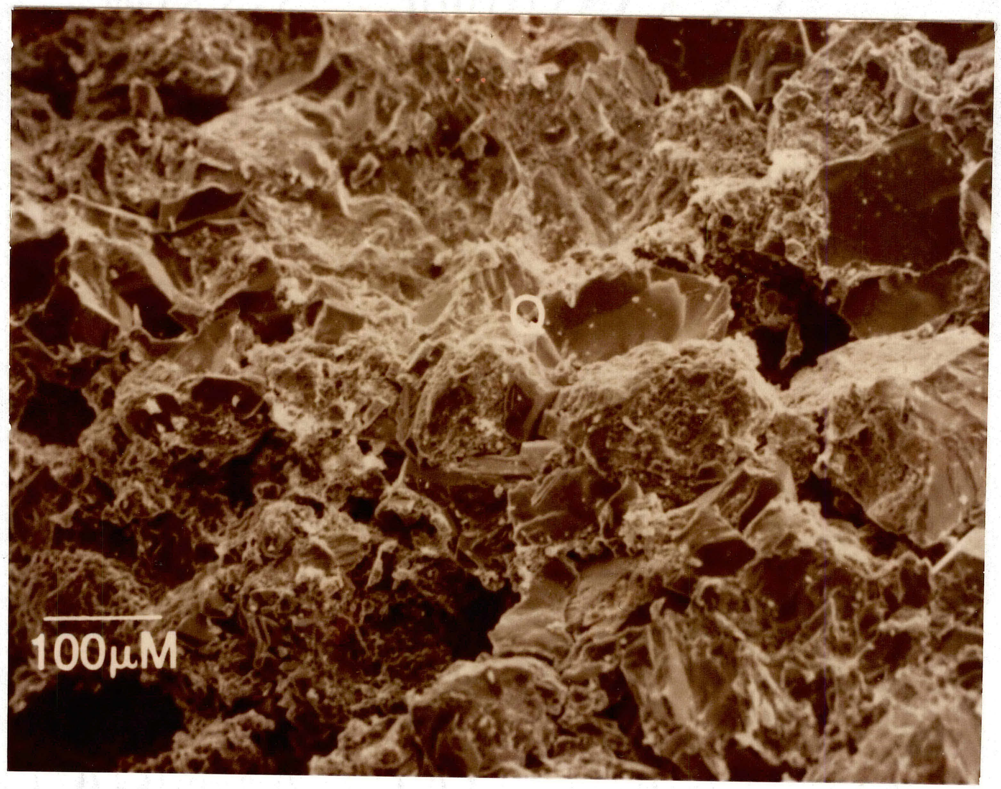



Figure 26. SEM View of the Texture of the Upper Cottage Grove Sandstone (Carrie Evans No. 7-2, 8080')

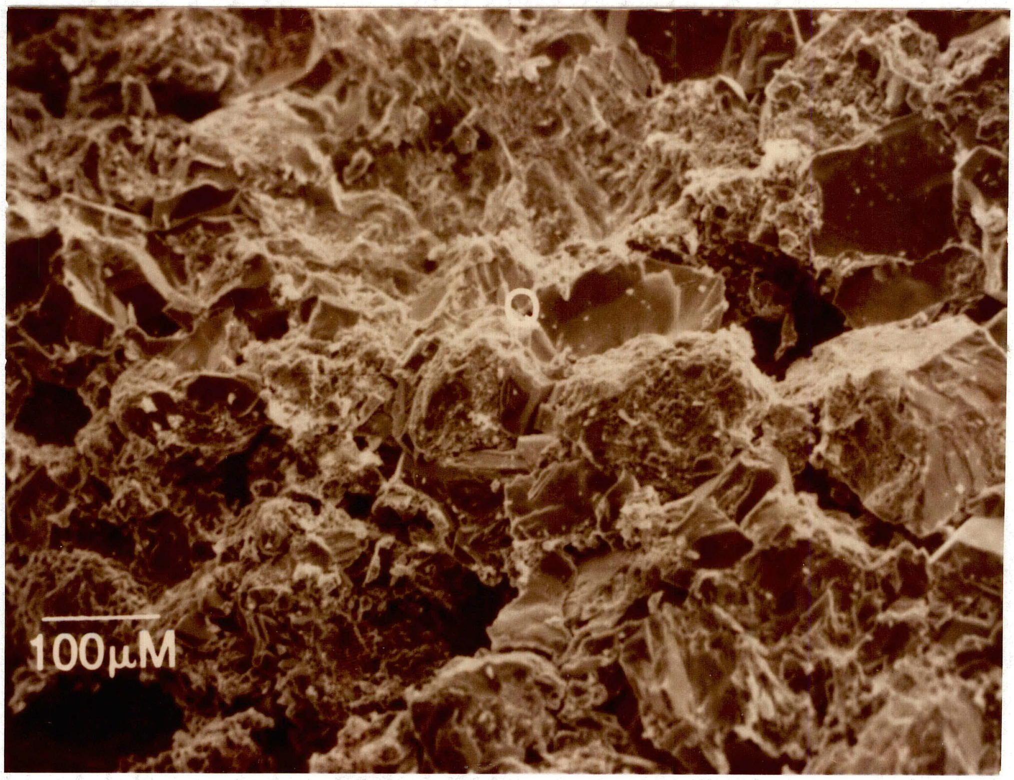



Figure 27. SEM View of the Lower Part of the Upper Cottage Grove Sandstone (Carrie Evans No. 7-2, 8090')

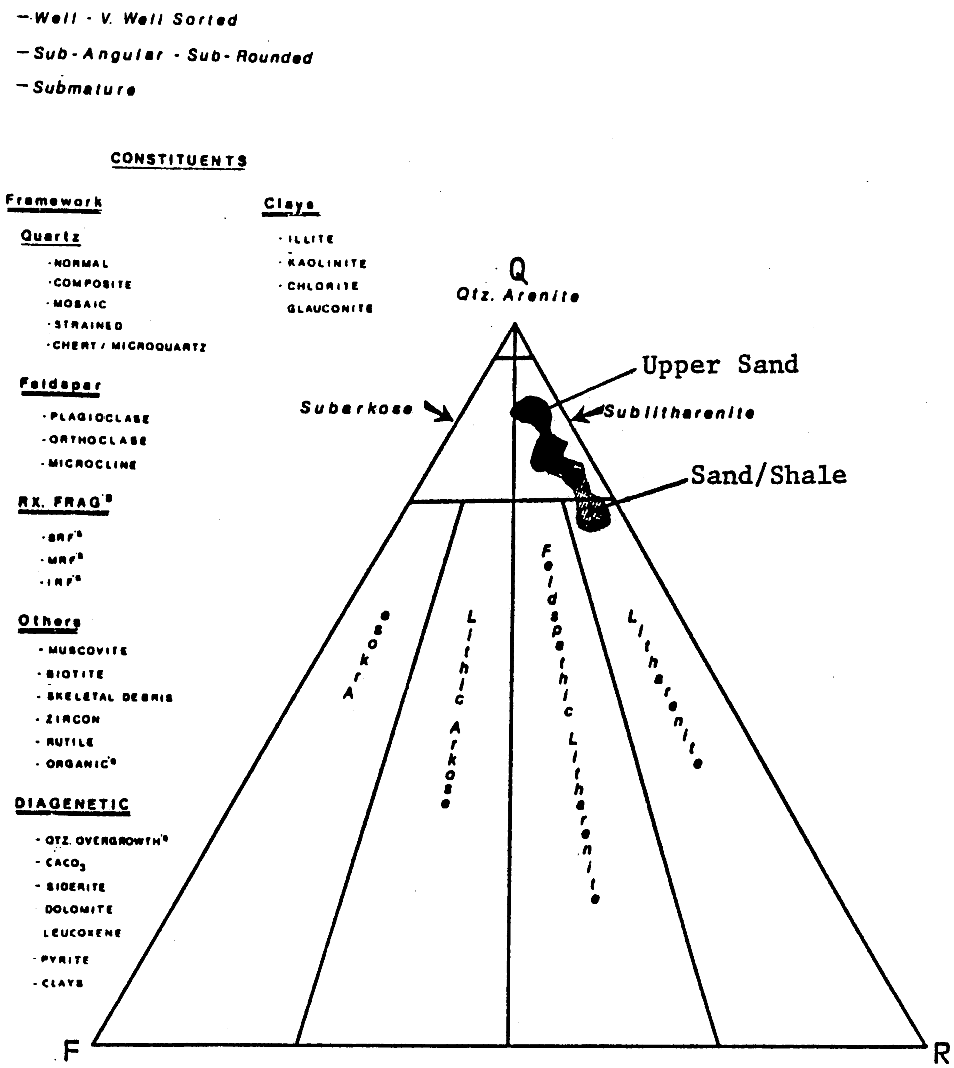



Figure 28. Classification Diagram and Constituents of the Cottage Grove Sandstone

## Provenance

Distribution of the Cottage Grove within the study area indicates a south-southeastern source. The lack of coarse clastic material and the low feldspar content of the Cottage Grove Sandstone eliminates the Wichita-Amarillo uplift as a source area. However, uplifted sedimentary rock from the Wichita-Amarillo uplift could have contributed source to the study area. The overall transition of a clastic to a carbonate facies to the north towards Kansas and to the west towards Texas eliminates sources from the north and northwest.

The abundance of very fine grained, subrounded quartz sand and the extreme rounding of the opaque minerals indicates preexisting sediments in the source area. These sediments were probably sandstones and siltstones. Sedimentary rock fragments in the Cottage Grove Sandstone were most likely derived from within the depositional basin during transport. It is possible that some shale clasts were derived from the source area. Most likely the shale clasts were derived from local erosion by the channel in the delta plain. The presence of metamorphic rock fragments and metamorphic types of quartz indicates that metamorphic rocks were present in the source area. The low grade of the metamorphic rock fragments in the Cottage Grove Sandstone suggests the source consisted of schists, slates, phyllites, and metaquartzites.

The source area of the Cottage Grove Sandstone appears to have been a complex terrain of sedimentary, metamorphic, and minor amounts of volcanic and intusive rocks. This association of rock types is common within geosynclines. All evidence suggest the tectonically deformed Ouachita geosyncline was the source for the Cottage Grove Sandstone.

# CHAPTER VII

# DIAGENESIS

## Introduction

The recognition of diagenetic processes that can modify reservoir properties is important. Certain diagenetic reactions can enhance porosity and permeability tremendously. An understanding of these processes could help to predict porosity trends. Several distinct diagenetic processes enhancing secondary porosity affected the Cottage Grove Sandstone. Factors controlling diagenesis in the Cottage Grove Sandstone appear to be closely related to the original depositional system. The Cottage Grove depositional system produced certain lithofacies with differing petrophysical characteristics. These characteristics controlled the migration of fluids through the sand after burial. The depositional environment also governed the types of initial pore fluids which seem to have played an important role in the present porosity trends.

## Diagenetic Model

Secondary porosity can originate anywhere in the sedimentary crust: (1) before effective burial in the environment of deposition (eogenetic); (2) at any depth of burial above the zone of metamorphism (mesogenetic); (3) during exposure following a period of burial (telogenetic) (Schmidt and McDonald, 1979). Schmidt and McDonald proposed four textural stages of sandstone mesodiagenesis that are defined by four petrographically recognizable stages of the burial diagenesis. These are in order of progressive burial: (1) immature stage; (2) semimature stage; (3) mature stage; and (4) supermature stage. An illustration of the textural stages of mesodiagenesis can be seen in Figure 29.

The mineralogy and original texture of a sand control the extent of diagenetic alterations. Generally, the mineralogy and texture of a sandstone after diagenesis is different than when it was deposited. Diagenetic minerals increase in percentage at the expense of less stable detrital constituents. Framework grains and detrital matrix can be dissolved, replaced, or altered for porosity enhancement. Estimations of the original rock type can be made by detailed petrographic analysis. Schmidt and McDonald (1979) constructed diagenesis diagrams for various rock types. These diagrams show the relationships between the rock, primary porosity, cements, and secondary porosity through the stages of diagenesis.

The diagram that most closely resembles the diagenetic pathway of the Cottage Grove Sandstone is that of the quartz-arenite with sedimentary and eogenetic carbonate. The Cottage Grove Sandstone has a slightly higher percentage of feldspars and rock fragments than a quartz-arenite, but the low percentages and stability of the feldspars should allow an accurate comparison. In Schmidt and McDonald's diagram (Figure 30) the original sand contains some sedimentary (detrital) carbonate and eogenetic (precipitated) carbonate fills part of the intergranular porosity. Because of this eogenetic carbonate cement, the rock is lithified and no mechanical compaction occurs during the immature stage of mesodiagenesis. Chemical compaction takes place

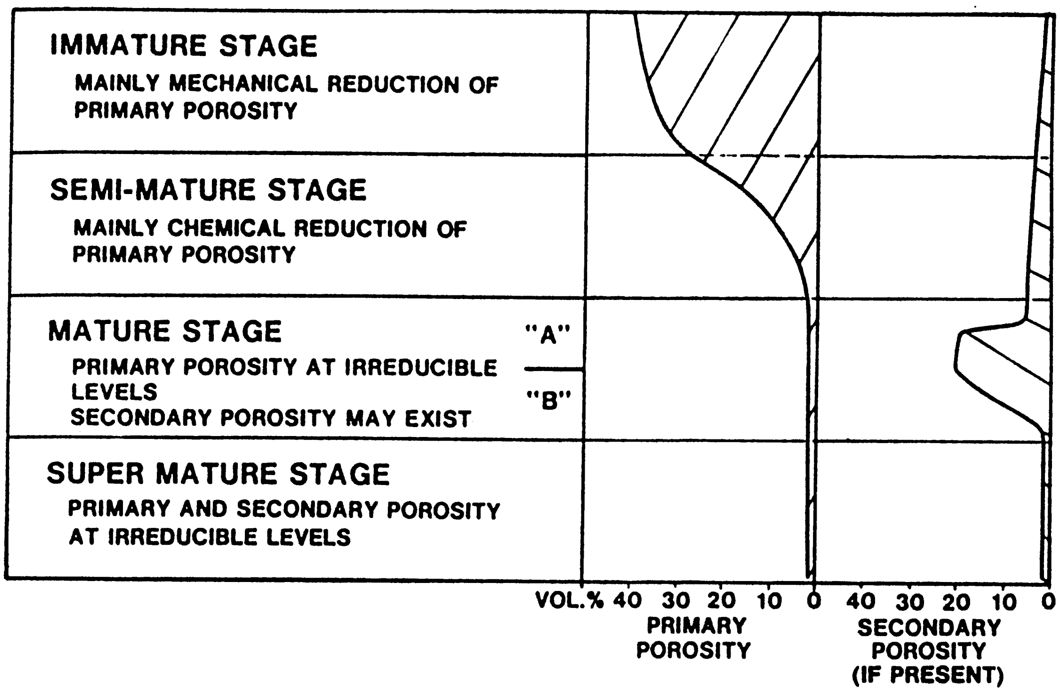



Figure 29. Textural Stages of Mesodiagenesis
(Schmidt and McDonald, 1979)

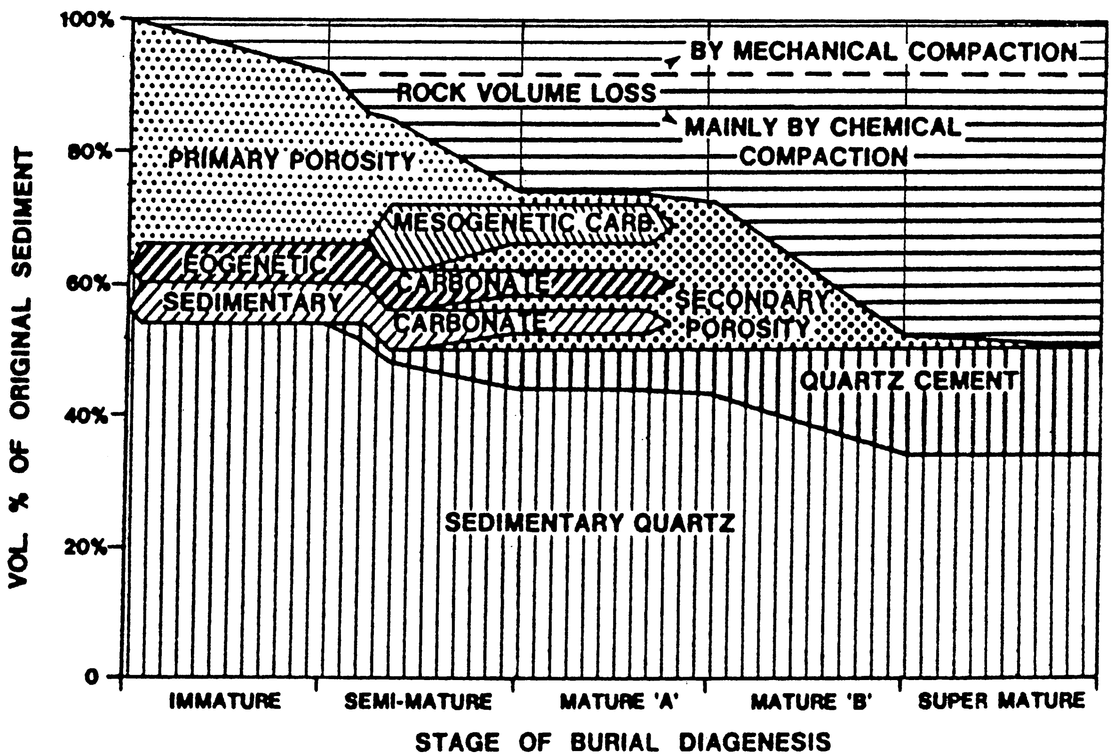



Figure 30. Burial Diagenesis of a Quartz Arenite with Eogenetic and Mesogenetic Carbonates (Schmidt and McDonald, 1979)

during the semimature stage which considerably reduces rock volume and porosity. The dissolved silica originating from the chemical compaction reprecipitates as intergranular cement, further reducing primary porosity.

At the beginning of the mature stage "A," the sand contains only irreducible lamellar porosity. A considerable amount of secondary porosity is subsequently created by the leaching of pore filling and replacive carbonates by acidic formation waters. This enhancement of porosity by the removal of carbonates is called decarbonitization. Most of the mesogenetic decarbonatization results from the decarboxylation of organic matter in strata adjacent to the sandstone during the course of organic maturation. The process of decarboxylation leads to the generation of carbon dioxide which, in the presence of formation water, produces carbonic acid (Schmidt and McDonald, 1979). This acidic leaching solution migrates closely ahead of newly formed migrating hydrocarbons. This close association of leaching and hydrocarbon migration favors the accumulation of hydrocarbons in secondary porosity (Schmidt and McDonald, 1979).

Minor mechanical and chemical compaction occurs during the remaining mature stage "A." Chemical compaction becomes active again during the mature stage "B" and the secondary porosity declines to an irreducible lamellar porosity. At this point the supermature stage is reached. Schmidt and McDonald also state that decarbonatization can occur at any stage of burial diagenesis and individual sandstones may be subjected to one or more episodes of decarbonatization. Multiple stages of decarbonatization would be extremely difficult to recognize petrographically. It is also possible that decarbonatization might not occur if there is an absence of source rock to generate leaching solutions.

Schmidt's and McDonald's principal observations concerning burial diagenesis are summarized in Figure 31. The sequence of diagenetic events is mainly controlled by residence temperature and residence time (Schmidt and McDonald, 1979). Secondary porosity is a complex function of pressure, constituents, water composition, and source-rock character as well as depth, temperature, organic metamorphism, and age (Al-Shaieb and Shelton, 1981).

## Cottage Grove Diagenetic Scenario

Chronological order of the diagenetic events was determined by inductive inference and the method of multiple working hypothesis utilizing depositional environment information, cores, and petrographic data. Recognition of the ancient depositional environment was crucially important in delineating the paragenetic sequence.

Shallow marine environments dominated the North Concho area during Cottage Grove deposition. Carbonate saturated marine waters precipitated high-Mg calcite. The rhythmic sedimentation of the underlying sand/shale sequence allowed minor precipitation of high-Mg calcite into pore spaces. As the supply of clastic material to the area increased, distal fluvial-deltaic processes dominated the area. Within the study area, fresh waters carrying the sediment from the distant Ouachita source mixed with the marine waters. This diluted the carbonate saturated waters near areas of fresh water input. As a result, carbonate precipitation was hindered and waters undersaturated with respect to carbonates were incorporated in the sand pores.

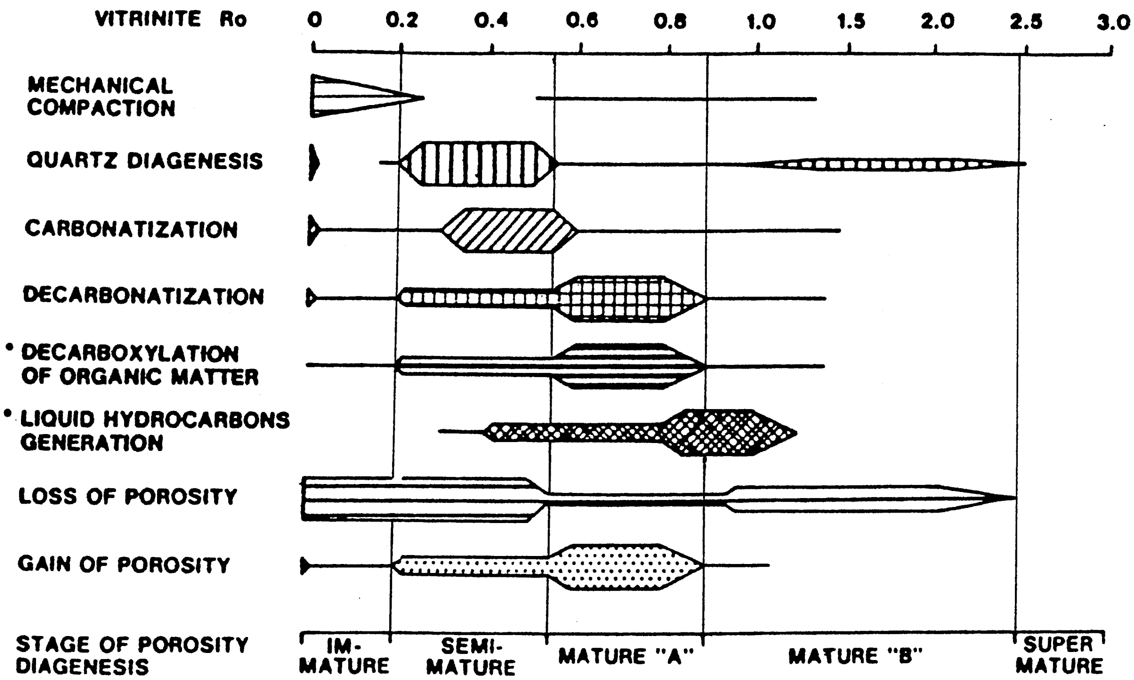



Figure 31. Burial Diagenesis of Quartz Arenites
(Schmidt and McDonald, 1979)

Carbonate precipitation in marine environments has been found to be retarded by the input of detrital material, as seen around the Mississippi Delta in the Gulf of Mexico (Leeder, 1982). When the major episodes of sand influx began to slow, carbonate precipitation was no longer affected. After siliciclastic sedimentation ceased, the entire sand body was submerged and reworked by marine organisms. Approximately two feet of the top of the sand is heavily reworked and carbonate cemented. After the sand was reworked, a black fissile shale was deposited on top of the Upper Cottage Grove Sandstone. The eogenetic carbonate derived from the marine environment partially cemented the sand which slightly consolidated the framework. This kept early mechanical compaction to a minimum allowing the preservation of primary porosity and permeability. Thus, fluid flux through the sand was still possible.

During early burial minor authigenic recrystallization of detrital matrix and minor illitization occured. The early illite phase was determined by the existence of an illitic dust rim around detrital quartz under the authigenic quartz overgrowths (Figure 22). Chemical compaction and the release of silica from the smectite to illite transformation in the adjacent shales provided an abundance of silica. It has been estimated that a temperature of 60 degrees centigrade (140 degrees F) is needed for the formation of quartz overgrowths (Boles and Franks, 1979). Compared to today's geothermal gradient in the North Concho area (0.0115 degrees F) this correspondes to a depth of approximately 7,300 feet. Vitrinite reflectance values around the area reveal that the rocks have been subjected to higher temperatures than today's geothermal gradients would allow at present depths (Al-Shaieb, 1984). This could be caused by the erosion of a large sequence of rock that once covered the area, recycled organic debris, or an increase in the geothermal gradient due to the uplift of deeply seated basement rock during episodes of mountain building. Some of the high vitrinite reflectance is probably caused by the effects of time (Hunt, 1979).

Authigenic silica increases towards the top of the upper sand. However, intense carbonate cementation and replacement (Figure 32) make it hard to discern the overgrowths within the top few feet of the sand. Quartz overgrowths are most common in areas where diagenetic modification is least apparent and direct framework dissolution occurs. These are areas where little carbonate cement was precipitated, possibly because of the presence of the fresh water in the pores. Original porosity and permeability were probably high except in the very top of the upper sand, where the intense carbonate plugging occured.

The low pH's required for the precipitation of the quartz overgrowths are accompanied by an abundance of hydrogen ions. Feldspars can incorporate hydrogen ions into their lattices and thus be altered to clay minerals. During the later stages of quartz overgrowth formation, when pH's were still low, authigenic clays were formed from feldspar alteration. This consumption of hydrogen ions would cause an increase in the pH. The solubility of silica can be accomplished by this increase in pH or an increase in temperature (Figure 33; Krauskopf, 1977). Silica is stable at lower pH's and carbonates are stable at higher pH's (Figure 34). This inverse relationship often allows silicate minerals to be replaced by carbonate minerals in high pH environments (Figure 35). If acidic solutions are later introduced into a sand, these replacive carbonates can be dissolved to generate

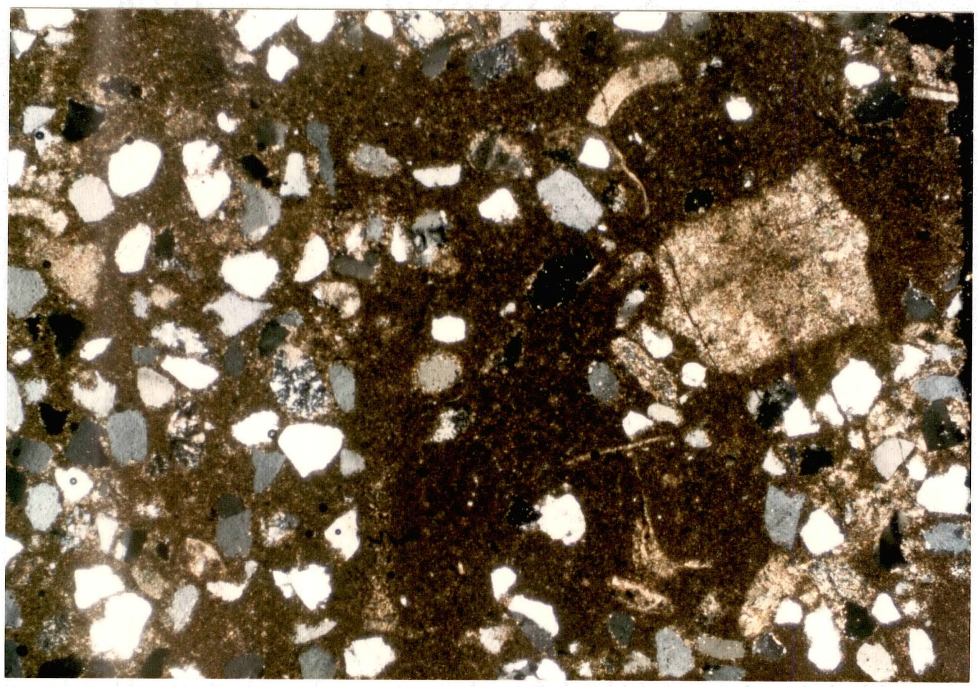


Figure 32. Intense Carbonate Cementation at the Top of the Sand (Burkhead No. 3) 40X

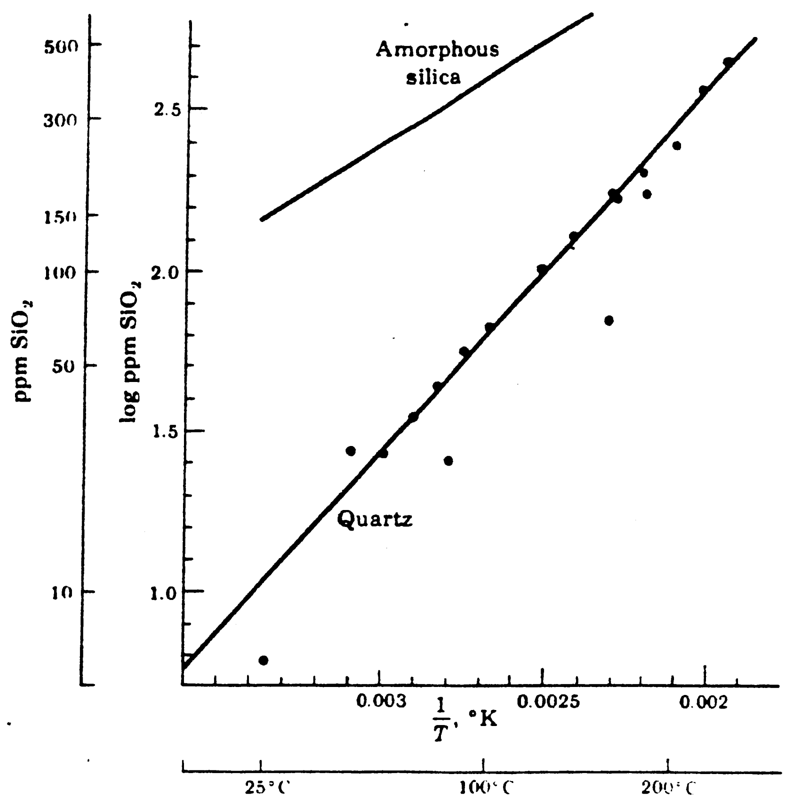



Figure 33. Solubility of Silica as a function of Temperature, Plotted as Log ppm $SiO_2$ against Reciprocal of Absolute Temperature (Krauskopf, 1979)

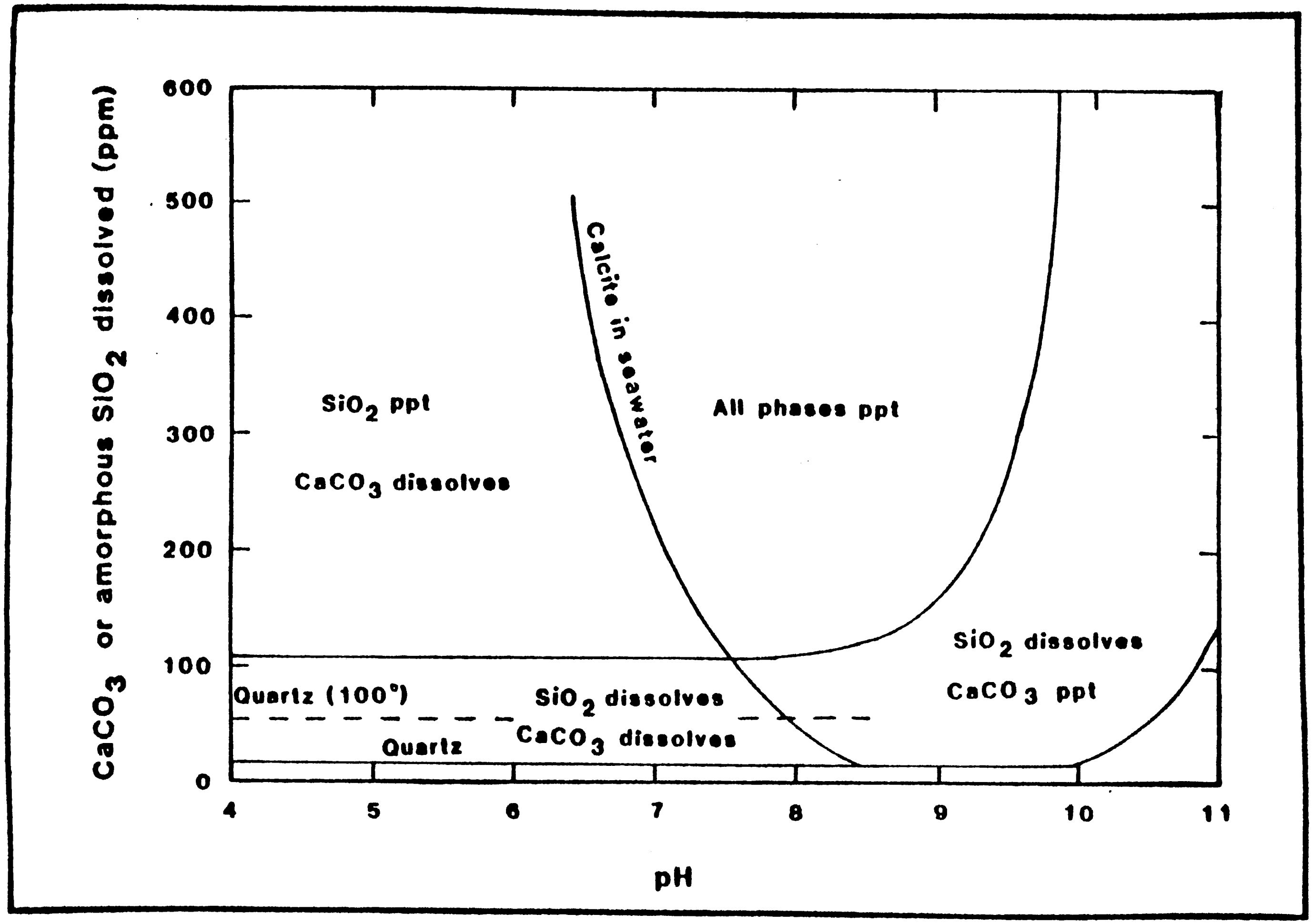



Figure 34. Phase Diagram Showing the Relationships between Calcium Carbonate or Silica Concentration Versus pH (Blatt, 1982)

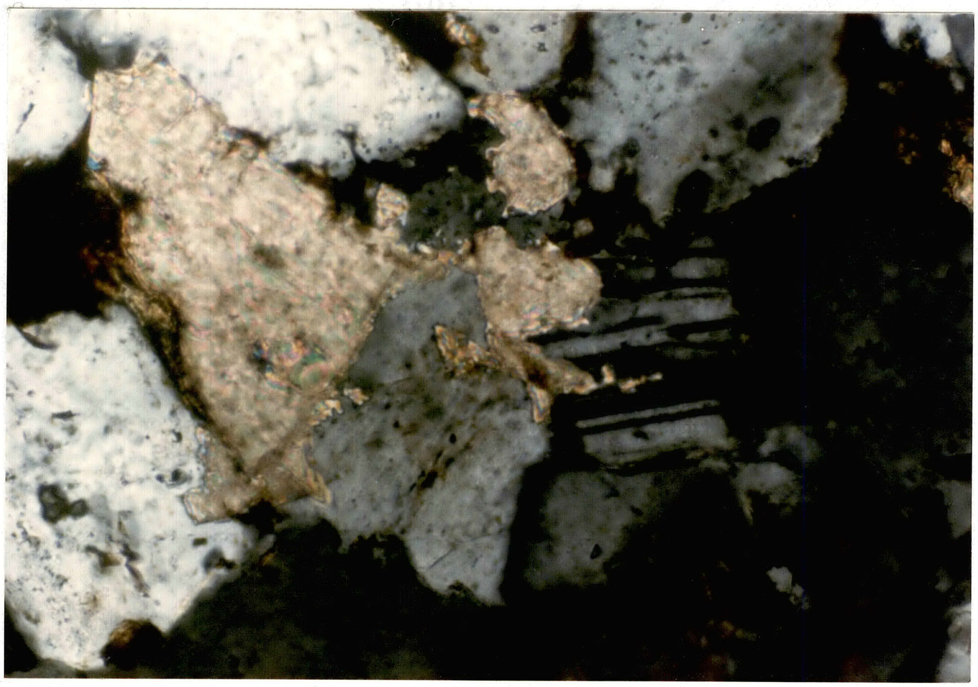


Figure 35. ~~Plane~~ C.N Light View of Calcium Carbonate
Replacing Feldspar and Quartz 400X

secondary porosity. This type of secondary porosity can be mistaken for the direct dissolution of the silicate minerals (Schmidt and McDonald, 1979). Quartz overgrowths preceded secondary porosity because they are usually corroded and secondary pores cut through the overgrowths.

There appear to be two stages of carbonate cementation. The first of these is associated with the marine environment and skeletal fragments. During compaction, pressure solution dissolved and reprecipitated this early eogenetic cement. A second carbonate stage seems to have occured after the precipitation of quartz overgrowths and authigenic clays. This second stage of carbonate replaced various constituents and further filled primary pores. The second carbonate phase shows iron and magnesium enrichment towards the top of the sand by the increase of siderite and dolomite. Chlorite, which is rich in iron and magnesium, was also found to be in greater abundances in the top of the sand near the sand-shale contact. This suggests the movement of material from the overlying shale into the sandstone during progressive diagenesis. Other authors have proposed that mineralization was derived from adjacent shales (Boles and Franks, 1979; Land and Dutton, 1978).

Direct framework dissolution occurred in the middle of the upper sand without any sign of previous carbonate replacement. Calcite was the only carbonate found below the top of the sand and here it occurred as patchy pore filling cement with very minor replacement. Towards the top of the sand, framework grain replacement becomes more common. The existence of carbonate replacement in the upper part of the sand and direct framework dissolution below suggest that a chemically open hydrologic system had to have existed in the middle of the sand. This hydrologic pathway was probably controlled by the presence of the fresh pore waters in the sand during early burial. Most diagenetic features in the Cottage Grove Sandstone may be relicts of earlier fluid regimes. The reworked carbonate-plugged sand near the top had relatively low initial porosity and permeability, thus hindering fluid flux. This could have restricted shale water penetration to the upper few feet of the sand. Figure 36 illustrates the relationships between carbonate content, relative abundances of the clays, porosity, and permeability. These averaged values are plotted along with average lithology and sedimentary structures that are characteristic of the Cottage Grove Sandstone in the North Concho area.

The relative abundances of clay minerals determined by x-ray analysis indicate chlorite to be more abundant in the top few feet of the sand. The chlorite can be accounted for by the presence of high concentrations of magnesium and iron in the top of the sand. Chlorite is most likely formed from magnesium and iron lost by the smectite to illite transformation (Hower et al, 1976). Kaolinite did not occur in high enough percentages to determine its relationship with the sand-shale interface or the exact timing of its formation. The distribution of kaolinite reflects a combination of dissolution, transport, reprecipitation, and grain alteration. Kaolinite formation probably started when the pH was low enough for an abundance of hydrogen ions to be present. Kaolinite was often found to fill pores, whereas small amounts of illite lined the pores. The illite lining the pores occurred after quartz overgrowth precipitation and is part of the second stage of illitization. This relationship suggests kaolinite formation took place after the start of the second stage of illitization. The acidic

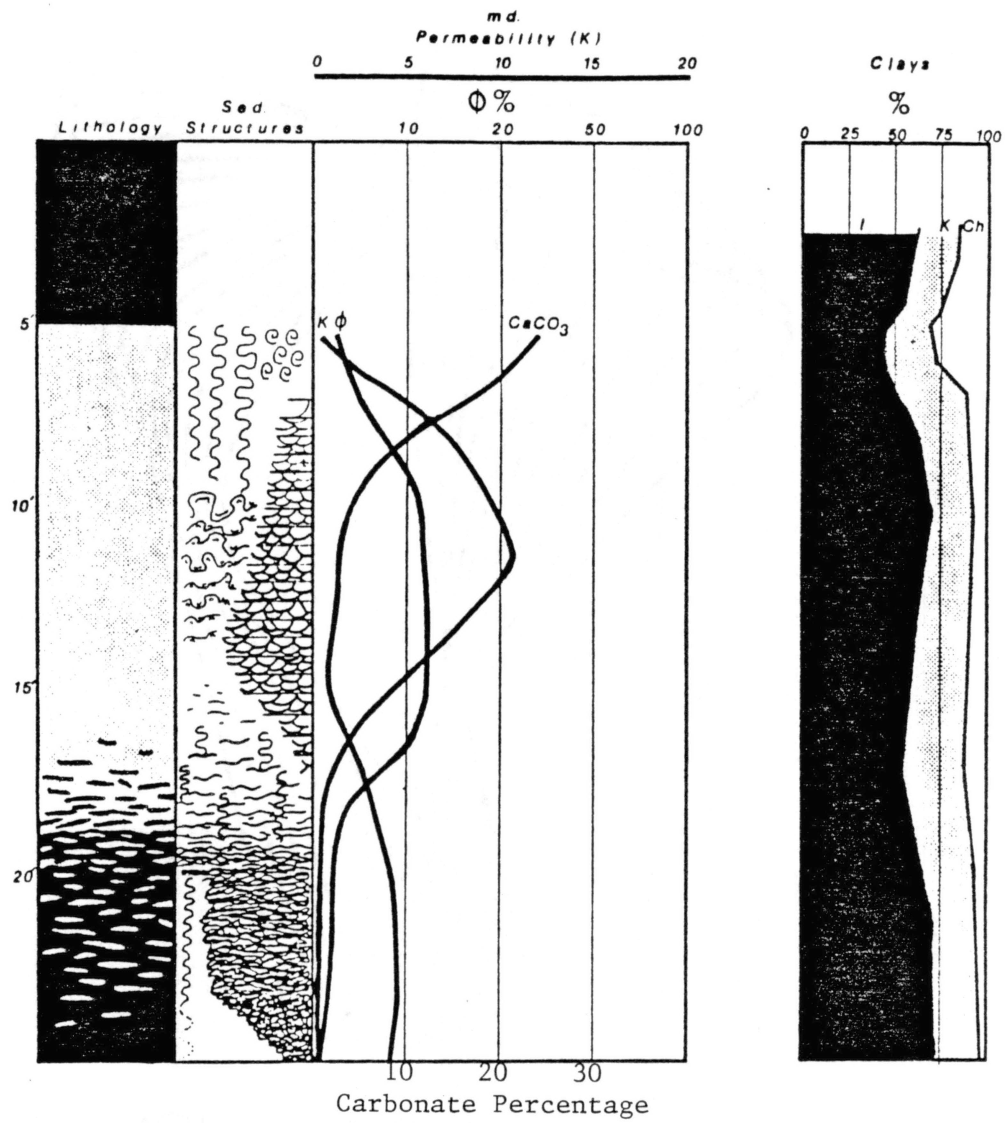



Figure 36. Relative Abundance of Clays, Carbonate Content, Porosity, and Permeability Plotted along a Type Log Representative of the Cottage Grove Sandstone in the North Concho Area

environment needed for the formation of kaolinite would place it before the second carbonate phase.

Carbonaceous material and styolites were being vitrinized during progressive diagenesis by the increasing heat. During or after the second phase of carbonate precipitation, decarboxylization of adjacent source rocks generated acidic formation waters. This solution migrated through the sand just ahead of the hydrocarbons. The only pathway it could take was through the remaining flow regime that was unaffected by diagenetic cementation. This pathway was created by the channel systems of the deltaic splay. Leaching of various components in the Cottage Grove Sandstone opened pore space for the migrating hydrocarbons. Hydrocarbon emplacement hindered further diagenetic reactions. The only detectable mineral formed after hydrocarbon emplacement is pyrite. It occurs in trace amounts and is found to replace bitumen. The association of dolomite with hydrocarbons is not well understood, but the two could be related in this diagenetic scenario. Figure 37 shows the paragenetic sequence of diagenetic events detected in the Cottage Grove Sandstone. Diagenetic events along the vertical axis are plotted in reference to relative time (horizontal axis). Figure 38 was constructed to illustrate the location of various diagenetic minerals and fossil content within a vertical sequence characterizing the Cottage Grove Sandstone.

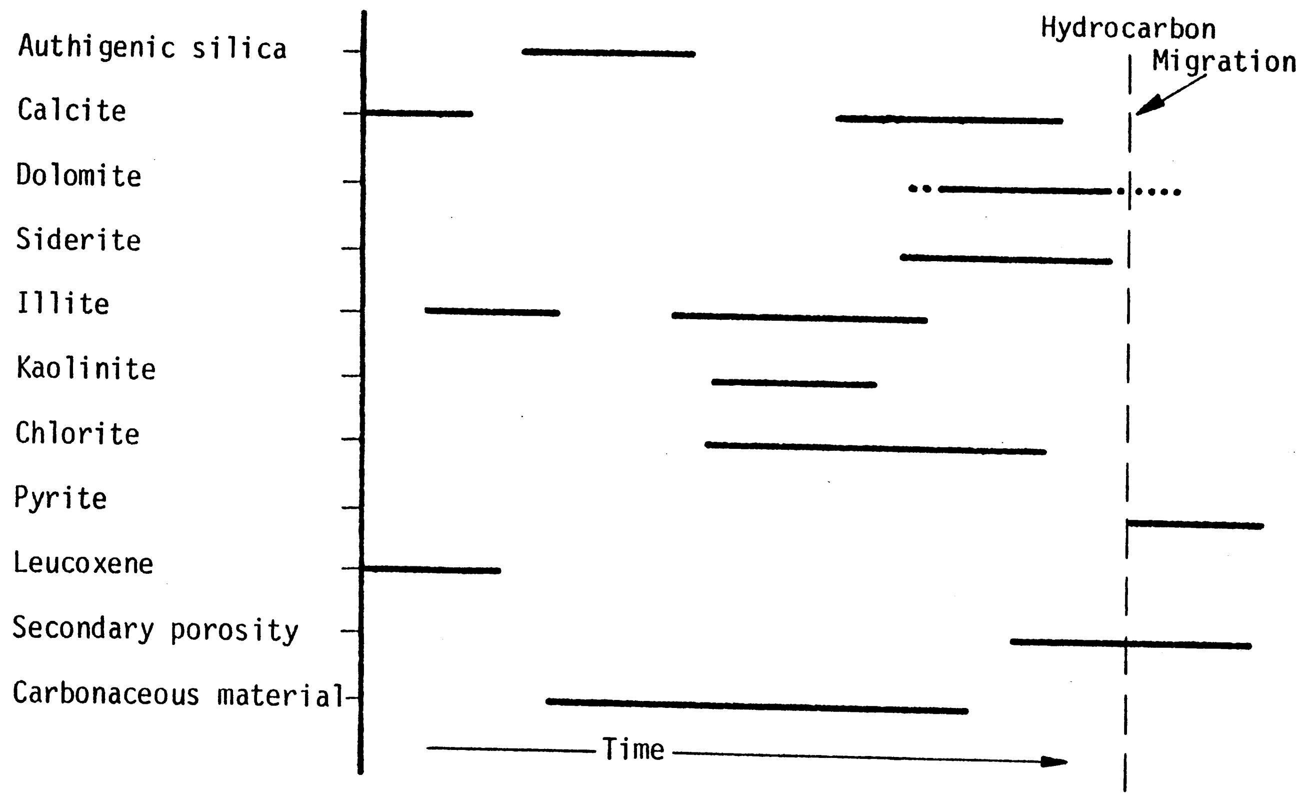



Figure 37. Paragenetic Sequence of Diagenetic Events in the Cottage Grove Sandstone

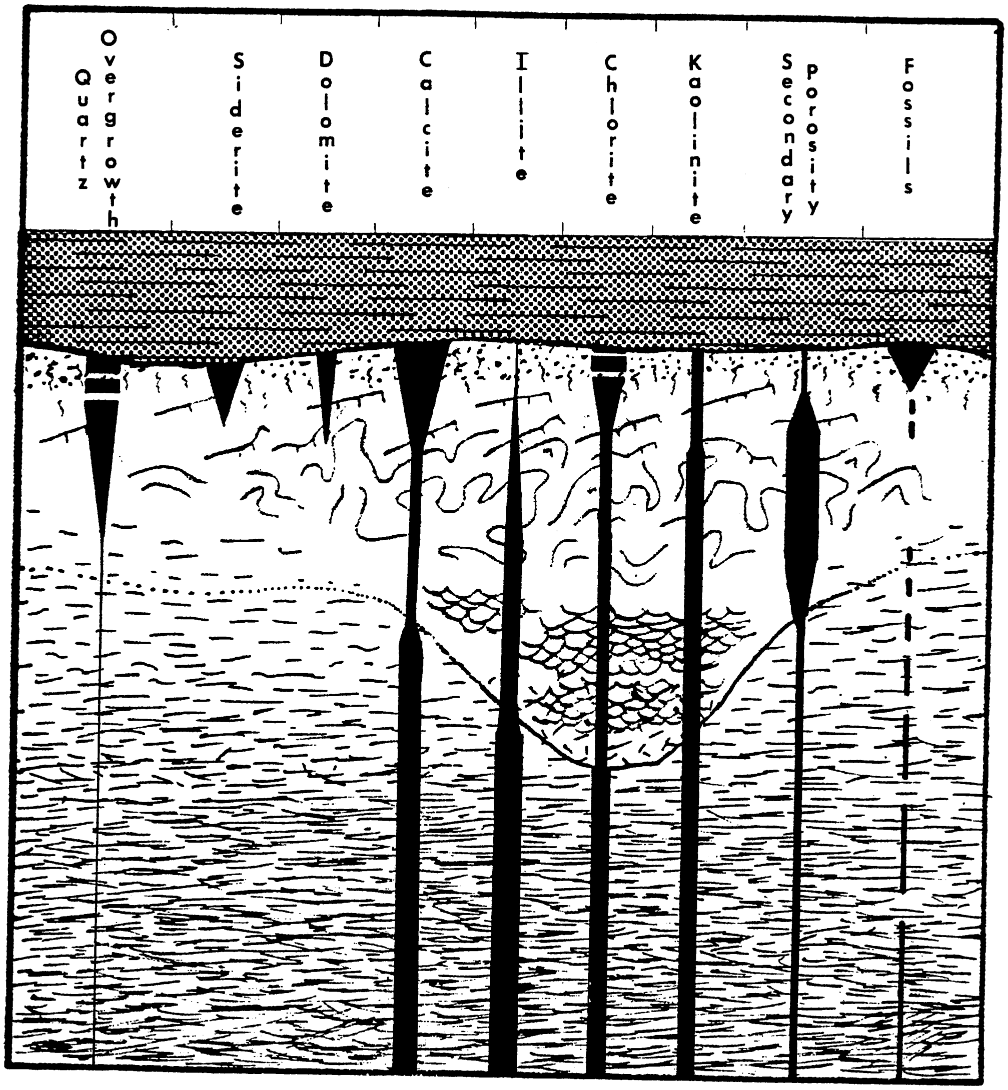



Figure 38. Sketch Illustrating Positions of Diagenetic Mineralization through a Cross Section of the Sand. Fossil Content was included

# CHAPTER VIII

# POROSITY

## Introduction

Primary porosity types in sandstones include 1) intergranular, 2) intragranular, and 3) intercrystal porosity. Intergranular porosity is the most common primary porosity type. Intragranular primary porosity occurs within rock fragments or skeletal grains that contain voids of primary origin. Intercrystal porosity is rare and forms within detrital clays.

Secondary porosity occurs as the result of a variety of diagenetic processes. The fundamental secondary porosity types include 1) dissolution of detrital components (i.e., rock fragments. grains and matrix); 2) dissolution of authigenic pore filling cements; 3) dissolution of authigenic replacive minerals; 4) fracture porosity; and 5) shrinkage porosity (Schmidt & McDonald 1979). The terms preserved, reduced, enlarged, and filled are often used as genetic terms associated with primary or secondary types (Schmidt and McDonald, 1979). Thin section examination was the mode of investigation for estimating porosity types.

## Porosity Types

Primary porosity in the Cottage Grove Sandstone was not significant. Primary intergranular porosity was often plugged with carbonate cement or authigenic quartz overgrowths. Where primary porosity is preserved, it occurs as reduced intergranular porosity characterized by uncorroded pore rimming euhedral quartz overgrowths. This porosity type occurs where sedimentary carbonate, or very early carbonate cement did not completely fill the interparticle pore space. Primary porosity was less than 0.5% in the top of the sand, which is dominated by carbonate cement. Primary porosity in the Cottage Grove Formation was not observed in amounts greater than 2% in the North Concho Field.

Most of the porosity observed was of a secondary origin. It occurred in percentages up to 13% in the cores examined. The most common types of secondary porosity in the Cottage Grove Sandstone are: partial to complete dissolution of rock fragments; framework grain dissolution; dissolution of replacing authigenic cement; intragranular (skeletal dissolution) and fracture. Other types occur in minor amounts. Where authigenic carbonate is abundant, dissolution of the authigenic replacive and pore filling cement is the major porosity contributor (Figure 39). In the middle of the sand, where carbonate is not as common, direct dissolution of detrital constituents occurs. Direct dissoulution of the framework grains can be mistaken for primary porosity, but it is actually enlarged intergranular porosity of secondary origin. Dissolution of the detrital clay matrix is the dominant secondary porosity contributor when authigenic carbonate is in low percentages (Figure 40). Floating clay matrix patches and matrix rimmed pores are common where clay matrix dissolution was partial. Complete clay matrix dissolution is characterized by corroded and welded

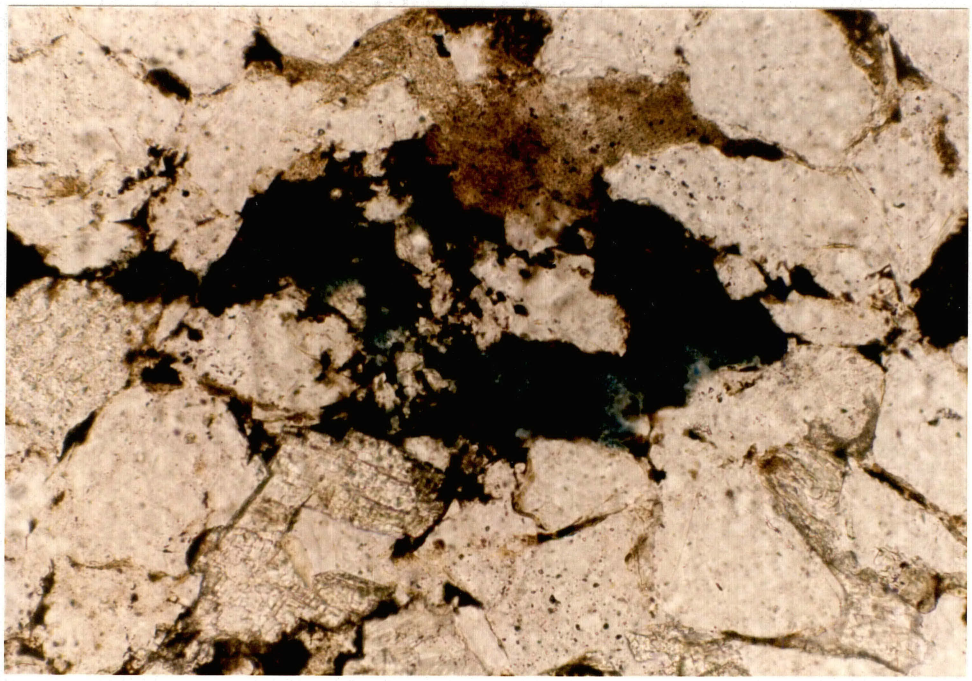


Figure 39. ~~Crossed Nicols~~ Plane Light Photograph of the Partial Dissolution of Authigenic Carbonate Cement and Detrital Matrix Creating Secondary Porosity 200X

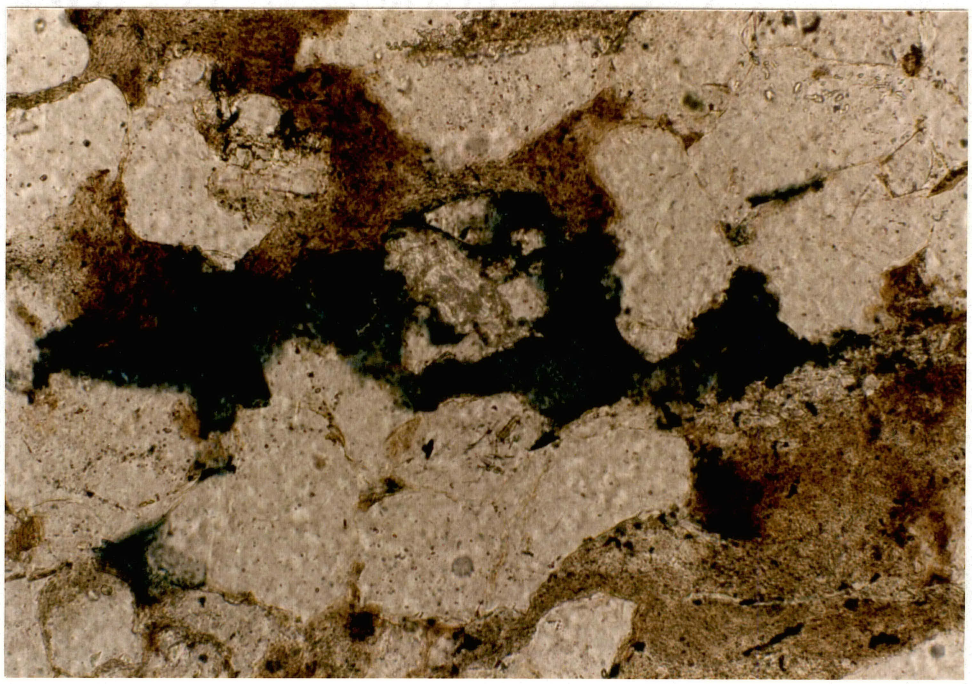


Figure 40. ~~Crossed Nicols~~ Plane Light Photograph of the Dissolution of Detrital Matrix. No Carbonate Cements were involved 200X

quartz grains and quartz overgrowths rimming oversized pores (Figure 41).

Dissolution of glauconite and sedimentary rock fragments also contributed to secondary porosity (Figure 42 and 43). These porosity types are not significant because of the low percentages of these constituents. An increase in the percentage of glauconite or sedimentary rock fragments could generate significant porosity.

Porosity generated from partial to complete dissolution of quartz overgrowths often occurs in association with the partial dissolution of detrital quartz grains. Partial to complete quartz overgrowth dissolution occurs along oversized and elongate pores (Figure 44). Floating quartz grains were also observed to be completely surrounded (two dimensionally) by secondary porosity (Figure 45). Significant quartz dissoulution occurs in the middle section of the sand. Here, small amounts of authigenic cements are found and direct framework dissolution occurred.

Small amounts of intrapartical porosity resulted from the dissolution and replacement of skeletal fragments. This type of porosity was only observed in the top of the sand (Figure 46).

Fracture porosity was also present in the Cottage Grove sandstones. Where observed, fracturing occurred in individual grains and cut across large areas. Fracturing could be the result of natural processes, coring and sample preparation, or both.

The dissolution of authigenic clay minerals may occur but it is not easily distinguished between detrital clay dissolution.

Figure 41. Complete Dissolution of Detrital Matrix with Corroded and Uncorroded Quartz Overgrowths. Crossed Nicols 400X
Plane Light

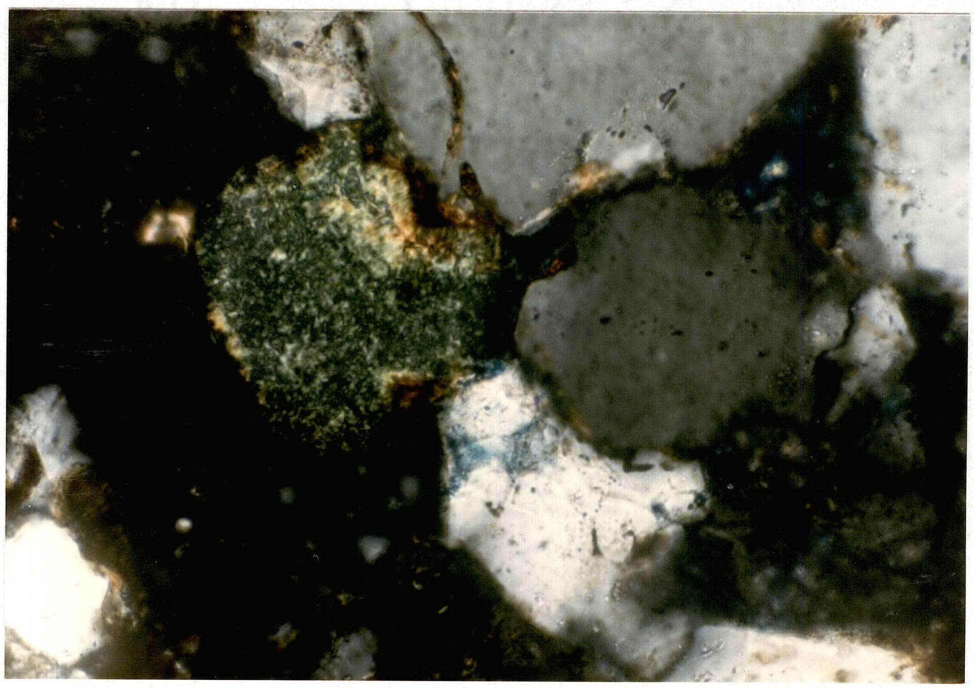


Figure 42. Partial Dissolution of Glauconite Grain.
Note Kaolinite in Bottom Right Corner.
Crossed Nicols 400X

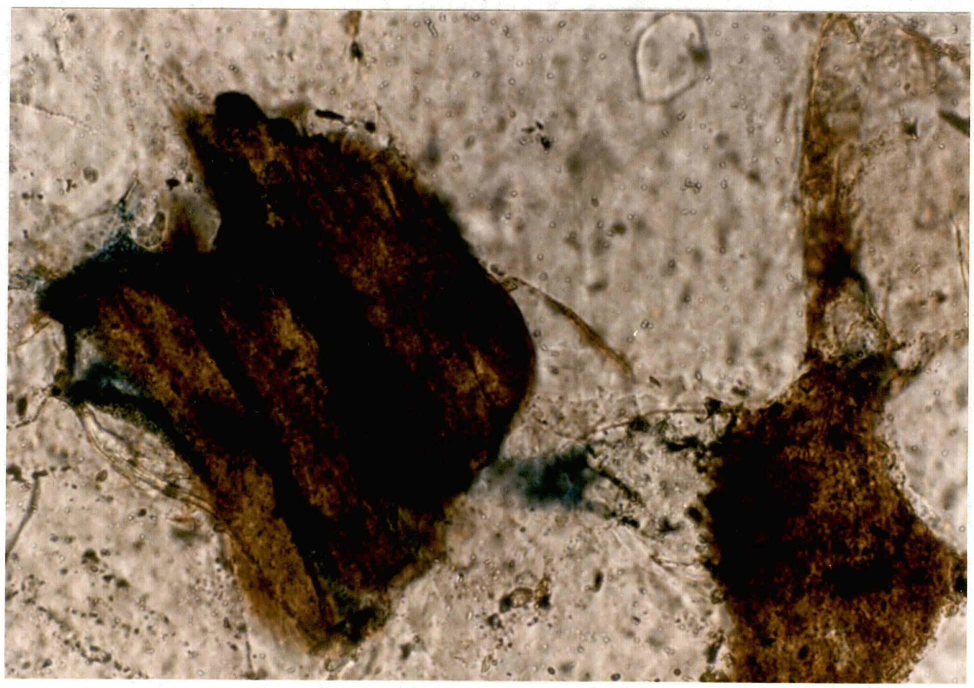


Figure 43. ~~Crossed Nicols~~ Plane Light Photograph of Partial Sedimentary Rock Fragment Dissolution 400X

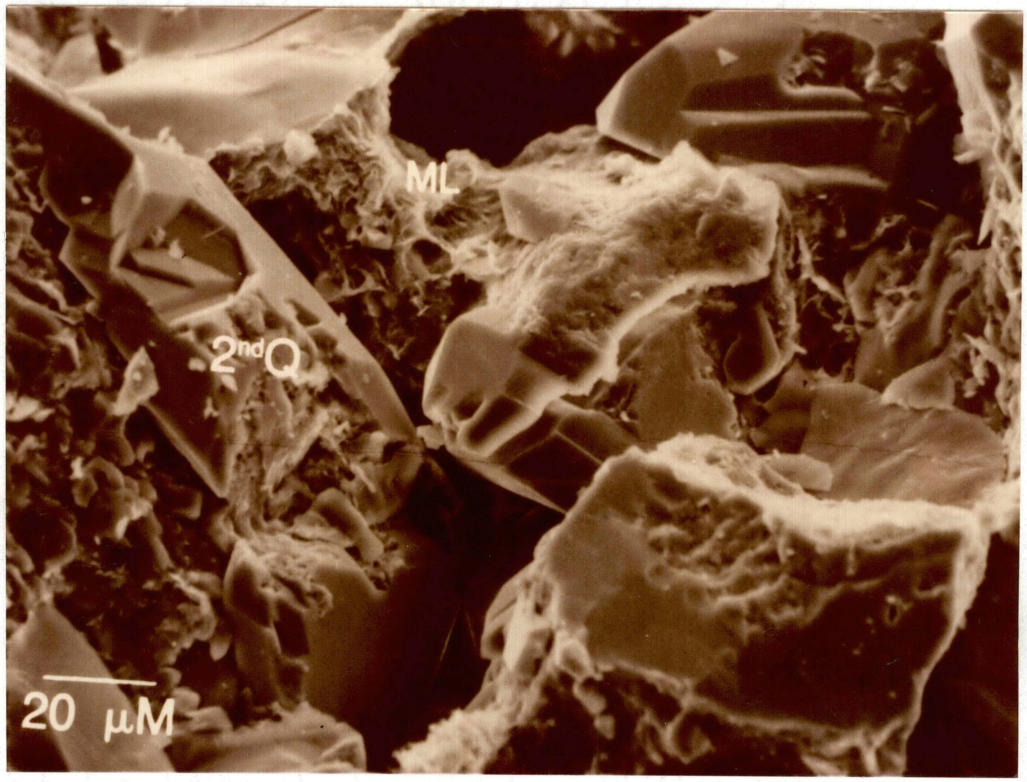



Figure 44. SEM Photograph of the Dissolution of Secondary Quartz and Detrital Matrix

Figure 45. Floating Quartz Grain Surrounded by Secondary Porosity and Bitumen. Outline of Dissolved Overgrowth can be seen. ~~Crossed Nicols~~ 400X
Plane Light

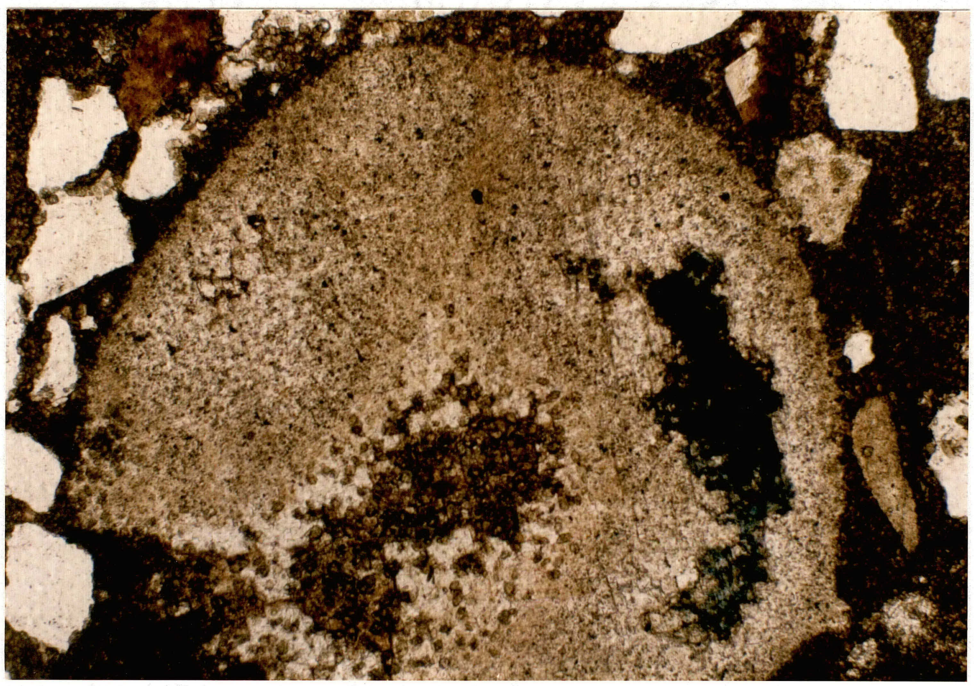


Figure 46. Secondary Porosity Resulting from the Dissolution and Replacement of a Crinoid Partical. ~~Crossed Nicols~~ Plane Light 40X

## Porosity Trends

Plate 11 is a isolith map contoured on total footage with greater than 8% porosity. Porosities were determined from density and sonic logs. Only the Upper Cottage Grove Sandstone porosity was mapped due to the lack of porosity logs in the lower sand.

Although porosity is primarily the result of diagenetic alterations after burial, porostiy appears to be somewhat related to the sedimentary structures. Porosity values from the cores are higher in the cross-stratified and soft sediment deformation structures. These structures are common in the thicker sections of sand that are characteristic of the channel deposits.

Porosity trends in the upper sand appear channel-like and closely correlate with log signatures characterizing channels within the sand splay. Contoured porosity trends are very similar to contoured sand trends shown on the gross sand isolith (Plate 9).

Production in the North Concho Field appears to be restricted to sands with greater than 4 feet of 8%+ porosity. Porosity trend pinchouts correlate closely with gross sand thinning. The overall porosity trends reflect good porosity development within the channel systems in the sand splay.

# CHAPTER IX

# PETROLEUM GEOLOGY

## Introduction

The North Concho Field was discovered in 1960. Field development began approximately 20 years after the initial discovery well, when the potential of the Cottage Grove Sandstone was recognized. A few wells were drilled before the heavy activity began. There are approximately 150 Cottage Grove wells in the study area at the present. As of June, 1985, the North Concho Field has produced over 3.5 million bbls of oil and 2 bcf of casing head gas (Petroleum Information, 1985).

The areal extent of the Upper Cottage Grove Sandstone in the North Concho Field has been recognized. Any future Upper Cottage Grove wells in the area are restricted to development-type wells. The importance of a study such as the present one is to provide awareness of all of the variables controlling production and how to recognize them in future exploration programs.

## Log Corrections

Recognizing the effects of the mineralogy on the log signature characteristics is important. Many prolific sands have been overlooked in the past because their potentials were not apparent on logs.

The descriptions of the mineralogy were used along with grain density measurement data from Core Laboratories to estimate the matrix density of the Cottage Grove Sandstone. The average matrix density of the Cottage Grove Sandstone in the North Concho area is 2.66. This is close to the matrix density value of 2.65 used for sand analysis by most service companies. Therefore, the standard 2.65 matrix density was used in this study.

Log porosities were compared to the Core Laboroatories porosity results and the visual estimations of porosity obtained from thin section analysis. Visual porosity estimations and porosity data from Core Laboratories were close in comparison. Core Lab porosity values were then plotted with the neutron-density log signature for a comparison. An example of Core Lab porosity values plotted with the neutron-density log signatures can be seen in Figure 47. The porosity values were similar except in areas where the gamma ray log signature indicated increasing mud. Here, the Core Lab values decreased in porosity and permeability and the neutron log signature increases in porosity. This is common for a neutron signature in the presence of shale.

The relative abundances of the clays from the Armacost 19-1 well were determined by x-ray diffraction methods and compared to the induction log responses (Figure 48). The mineralogy appears to have affected the induction log response to a moderate degree due to the presence of clays. Clays are conductive because of their high adsorbed water content (caused by surface charges and high surface areas). Adsorbed water provides a conductive pathway and increases conductivity. Thus, clays serve to increase conductivity and suppress the induction log response. There appears to be a decrease in the deep resistivity curve where the relative abundance of illite increases. A suppression

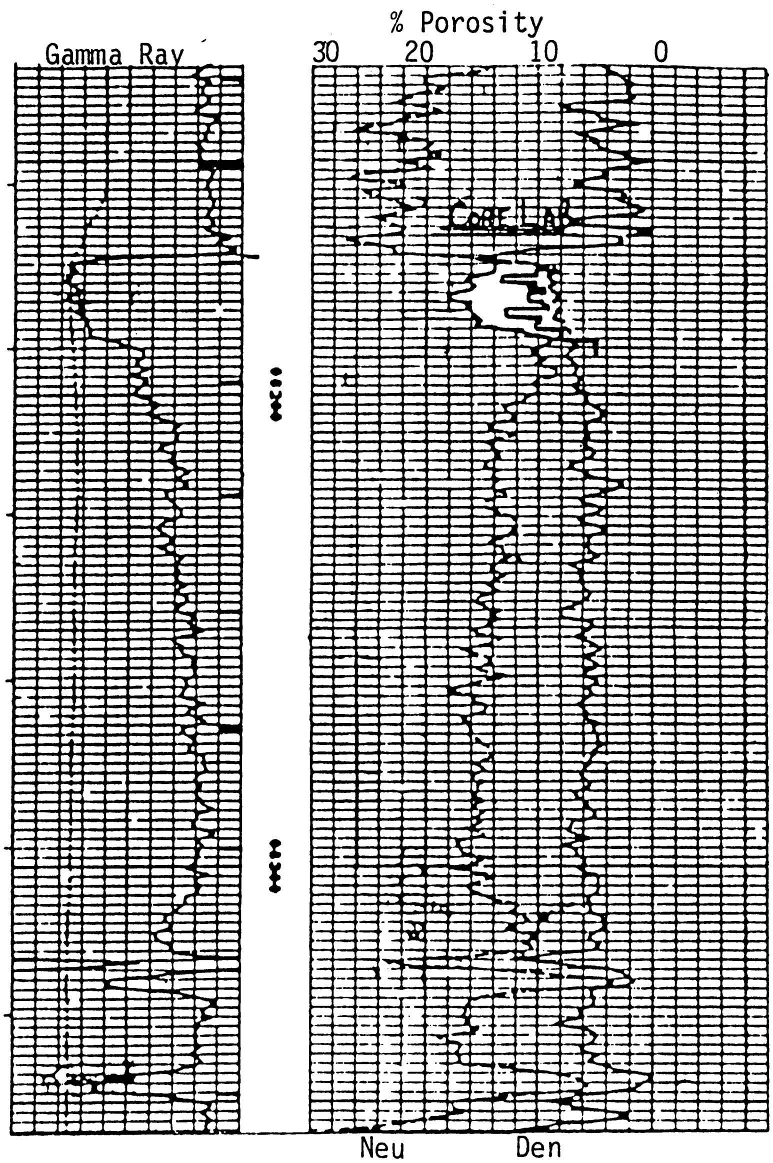



Figure 47. Correlation of Core Laboratories Porosity with Neutron-Density Log from the Armacost 19-1 Well

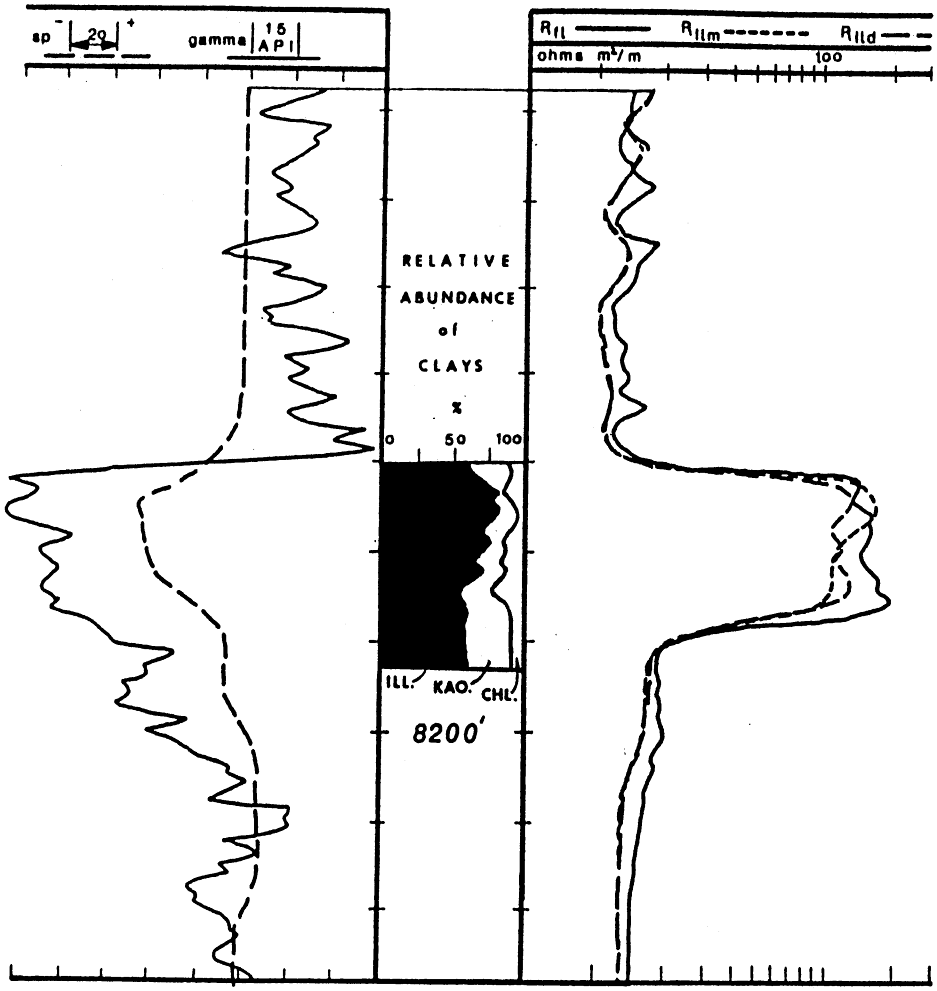



Figure 48. Relative Abundances of Clays Present in the Armacost 19-1 Core with Induction Log Responses.

resulting in the resistivity will cause water saturation calculations made using the induction log response to be pessimistic.

The mineralogy has a very minor effect on the gamma ray log due to the low percentages of potassium-rich minerals. An abundance of these minerals would create an increase in API gamma ray units and cause the entire interval to appear shaly. Negligable amounts of potassium-rich framework grains insures that an increase of API units on the gamma ray signature results from the presence of shale. Comparison of the gamma ray to the relative abundances of the clays in Figure 48 reveals an increase in the relative abundance of the potassium-rich illite clay where the gamma ray deflects to the right. The overall percentage of clays increases towards the underlying interlaminated sand and shale.

Water saturation in the Armacost 19-1 well was calculated at two foot intervals using an RW value of 0.03 ohms (at formation temperature). Water resistivity was determined from water samples in the field. Water saturation calculations were made using uncorrected and somewhat suppressed deep induction log responses; therefore, as stated above, the saturations are pessimistic and represent a worst case scenario (Asquith, 1982). The results of these calculations can be seen in Figure 49. The water saturation values calculated for the Armacost 19-1 well correlated well with actual production results. The comparisons made from all relevant data justify the reliability of future open hole log analysis in the area.

## North Concho Oil Field Production

Several cored wells in the North Concho Field were analyzed for economics and related to completion techniques and permeabilty. The

**ARMACOST 19-1**
**C SW NE**
**19-13N-8W**

**KB** =1398'
**TD** =8400'
**BHT** =150 F
**RW** =0.03 @ 147 F
**Rm** =1.7 @ 51 F
**Rmf** =1.4 @ 51 F
**Rmc** =2.2 @ 51 F

$$SW^2 = \frac{F \times Rw}{RT}$$

$$F = \frac{0.81}{\phi^2}$$

| Depth | RW | RT | ØD | ØN | Ø | F | SW (%) |
|---|---|---|---|---|---|---|---|
| 8172 | 0.03 | 90 | 14 | 10 | 12.1 | 55.3 | 13.6 |
| 8174 | 0.03 | 125 | 15 | 8.5 | 12 | 56.3 | 11.6 |
| 8176 | 0.03 | 117 | 16 | 9 | 12.7 | 50.2 | 11.3 |
| 8178 | 0.03 | 110 | 17 | 9 | 13.3 | 45.8 | 11.2 |
| 8180 | 0.03 | 112 | 17 | 9 | 13.3 | 45.8 | 11.1 |
| 8182 | 0.03 | 112 | 16 | 8 | 12.3 | 53.5 | 12.0 |
| 8184 | 0.03 | 117 | 15.5 | 8 | 12 | 56.3 | 12.0 |
| 8186 | 0.03 | 100 | 14 | 7.5 | 11 | 66.9 | 14.2 |
| 8188 | 0.03 | 30 | 9 | 7 | 8 | 126.6 | 35.4 |

Figure 49. Armacost 19-1 Log Calculations.

major controlling factor on production seems to be permeability and well position within the sand body. Wells penetrating 6 feet of sand or less generally are too tight to produce economically. The ideal location for a well in the North Concho Field seems to be at the northern end near the updip pinchout in sand thicknesses greater than six feet. Here the wells have the highest initial production and the largest amounts of cumulative reserves. There are cases of wells within the channel system with high permeabilities and sand thicknesses less than 6 feet.

Several different completion techniques were applied to the Cottage Grove Sandstone in the North Concho Field. Open hole completion stimulated with 37,500 gallons of 7.5% gelled acid and 51,000 pounds of 20/40 sand was performed on the Elmenhorst 29-2 well (see Plate 1). Average permeability in the completion interval was 18 millidarcies with an average "maximum permeability" of 28 millidarcies. Maximum permeability was determined by Core Laboratories on each sample and is thought to represent fractures. The Elmenhorst 29-2 well was completed in April, 1984, and is located 6 miles south (down-dip) of the Armacost 19-1 well. Initial production from the Elmenhorst 29-2 well was approximately 400 bbls per month and has declined 50% per year. The major factor resulting in poor production in this well seems to be its downdip structural position in the field. Cumulative production to date is 2440 bbls.

The Burkhead 3-6 was completed in August, 1982, and is located 4 miles up-dip from the Armacost 19-1. This well averaged 4 millidarcies permeability with an average "maximum permeability" of 51 millidarcies in the perforated interval. The well was stimulated with 20,000 pounds of sand and 28,000 gallons of slightly acidic water. Initial production from this well was approximately 8000 bbls per month and declines at 53% per year. This well is located around some of the best production in the field. Cumulative production to date is 79,052 bbls.

The Verna-Leighton 7-1 is located 3 miles north of the Armacost 19-1 and has an average permeability of 13 millidarcies. This well was completed in June, 1983. Maximum permeability tests were not performed on this core. After acid and frac the well produced approximately 4500 bbls per month and has had an annual decline of 47%. Cumulative production to date is approximately 49,000 bbls.

The OU #1 well had an average permeability of 14 millidarcies and an average "maximum permeability" of 133 millidarcies. This well is located 5 miles north of the Armacost 19-1 and is close to the pinchout of the sand in the north. It was completed in July, 1982. The initial production of this well was approximately 9300 bbls per month and has since declined at 63% annually. The OU #1 well was acidized with 1000 gallons of acid and fraced with 25,500 pounds of sand. The cummulative production to date is 63,703 Bbls.

## Armacost 19-1 Production History

The Armacost 19-1 was spudded on 10/21/81 and completed on 11/30/81 by Towner Petroleum Company. Total depth of the well was 8400 feet and the Cottage Grove Sandstone was encountered at 8170 (-6781). Production was initiated out of perforations from 8170-89 after stimulation. The stimulation procedures performed on the Armacost 19-1 well were as follows:

Acid Job

Perfs = 2 shots per foot from 8170 to 8189

2000 gallons 7.5% HCL and 52 ball sealers

4 barrels per minute

balled off to 4000 pounds

ISIP = 500 pounds

Frac Job

40,000 gallons gelled KCL water with 3% acid

52,500 pounds (20/40 sand)

maximum 2.5 pounds per gallon

40 barrels/minute at 3000 pounds

ISIP = 600 pounds

After 15 minutes = 500 pounds

The initial production from the Cottage Grove was 235 BOPD and 13 BW on a 24 hour test. Gas production was too small to measure. An economic analysis of Armacost production can be found in Figure 50. Casinghead gas was not added in the analysis. Cumulative casinghead production to date is 8 MMcf. Cumulative oil production to date is 32,377 Bbls. Average permeablity in the perforated interval was determined from core analysis and is also shown in Figure 50.

Parameters used in the economic analysis were estimated from similar offset wells when correct values were unknown. Average monthly operating expenses for a Cottage Grove well in the North Concho Field are $1,500. The Armacost well has had mechanical problems resulting in prolonged shut in periods. It is possible that the operating expenses for the Armacost well have exceeded an average of $1,500 per month. An oil price of $26 was used in the evaluation. Average completed well

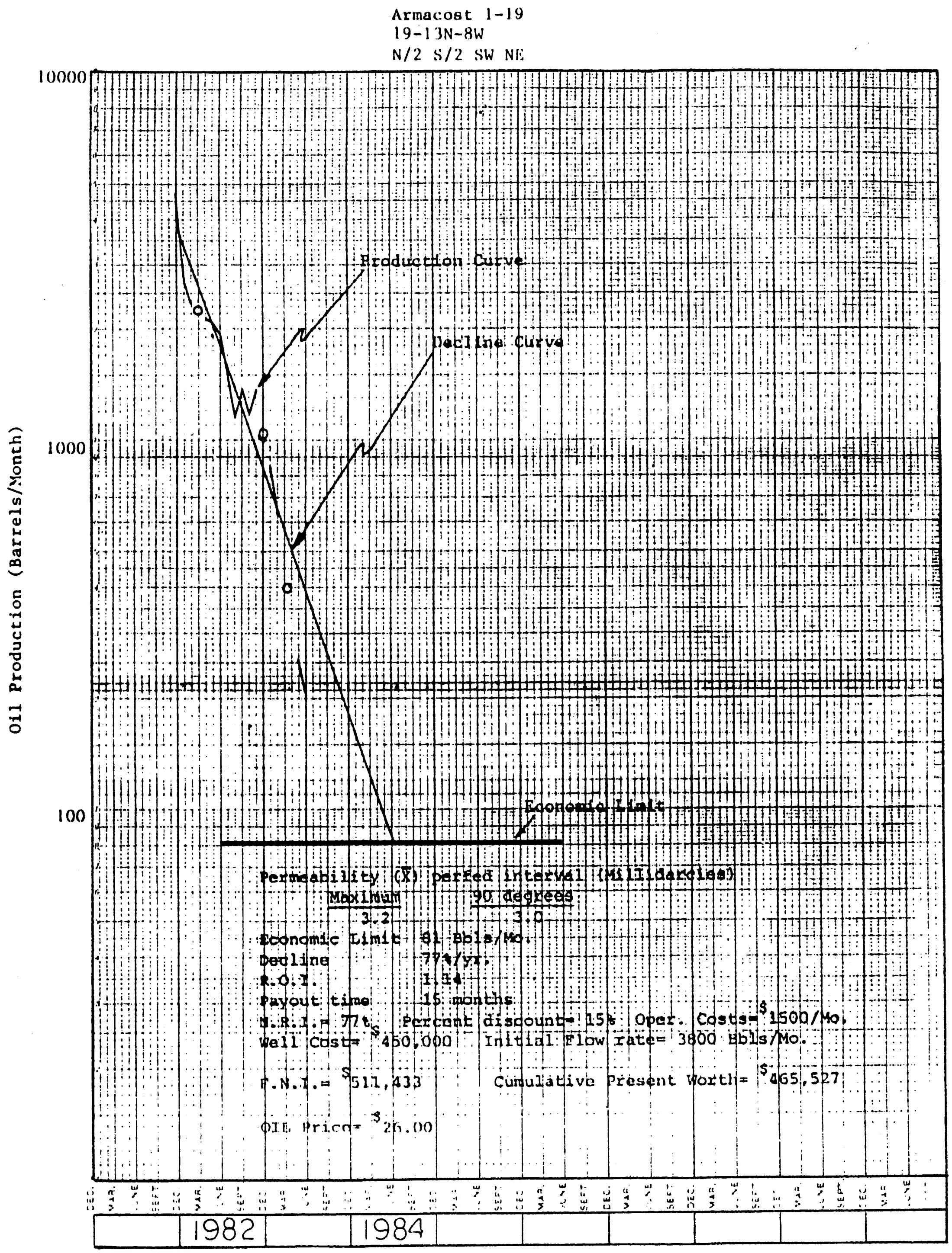



Figure 50. Decline Curve and Economic Analysis of the Armacost 19-1 Well

cost in the area is $450,000. Net revenue interest for the well is estimated at 77% and a present worth discount of 15% was used. All oil production was plotted and a best fit decline curve was drawn through the production curve. This resulted in an initial flow rate of 3,800 bbls per month with an annual decline rate of 77% per year. An economic limit of 81 bbls per month was calculated and any production less than this would result in a finacial loss. The future net income for the gross ultimate reserves is $511,433 with a cumulative present worth of $465,527. Based on this evaluation, payout time will occur at 15 months of production and the return on investment is 1.14:1.

The Davis OU #1 well was also economically evaluated and is shown in Figure 51. This well has higher permeability and is located several miles up-dip from the Armacost 19-1 well.

## Completion Evaluation

Comparisons of completion methods and production results from the cored wells also suggests that better wells seem to be controlled by permeability and location within the sand body. The Glenn Miller 29-1 was completed approximately 1.5 miles northeast of the OU #1, penetrating approximately 6 feet of sand with greater than 10% porosity. This well was drilled with foam, open hole completed, and stimulated with diesel to keep water contamination to a minimum. The frac apparently screened out, indicating a tight sandstone. Several wells in the southern, down-dip section of the field were also completed using this procedure. Special attention was given to these wells during drilling and completion so that very minimal amounts of water contamination would occur. None of these wells are economically

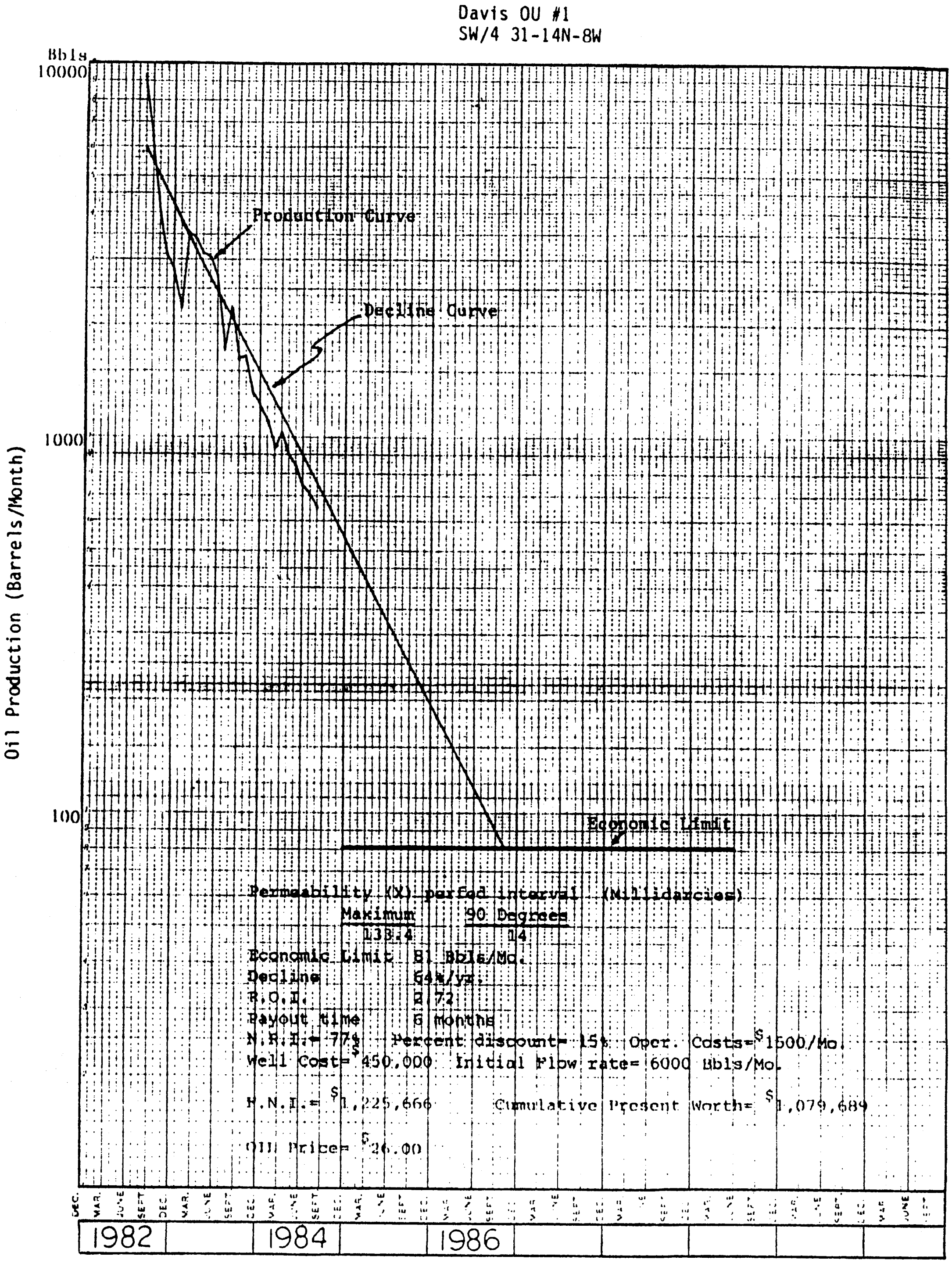



Figure 51. Decline Curve and Economic Analysis of the OU No. 1 Well

feasible and good sections of sand with high porosity and permeability are present in each well. This demonstrates the importance of placing the wells within the permeability barrier created by the sand pinchout and the importance of the structural location of the wells. Several of the older wells completed in the high production area were stimulated with weak acid and sand only and no caution was taken to prevent water contamination. Those wells recieving water contamination from drilling fluids, cementing techniques, and stimulation appear to have no formation damage. These wells were not cored, therefore permeability and mineralogical information were not available. However, the mineralogy of the other cores in the North Concho area was consistant, suggesting a uniform mineralogical content.

## Fluid Sensitivities and Exploitation

The Cottage Grove Sandstone demonstrates porosity and permeability capable of holding and producing hydrocarbons. This sand also shows potential for fines migration and sensitivity to hydrochloric acid. Illite and kaolinite can easily migrate from their pore sites upon turbulent flow in the reservoir. The low percentages of these two clays in the area reduces the chances of formation damage. However, a clay stabilizer mutual solvent system should be added to the completion fluids to prevent possible fines migration and subsequent permeability damage. Hydrochloric acid will react with siderite and chlorite to form a ferric hydroxide gel in the reservoir rock. An iron sequestering agent should be added to the completion fluids to keep iron in solution. No clays in the Cottage Grove Sandstone are capable of swelling. Water adhesion to the clay surfaces is the only problem that results in a permeability reduction. The highest percentages of siderite and chlorite are consistantly found in the top two feet of the sandstone. The decrease in the porosity caused by this increase in carbonate material and chlorite can be detected by the induction log and the neutron-density log signatures. Perforations starting immediately below this porosity-plugged interval would reduce the chance of ferric hydroxide gel formation.

Ideal completion procedures to maximize hydrocarbon production with minimum damage to the formation are as follows:

The zone of interest should be perforated at four shots per foot in an unbalanced condition. The perforating solution should be a clean 2% KCL-based system. Swab or flow test for production.
If oil is the primary productive phase after perforation, a hydrocarbon-based breakdown and a gelled diesel and sand stimulation should induce the desired production. If production is not encountered after perforating and swabbing, the following breakdown is recommended:

7.5% hydrochloric acid-based system
Clay stabilizer
Mutual Solvent
Iron sequestering agent
Nonionic surfactants

If oil is the primary productive phase after breakdown, a gelled diesel and sand stimulation is recommended.

Formation damage is not common in the Cottage Grove Sandstone in the North Concho area due to the low percentages of sensitive minerals. The preceding completion procedure is recomended to insure no formation damage in an area that is possibly enriched in sensitive minerals.

## Reservoir Characteristics

The first well in the Upper Cottage Grove Sandstone in the North Concho Field was completed in 1960. A wireline test that was opened for 45 minutes recovered a slight show of gas and had a shutin bottom hole pressure of 2875 psi after 3 minutes. This well is located in 6-12N-8W. Initial production from the well was 143 barrels of oil per day. Cummulative production as of December, 1984 was 160,277 bbls of oil. This well produced for some time before any other Cottage Grove wells were drilled in the area. North Concho Field development started approximately 20 years after the initial well when the potential of the Cottage Grove was recognized. A few wells were drilled in the area before major field development began.

The North Concho Field produces solely as the result of the expansion of natural gas liberated from solution from the oil (Solution-gas drive). Bottom hole pressures from the northern end of the field indicate initial reservoir pressure to be approximately 3442 psi, a gradient of 0.43 psi per foot. Initial GOR values for the field varied between 350-400 scf/stb. Recently GOR values at the northern end of the field have increased dramatically. Some GOR's have increased to 45,000 scf/stb while the average is approximately 1,500 scf/stb. Pressures in the field have obviously declined below the bubble point. Secondary mobile gas saturation is probably migrating to the up-dip end of the field. Future production will be affected by relative permeability factors. The initial estimated recovery factor in the North Concho Field was 100 bbls per acre foot. It has since been approximated to a present recovery factor of 85 bbls per acre foot.

Production in the field seems to be controlled by structural position of the sand and proximity to the channel systems.

## CHAPTER X

## CONCLUSIONS

Conclusions concerning results determined from this study are listed in this chapter. All conclusions were derived with respect to the Upper Cottage Grove Sandstone in the North Concho Field unless specifically noted. The principal conclusions of this study are as follows:

1. The North Concho Field is located within an area characterized by gentle basinward warping on a relatively stable "shelf" setting. No significant structural closures were contoured.

2. There appears to be no consistant relationship between the structure maps and Cottage Grove Sandstone thickness. This suggests that regional warping occurred after Cottage Grove deposition and any structural relief or closure is a compactional phenomenon resulting from the dewatering and warping of the basin.

3. Stratigraphic and sedimentologic evidence suggest the present structural dip is reversed from the depositional dip.

4. The Cottage Grove Sandstone is of a marine origin and represents an elongate, fan-shaped, north-south trending sand body ranging from 0 feet in thickness in the north (pinchout) to 40+ feet in the southern part of the study area. The deltaic deposit was classified as a high-constructive, elongate delta.

5. This updip sand pinchout is the stratigraphic hydrocarbon trap responsible for oil and gas production.

6. Basal contacts with the underlying sand/shale facies are abrupt to gradational and the contact with the overlying black shale is abrupt.

7. The presence of the underlying Lower Cottage Grove Sandstone appears to have had an effect on the distribution of the Upper Cottage Grove Sandstone.

8. A distinct coarsening-upward sequence is present from the base of the underlying sand/shale facies to the top of the sand.

9. Channels were detected in core and compared to log signatures to enable the location of channel trends.

10. The common vertical sequence of sedimentary structures from the basal contact with the underlying sand/shale sequence is as follows: rip-up clasts, small-scale cross-stratification, herring bone cross-stratification, interstratification, small-scale cross-stratification, and bioturbation. Soft sediment deformation occurs with all of these structures. Not all of the sedimentary structures are always present and the order of them may vary slightly depending on the location of the core within the sand body.

11. Marine fossils and bioturbation were common at the top of the sand and found in traces throughout the entire interval. The top of the sand is characteristic of an abandonment stage from a deltaic-splay.

12. Distribution of the sand, mineralogical content, texture, and basin subsidence comparisons indicate the Cottage Grove sediment source was the Ouachita uplift of Southeastern Oklahoma.

13. The Cottage Grove Sandstone was classified as a sublith-arenite. The sands are uniformally very fine to fine grained. Average framework grain size varies from 0.08 mm near the base of the sand to 0.17 mm at the top. The sand is well to very well sorted and subangular to subrounded.

14. Secondary porosity is the dominant porosity type in the Cottage Grove sand. Primary porosity occurs in negligible amounts.

15. Dissoulution of authigenic carbonate, detrital clay matrix, and direct framework dissolution are the major mechanisms responsible for the generation of secondary porosity in the reservoir sand.

16. The areal distribution of porosity in the area reflects the distribution of the channels within the sand splay. Porosities generally range between 5 and 13 percent.

17. The depositional system produced certain lithofacies with differing petrophysical characteristics which later controlled the migration of fluids through the sand after burial. The depositional system also governed initial pore fluids which seem to have played an important role in the present porosity trends.

18. The mineralogy of the sand appears to have affected the induction log and porosity logs moderately; and had a very minor affect on the gamma ray log.

19. Water saturation calculations in the field appear to correlate closely with actual production results.

20. Minerals sensitive to completion procedures are present in low percentages in the sand. However, water-free completion procedures are recommended to insure no formation damage in areas that are possibly enriched in sensitive minerals.

21. Production in the field appears to be controlled by the structural position of the sand and proximity to the channel systems.

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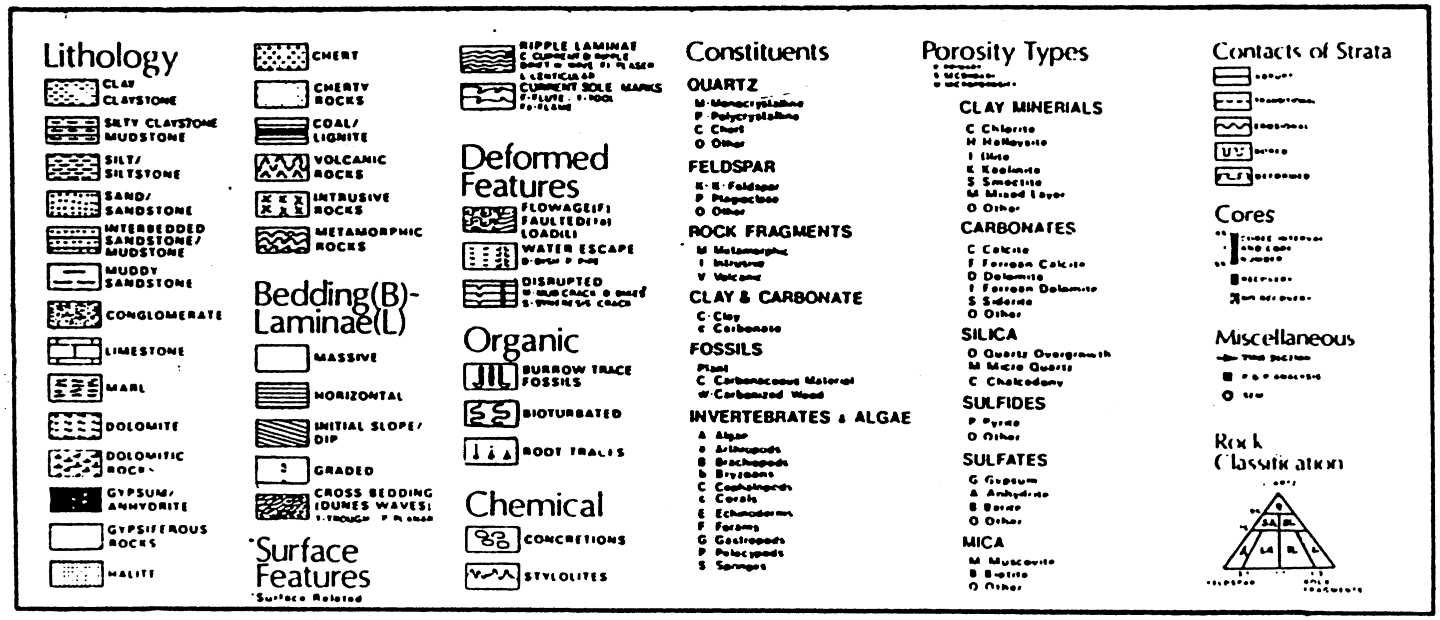
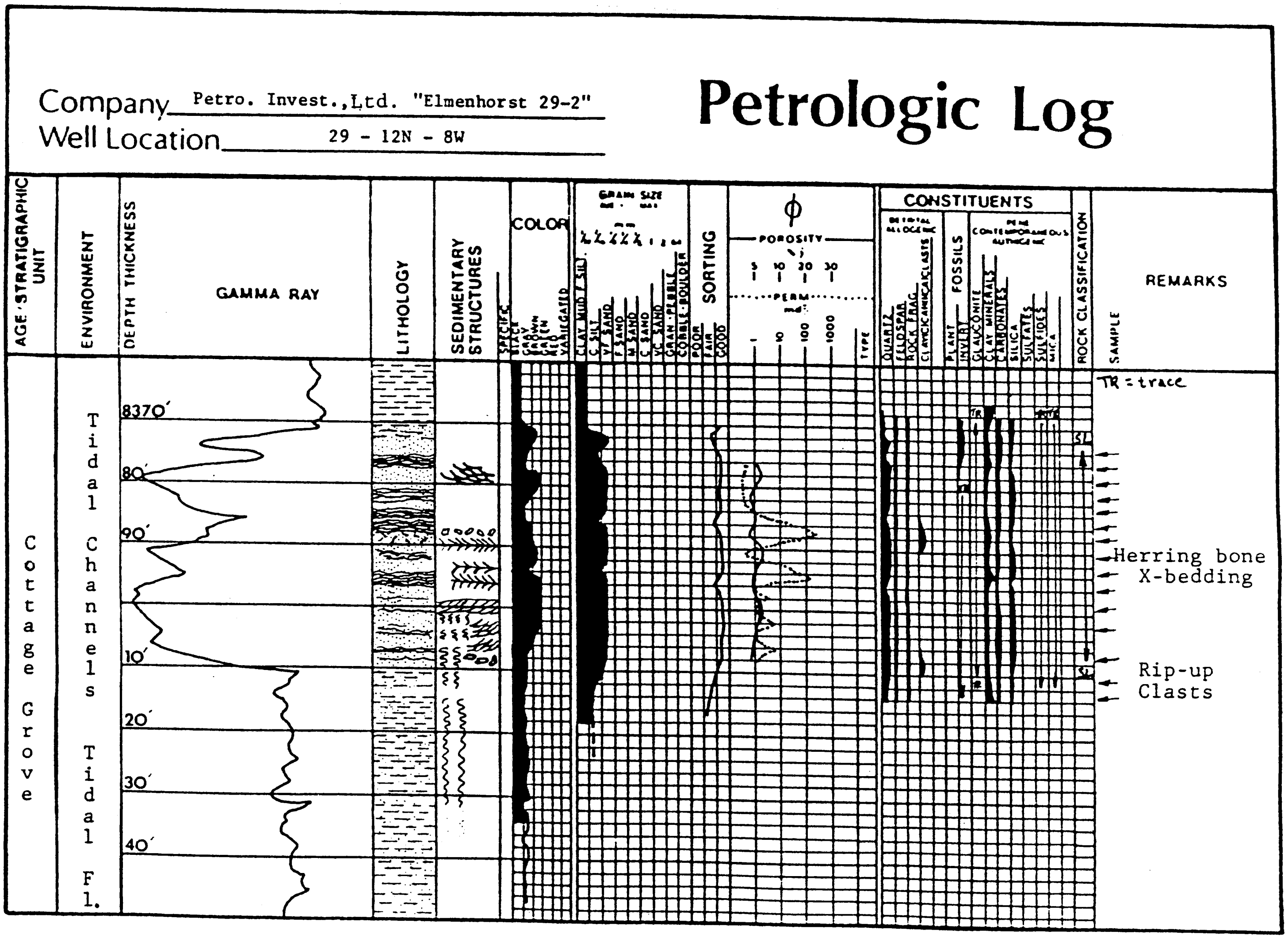
# APPENDIX

## CORE ANALYSIS DATA




Key Symbols Used in Petrologic Logs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Company Petro. Invest.,Ltd. "Elmenhorst 29-2"
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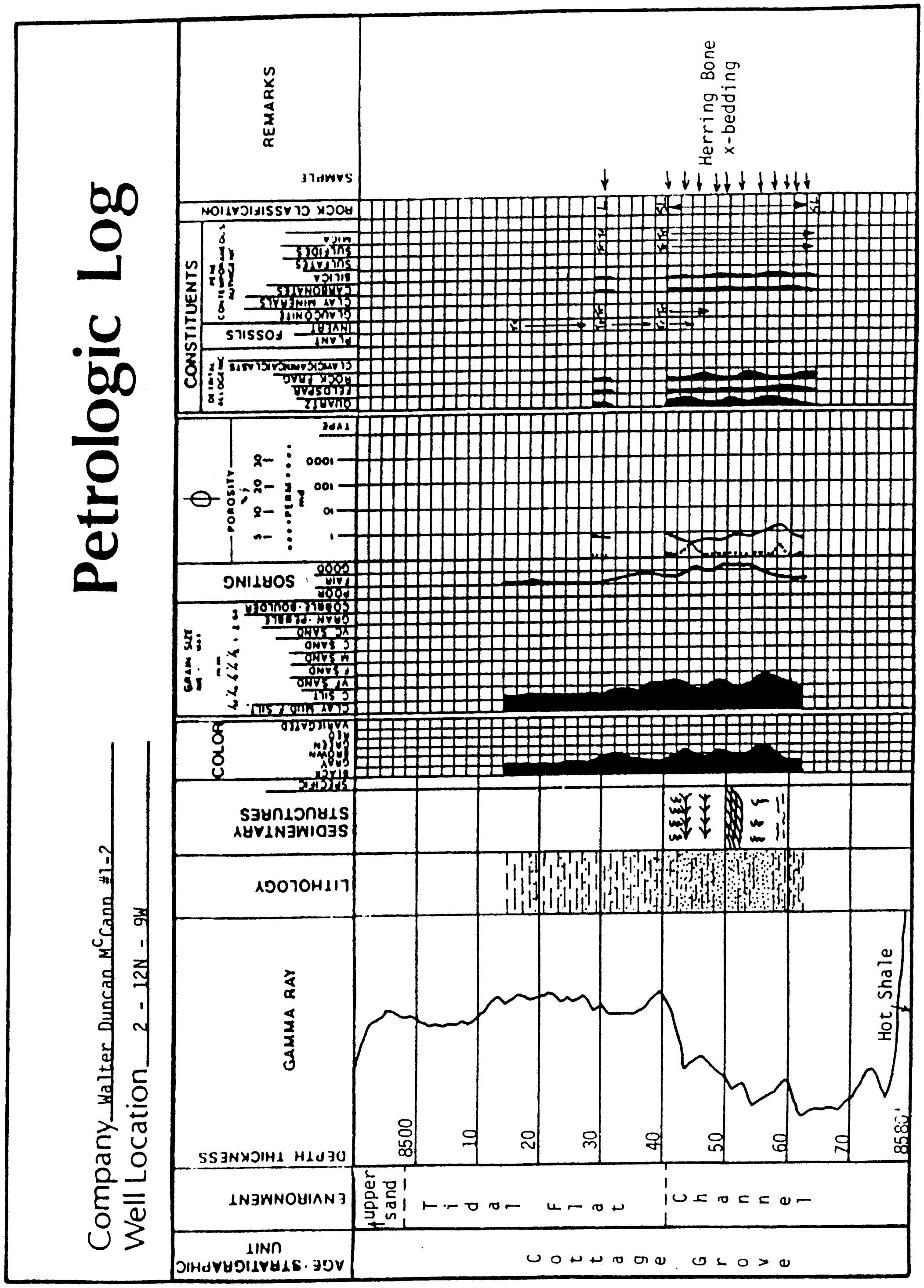
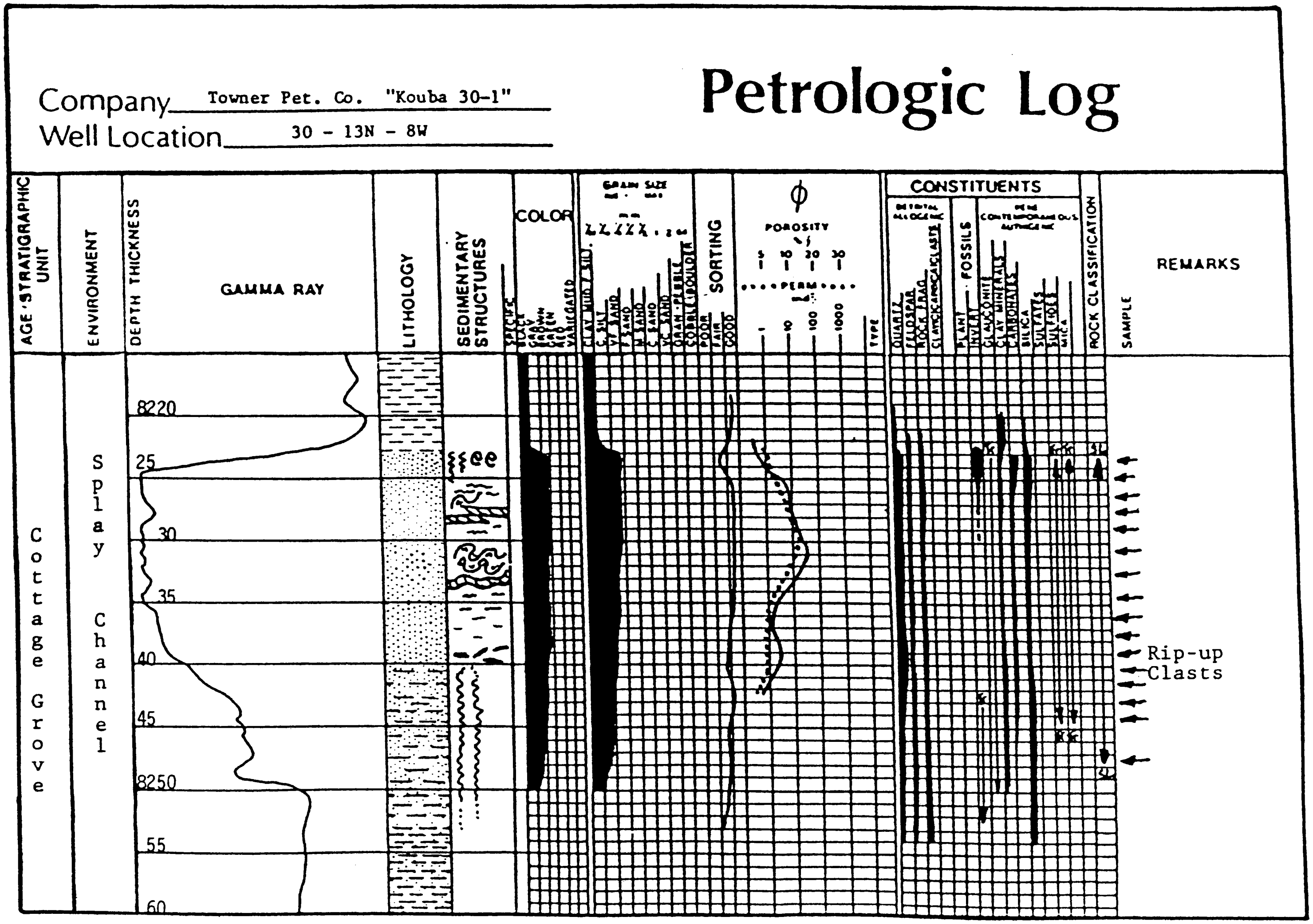
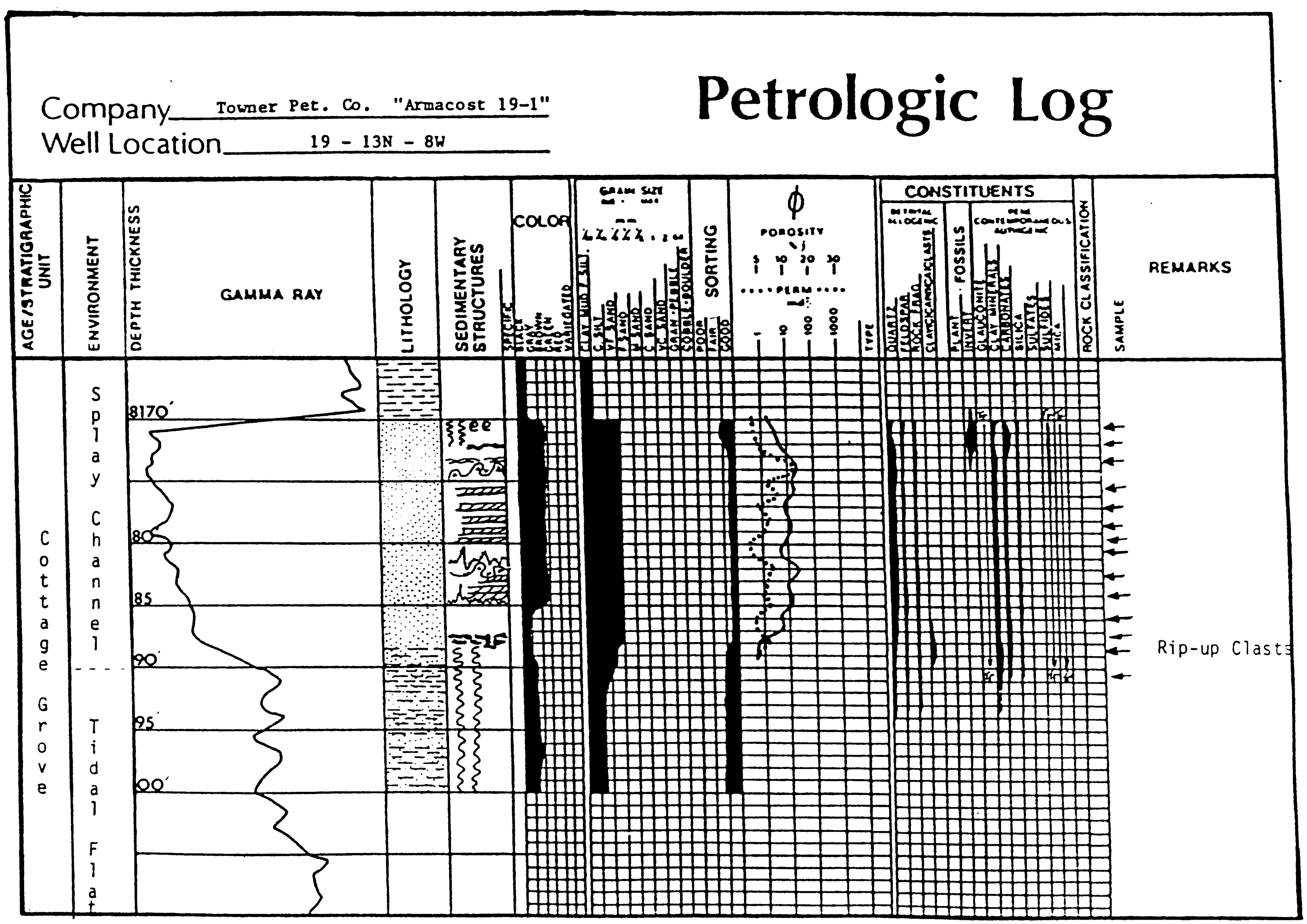
AGE-STRATIGRAPHIC UNIT
ENVIRONMENT
DEPTH THICKNESS
GAMMA RAY
LITHOLOGY
SEDIMENTARY STRUCTURES
COLOR
GRAIN SIZE
SORTING
POROSITY
PERM
CONSTITUENTS
FOSSILS
ROCK CLASSIFICATION
SAMPLE
REMARKS
Cottage Grove
Tidal Channels
Tidal Fl.
8370'
80'
90'
10'
20'
30'
40'
TR = trace
Herring bone X-bedding
Rip-up Clasts



Petrologic Log
Company Walter Duncan McCann #1-2
Well Location 2 - 12N - 9W
AGE STRATIGRAPHIC UNIT
ENVIRONMENT
DEPTH THICKNESS
GAMMA RAY
LITHOLOGY
SEDIMENTARY STRUCTURES
COLOR
SORTING
POROSITY
PERM
CONSTITUENTS
FOSSILS
ROCK CLASSIFICATION
SAMPLE
REMARKS
Herring Bone x-bedding
Hot Shale
8500
10
20
30
40
50
60
70
Upper Sand
Tidal Flat
Channel
Cottage Grove

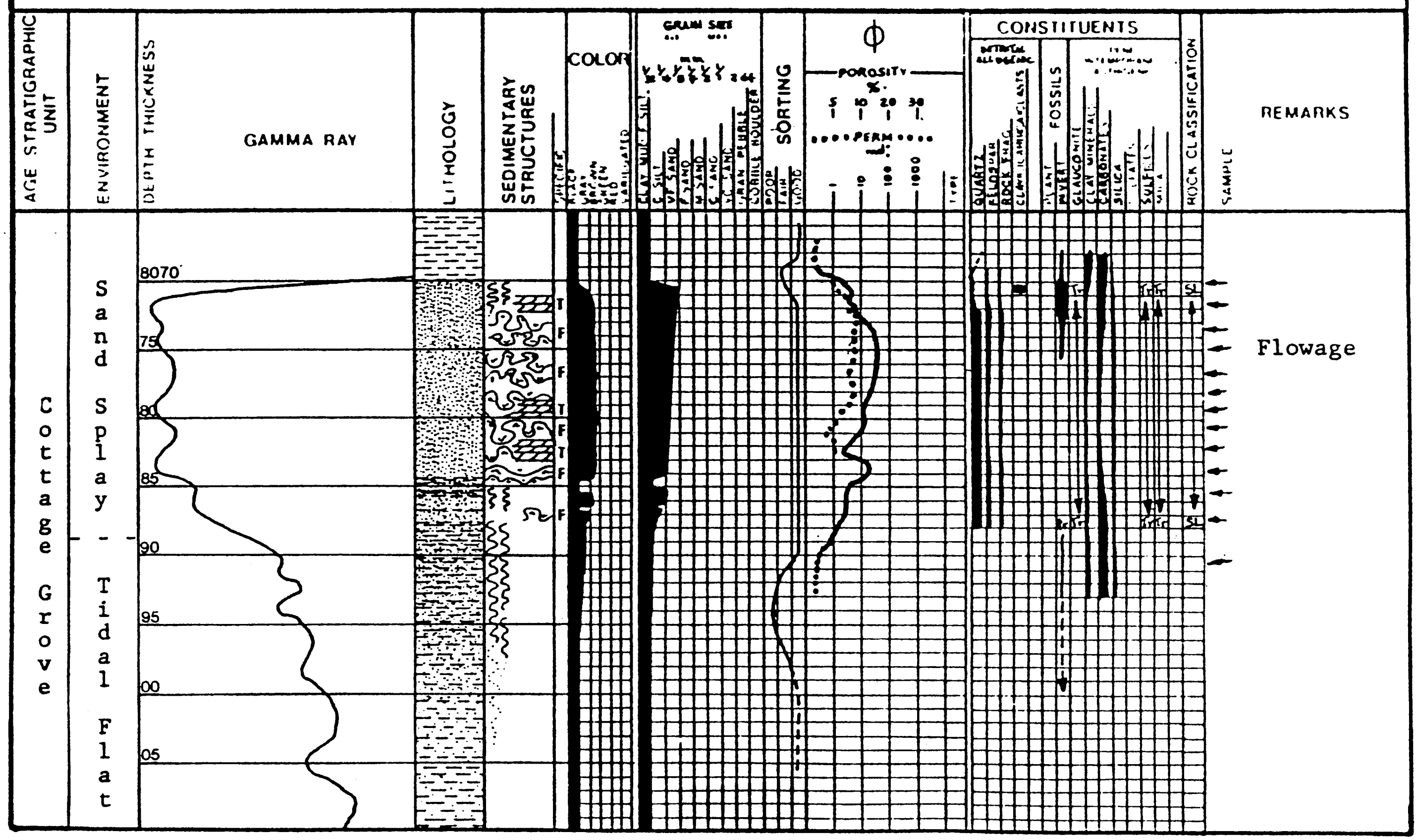

Petrologic Log
Company Towner Pet. Co. "Kouba 30-1"
Well Location 30 - 13N - 8W
AGE-STRATIGRAPHIC UNIT
ENVIRONMENT
DEPTH THICKNESS
GAMMA RAY
LITHOLOGY
SEDIMENTARY STRUCTURES
COLOR
SORTING
POROSITY
PERM
CONSTITUENTS
FOSSILS
ROCK CLASSIFICATION
SAMPLE
REMARKS
8220
25
30
35
40
45
8250
55
60
Cottage Grove
Splay Channel
Rip-up Clasts

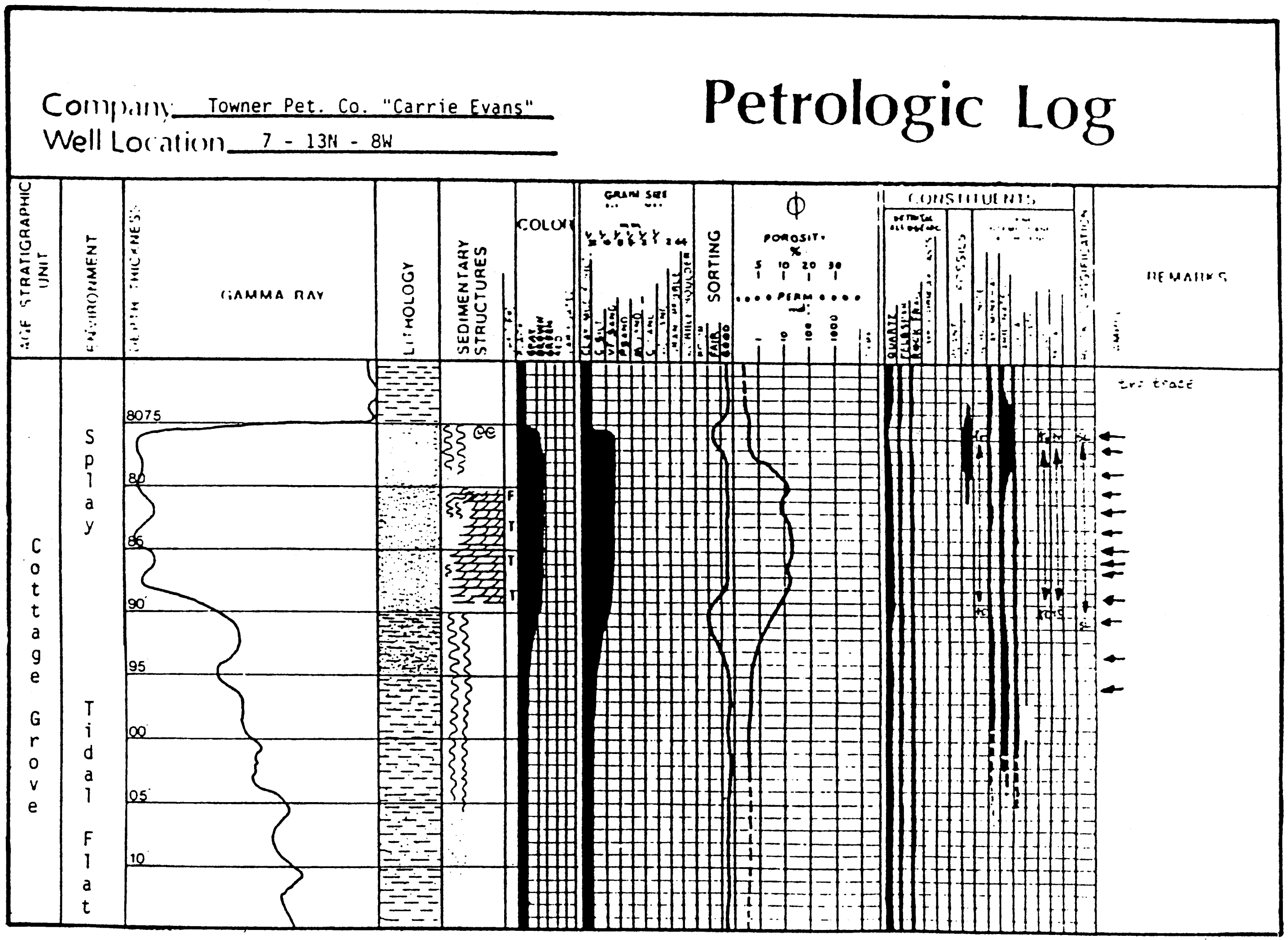

Petrologic Log
Company Towner Pet. Co. "Armacost 19-1"
Well Location 19 - 13N - 8W
AGE/STRATIGRAPHIC UNIT
ENVIRONMENT
DEPTH THICKNESS
GAMMA RAY
LITHOLOGY
SEDIMENTARY STRUCTURES
COLOR
SORTING
POROSITY
PERM
CONSTITUENTS
FOSSILS
ROCK CLASSIFICATION
SAMPLE
REMARKS
Cottage Grove
Splay Channel
Tidal Flat
8170'
80
85
90'
95'
00'
Rip-up Clasts

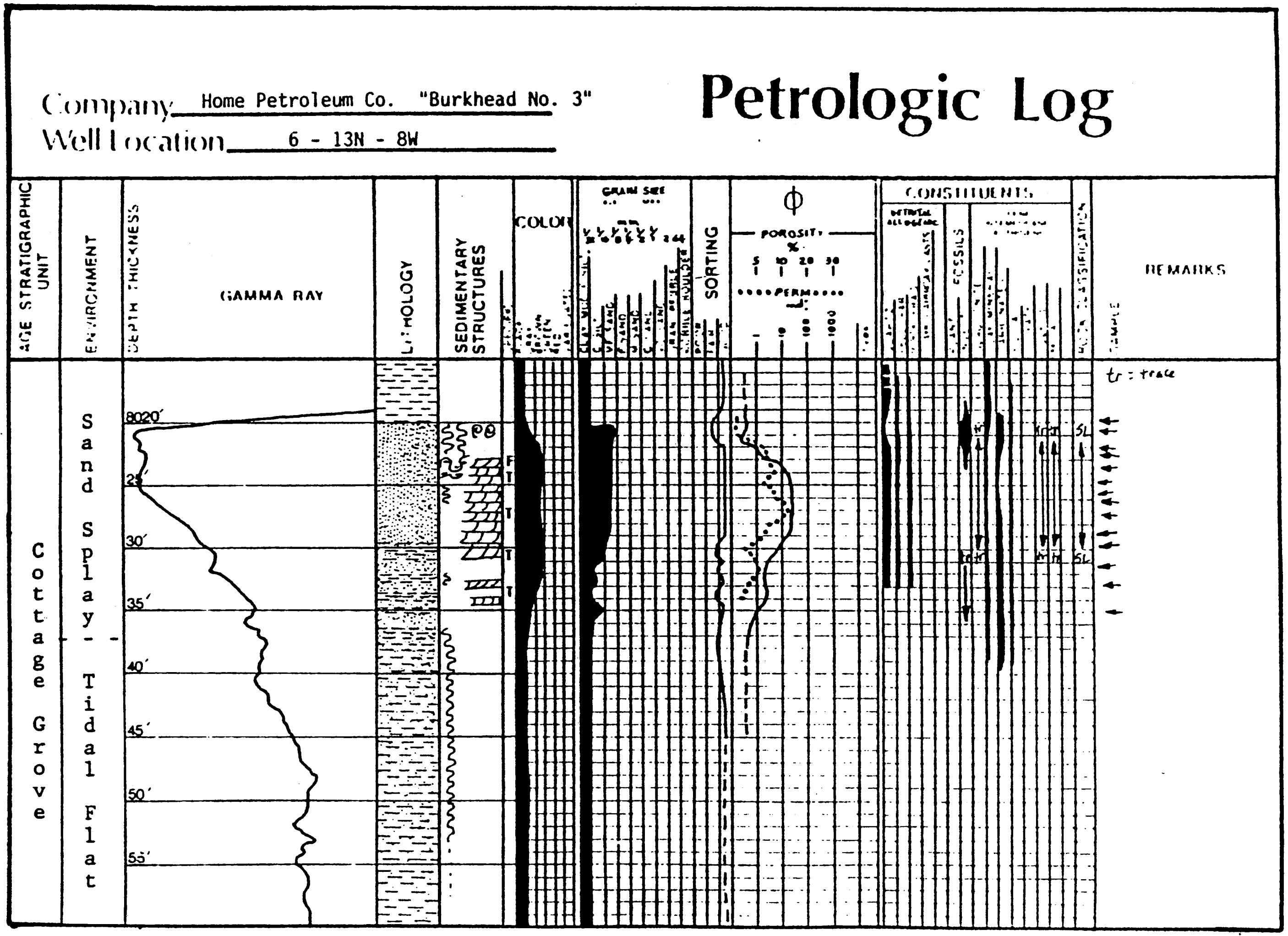
Company Towner Pet. Co. "Verna - Leighton"

Well Location 7 - 13N - 8W

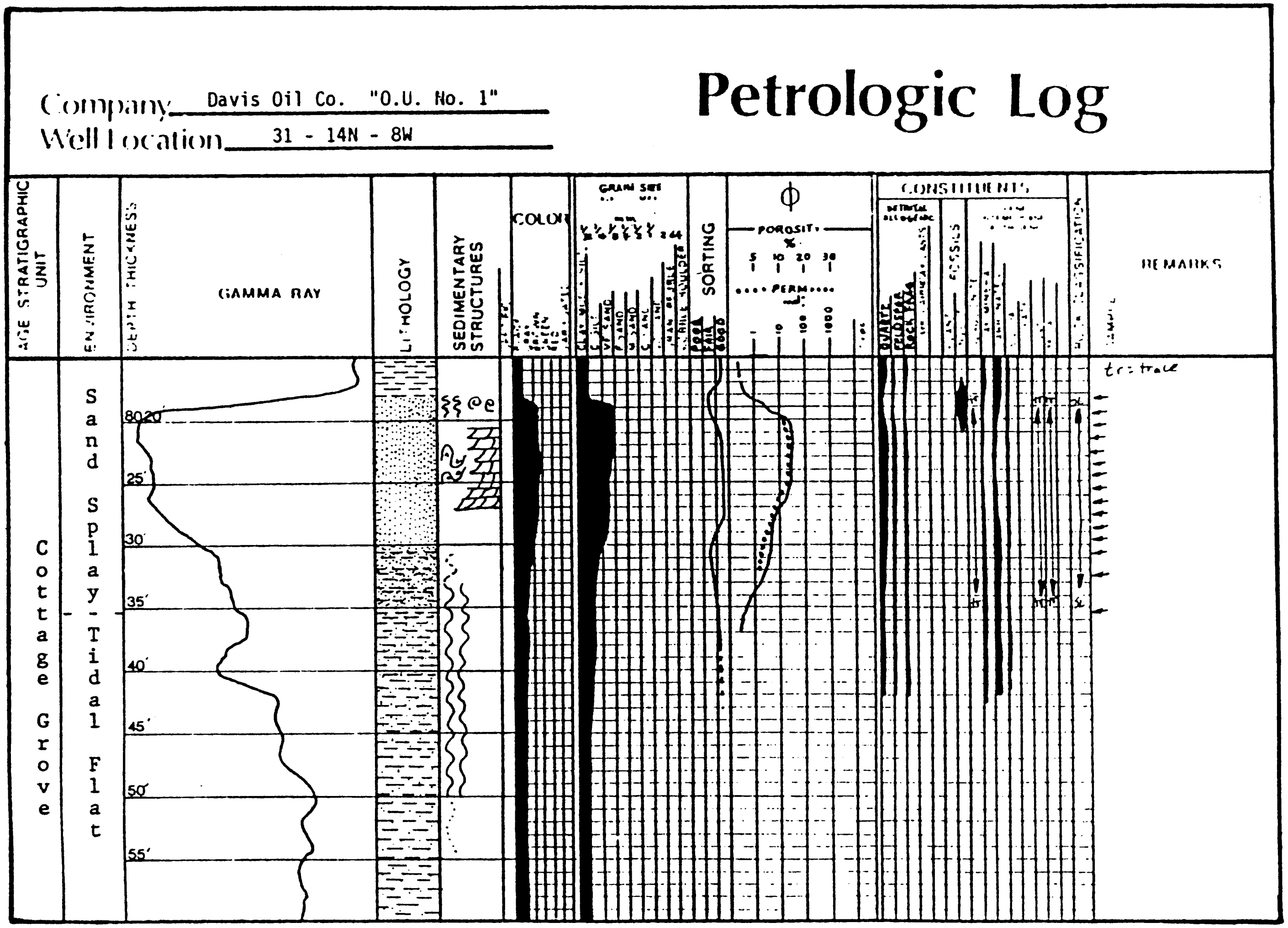
# Petrologic Log




Company: Towner Pet. Co. "Carrie Evans"
Well Location: 7 - 13N - 8W
Petrologic Log
AGE STRATIGRAPHIC UNIT
ENVIRONMENT
DEPTH THICKNESS
GAMMA RAY
LITHOLOGY
SEDIMENTARY STRUCTURES
COLOR
SORTING
POROSITY %
5 10 20 30
PERM
CONSTITUENTS
REMARKS
8075
80
85
90
95
00
05
10
Cottage Grove
Splay
Tidal Flat



Company Home Petroleum Co. "Burkhead No. 3"
Well Location 6 - 13N - 8W
Petrologic Log
AGE STRATIGRAPHIC UNIT
ENVIRONMENT
DEPTH THICKNESS
GAMMA RAY
LITHOLOGY
SEDIMENTARY STRUCTURES
COLOR
GRAIN SIZE
SORTING
ϕ
POROSITY %
5 10 20 30
PERM
CONSTITUENTS
FOSSILS
REMARKS
tr = trace
Cottage Grove
Sand Splay
Tidal Flat
8020′
25′
30′
35′
40′
45′
50′
55′



Company Davis Oil Co. "O.U. No. 1"
Well Location 31 - 14N - 8W
Petrologic Log
AGE STRATIGRAPHIC UNIT
ENVIRONMENT
DEPTH THICKNESS
GAMMA RAY
LITHOLOGY
SEDIMENTARY STRUCTURES
COLOR
GRAIN SIZE
SORTING
POROSITY %
5 10 20 30
PERM
1 10 100 1000
POOR FAIR GOOD
CONSTITUENTS
QUARTZ FELDSPAR ROCK FRAG
FOSSILS
REMARKS
tr: trace
Cottage Grove
Sand Splay-Tidal Flat
8020'
25'
30'
35'
40'
45'
50'
55'

# VITA

R. Bryan Waller

Candidate for the Degree of

Master of Science

Thesis: DEPOSITIONAL ENVIRONMENT, PETROLOGY, DIAGENESIS, AND PETROLEUM GEOLOGY OF THE COTTAGE GROVE SANDSTONE, NORTH CONCHO FIELD, CANADIAN COUNTY, OKLAHOMA

Major Field: Geology

Biographical:

Personal Data: Born in Great Bend, Kansas, August 14, 1961, the son of Mr. and Mrs. Robert L. Waller.

Education: Graduated from Piedmont High School, Piedmont, Oklahoma, in May, 1979; recieved Bachelor of Science degree in Geology from Oklahoma State University, in May, 1983; completed requirements for Master of Science degree at Oklahoma State University in December, 1985.

Professional Experience: Junior member of The American Association of Petroleum Geologists; member of the Oklahoma City Geological Society; member of the Society of Professional Well Log Analysts; Oil Field Pumper, Ramsey Engineering, 1978-1981; Geologist, Ramsey Property Management, 1983-Present.


# CROSS-SECTION AND CORE LOCATIONS

CORE = ◎

PLATE I



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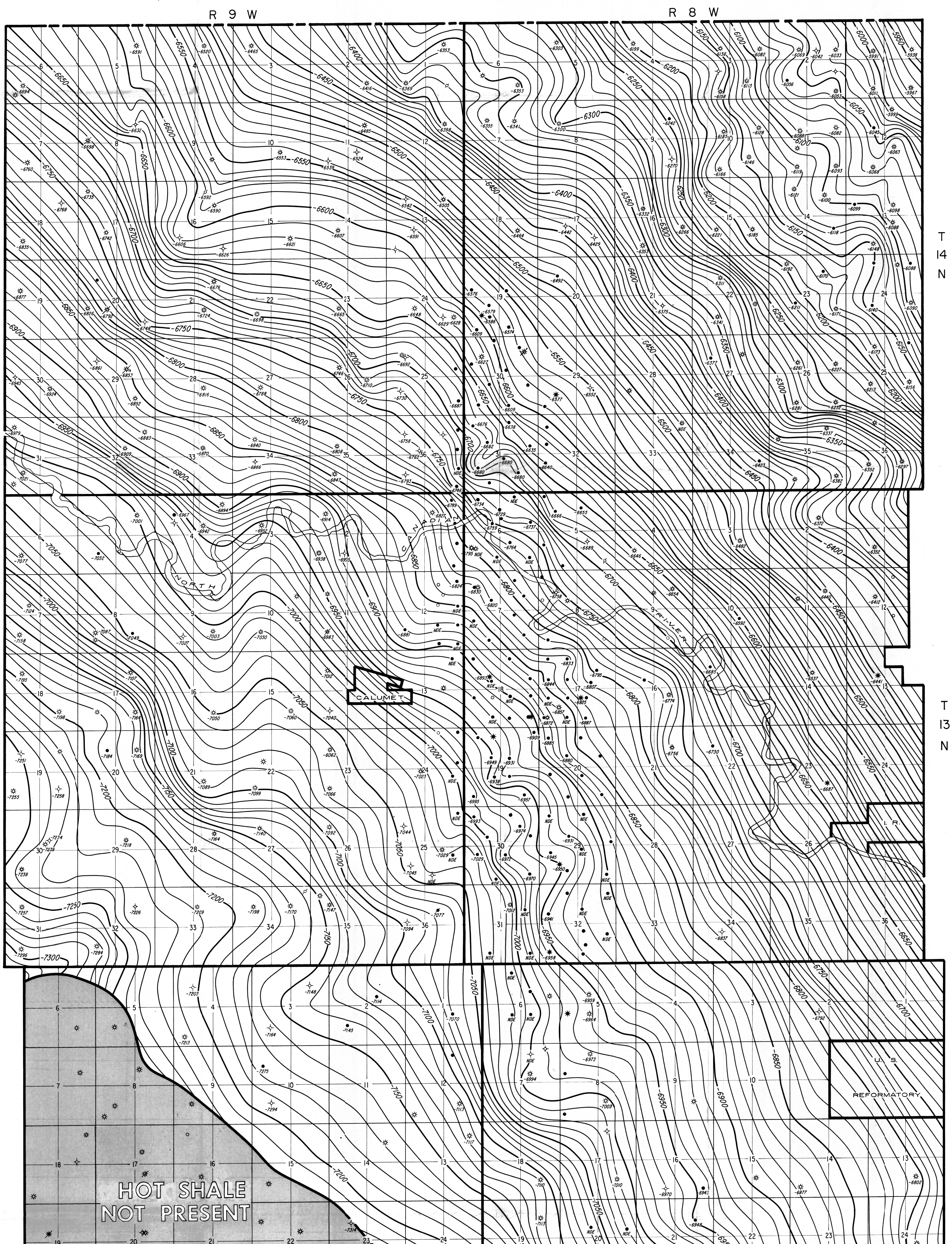


Structure Map
"HOT SHALE"
ON
TOP OF HOGSHOOTER LIME
C.I.=10'

PLATE 2



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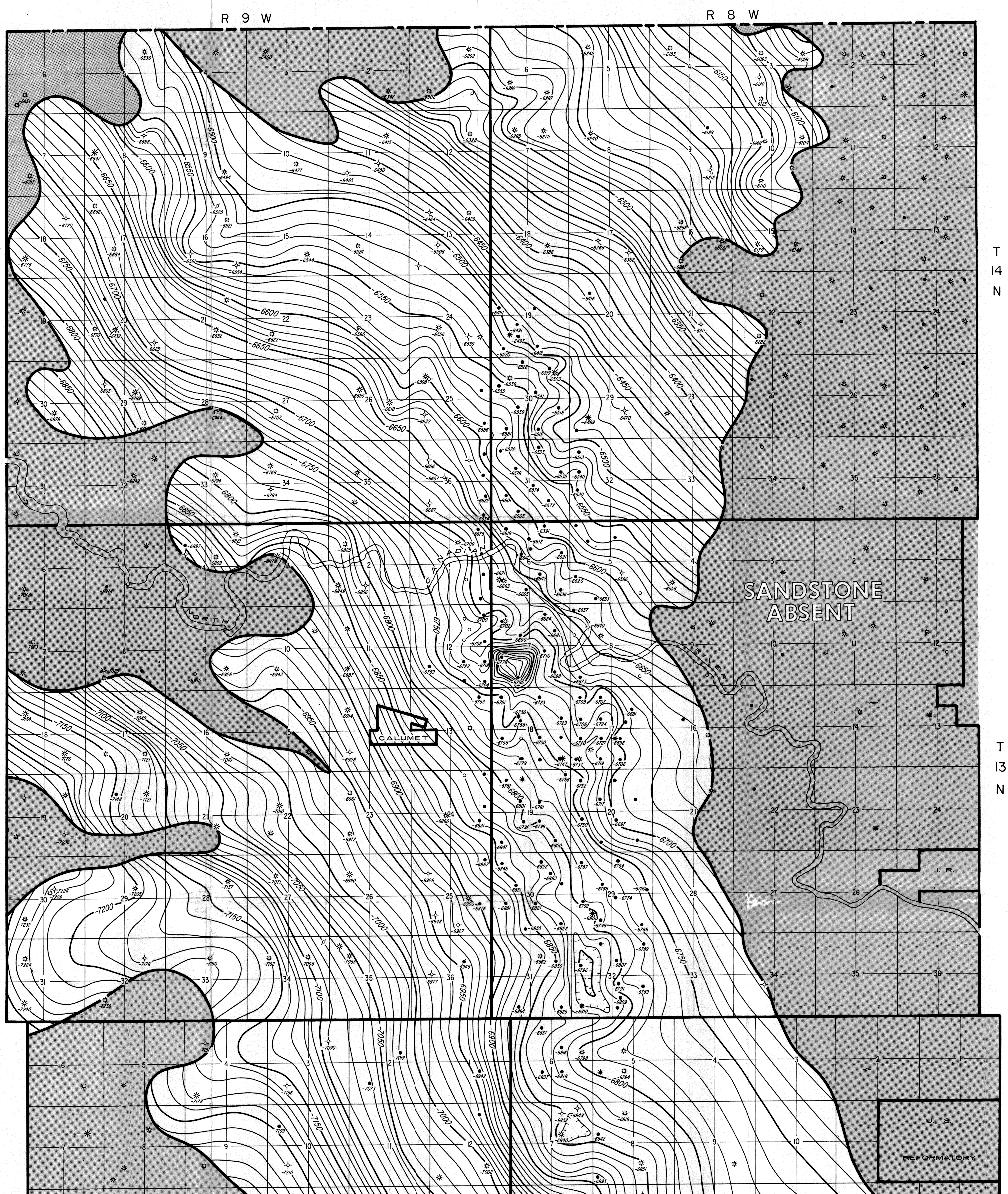


Structure Map

*TOP OF COTTAGE GROVE SS.*

C.I.=10'

PLATE 3

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Lithostratigraphic Cross-Sections
of
COTTAGE GROVE SANDSTONE
(SW-NE)
HORIZONTAL SCALE: 2"=1 Mile
VERTICAL SCALE: 2.5"=100'
DATUM: TOP OF SAND
LOG SIGNATURE CURVES ARE GAMMA RAY AND DEEP RESISTIVITY
A
CONTINENTAL OIL CO. Small Unit No. 1 31-14N-9W SW
TENNECO OIL CO. Woman Warrior No. 1-29 29-14N-9W NW
GETTY OIL CO. M.L. Harrington No. 2 21-14N-9W NE
UNIVERSAL RESOURCE CORP. Wilhoit No. 1-11 11-14N-9W SW
PHILLIPS PET. Billers "A" No. 1 11-14N-9W NE
CUMA OIL CO. Schweitzer "A" No. 1 1-14N-9W SW
PHILLIPS PET. CO. Alig Trust "A" No. 1 1-14N-9W NE
A'
DATUM
TOP OF UPPER SAND
"HOT SHALE"
B
CONTINENTAL OIL CO. H. Von tungelin Unit No. 1 29-13N-9W SW-NE
CONTINENTAL OIL CO. Ida McEvoy Unit No. 1 21-13N-9W NW-SE
CONTINENTAL OIL CO. Crowley No. 1 11-13N-9W SW
TOWNER PET. Bornemann No. 1-1 1-13N-9W C-W/2-NE
DAVIS OIL CO. O.U. No. 2 31-14N-8W SE-NW-SW
DAVIS OIL CO. Elsi Brooks No. 1 31-14N-8W SE-NE
O.I.L. ENERGY Rukes No. 1-29 29-14N-8W NW-SE
PAN AMER. PET. CORP. Schroder Unit No. 1 21-14N-8W NW-SE
PHILLIPS PET. CO. Rother No. A-1 15-14N-8W SW
ANDOVER OIL CO. Rother No. 11-4 11-14N-8W SE-SW
ANDOVER OIL CO. Rother No. 11-3 11-14N-8W SE-NE
ANDOVER OIL CO. Wittrock No. 1-3 1-14N-8W SE-SW
ANDOVER OIL CO. Wittrock No. 1-2 1-14N-8W SE-NE
B'
LOWER CHANNEL SAND
UPPER SPLAY SAND
"HOT SHALE"
DATUM
TOP OF UPPER SAND
C
JONES & PELLOW Fread No. 1 17-12N-9W SE
WOODS PET. CO. Boone No. 1 10-12N-9W SW
WALTER DUNCAN McCann No. 1 2-12N-9W SW
WALTER DUNCAN Audrey McCann No. 1 2-12N-9W SW-NE
HOOVER & BRACKEN Ellison No. 1 36-13N-9W SW-SW-SE-NW
DAVIS OIL CO. Coffey No. 1-36 36-13N-9W NE
SAMEDAN OIL CORP. Crowley No. 1 31-13N-8W W/2-NE/4
DAVIS OIL CORP. Nitzel No. 1 29-13N-8W SW-SW-NE-SW
TOWNER PET. CO. Mesch Berger No. 21-1 21-13N-8W NE
TOWNER PET. CO. Lorena No. 15-1 15-13N-8W NW
LAGUNA PET. CO. LaFlore No. 1-11 11-13N-8W NE
C'
DATUM
TOP OF UPPER SAND
UPPER "SPLAY" SAND
UPPER CHANNEL SAND
"HOT SHALE"
D
ANDOVER OIL CO. Courtney No. 30-1 30-12N-8W NE
L.G. WILLIAMS Kullman No. 1 29-12N-8W NE
PETROLEUM INVESTMENTS, LTD. Hunt No. 28-1 28-12N-8W NW-NW
UNION OF CALIF. Reuter No. 1-21 21-12N-8W 1420' FSL & 1320' FEL
UNION OF CALIF. Irene Brown No. 1-21 21-12N-8W 1520' FNL & 1320' FEL
PORTS OF CALL OIL CO. Swingle No. 16-1 16-12N-8W SE-SE
UNION OF CALIF. U.S. Government No. 1-2 2-12N-8W NE-SW
D'
DATUM
TOP OF UPPER SAND
"HOT SHALE"
UPPER TIDAL CHANNEL SAND
LOWER CHANNEL SAND
R 9 W
R 8 W
T 14 N
T 13 N
T 12 N
PLATE 4
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Lithostratigraphic Cross-Sections
of
COTTAGE GROVE SANDSTONE
(NW-SE)
HORIZONTAL SCALE: 2"=1 Mile
VERTICAL SCALE: 2.5"=100'
LOG SIGNATURE CURVES ARE GAMMA RAY AND DEEP RESISTIVITY
E
PHILLIPS PET. CO.
Hufnagel "A" #2
6-14N-8W
SE
CUMA OIL CO.
Hufnagel "
8-14N-8W
NW
ANDOVER OIL CO.
Nicholson #16-1
16-14N-8W
SE NW
SANTA FE & ANDOVER OIL CO.
Biller #16-1
16-14N-8W
SW
PHILLIPS PET.
Bomhoff #B-1
23-14N-8W
NE
PHILLIPS PET
Wiewel No. A-1
36-14N-8W
N/2-SE
E'
UPPER SPLAY S.S.
DATUM
TOP OF UPPER SAND
HOT SHALE
F
PETROLEUM INC.
Tech Unit #1
6-14N-9W
C-SW
KAISER FRANCIS OIL
Tech #1
8-14N-9W
W/2 W/2
TEXAS OIL&GAS CORP.
Kennedy #1
16-14N-9W
SE SE SE
PAN AM PET. CORP.
Smith Unit "G" #1
22-14N-9W
SW NE SW
PAN AM PET. CORP.
Steanson No. 1
26-14N-8W
SE-NW
AMOCO PROD. CO.
Steanson Unit No. 2
26-14N-9W
250' S OF C-E/2
KELLOIL, INC.
Hanson Farms No. 1
36-14N-9W
SE-SE-NW
AUSTIN PROD. CO.
Synder No. 1-36
36-14N-9W
SE-SE-SE
HOME PET. CORP.
Burkhead No. 1-6
6-13N-8W
NW-SE
SAMEDAN OIL CORP.
Spear No. 1-8
8-13N-8W
C-NW
SANTE FE MINERALS
Gordon Miller No. 16-2
16-13N-8W
SW NW
TOWNER PET. CO.
England No. 22-1
22-13N-8W
C-NW
F'
UPPER SPLAY SANDSTONE
DATUM: TOP OF UPPER SAND
G
UNION OIL of CALIF.
Penwright Unit #1-6
6-13N-9W
SW
SINCLAIR OIL & GAS
Wilson Unit #1
8-13N-9W
AMOCO PROD. CO.
L.K. Payne Unit #2
17-13N-9W
SE
CONTINENTAL OIL CO.
Ida McEvoy Unit #1
21-13N-9W
NW SE
AMOCO PROD. CO.
Lowder "A" #1
22-13N-9W
SW
PAN AM PET. CORP.
Crump Unit No. 1
26-13N-9W
NW
DAVIS OIL CO.
Coffey No. 1-36
36-13N-9W
NE
TEXAS OIL & GAS CORP.
Calumet No. 1
6-12N-8W
S/2-SE/4-NE/4
TXO PROD. CO.
Heckes No. 1
8-12N-8W
660' FNL & 1980' FWL
TEXAS OIL & GAS CORP.
Wier No. 1
8-12N-8W
SE
PORTS OF CALL OIL CO.
Swingle No. 16-1
16-12N-8W
C-SE-SE
JONES & PELLOW OIL CO.
Branelly No. 22-1
22-12N-8W
SW
JONES & PELLOW OIL CO.
LaFollette No. 26-1
26-12N-8W
SW
G'
LOWER CHANNEL SANDSTONE
UPPER SPLAY (CHANNEL) SANDSTONE
DATUM: TOP OF UPPER SAND
UPPER TIDAL CHANNEL SANDSTONE
LOWER CHANNEL SANDSTONE
"HOT SHALE"
R 9 W
R 8 W
T 14 N
T 13 N
T 12 N
PLATE 5
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SOUTH
NORTH
SAMEDAN OIL CORP. Smith No. 1-20 20-12N-8W SE-NW
SAMEDAN OIL CORP. Lorenzen No. 1 18-12N-8W C-SE/4
SAMEDAN OIL CORP. Henry Jo No. 1-7 7-12N-8W SW-NE
TOWNER PET. CO. Virginia No. 30-1 30-13N-8W SE-SE
ANDOVER OIL CO. Reese No. 18-1 18-13N-8W SE-NW
TOWNER PET. CO. Jack Evans No. 7-1 7-13N-8W SE-NW
DAVIS OIL CO. Crouch No. 1 6-13N-8W C-N/2
MUSTANG PROD. CO. Heupel 30-14N-8W C-NW/4
PHILLIPS PET. CO. Schweitzer "C" No. 1 18-14N-8W C-SE/4
GR
Res
LIMESTONE MARKER
L. MEDRANO ZONE
DATUM: AVANT LIMESTONE
HEDLUND ZONE
COTTAGE GROVE SS.
UPPER "SPLAY" SANDSTONE
UPPER TIDAL CHANNEL SANDSTONE
HOGSHOOTER MARKER "HOT SHALE"
APPROXIMATE
PALEO-DIP DIRECTION (Cottage Grove Deposition)
PRESENT DIP DIRECTION
North-South Statigraphic Cross-Section
AVANT TO HOGSHOOTER
★ —COTTAGE GROVE PRODUCER
LOG SIGNATURE CURVES ARE GAMMA RAY AND DEEP RESISTIVITY
HORIZONTAL SCALE: 2"=1 Mile
VERTICAL SCALE: 2.5"=100'
R. BRYAN WALLER
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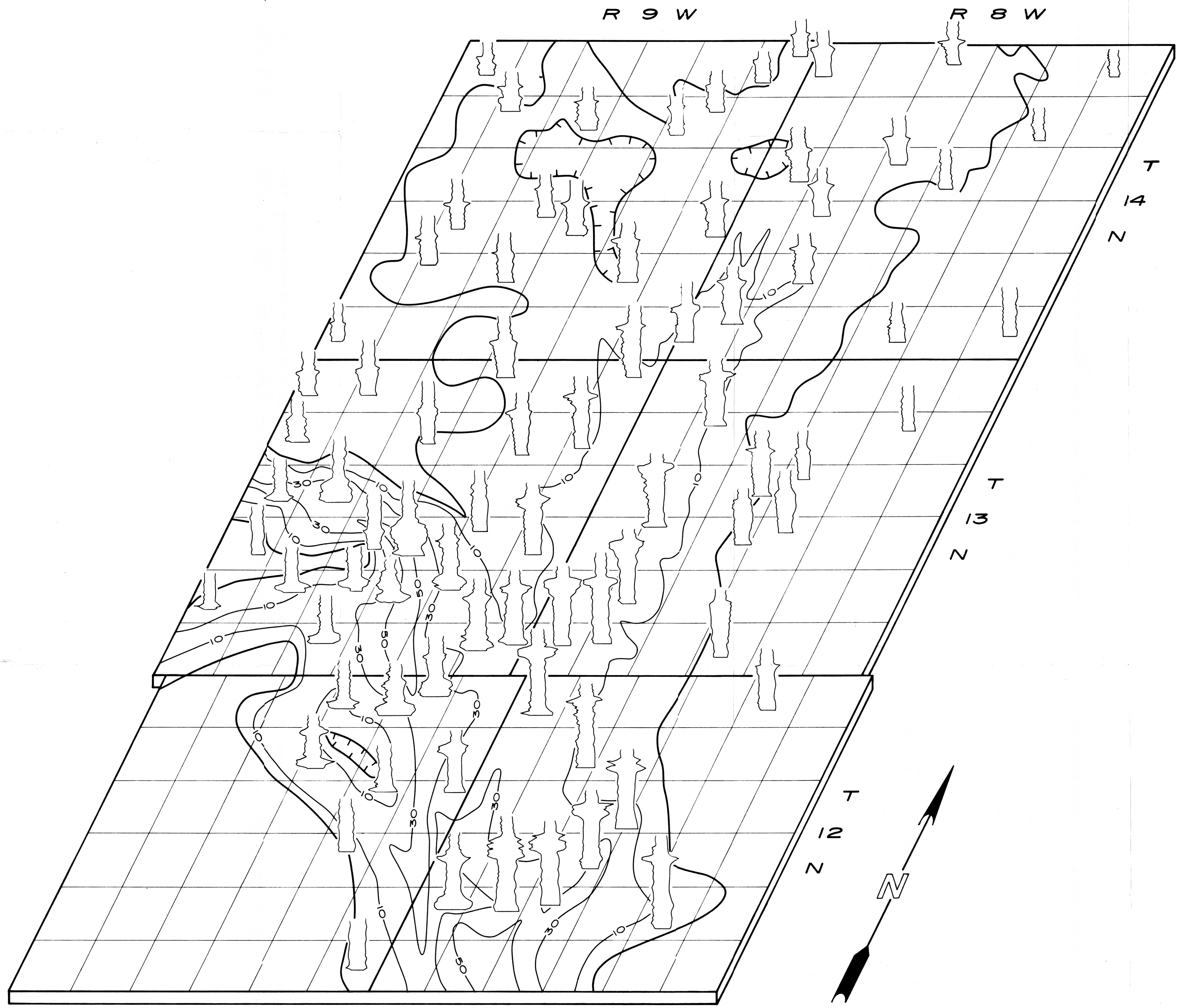
PLATE 6




# LOG SIGNATURE MAP

C.I. = 20'

PLATE 7



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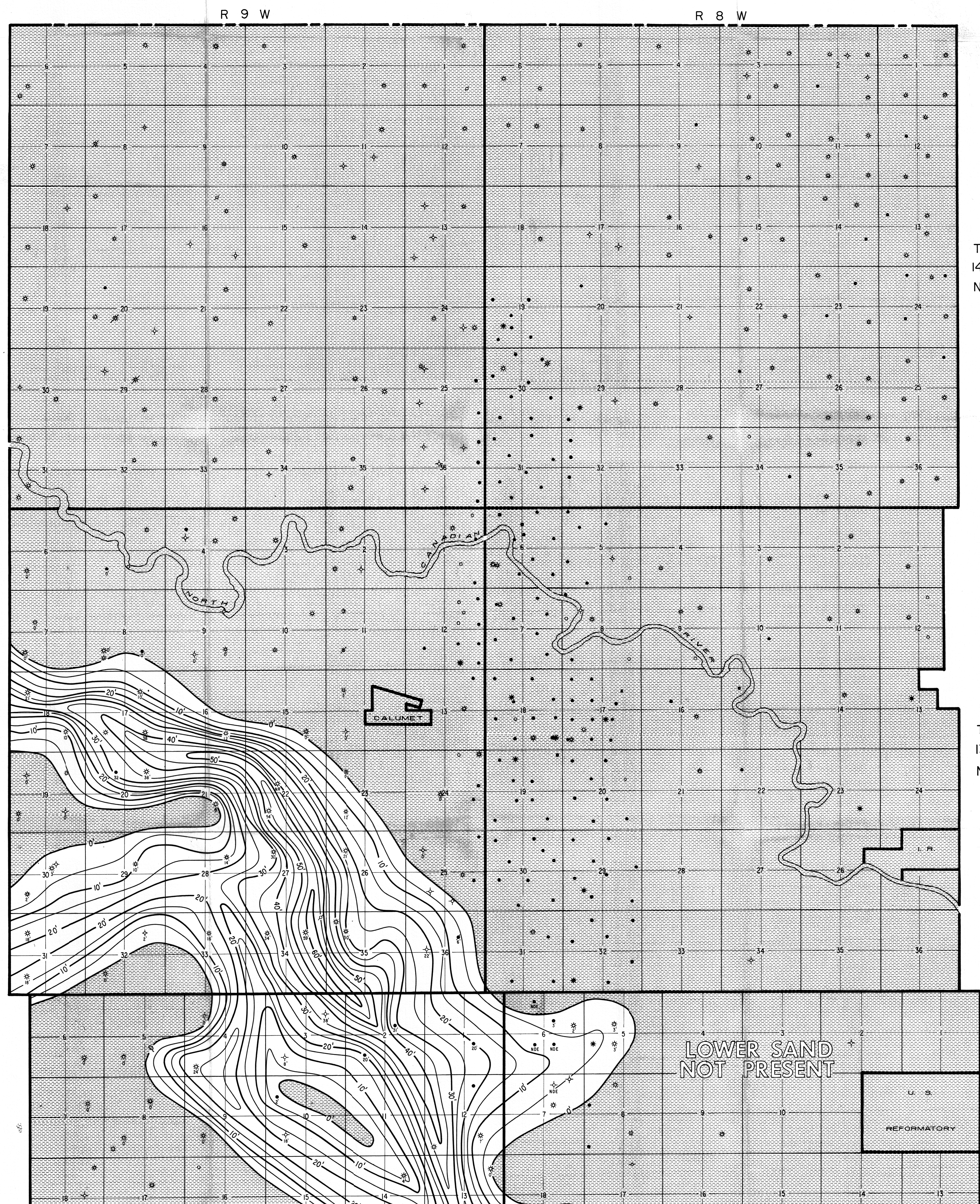


Gross Sandstone Isolith Map

"LOWER COTTAGE GROVE"

C.I.=5'

PLATE 8



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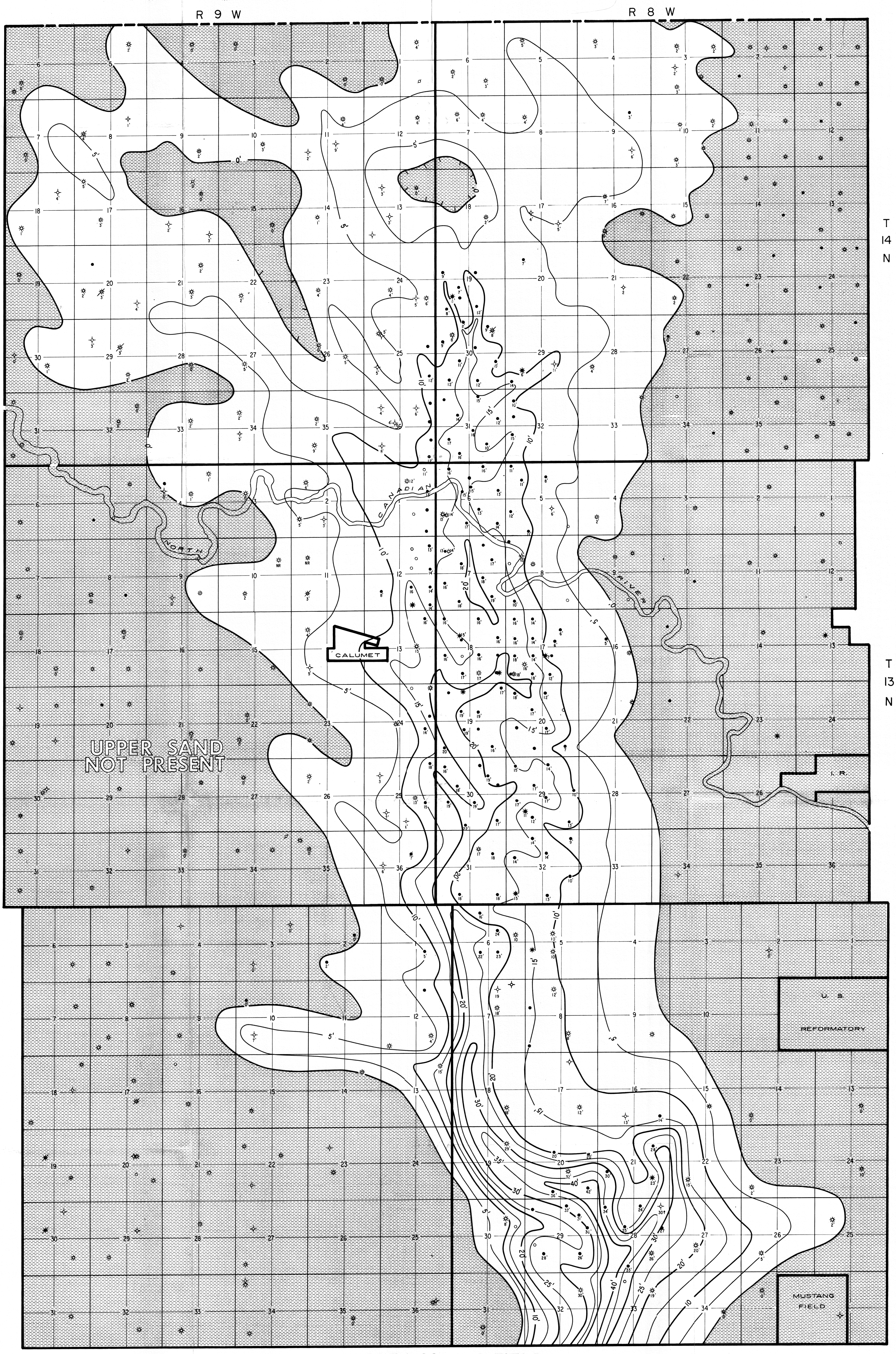


# NORTH CONCHO FIELD

Gross Sandstone Isolith Map

*"UPPER COTTAGE GROVE"*

C.I.=5'



PLATE 9

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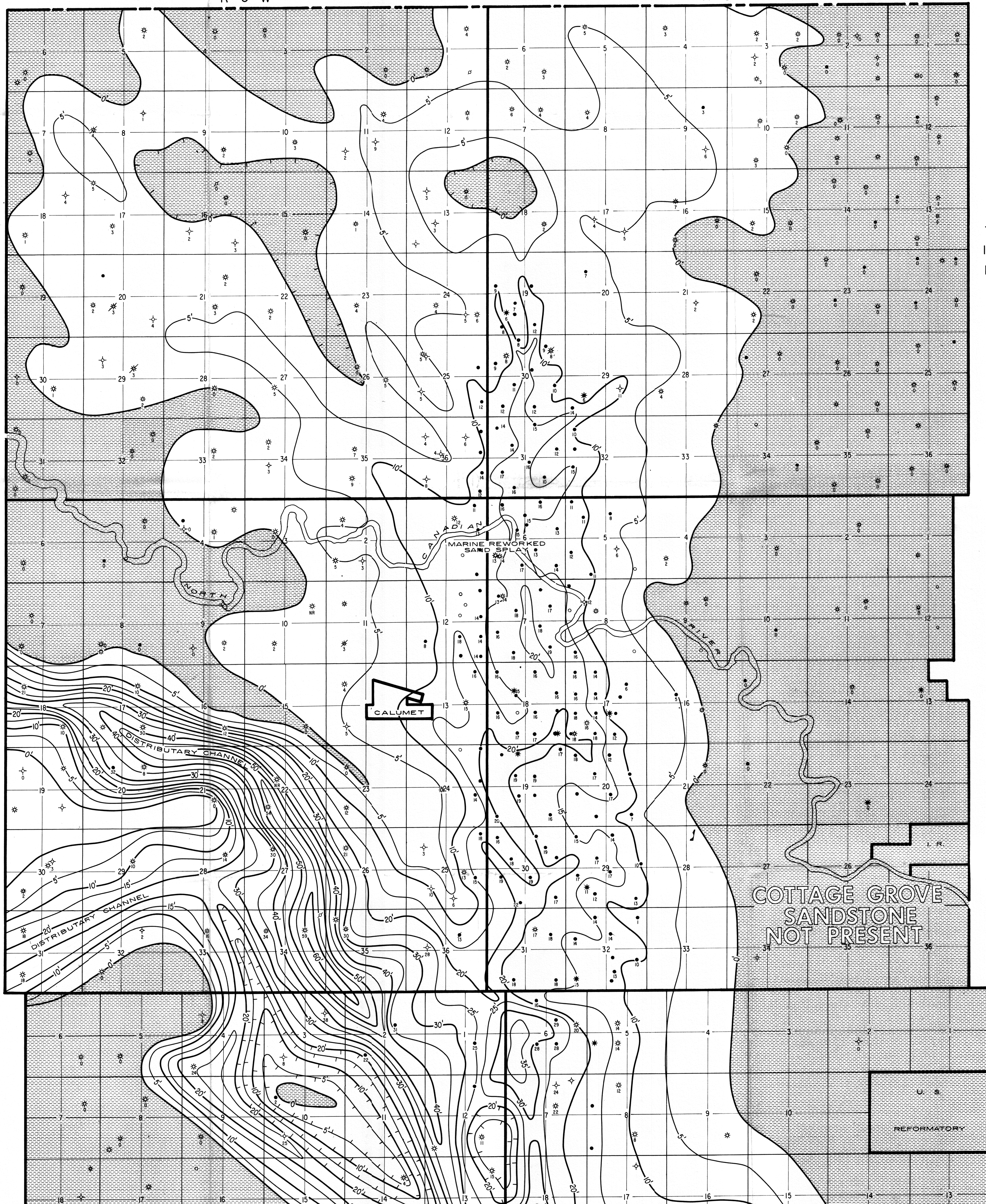


# Gross Sandstone Isolith Map

## *UPPER AND LOWER COTTAGE GROVE*

C.I.=5'

PLATE 10



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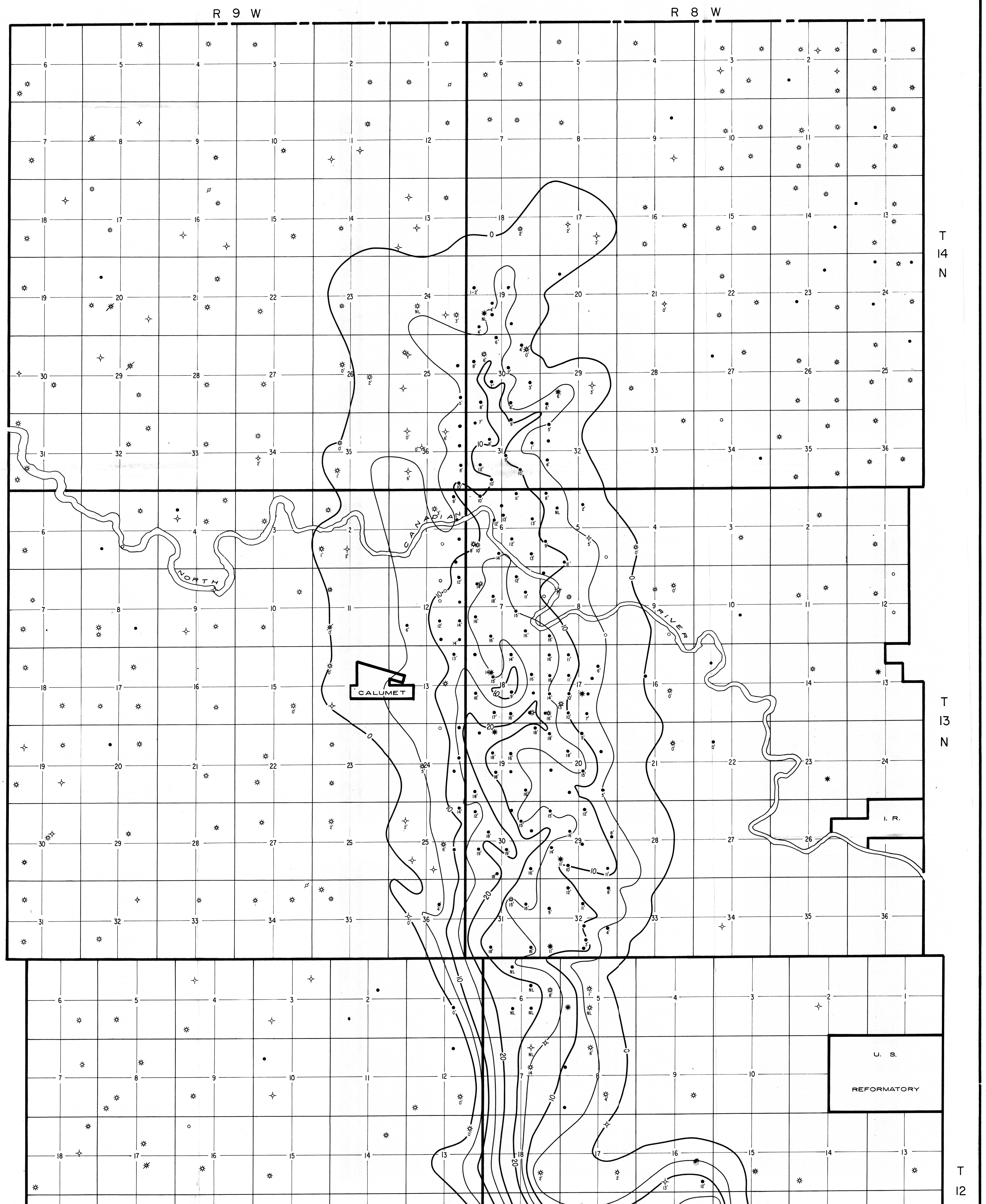


# NORTH CONCHO FIELD

## Net Sandstone Isolith Map

## "UPPER COTTAGE GROVE"

>8%Ø

C.I.=5'

PLATE II

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# NORTH CONCHO FIELD

## Production Map

## *COTTAGE GROVE SANDSTONE*

*● 4/84 — DATE OF DISCOVERY*
*3507 — CUMULATIVE OIL PRODUCTION*
*30 BO, 36 MCF, 3 BW — INITIAL PRODUCTION (24 HRS.)*
*ALL INFORMATION IS FROM PETROLEUM INFORMATION, INC.*

PLATE 12

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