# THE PETROGRAPHY, DIAGENESIS AND DEPOSITIONAL SETTING OF THE PENNSYLVANIAN COTTAGE GROVE SANDSTONE IN DEWEY, ELLIS, ROGER MILLS, AND WOODWARD COUNTIES, OKLAHOMA

By

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# CHAPTER I

# INTRODUCTION

The subject of this investigation is the Cottage Grove Sandstone (Ochelata Group, Missourian Series, Pennsylvanian System) in west central Oklahoma. In the study area, the Cottage Grove produces oil and gas from a series of linear sandstone trends in the East Harmon, West Sharon, and North Ioland fields.

## Objectives

This study focuses on the depositional environments, lithology, diagenesis, and well-log signatures of the Cottage Grove. Specifically, the objectives of this investigation were to:

1. determine the structural and stratigraphic settings of the Cottage Grove Sandstone,

2. explicate the lithologic, petrographic, and sedimentary attributes of the Cottage Grove Sandstone,

3. characterize the depositional environments associated with the deposition of the Cottage Grove Sandstone,

4. determine the diagenetic character and nature of porosity in the Cottage Grove Sandstone, and

5. delineate relationships that exist among the

petrology, diagenesis, and well-log surveys of the Cottage Grove Sandstone.

## Location

The study area consists of 15 townships, 3 east-west by 5 north-south. Included are T17N through T21N, and R20W through R22W, in portions of Dewey, Ellis, Roger Mills, and Woodward counties, Oklahoma (Figure 1). Elevations below sea level to the top of the Cottage Grove interval in the study area range from -4850 feet in the north to -6650 feet in the south.

## Methods of Study

To accomplish the objectives of this study a spectrum of investigative techniques were employed. A summary of these methods includes:

1. Literature review - Review of literature included topics in diagenesis, depositional environments, stratigraphy and structural geology.

2. Core evaluations - Five cores of the Cottage Grove from the study area were studied and a petrolog prepared for each; petrologs include graphic summaries of lithology, sedimentary structures, color, grain size, and various constituents.

3. Thin section evaluation - Thin sections, drawn from the five cores, were evaluated quantitatively; X-ray diffraction and scanning electron microscopy were used in

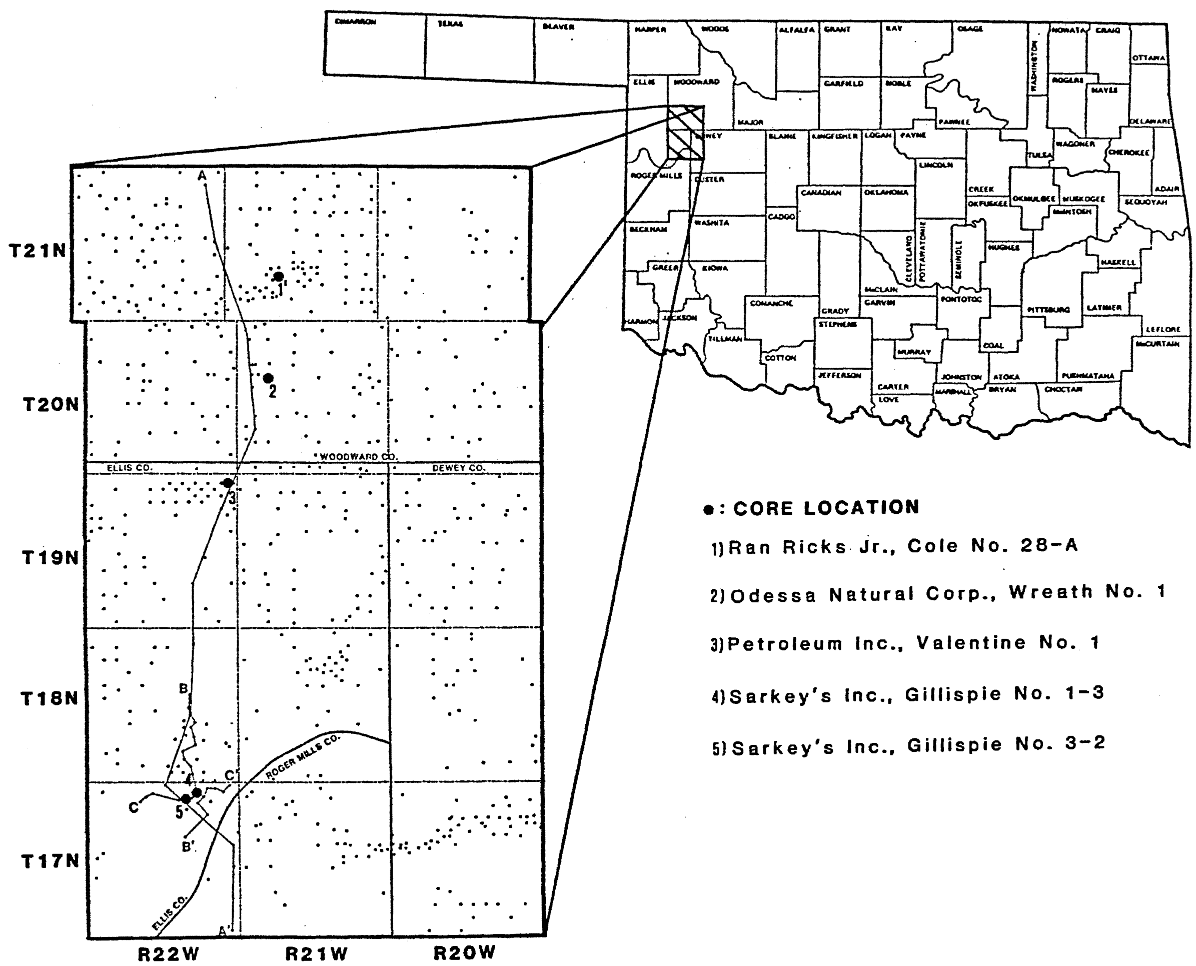


Figure 1. Location Map of the Study Area

conjunction with thin-section point count data to identify petrologic and diagenetic attributes of the Cottage Grove Sandstone.

4. Cross-section preparation - Regional and local well-log cross-sections were constructed to evaluate rock-stratigraphic relationships of the Cottage Grove Sandstone.

5. Subsurface-map preparation - Subsurface maps incorporating more than 660 suites of well surveys were prepared, to determine the geometric configuration and structural setting of the Cottage Grove Sandstone. Well-log data were entered into a mapping system spreadsheet using an IBM XT personal computer; base maps were prepared using an Houston Instruments DMP-29 plotter. Well-log data sheets are contained in Appendix A.

6. Well-log signature evaluation - An integrated study of log-survey, core-lab and petrographic data were made to characterize various well-log responses in the Cottage Grove.

7. Data preparation - Graphs, plots, and figures were prepared to aid in the interpretation of various aspects of the study. Thin-section, core-lab, and well-log data were entered into a Lotus 1-2-3 spreadsheet to facilitate manageability of data, and to generate the statistics, tables, and graphs presented in this work.

## Previous Investigations

Relative to other Pennsylvanian sandstones in the Anadarko Basin the Cottage Grove has received little attention in print. Although a large number of publications make reference to the Cottage Grove, only a few discuss it in detail. Therefore, the following paragraphs contain highlights only of those articles deemed appropriate to this study.

The Cottage Grove Sandstone was named by Norman Newell after the Cottage Grove township in southern Allen County, Kansas (Moore, 1932). From an exposure in Washington County, Oklahoma, Oakes (1940) described the Cottage Grove as a buff-colored, fine-grained, massive to thin-bedded sandstone. Pate (1959) evaluated the Cottage Grove Sandstone in his study of stratigraphic traps on the northern shelf of the Anadarko Basin. He determined that many stratigraphic trap possibilities exist within the sequence of Paleozoic rocks because of onlap, interruption in deposition of sands and reef limestones, and convergence due to truncation.

Capps (1959) included the Cottage Grove in his assessment of Missourian and early Virgilian stratigraphy in northwest Oklahoma. From well samples, subsurface maps, and cross-sections he concluded that the Cottage Grove was deposited on a shallow marine shelf and that the source direction predominantly was to the south. Gibbons (1960) determined that the Cottage Grove was the western extension of strata east of the Nemaha ridge. He reported that the Cottage Grove interval of Woods County contained lenses of sandstone enclosed in siltstone and shale. He noted that these sandstones were isolated from larger sheet sands to the south. Rascoe (1962) described the distribution of the Cottage Grove in the Anadarko Basin; he considered its development to be related to the union of the Anadarko and McAlester basins, which formed a sedimentary trough across Oklahoma during Missourian time.

Holmes' (1966) study of the Cedardale Field in portions of Woodward and Major Counties, Oklahoma included the Cottage Grove. He interpreted the Cottage Grove as a series of submarine bars trending northeastward. He concluded that oil and gas accumulations occurred where bar sands wedged out updip into shales. Swanson (1967) described hydrocarbon accumulations that occur commonly as the result of marked facies changes along hinge zones. He used the Cottage Grove as an example, for it shows evidence of this type of entrapment along the northern hinge zone of the Anadarko Basin.

Lalla (1975) made a stratigraphic study of the Osage-Layton Sandstone (Cottage Grove equivalent) in north-central Oklahoma and determined that east of the Nemaha ridge, the Cottage Grove was deposited in a deltaic complex. Similar to Lalla's findings, Rascoe (1978) proposed that Missourian sandstones in central Oklahoma are the record of fluvial-deltaic conditions, but he added that equivalent sandstones in western Oklahoma formed under marine influences. Rascoe (1978) and Rascoe and Adler (1983) suggested that the source of Missourian clastics (including the Cottage Grove) was from the Ouachita foldbelt. This inference was based on the evidence that Missourian sandstones grade from deltaic to marine east-to-west, that the sandstone content of this interval increases from west to east, and that clastic input from the south would account for the general confinement of equivalent carbonate deposits (Kansas-Lansing Group) to the north. However, this work introduces petrographic evidence suggesting that an additional or alternative source area may have existed.

In the last decade, Towns (1978) and Fruit (1986) reported similar depositional environments for the Cottage Grove in two areas of northwestern Oklahoma. Towns (1978) described the Cottage Grove Sandstone in the South Gage Field, Ellis County as an offshore shallow-marine bar. In a region approximately 12 miles east of the present study area, Fruit (1986) interpreted the Cottage Grove as an open-marine shelf deposit consisting of linear sand ridges encased in shale.

# CHAPTER II

# STRUCTURAL FRAMEWORK

## Regional Setting

The study area is located on the northern flank of the Anadarko Basin (Figure 2). The basin is an elongate, west-northwest trending, asymmetric feature that encompasses roughly 35,000 square miles in western Oklahoma, the northern Texas Panhandle and southwestern Kansas (Kennedy, 1982).

Major tectonic elements adjacent to the Anadarko Basin include the Nemaha Ridge, which separates the basin from the Central Oklahoma Platform to the east, and the parallel-trending Amarillo-Wichita Mountains, which bluntly mark its southern border. The basin is bounded on the northeast by the Central Kansas Uplift, on the northwest by the Las Animas Arch, and on the west by the Cimarron Arch-Keys Dome (Figure 2), (Moore, 1979).

## Regional Geologic History

Before the Anadarko Basin developed as a distinct cratonic feature, most of southern Oklahoma was a geosynclinal area. The geosyncline had formed on the Pre-Cambrian basement rocks of southern Oklahoma and northern Texas. This area was described first by Schatski (1946) as

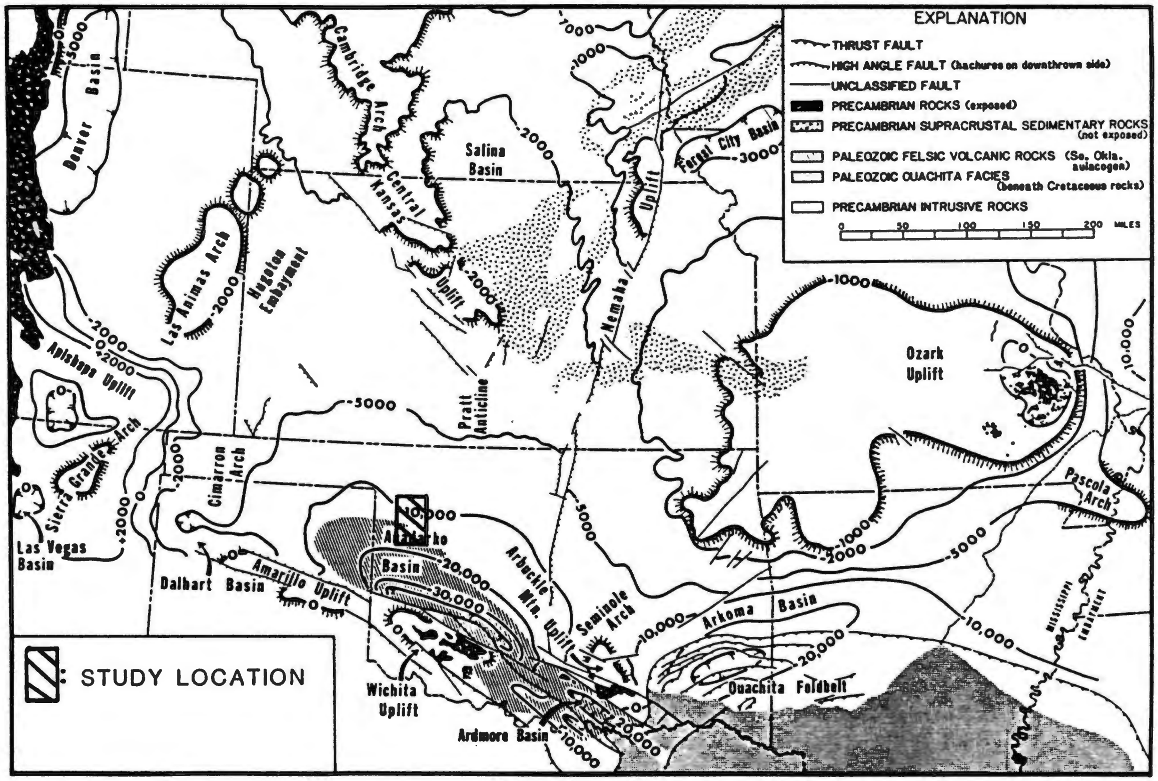


Figure 2. Basement Structure of the Mid-Continent and Location of Study Area (After Rascoe and Adler, 1983).

an example of an aulacogen. A study by Burke and Dewey (1973) explained the origin of aulacogens using the idea of a mantle plume or hot spot in conjunction with plate tectonics.

Aulacogens are formed in the later stages of an "evolutionary sequence" from uplift, through rifting and uplift generated triple-junction formation, to continental breakup (Burke and Dewey, 1973). In the initial stages the crust of the earth is upwelled due to a convective plume within the mantle. As upwelling continues, three rift arms developed into a "rrr" (ridge, ridge, ridge) triple junction. In general, this type of junction results in arms or rifts that are oriented at angles of approximately 120 degrees to each other. In subsequent stages, two of the rift arms form a single accretionary plate margin (ridge), and continental separation ensues, leaving the third rift arm (failed arm) as a graben. The graben extends into the continent and it develops as a mechanically weak zone in the lithosphere. Rifting stages usually are accompanied by igneous activity. As the aulacogen moves away from the hot spot it cools and subsides. The resultant low area is then the site of extensive sedimentation. Next, the ocean area that forms due to the spreading of the two active rifts may develop a subduction zone and begin to close. With closing, two plates converge, resulting in the "deformation stage". The tectonically weak aulacogen selectively is the site of major amounts of tectonism (Burke and Dewey, 1973).

The concept of aulacogens and their evolution has been applied directly to the formation of the Anadarko Basin (Rascoe and Adler, 1983). In Middle Cambrian, during the rifting stages, sediments filled this failed-arm graben. The Pre-Cambrian Tillman Group, deposited in the pre-aulacogenic basin, were metamorphosed during igneous events of the early rifting stages (Ham et al., 1964). In early phases of rifting, bi-modal igneous rocks were emplaced in southern Oklahoma. These rock-stratigraphic units are the Raggedy Mountain Gabbro and the Navaho Mountain Basalt. During the next phase, acidic rocks were emplaced, which include the Wichita Granite, and the Carlton Rhyolite.

Evidence of the subsident stage of the aulacogen is seen in Late Cambrian Reagan sandstone. The overlying stratigraphic sequence is predominantly carbonates, which were deposited during the Ordovician, Silurian and Devonian, culminating with the Devonian Hunton Group. Unconformities in Mississippian carbonates may represent epiorogenic activity (Al-Shaieb, 1986). These pulses of early uplift were precursors of the continental collision that closed the "Proto-Atlantic" ocean during the Pennsylvanian.

The deformational stage is recorded by siliceous clastic rock of Pennsylvanian age. The collision that culminated during the Atokan marked the beginning of clastic-dominated sedimentation in the basin. The uplifts that formed in direct relationship with the compressional tectonism included the Amarillo-Wichitas, the Arbuckles, and the Ouachitas. Their formation was largely controlled by the fault lines of the failed arm.

Granite washes from the uplifted Wichita Mountains were deposited into the rapidly subsiding Anadarko Basin, while Pennsylvanian marine clastics interfingered predominantly from the north and east (Moore, 1979). In Late Pennsylvanian time compression caused the thrusting of flysch-type sediments onto the Arkoma foreland basin. The uplift (Ouachita Mountains) of this large sedimentary pile of recycled continental-margin sediments provided a major source of clastic material for Oklahoma basins (Krumme, 1975).

The Anadarko Basin continued to fill with sediment as the basin subsided. Deposition in the southern Mid-Continent was coextensive with widespread shallow marine, deltaic, evaporite, and redbed deposits of the northern shelf of the Midland and Delaware Basins. Permian rock-stratagraphic units mark the final withdrawal of the Paleozoic seas from the Southern Mid-Continent (Moore, 1979).

## Regional Paleogeography and Source Areas

Most authors, including Rascoe (1978), Towns (1978), Waller (1985), Moore (1979), Adler (1971), Gibbons (1960), and Capps (1959), have hypothesized or alluded to evidence suggesting that the source for the Cottage Grove Sandstone was the Ouachita mountains. The paleogeography of the area, together with known stratigraphic relationships of Missourian rocks, tend to support this interpretation.

Missourian paleogeography (Figure 3) illustrates the geomorphic configuration of tectonic features in Oklahoma and general thickness of Missourian rocks. In this interpretation, carbonate rocks of the Kansas-Lansing Group separate the clastic-rock terrain of the study area from the clastic wedges that were deposited in front of the Ancestral Rockies (Apishapa-Sierra Grande uplift). In addition, coarse-grained sediments that were shed northward from the Amarillo-Wichita are segregated from the study area by the axial trough of the Anadarko Basin. Apparently, a distant

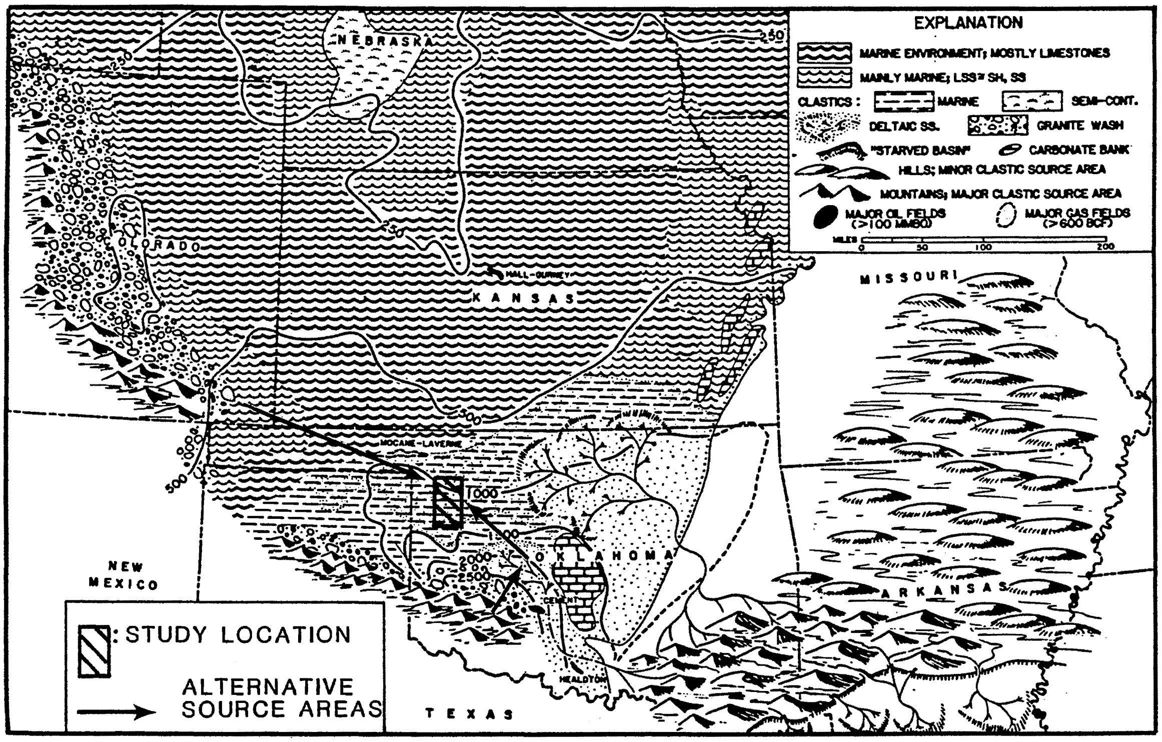


Figure 3. Paleogeographic Map of the Mid-Continent during Missourian time (After Rascoe and Adler, 1983).

continental interior source of the Cottage Grove sediments is not likely, a judgment based on the types of Missourian rocks in southeastern Kansas and northeastern Oklahoma (the area over which clastics would have prograded to reach the Anadarko shelf).

Based on evidence cited by the aforementioned authors, I tend to agree that the Ouachita Mountains were the primary source of sediments in Cottage Grove. However, a petrographic study done in this work (see Chapter IV) reveals occasional granitic rock fragments in the Cottage Grove

Sandstone. These rock fragments are inconsistent with the theory that the Ouachita Mountains were the only source area. The Ouachitas are composed mostly by metamorphic and siliceous rocks, but plutonic rocks have not been recorded.

As previously mentioned, this author asserts that the Ouachita Mountains are the principal source area for Cottage Grove sediments. I concur with the consensus of other the presence of granitic rock fragments. The position of the secondary source requires investigation beyond the limits of this study. However, I believe that the Ancestral Rockies or the Wichita Mountains are the most likely terrain because they were the closest plutonic entities during Missourian time.

## Local Structure

Structural features in the study area are illustrated by a structural contour map of the base of the Avant limestone (Plate I). The Avant was used as a reference because at its base is a "hot shale" marker bed which is present throughout the study area (See Figure 5, Chapter III).

No significant closure or faults are exhibited by the Avant structural contour map. The map reveals a relatively constant, southerly dipping, homoclinal surface. The average regional dip of this surface is approximately 57 feet per mile; however, dip locally is as much as 110 feet per mile. Structural sub-sea-level elevations range from approximately -4850 feet in the north to -6650 feet in the south.

Superimposed upon the homocline are anticlinal noses, synclinal noses and a few local anticlines.

A regional anticlinal nose is expressed in the eastern third of the mapped area in R20W., from T18N. through T20N.. Apparently, this positive feature existed through deposition of the Tonkawa, and was present as far back in time as deposition of the Oswego Limestone (Evans, 1979). This anticlinal nose seems to have partially controlled the deposition of the Cottage Grove Sandstone.

A local synclinal feature is expressed in the NE quadrant of T18N., R22W. Assuming that paleostructure was partially preserved or even enhanced by compaction, contours suggest that this depression represents a ravine that was carved out or already existed during the deposition of sands found immediately to the south in the North Ioland Field. This interpretation is supported by a southerly inversion of the structural contour lines from a syncline in the north to an anticline the south; the syncline may represent an area of sediment bypass, and the anticline an area of structural draping and differential compaction across the sand deposit.

Local anticlinal noses are also in Township 17 North and Ranges 20 through 21 West. These noses coincide with thick sand accumulations in the Cottage Grove interval. They, like the anticline described above, are attributed to draping and differential compaction of sediments during dewatering and subsidence of the basin.

There is a notable, relatively consistent relationship between the anticlinal noses along the monocline and the presence of the Cottage Grove Sandstone. However, this relationship seems to be dependent on the orientation and thickness of the sand body with respect to structural strike. Hence, if the sand body were thin and/or roughly parallel to strike then it became masked or otherwise scarcely manifest; the more dip oriented and/or thicker the sand body, the more likely it was to have been expressed as a anticlinal nose.

# CHAPTER III

## STRATIGRAPHIC FRAMEWORK

### Introduction

The Cottage Grove Formation is in the lower part of the Ochelata Group of the Missourian Series, Pennsylvanian System (Figure 4). The Missourian Series includes the rocks from the top of the Marmaton Group to the base of the Virgilian Series (Capps, 1959). Missourian rocks consist of granite wash and carbonate wash along the Wichita Mountain front, whereas northward onto the shelf the sequence consists of shales, siltstones, sandstones and carbonates. These rocks grade northward into the carbonates of the Lansing-Kansas City Group in Beaver, Harper and Woods Counties (Gibbons, 1960).

The Missourian Series is divided into the Ochelata Group above and Skiatook Group below (Lukert, 1949). The Hoxbar Group of southern Oklahoma is a rock-stratigraphic unit regarded as being equivalent to both the Ochelata and the Skiatook Groups. In the study area the Cottage Grove Sandstone is contained within a "package" of interbedded sandstone and shale; the package is bounded by limestone. The upper bounding unit contains the Avant Limestone of the Ochelata Group; whereas the lower bounding unit contains the

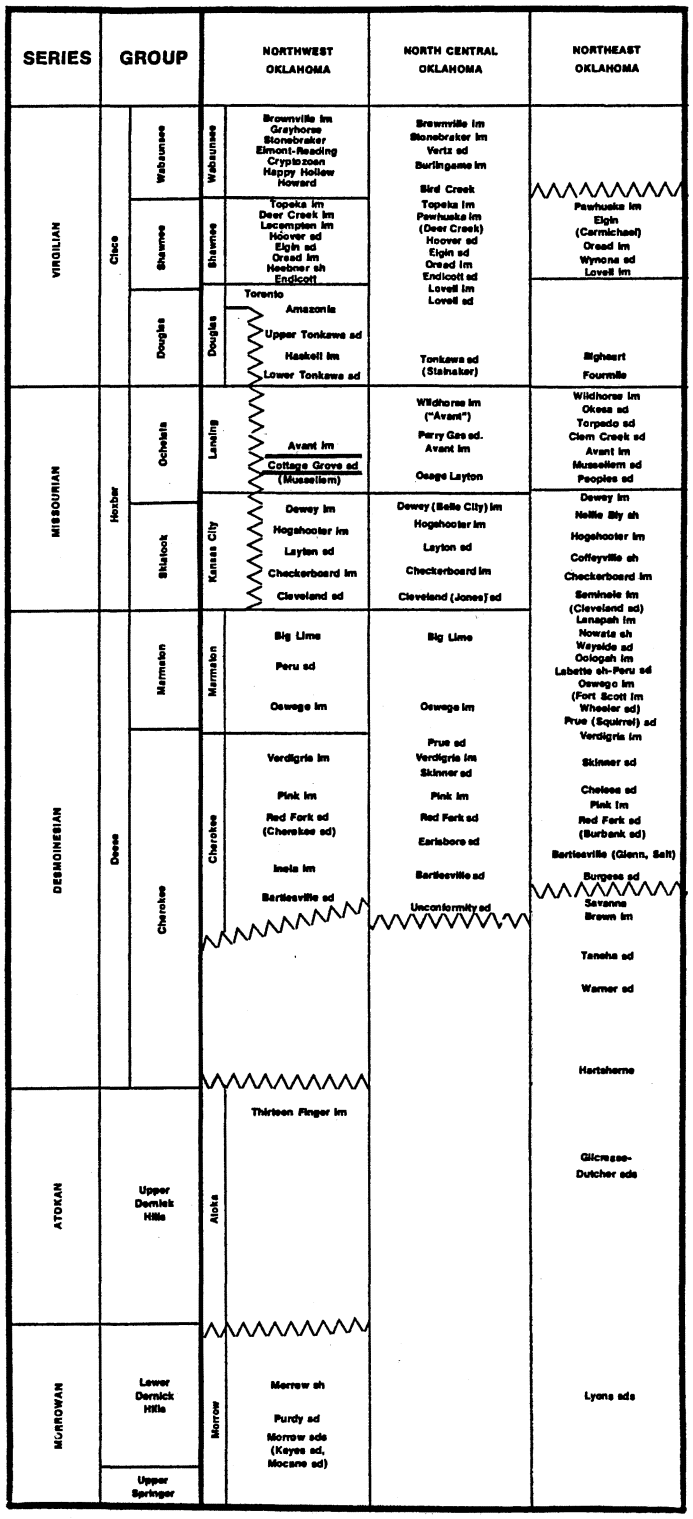


Figure 4. General Geologic Section Illustrating Stratigraphic Nomenclature in Northern Oklahoma (After Chenoweth, 1979).

Hogshooter Limestone of the Skiatook Group. These limestones are regarded as being equivalent to shelf cyclothem members of the Lansing-Kansas City Group, which were deposited during maximal transgression (Rascoe and Adler, 1983). The boundary between the Ochelata and Skiatook Groups, as defined by Capps (1959), is at the base of the Cottage Grove Sandstone. In Kansas and eastern Oklahoma the Cottage Grove Sandstone has been referred to in the subsurface as the Osage-Layton, Broyles-Layton, Peoples-Layton, and Musselem sandstones (Jordan, 1957). In outcrop, the term Nellie Bly has been applied to the stratigraphic equivalent of the Cottage Grove Sandstone (Lalla, 1975).

Regionally correlative "hot" shale beds are associated with both the Avant and Hogshooter Limestone intervals. Figure 5 shows a type log from the study area that illustrates partial Pennsylvanian stratigraphy and the relative positions of the Avant and Hogshooter "hot" shale markers. Logs of both limestone intervals include two pronounced rightward deflections of the gamma-ray curve ("hot" shale markers). The lowermost shale deflections of the Avant and Hogshooter intervals were used as markers for correlations and mapping.

The Cottage Grove interval is defined as the stratigraphic section above the Hogshooter "hot" shale marker and below the Avant "hot" shale marker. The Cottage Grove proper is defined as only that portion of the Cottage Grove interval characterized by course clastics, which is

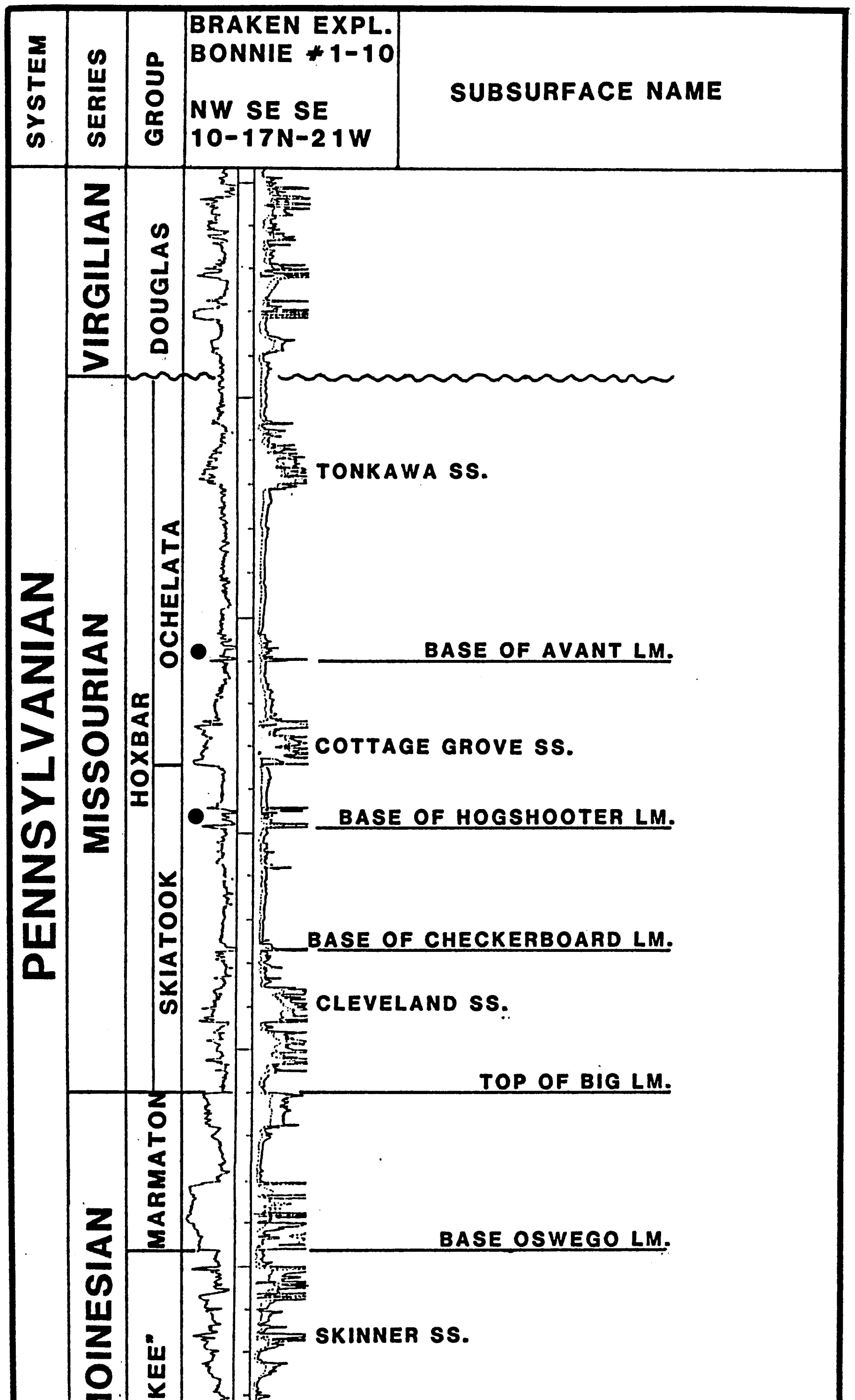


Figure 5. Type Log of Study Area Illustrating Partial Pennsylvanian Stratigraphy; ●: Positions of Gamma Ray "Hot Shale" Markers.

recognized by a gamma-ray deflection of magnitude distinctively larger than that of the shales both above and below the unit.

## Correlations

One regional and two local stratigraphic cross sections (Plates II, III, and IV) were constructed to show characteristics of the Cottage Grove Sandstone and its relationships to adjacent units. Markers used in the regional north-south cross section include (1) the "hot" shale markers at the Avant and Hogshooter intervals, (2) the base of the Checkerboard Limestone below, and (3) the base of the Tonkawa Sandstone above. Markers used in the more detailed local north-south and east-west cross sections include (1) the Avant "hot" shale marker (2) non porous, "tight" deflections exhibited by porosity curves (neutron-density, sonic, or density) within the Cottage Grove Sandstone and (3) gamma-ray and porosity curve log signature "shoulders" or "stair-steps" which express variations in the shale content of the upper Cottage Grove Sandstone (Figure 6).

## Cottage Grove Net Sandstone Isolith Map

The Cottage Grove Isolith map (Plate V) illustrates a series of sand bodies that with only one exception trend east north-eastward. The exception is a sand trend in T18N and R22W that is oriented northward. The depositional

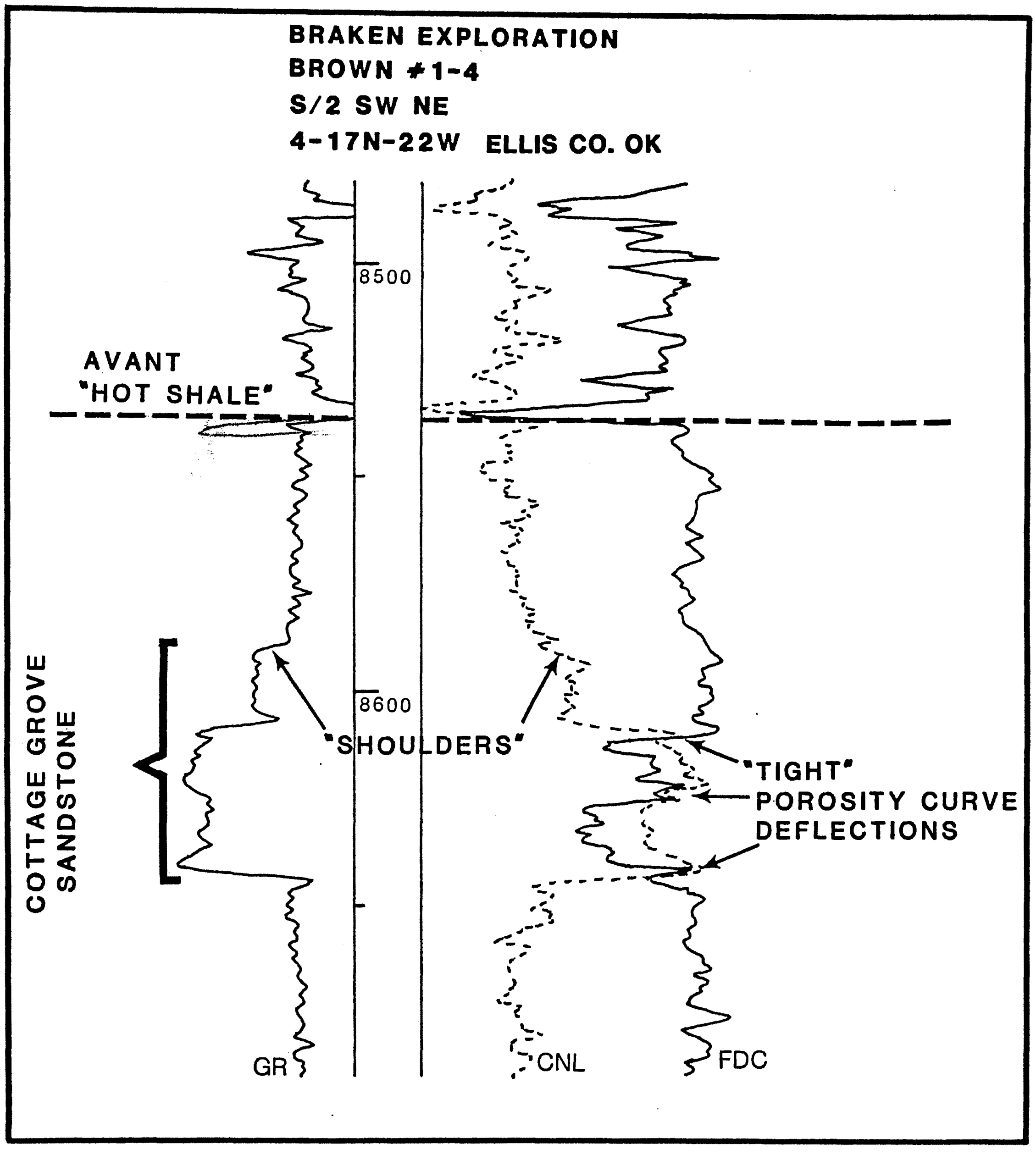


Figure 6. Well-log Coorelation Markers used in Local Cross Sections.

environment of the north trending sand deposit is considered to have been different than that of the east-west trending sands.

In the northern half of the study area, sand isolith thicknesses rarely exceed 35 feet, whereas, in the southern half are as much as 96 feet. Sand deposits in the north measure from 1 to 1 and 1/2 miles wide by 2 to 7 miles long. In the south log signature evidence suggests that several sands are stacked. The dimensions of the individual sand deposits in this area cannot be assessed due to the merging effect of the isolith map.

Delineation of individual sand deposits in areas of stacking is rather complicated. In the author's opinion, the gamma-ray and neutron-density curves, are best suited for correlations of this type, because in the study area, resistivity curves tended to be less responsive to lithologic variations in the Cottage Grove than neutron-density curves. Also, the SP curve commonly is suppressed in instances where the gamma-ray curve indicates a well developed sand.

## Paleostructure and Sand Distribution

Paleostructural geology may have influenced distribution of the Cottage Grove Sandstone in the study area. The Avant structural contour map (Plate I) exhibits a broad anticlinal feature that extends from T18N to T21N of R20W. This area is devoid of Cottage Grove sands, as shown by Plate V. Evans (1979) indicated that an anticline existed in this approximate area in the time-interval from deposition of the Oswego to deposition of the Tonkawa. He added that carbonate banks intermittently were superimposed upon this anticline. Assuming that relief on the sea floor was generated by the anticline, clastic sediments should have been closer to sea level, and could have been in realm of wave reworking. If this were the case, then wave action could have prevented sands from accumulating in this area. Sand ridges could have formed selectively in deeper water, off the crest of this feature.

## North-South Regional Cross Section A-A'

The north-south regional cross-section A-A' was constructed to (1) evaluate variations in the Cottage Grove interval, (2) determine the position of the sandstone within the interval, (3) examine lateral variations of the sandstone facies, and (4) depict, if present, any changes in paleodepositional slope.

### Variations in the Cottage Grove Interval

Cross section A-A' (Plate II) indicates that the Cottage Grove interval increases in thickness southward. Along the path of this section, the interval varies in thickness from approximately 235 feet in the north to 390 feet in the south. The rate of interval thickening is relatively constant from T21N to the central part of T18N at approximately 2 feet per mile; however, from the middle part T18N through T17N the rate increases to approximately 14 feet per mile.

### Stratigraphic Position of the Cottage Grove Sandstone

The stratigraphic position of the Cottage Grove Sandstone varies within the Cottage Grove interval from north to south. In the northern part of the study area, the top of the Cottage Grove Sandstone is 35 feet below the Avant "hot" shale marker, whereas to the south it is as much as 150 feet below the marker.

The variation in position of the sand may be explained by a marine transgression. Presumably, a brief regressive phase during an overall Missourian transgression brought course clastics (Cottage Grove Sandstone) from the east-southeast to the shelf. During early transgression following the regression, sand deposition may have migrated higher and northward onto the shelf.

### Lateral Variations and Slope Changes

Increase in the Cottage Grove interval described previously seems not to indicate a significant change in paleodepositional slope -- ie. a shelf/slope hingeline. The "transition zone" or area were the Cottage Grove interval begins to increase represents a change in dip of 0.13 degrees, from 0.02 in the north to 0.15 degrees in the south (based on differences measured between the Avant and Hogshooter hot shale markers). Typical shelf to slope breaks are marked by dip changes of 3.0 degrees or more; from shelves with mean inclinations of 0.07 degrees to slopes with average dips of 4 degrees or more (Davis, 1983). Furthermore, the Avant Structure Map does not indicate a change in slope suggestive of a hingeline.

Based on this evidence it appears as though an actual shelf break or hingeline is not within the 30-mile north-south dimension of the study area.

## Interval Thickness Compared to Sandstone Thickness

Thickening of the Cottage Grove interval in the southern part of the study area coincides with a marked increase in sandstone thickness. North of central T18N, sand thicknesses do not exceed 30 feet; south of this point thicknesses range up to 90 feet. Two hypothesis have been developed to explain the relationship between sandstone thickness and interval thickness. One hypothesis is related to differential compaction and the other to basin subsidence.

In the first explanation, thinning of the Cottage Grove interval is attributed to differential compaction of the section in the presence of thicker sandstone deposits. This process would have led to the illusion of local thickening of section. Towns (1978) and Fruit (1986) documented examples of interval thickening associated with the presence of sandstone in the section. However, the interval thickness in well 11 of cross section A-A', at least in part appears to be independent of the sandstone thickness. In this well, the Cottage Grove interval is thickened but rather than a thick sandstone unit as might be expected, a relatively thin sand body is present instead. This suggests that one or more other mechanisms may be involved in the interval-thickening of this area.

In the second explanation, thickening is attributed to subtle downwarping associated with basin deepening. This downwarping, if associated with more-or-less continual deposition, would result in vertical stacking of sediments over time. Several log signatures in the southern area have indicated the presence of stacked sand bodies. This working hypothesis differs from the first in that interval thickness is a function of basin subsidence and not necessarily of sandstone thickness.

## Local East-West and North-South Cross Sections

North-south (B-B') and a east-west (C-C') cross sections (Plates III and IV) were prepared to examine the lateral and vertical stratigraphic relationships of the Cottage Grove Sandstone in the southwest part of the study area. Two separate sand facies are delineated; designated facies "A" and facies "B". Facies A represents an east-trending sandstone unit that is interpreted as a marine bar sequence, and facies B represents a north-trending sandstone unit that is interpreted as a marine channel. Criteria used to interpret the depositional environments of these sands are listed in Chapter VII.

## Cross-section B-B'

Facies A and B overlap in the vicinity of the border between Townships 17 and 18 North of Range 22 West. South of T18N facies B grades to shale. Facies A is present only in the area depicted in the southern half of cross section B-B'. In terrain where the facies overlap, facies B is best delineated from facies A as shown in well 12 of cross-section B-B' (well 8 of C-C'). In this well 10 feet of shale separates facies A from facies B. The shale break wedges out along B-B' and C-C' cross-sections, resulting in facies B overlying facies A directly.

## Cross-Section C-C'

Cross section C-C' illustrates how facies A and B vary from east to west. This cross section is strike-oriented with respect to facies B and approximately dip-oriented with respect to facies A.

As shown by this cross-section, sand development in facies B is separated laterally into two units. Sands of facies B sands are developed in wells 1 through 3 and wells 7 though 10. Presumably, the separate sands are evidence of the bifurcation of the north-trending channel of T18N, R22W.

# CHAPTER IV

# PETROLOGY

## Introduction

Five cores were logged and evaluated petrographically by analysis of 60 selected thin sections in order to provide a detailed lithologic appraisal of the Cottage Grove Sandstone. Thin-section examination consisted of at least three sets of 100 point counts each; each set was averaged to attain an estimated percentage of detrital and diagenetic constituents. Net constituent averages for each core are reported in Table 1. Results from individual thin-section analysis are contained in Appendix B.

Compositional percentages of detrital constituents are relatively uniform. However, diagenetic constituents vary so much as to produce major compositional differences in the cores. Ternary diagrams (Figures 7 through 11), normalized for quartz, rock fragments, and feldspar (standard Folkian plots), provide visual representation of the individual thin-section compositions from each core. Fourty-five of the thin-section samples plot as litharenites and 14 plot as sublitharenites. Lithic-constituent grains are sub-rounded to rounded, well sorted, and have moderate to high sphericity. Overall, grain size averages in the very-fine

# TABLE I

## Net Thin Sections Constituent Averages

| | S AVG. (%) | G AVG. (%) | W AVG. (%) | V AVE (%) | R AVG. (%) | NET AVERAGE (%) |
|---|---|---|---|---|---|---|
| DETRITAL CONSTITUENTS | 65.3 | 70.8 | 65.4 | 61.7 | 69.3 | 66.5 |
| QUARTZ | 45.6 | 51.5 | 40.7 | 43.3 | 47.1 | 45.6 |
| MONOCRYSTALLINE | 43.9 | 48.6 | 39.2 | 40.8 | 43.9 | 43.3 |
| POLYCRYSTALLINE | 1.7 | 2.9 | 1.5 | 2.4 | 3.3 | 2.4 |
| FELDSPAR | 3.5 | 3.6 | 3.5 | 2.9 | 3.8 | 3.5 |
| MICROCLINE | 1.4 | 0.9 | 0.4 | 0.5 | 0.4 | 0.7 |
| PLAGIOCLASE | 2.2 | 2.7 | 3.0 | 2.5 | 3.4 | 2.8 |
| ROCK FRAGMENTS | 7.3 | 8.5 | 8.5 | 6.3 | 8.4 | 7.8 |
| SHALE | 0.8 | 0.4 | 0.7 | 0.5 | 0.8 | 0.6 |
| CHERT | 0.8 | 2.1 | 1.6 | 1.0 | 1.4 | 1.4 |
| CARBONATE | 0.6 | 0.5 | 0.3 | 0.6 | 0.6 | 0.5 |
| SILTSTONE | 0.4 | 0.1 | 0.1 | 0.3 | 0.0 | 0.2 |
| METAMORPHIC | 5.4 | 5.6 | 6.0 | 4.1 | 5.7 | 5.4 |
| PLUTONIC | 0.0 | 0.2 | 0.1 | 0.0 | 0.1 | 0.1 |
| OTHER GRAINS | 8.8 | 7.1 | 12.7 | 9.3 | 10.0 | 9.6 |
| DETR. CHLORITE | 0.6 | 0.9 | 1.2 | 0.9 | 1.4 | 1.0 |
| GLAUCONITE | 0.5 | 0.4 | 0.5 | 0.4 | 0.4 | 0.4 |
| PHOSPHATE | 0.6 | 0.2 | 0.3 | 0.3 | 0.3 | 0.3 |
| MUSCOVITE | 2.0 | 2.8 | 4.8 | 4.5 | 4.6 | 3.7 |
| BIOTITE | 0.6 | 0.8 | 0.9 | 0.9 | 0.6 | 0.8 |
| ZIRCON | 0.5 | 0.5 | 0.7 | 0.5 | 0.6 | 0.6 |
| TOURMALINE | 0.5 | 0.6 | 0.6 | 0.5 | 0.5 | 0.5 |
| LEUCOXENE | 0.6 | 0.7 | 0.8 | 0.8 | 1.1 | 0.8 |
| FOSSIL FRAGS. | 11.8 | 0.8 | 5.4 | 1.0 | 0.8 | 4.0 |
| DETRITAL MATRIX | 2.2 | 2.4 | 2.0 | 5.0 | 2.9 | 2.9 |
| ILLITE | 1.7 | 2.1 | 1.6 | 4.3 | 2.4 | 2.4 |
| CHLORITE | 0.5 | 0.3 | 0.4 | 0.8 | 0.5 | 0.5 |
| DIAGENETIC CONSTS. | 32.5 | 26.8 | 32.5 | 33.3 | 27.8 | 30.6 |
| CEMENTS | 25.0 | 21.2 | 23.2 | 28.5 | 18.6 | 23.3 |
| QUARTZ | 4.4 | 3.1 | 2.1 | 1.8 | 0.8 | 2.4 |
| FELDSPAR | | 0.5 | 0.0 | 0.0 | 0.0 | 0.1 |
| CALCITE | 10.2 | 6.9 | 7.2 | 3.7 | 9.1 | 7.4 |
| DOLOMITE | 1.1 | 2.8 | 1.5 | 0.5 | 0.1 | 1.2 |
| FE DOLOMITE | 13.3 | 8.4 | 10.8 | 21.8 | 8.4 | 12.5 |
| BARITE | | 0.0 | 1.9 | 1.4 | 1.0 | 0.9 |
| AUTHIGENIC CLAYS | 2.0 | 1.8 | 1.8 | 1.7 | 1.8 | 1.8 |
| KAOLINITE | 1.4 | 0.7 | 0.6 | 0.7 | 0.3 | 0.7 |
| ILLITE | 0.7 | 0.7 | 1.0 | 0.8 | 1.1 | 0.9 |
| CHLORITE | 0.5 | 0.5 | 0.3 | 0.3 | 0.5 | 0.4 |
| HYDROCARBON | 0.5 | 0.3 | 0.5 | 0.4 | 0.4 | 0.4 |
| POROSITY | 5.3 | 3.5 | 7.1 | 2.7 | 7.0 | 5.1 |
| PRIMARY | 0.0 | 0.4 | 0.3 | 0.5 | 0.4 | 0.3 |
| SECONDARY | 6.4 | 3.3 | 6.9 | 2.6 | 6.8 | 5.2 |
| AVE. GRAIN SIZE (MM) | 0.12 | 0.13 | 0.1 | 0.08 | 0.1 | 0.1 |
| ****************************** | | | | | | |
| QRF NORMALIZED (%) | | | | | | |
| QUARTZ | 69.33 | 72.0 | 61.8 | 70.0 | 68.0 | 68.2 |
| ROCK FRAGMENTS | 25.26 | 22.6 | 32.9 | 25.2 | 26.5 | 26.5 |
| FELDSPAR | 5.41 | 5.4 | 5.3 | 4.8 | 5.5 | 5.3 |

S AVG. (%) G AVG. (%) W AVG. (%) V AVE (%) R AVG. (%) NET AVERAGE (%)

S = SARKEY'S GILLISPIE NO. 1-3
G = SARKEY'S GILLISPIE NO. 3-2
W = ODESSA NAT. CORP. WREATH NO. 1
V = PETROLEUM INC. VALINTINE NO. 1
R = RAN RICKS JR. COLE NO. 28-A

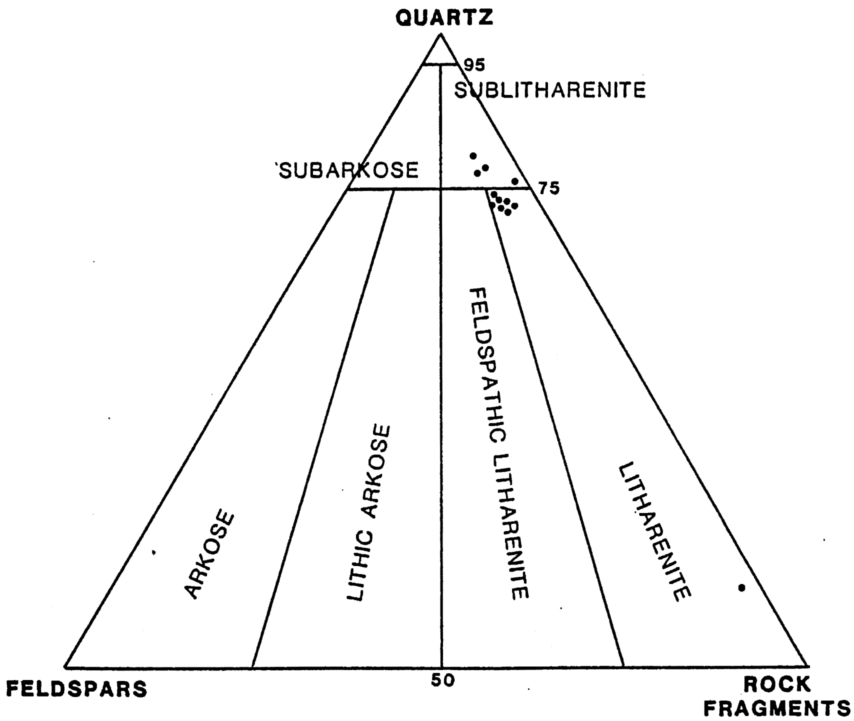


Figure 7. QRF Diagram Plot of Thin-section Compositions from the Sarkey's, Gillispie No. 1-3 Core.

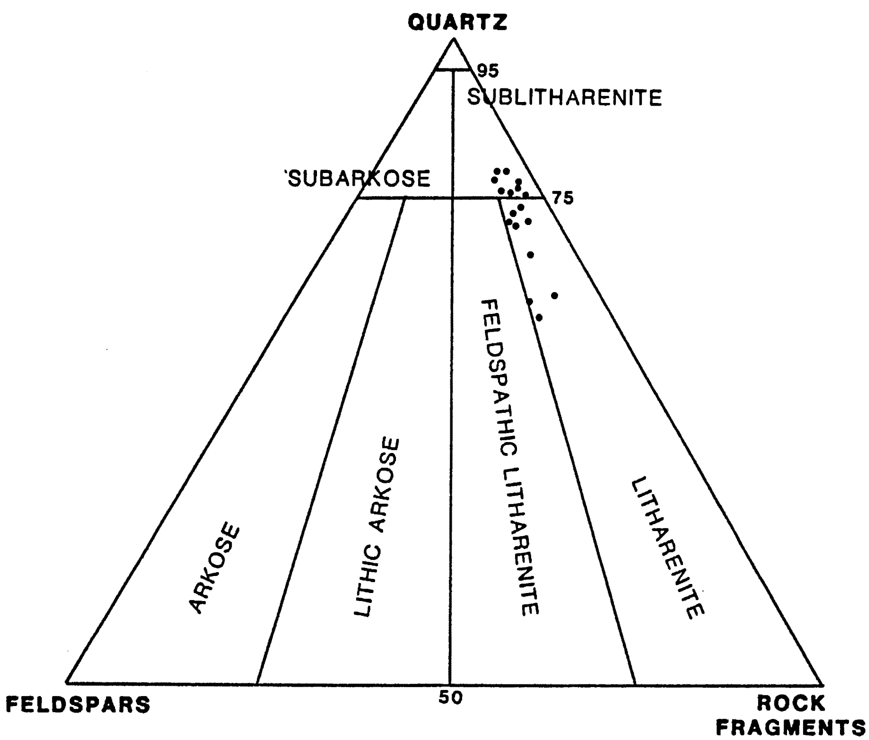


Figure 8. QRF Diagram Plot of Thin-section Compositions from the Sarkey's, Gillispie No. 3-2 Core.

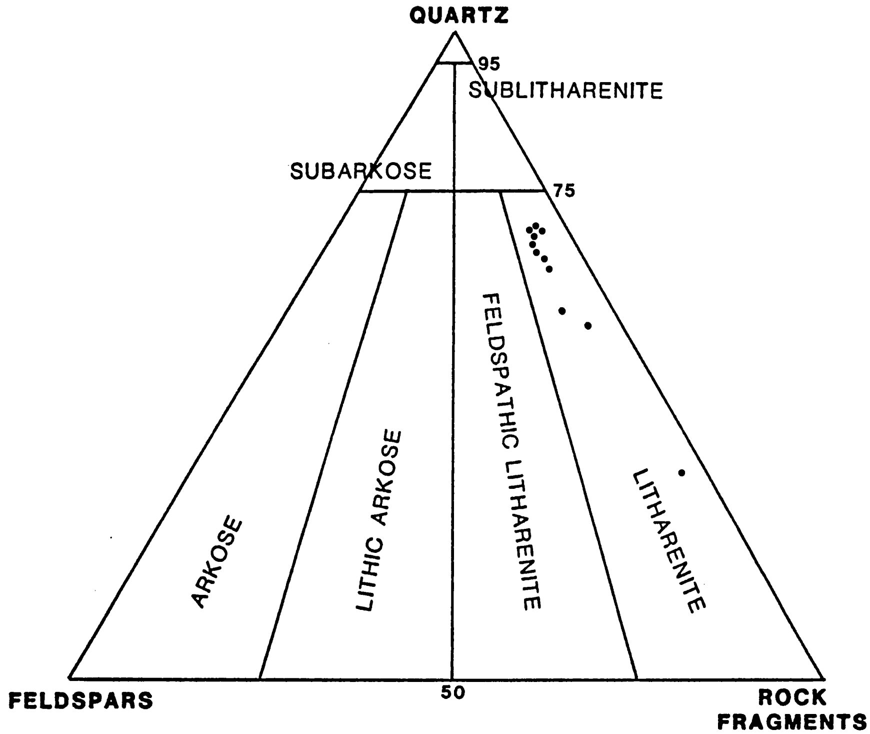


Figure 9. QRF Diagram Plot of Thin-section Compositions from the Odessa Natural Corp., Wreath No. 1 Core.

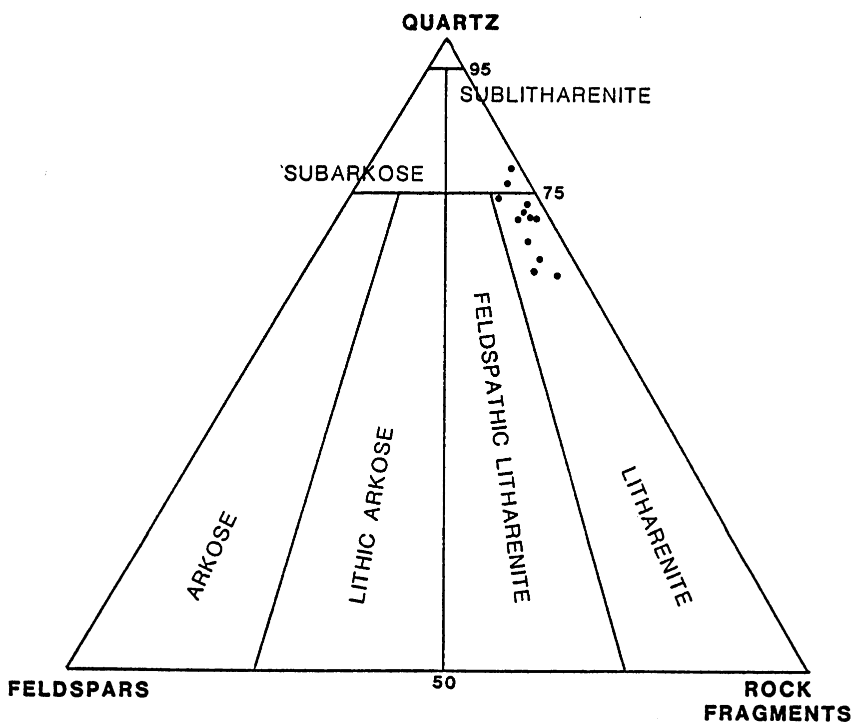


Figure 10. QRF Diagram Plot of Thin-section Compositions from the Petroleum Inc., Valentine No. 1 Core.

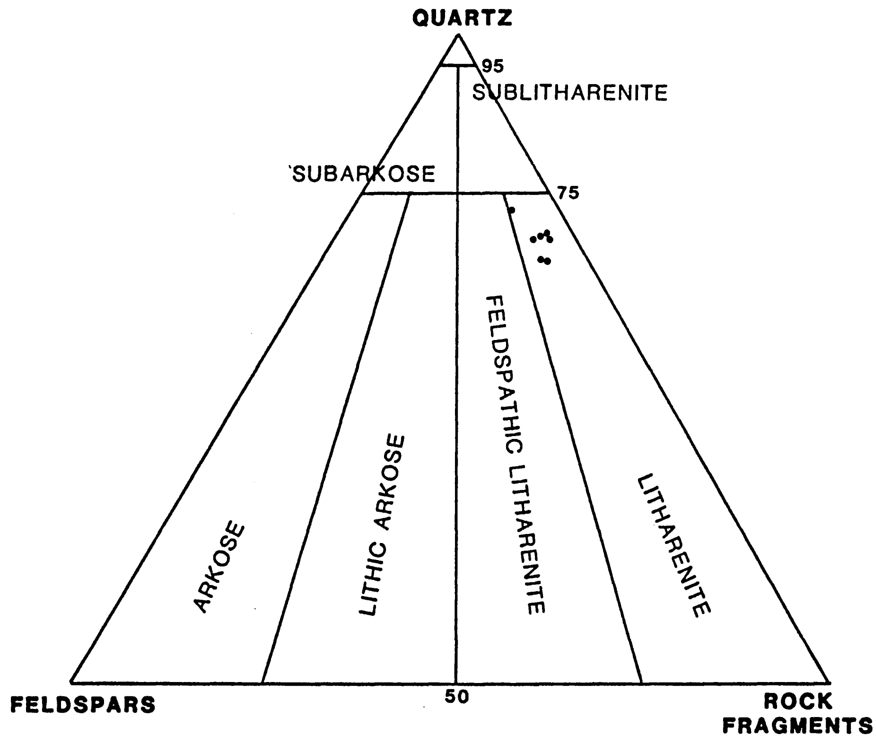


Figure 11. QRF Diagram Plot of Thin-section Compositions from the Ran Ricks Jr., Cole No. 28-A Core.

sand range (.063-.13mm).

## Detrital Constituents

### Quartz

Quartz is the dominant framework grain of the Cottage Grove Sandstone. Monocrystalline quartz comprises an average of 43 percent of the rock volume whereas polycrystalline varieties constitute only slightly more than 2 percent overall. Quartz grains range in size from course silt to fine sand (.05-.17mm), are subrounded to rounded, and have moderate to high sphericity. Syntaxial quartz overgrowths (Figure 12) constitute trace amounts to 8 percent of the rock. Most quartz grains display slightly undulose extinction and only a fraction contain mineral inclusions.

### Feldspar

Feldspars occur in small percentages within every thin section. The most abundant variety is albite (Figure 13) which averaged 3 percent and was identified by albite twinning. Microcline constitutes trace amounts to slightly more than 1 percent of the rock. Microcline grains are characterized by cross-hatch or "tartan" twinning.

Grains of feldspar show effects of dissolution that range from slight corrosion to complete eradication. Grain sizes of feldspars average as very-fine sand (.063-.13mm).

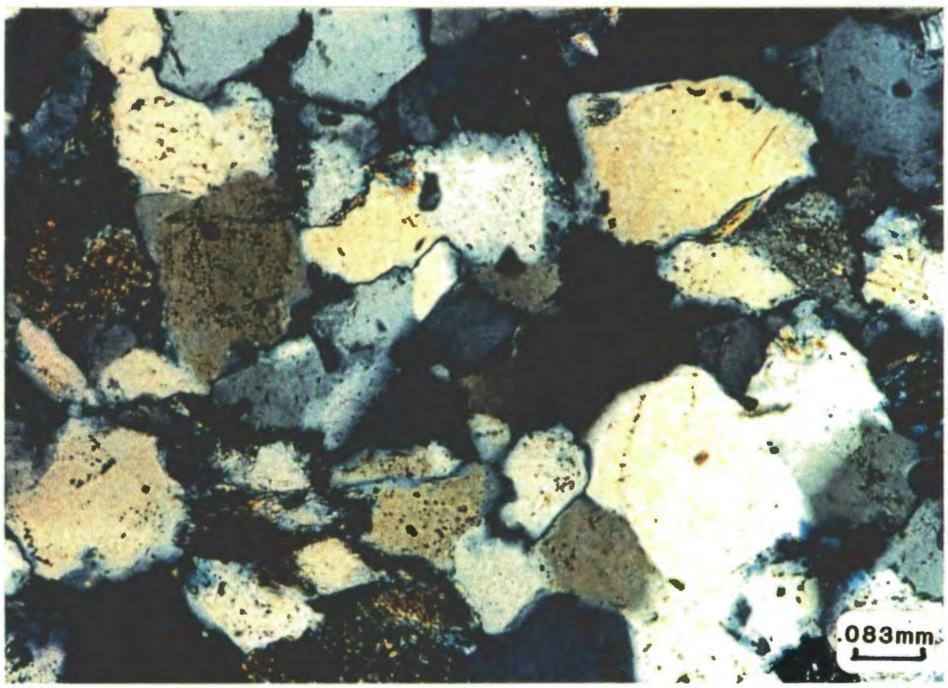


Figure 12. Quartz Grains and Syntaxial Silica Overgrowths with Crenulated Boundaries; Cross Polarized (100X).

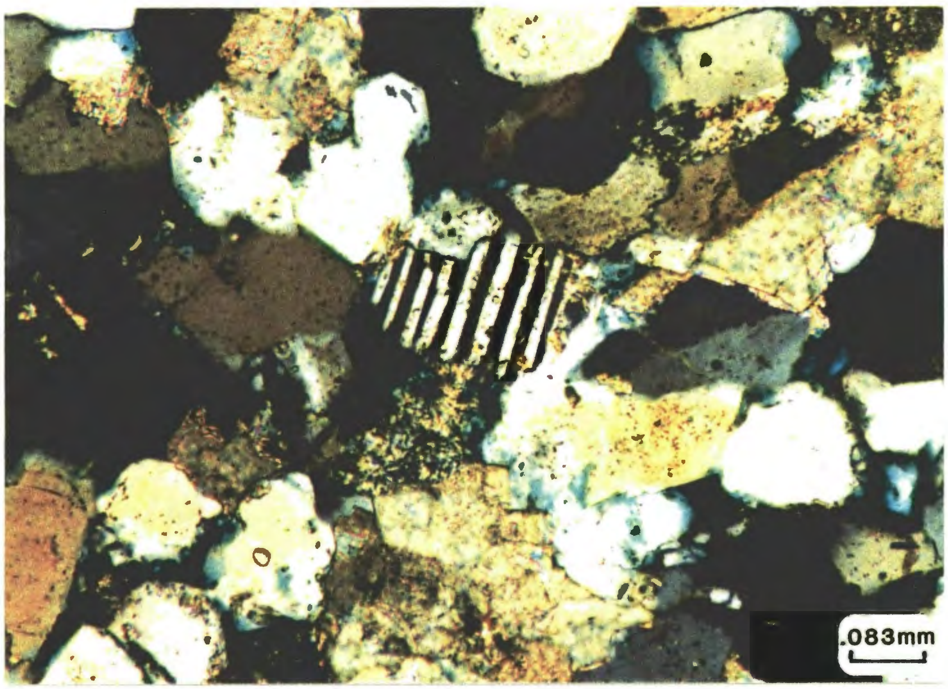


Figure 13. Characteristic Albite Grain in the Cottage Grove Sandstone; Cross Polarized (100X).

## Metamorphic Rock Fragments

Low grade metamorphic grains are the most common type of metamorphic rock fragment (MRF) noted in thin-sections. Low-rank fragments of the Cottage Grove display moderately high birefringence in thin-section and have elongate micaceous crystal habits. These grains are probably phyllites or low-grade schist. Other, less abundant metamorphic rock fragments display numerous, elongate, crenulated crystals that are typical of high grade varieties. Figure 14 shows examples of the low- and high-rank fragments in the Cottage Grove. On the average, metamorphic fragments are 5 percent of the total rock volume, but in some instances they constitute as much as 9 percent.

## Chert

Chert is typified by a microcrystalline quartz fabric and "salt and pepper" appearance under cross nicols. Chert was found in almost every sample and averaged 1.4 percent overall.

## Shale Rock Fragments

Rock fragments appearing very similar to low grade metamorphic rock fragments but possessing a "duller" appearance, and lacking a lineated fabric, were categorized as shale clasts. On the average, shale clasts are slightly larger than the mean grain size; they are associated with higher-energy bedforms. Shale clasts occur in trace amounts.

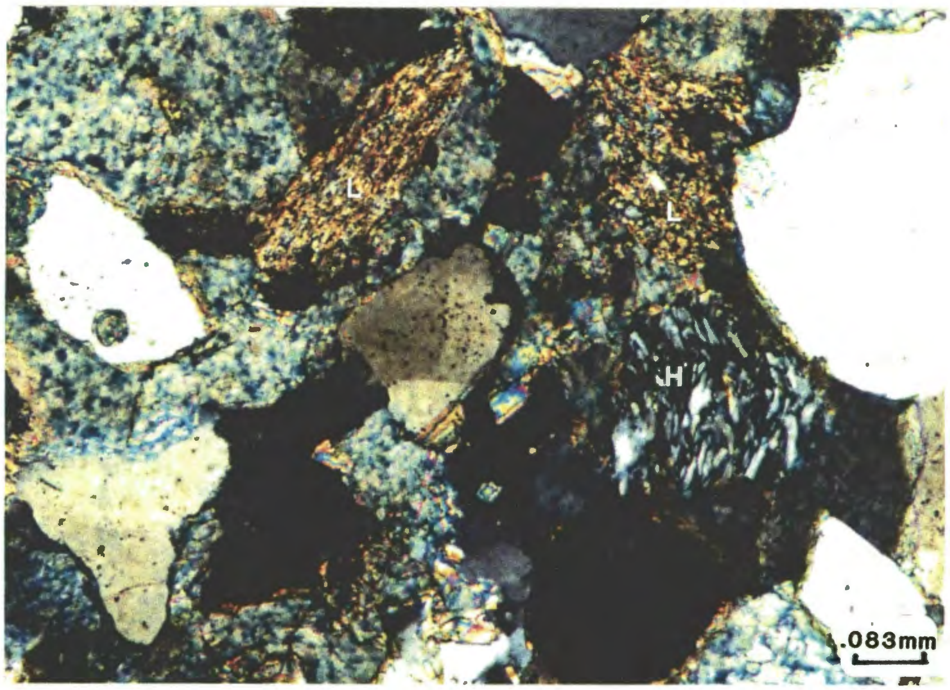


Figure 14. Representative Low Grade (L) and High Grade (H) Metamorphic Rock Fragments in the Cottage Grove Sandstone; Cross Polarized (100X).

## Carbonate Rock Fragments

Carbonate-rock fragments generally are found in bioclastic deposits. Carbonate fragments in the Cottage Grove are composed of micrite. Carbonate-rock fragments constitute as much as 2 percent of the rock in bioclastic deposits; in other rocks carbonate fragments rarely are more than trace amounts.

## Siltstone

Siltstone fragments are generally larger in diameter than the average framework grain. Siltstone was camouflaged in fine grain sediments of similar composition, especially where siltstone grain boundaries were squeezed. Siltstone fragments constitute trace amounts in approximately one-third of the thin sections.

## Plutonic Rock Fragments

Plutonic or granitic rock fragments (Figure 15) in several thin sections range from trace amounts to 2 percent of total sample. As discussed in Chapter II, plutonic rock fragments are not consistent with the theory that the Ouachita Mountains were the source area for these sediments. Granitic rock fragments in the Cottage Grove are characterized by siliceous grains containing laths of plagioclase minerals. Dimensions of granitic rock fragments are generally equivalent to those of other framework grains.

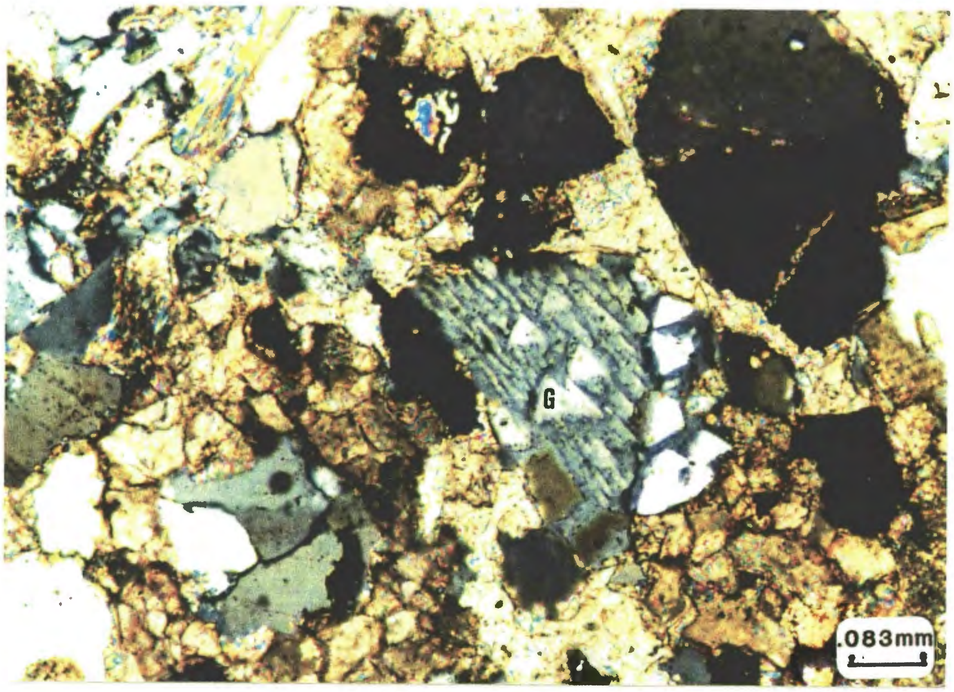


Figure 15. Typical Granitic Rock Fragment (G) in the Cottage Grove Sandstone; Cross Polarized (100X).

## Glauconite

Glauconite constitutes trace percentages in nearly every thin-section. Typically it occurs as well rounded, green grains (Figure 16) as observed in ordinary and polarized light. A ductile mineral, glauconite commonly is squeezed into pseudomatrix morphologies. Glauconite grains range from 0.06 to 0.10 mm in diameter.

## Mica

The most common mica in the Cottage Grove is muscovite. Muscovite averages 4 percent of the rock volume overall, but constitutes as much as 13 percent of some very-fine-grained samples. Detrital chlorite (a phyllosilicate) and biotite also are present in compositional averages of 1 and 0.8 percent respectively. Muscovite and biotite appear in thin-section as elongate, highly birefringent flakes; detrital chlorite displays more of a "book-like" morphology and is green to "ultra blue" under cross nicols.

Mica grains are commonly concentrated in stylolites where the mica exhibits elastic deformation due to compaction (Figure 17). Mica grains range from 0.04 to 0.30 mm in length.

## Fossil Fragments

The diversity of fossil fragments in the Cottage Grove is best expressed by basal bioclastic deposit of the Sarkey's Gillispie No. 1-3 core. A thin-section from this deposit

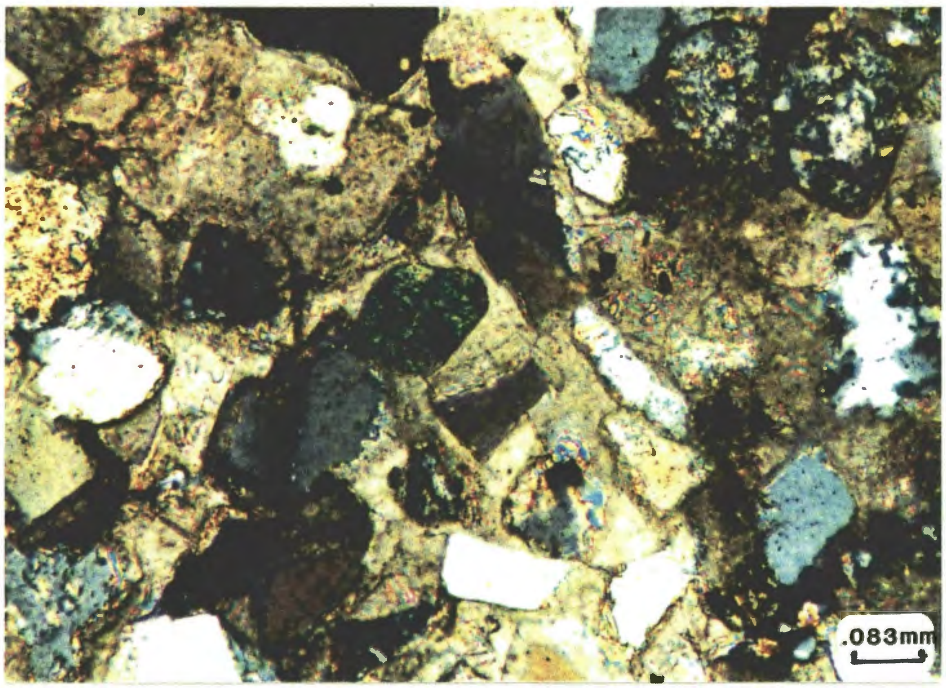


Figure 16. Glauconite Grain Encased in Poikilotopic Carbonate Cement; Cross Polarized (100X).

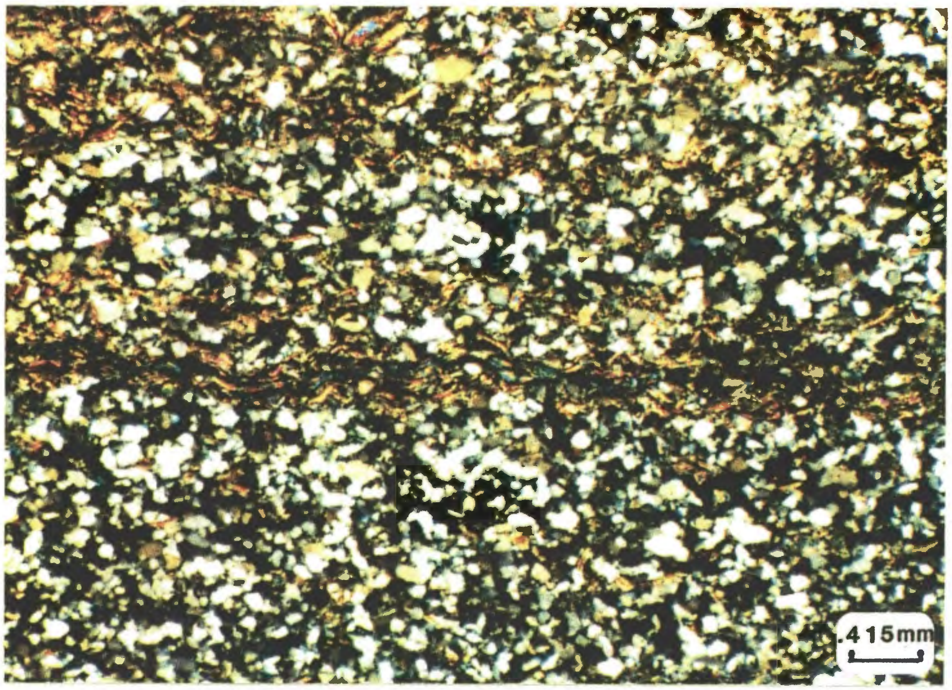


Figure 17. Muscovite Flakes Concentrated near Stylolite and Exhibiting Elastic Deformation due to Compaction; Cross Polarized (20X).

reveals a variety of marine fossil fragments, intraclasts, pelloids and ooids. Together these constituents comprise 45 percent of the sample. Fossil fragments include echinoderms, brachiopods, crinoids, bryozoans, pelecypods, gastropods, and foraminifera. Figure 18 displays a typical assemblage of fossil fragments from this deposit.

Fossil fragments obviously have been transported and re-deposited with the sands. The graded bioclastic deposits appear to have been transported by turbidity currents (see discussion in Chapter VII). The allochthonous nature of the fossils is supported by a micrite filled pelecypod (Figure 19) that was incorporated in the bioclastic deposit. This is a strong indication that the pelecypod had been deposited first in a relatively quiet, muddy shelf setting. Excluding bioclastic deposits, fossil fragments constitute trace percentages in approximately two-thirds of the thin-sections.

### Detrital Matrix

Detrital matrix in the Cottage Grove sandstone consists of illite and chlorite. An attempt was made to delineate the detrital clay from authigenic clay based on morphology and diagenetic relationships. In actuality, all clays deemed to be detrital appeared to be recrystallized (technically diagenetic) in thin-section. Clay recrystallization was also indicated by x-ray diffraction analysis (i.e., high crystallinity reflected by sharp diffraction peaks).

Detrital illite averages 2.5 percent overall, and detrital chlorite 0.5 percent. Illite and chlorite commonly are mixed (Figure 20). Detrital clay percentages range from trace amounts to 20 percent of the rock.

Detrital carbonaceous material is very uncommon in samples, but where present, was grouped with detrital illite for classification purposes. Carbonaceous material occurs in minute trace amounts and is concentrated near some of the stylolites.

### Accessory Minerals

The majority of thin sections contain trace amounts of zircon, tourmaline, and leucoxene. Only rare occurrences of phosphate, sphene and garnet were noted, also in trace amounts. Sphene and garnet were grouped with tourmaline. Accessory minerals range in diameter from 0.05 to 0.13 mm and generally are 0.02 to 0.04 mm smaller than the average framework grain size.

## Diagenetic Constituents

### Silica

Syntaxial quartz overgrowths constitute percentages that range from 0 to 8 percent of the rock, and average 2.4 percent overall. The precipitation of silica cement took place early, shortly after burial. Quartz overgrowths are present in nearly every thin-section except those with

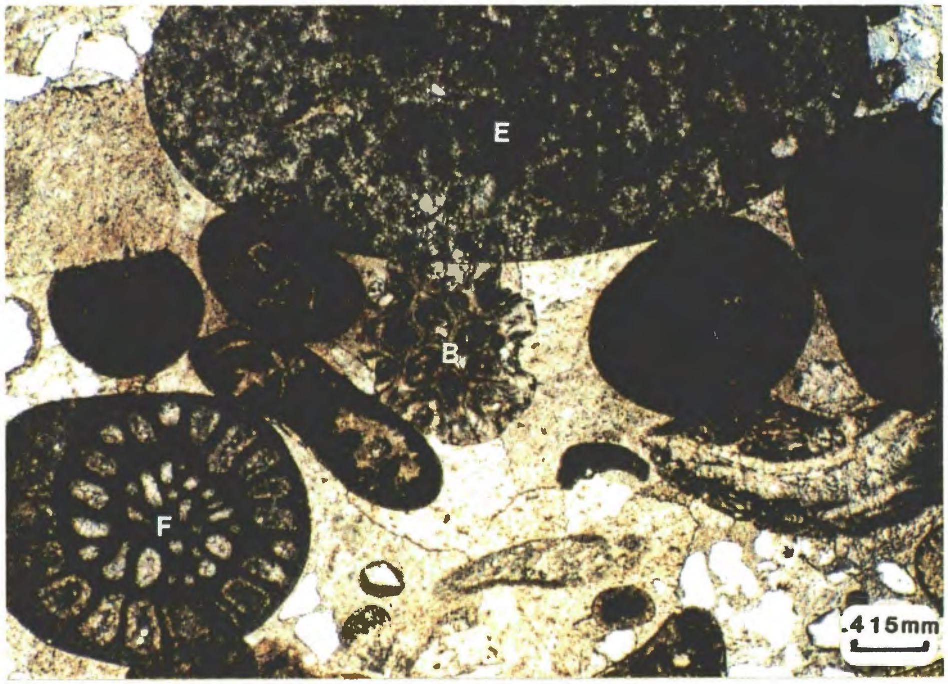


Figure 18. Bioclastic Deposit Fossil Assemblage Including a Foraminifer (F), Bryozoan (B), and an Echinoderm (E); Plane Polarized (20X).

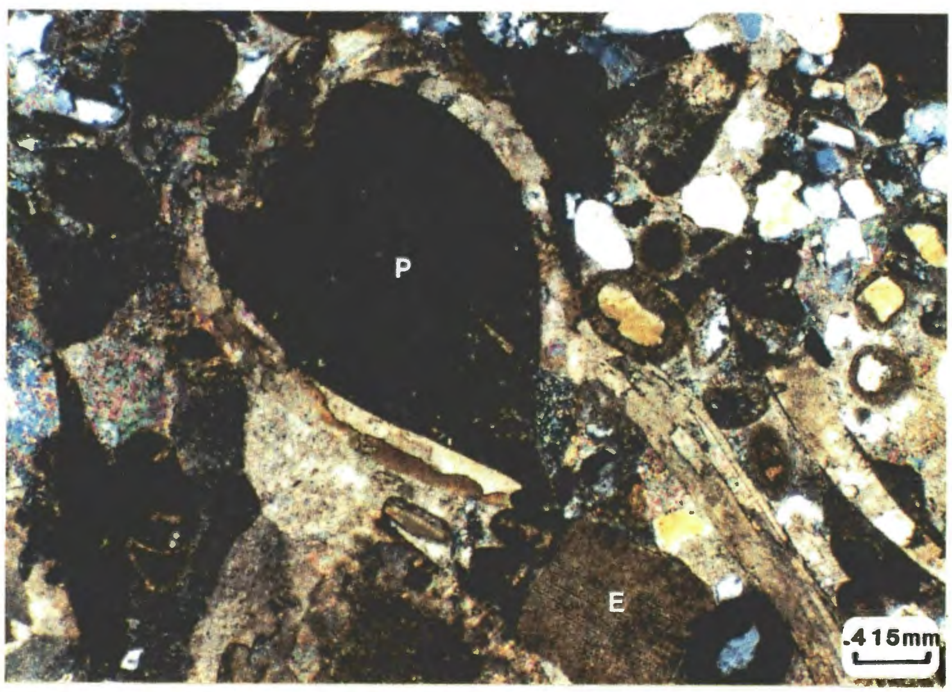


Figure 19. Mud-filled Pelecypod (P); An Echinoderm (E) and Several Ooids are also Pictured; Cross Polarized (20X).

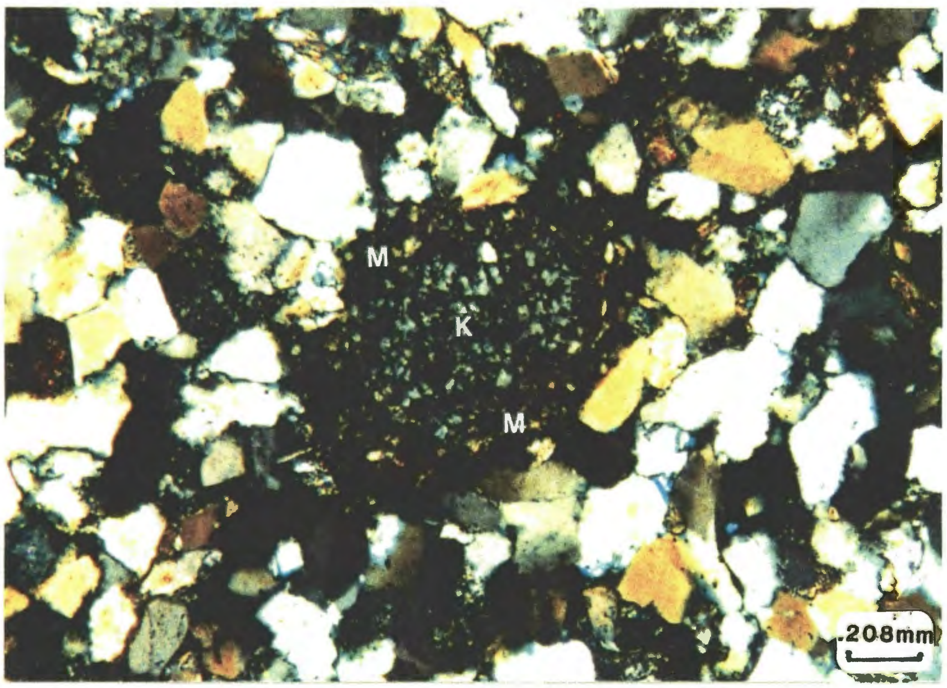


Figure 20. Recrystallized Detrital Illite and Chlorite Clay Matrix (M); Also note Authigenic Kaolinite (K) Which fills the Void lined by the Clays; Cross Polarized (40X).

large percentages of detrital matrix. In these samples detrital matrix inhibited silica cementation. The presence of sparse dust rims kept areas with abundant silica overgrowths from appearing as mosaics of interlocking crystals with no apparent nuclei (refer to Figure 12).

Carbonate Cements

Three types of carbonate cement are present in the Cottage Grove Sandstone: ferroan-dolomite, dolomite, and calcite. The most abundant variety is ferroan-dolomite followed by calcite then dolomite. Figure 21 illustrates a sandstone, the cement of which is divided between poikilotopic calcite and ferroan-dolomite cements. Ferroan-dolomite, calcite and non-ferroan dolomite cements constitute net compositional averages of 12.5, 7.4, and 1.2 percent respectively. Both ferroan dolomite and calcite are pore-filling cements and grain replacements. Nonferroan dolomite commonly occurs encased in ferroan-dolomite.

Feldspar

Feldspar overgrowths constitute minute trace amounts; they were recorded in only a few thin sections. In these rare instances, the syntaxial feldspar overgrowth formed in optical continuity with a partly altered feldspar grain (Figure 22). Overgrowths largely are inclusion-free and unaltered. They were judged to be authigenic because of their interlocking contacts with adjacent grains.

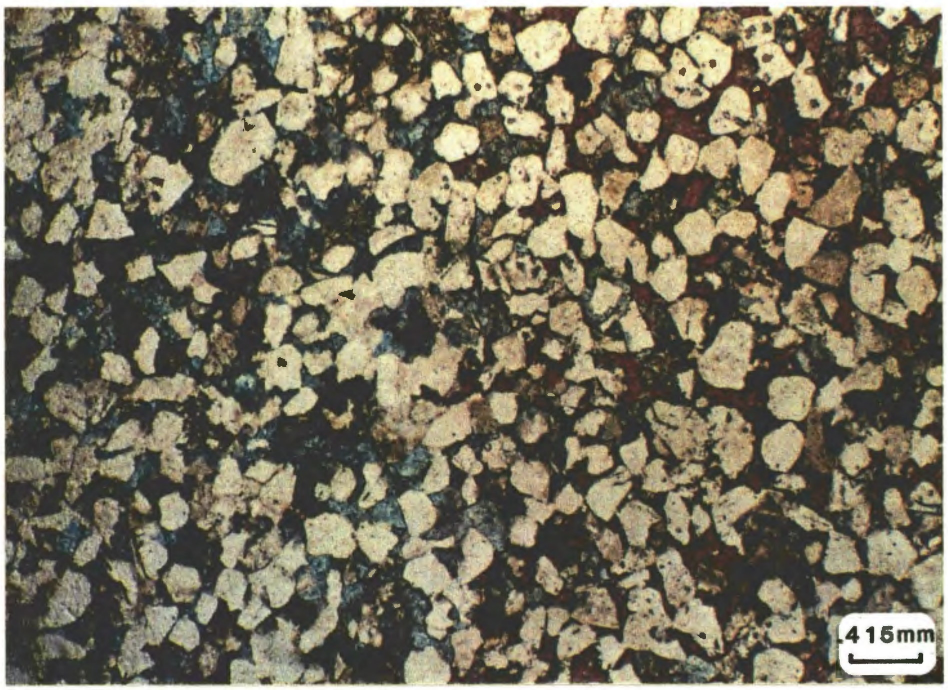


Figure 21. Calcite and Ferroan dolomite-cemented Sandstone. The Calcite has been Stained Red by Alizarine Red and the Ferroan dolomite Stained Blue by Potassium Ferricyanide; Plane Polarized (20X).

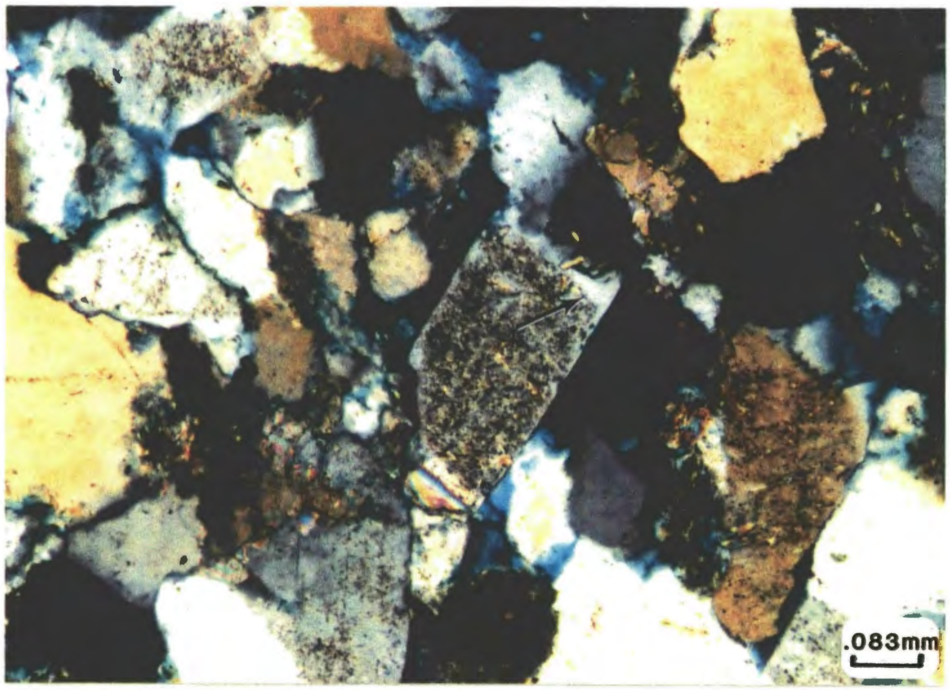


Figure 22. Feldspar Overgrowth in the Cottage Grove Sandstone; Cross Polarized (100X).

## Barite

Barite cement occurs in 3 of the 5 cores; it averages 1.5 percent of the net rock volume. Barite precipitated in scattered clusters of crystals as a pore filling, replacive and displacive cement (Figures 23 and 24).

## Clays

Three authigenic clays are noted in the Cottage Grove Sandstone. Overall, kaolinite, illite, and chlorite, compose 0.7, 0.9, and 0.4 percent of the total rock respectively.

Kaolinite precipitated in "booklet" fashion as a pore filling clay. Illite precipitated as a pore filling, pore bridging (Figure 25), and pore-lining clay. Chlorite precipitated as a pore-filling clay mixed with illite.

## Porosity

In thin-section, porosity values range from 0 to 16 percent, and averaged 6 percent. The porosity is almost exclusively secondary, owing primarily to dissolution of authigenic carbonate cements. A detailed discussion of porosity is found in Chapter VI.

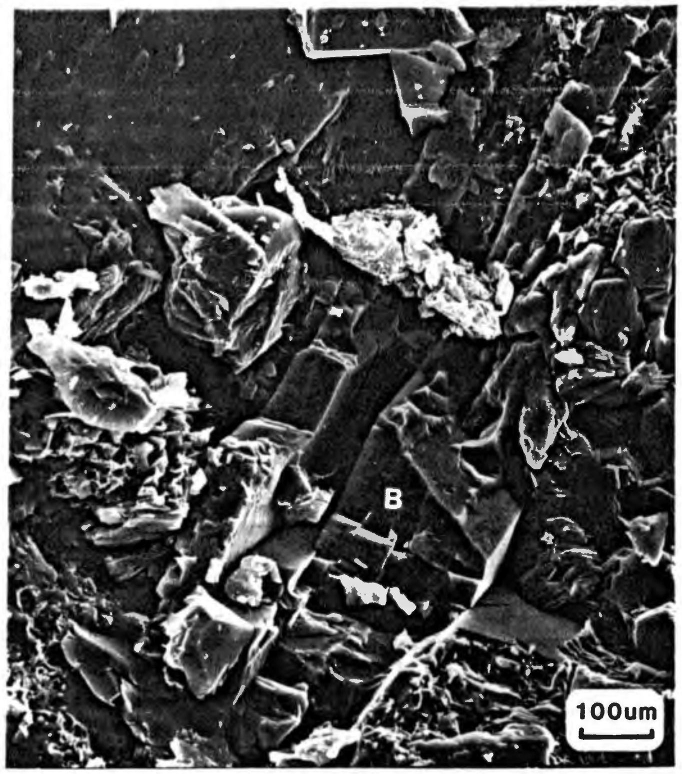


Figure 23. SEM Photomicrograph of Barite (B) in the Cottage Grove Sandstone; (1000X).

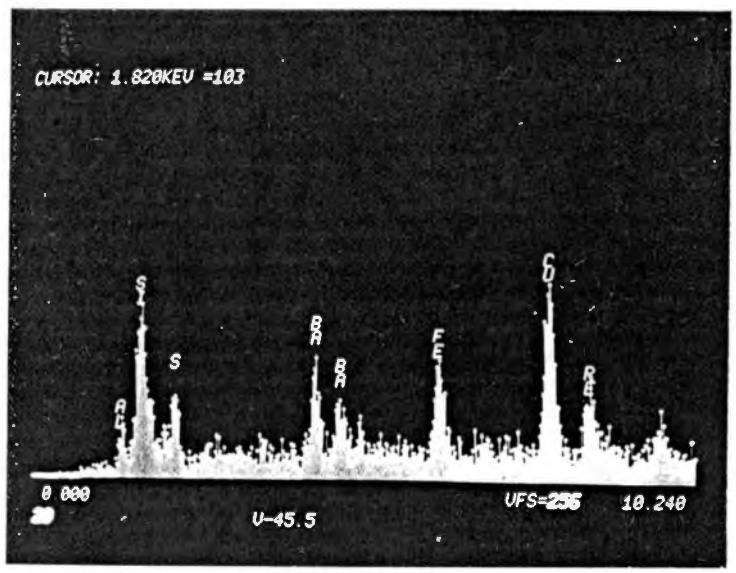


Figure 24. Associated EDAX Readings for Barite Sample Above.

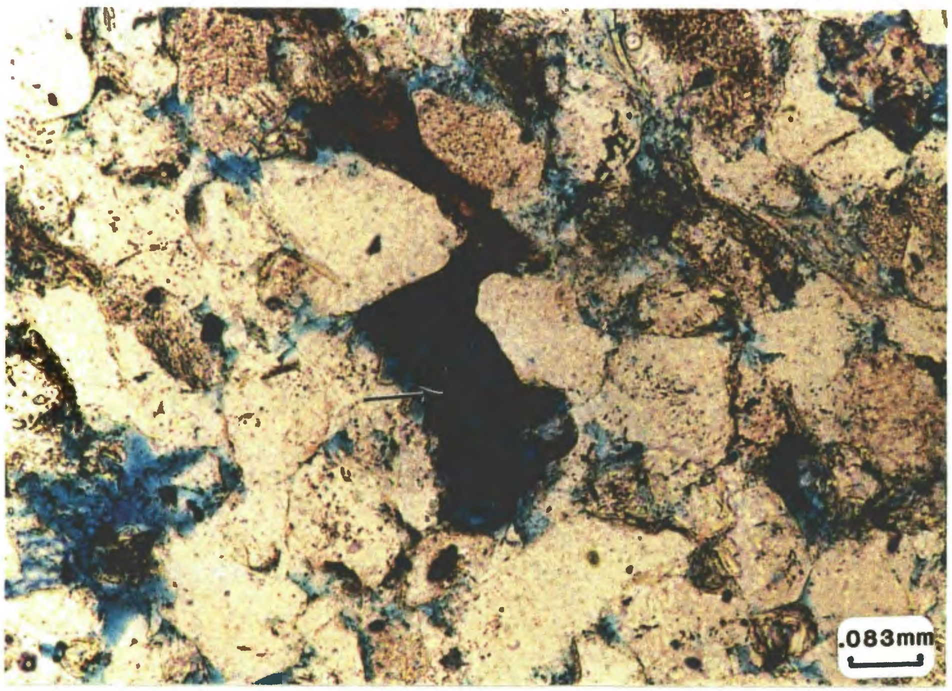


Figure 25. Pore-bridging Illite in Cottage Grove Sandstone; Cross Polarized (100X).

# CHAPTER V

# DESCRIPTIONS OF CORES

This chapter deals with the descriptive analysis of five Cottage Grove cores. The wells are located in the western half of the study area in Ellis and Woodward Counties, Oklahoma. Two cores are from T17N, R22W, one from T19N, R22W, one from T20N, R21W, and one from T21N, R21W (Refer to Figure 1). In order to be in concordance with the events of depositional history, the lowermost unit of each core is described first, and discussions of progressively younger units follow.

## Descriptions

The Sarkey's Inc., Gillispie No. 3-2 core was evaluated in conjunction with the Sarkey's Inc., Gillispie No. 1-3 core. These cores were taken from wells located approximately 1 mile apart in sections 2 and 3 of T17N, R22W. Well-log correlations and curve shapes from these wells indicate that the two wells penetrate the same sandstone body. However, neither core contains a complete sequence of the sandstone facies. The Gillispie No. 3-2 core contains the upper portion of the sandstone and a portion of an overlying shaly facies. The Gillispie No. 1-3 core contains the lower portion of the sandstone and the basal sandstone-shale contact. Hence, both cores were logged to define better the complete sandstone interval.

Sarkey's Inc., Gillispie No. 3-2

The Sarkey's No. 3-2 well is located at SE NW SE NW, Sec. 2, T17N, R22W, in the Ioland Field, Ellis Co., Oklahoma. The core from this well is approximately 42 feet long, from 8540' to 8581.5' core depths (-6443' to -6484.5' subsea) (Figures 26 and 27). Two facies are delineated, a lower sandstone facies (8552'-8582'), and an upper interbedded, very-fine sandstone and shale facies (8540'-8552').

The lower portion of the core (8552'-8574') exhibits a variety of sedimentary structures. These include horizontal plane bedding, inclined-plane bedding, small scale trough cross-bedding, and stylolites. Inclined-plane bedding (regarded as medium-scale tabular-planar cross-bedding) often contains shale clasts and fossil fragments (Figure 28). Grain sizes associated with inclined-planar sediment generally are slightly larger than that with other sedimentary structures.

Carbonate cements are distinguishable in hand specimen by differences in color. Sandstone cemented by calcite appears yellow; sandstone cemented by ferroan dolomite appears brown. Contacts between calcite and ferroan dolomite cements are displayed at 8578' and 8558' (See Figure 27).

Beginning at 8552' is an upward gradational change from the underlying sandstone facies to an interbedded thin shale

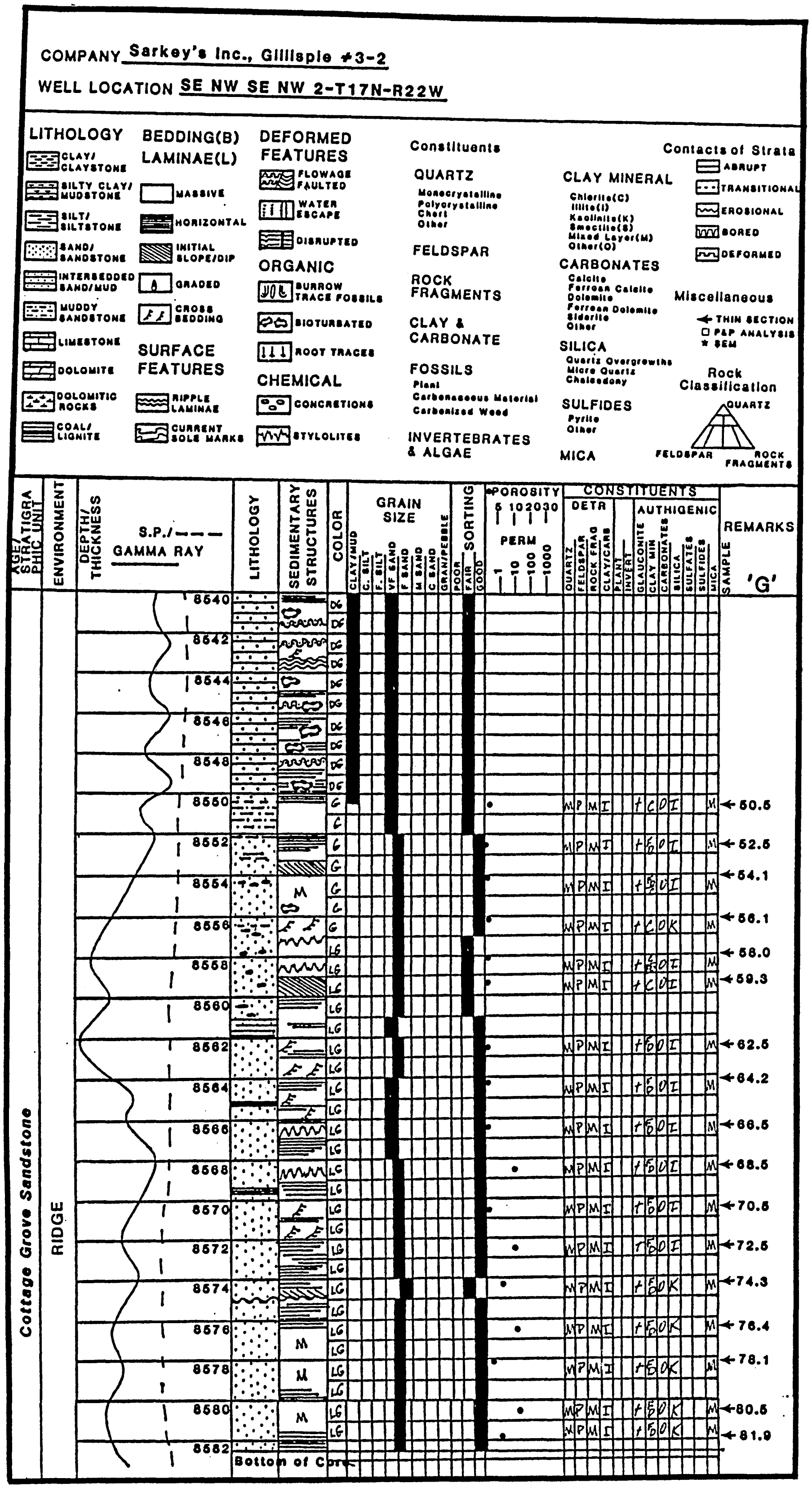


Figure 26. Petrolog of Sarkey's, Gillispie No. 3-2 Core.

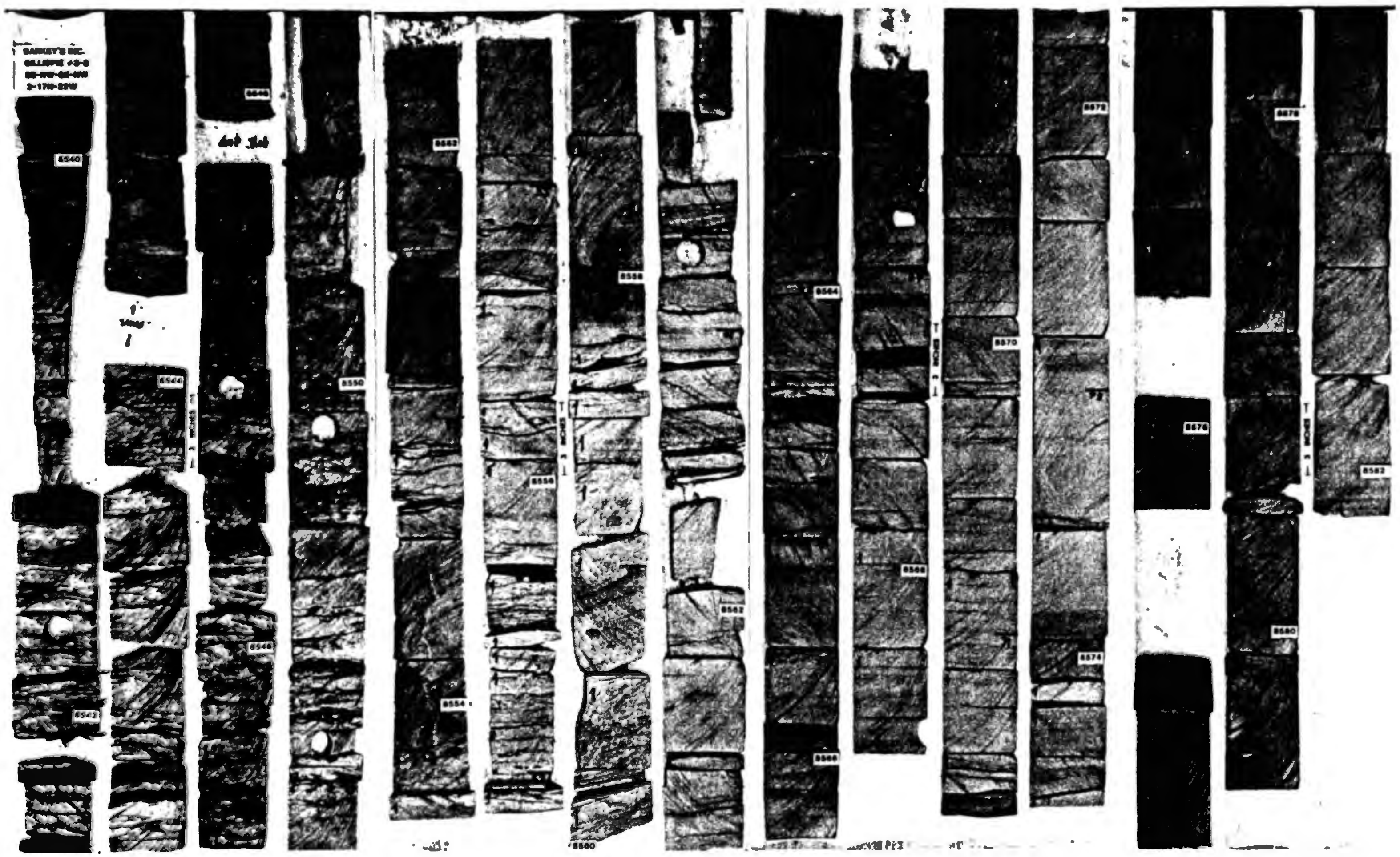

Figure 27. Sarkey's Inc., Gillispie No. 3-2 Core.

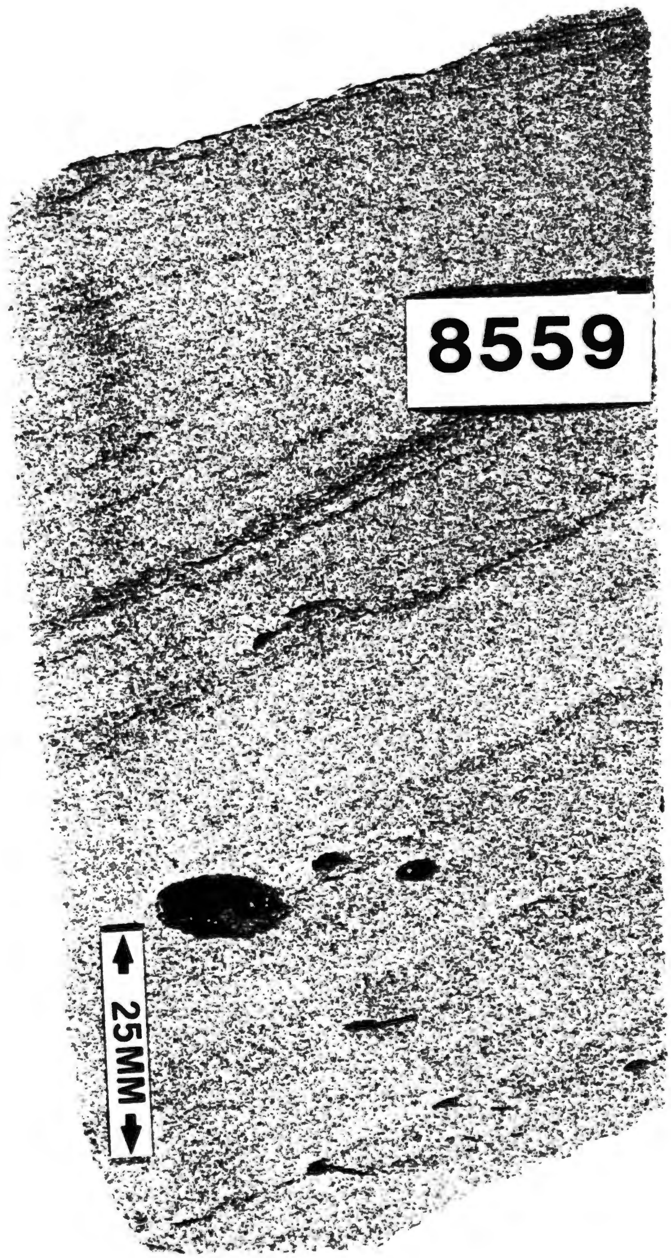


Figure 28. Inclined Planar-bedding containing Shale Clasts; Sarkey's, Gillispie No. 3-2 (8559').

and silty, very-fine sandstone facies. Common sedimentary structures in the interbedded interval include soft sediment deformation, ripple laminae, horizontal laminae and bioturbated rock. Figure 29 shows an example of the bioturbated material that is common in this interval.


Figure 29. Interbedded Siltstone and Shale with Horizontal Burrows; Sarkey's, Gillispie No. 3-2 (8550.2').

Sarkey's Inc., Gillispie No. 1-3

The Gillispie 1-3 well is located at E2 NE SE, Sec. 1, T17N, R22W, in the Ioland Field, Ellis Co., Oklahoma. The cored interval is approximately 19 feet long, from 8560' to 8578.9' core depths (-6520' to -6538.9' subsea) (Figure 30 and 31). A sandstone facies overlies a shale facies in the core. The lower facies is characterized by black, fissile marine shale. No evidence of sediment reworking is present in this facies.

The sandstone facies is punctuated by an abrupt contact at 7578.6'. Directly above the contact is a 2-inch layer of siltstone that contains a moderate amount of fossil-debris. This deposit grades upward abruptly (within 2 inches) to clay laminations that are overlain by 6 inches of siltstone. The siltstone is truncated at an erosive upper contact with graded "bioclastic" material at 8578'. The bioclastic fines upward to siltstone. Three additional, similarly graded deposits are present between 8577.6' and 8576'. Constituents in the graded deposits include shale clasts, ooids, pelloids, intraclasts and fossil-fragments (Figure 32). Fossils include brachiopods, pelecypods, echinoderms, foraminifera, gastropods, and bryozoans.

Above 8576' the sandstone facies is almost devoid of observable sedimentary structures. It is mostly massive, except for clay laminae at 8572'.

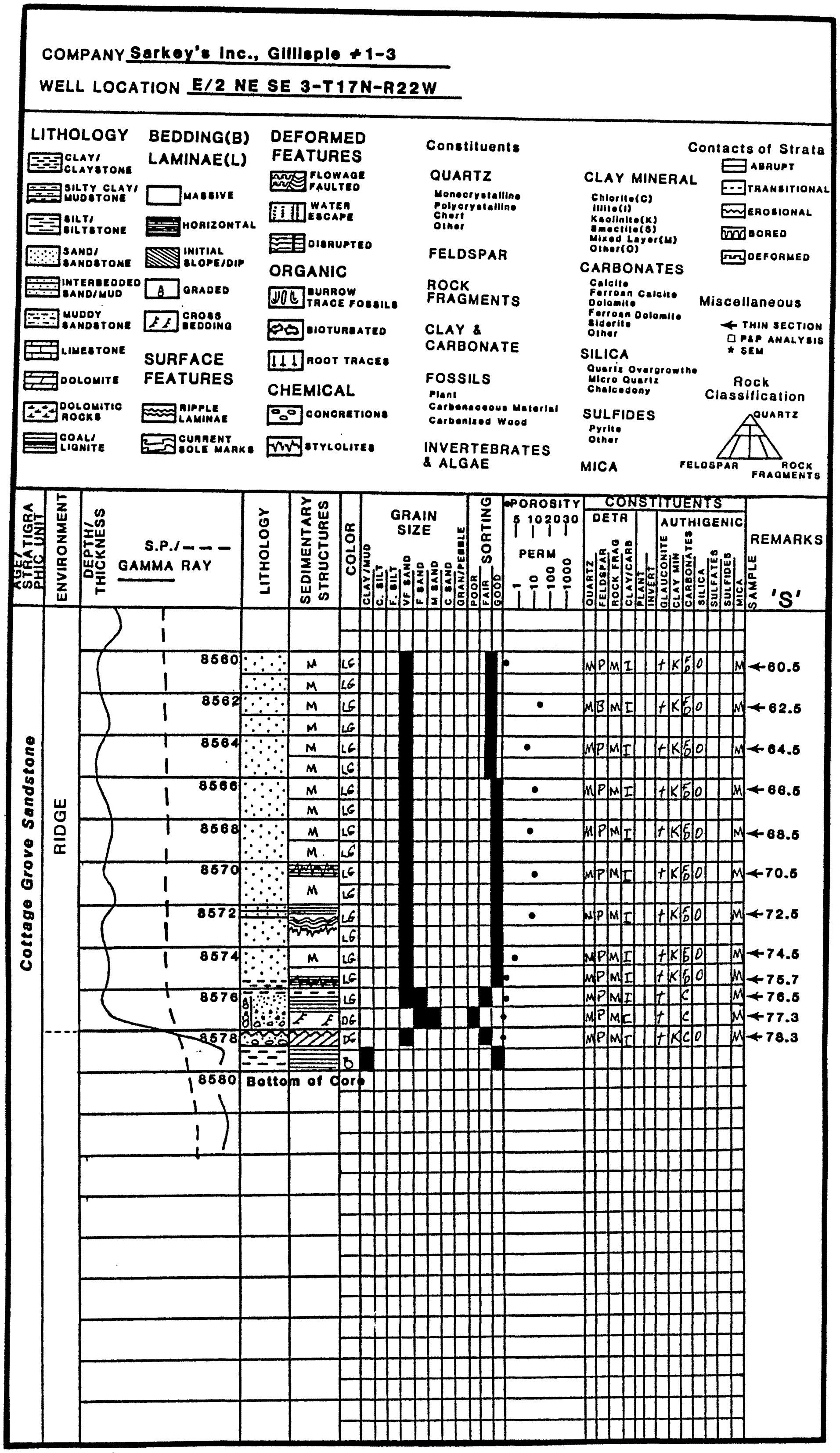


Figure 30. Petrolog of Sarkey's, Gillispie No. 1-3 Core.

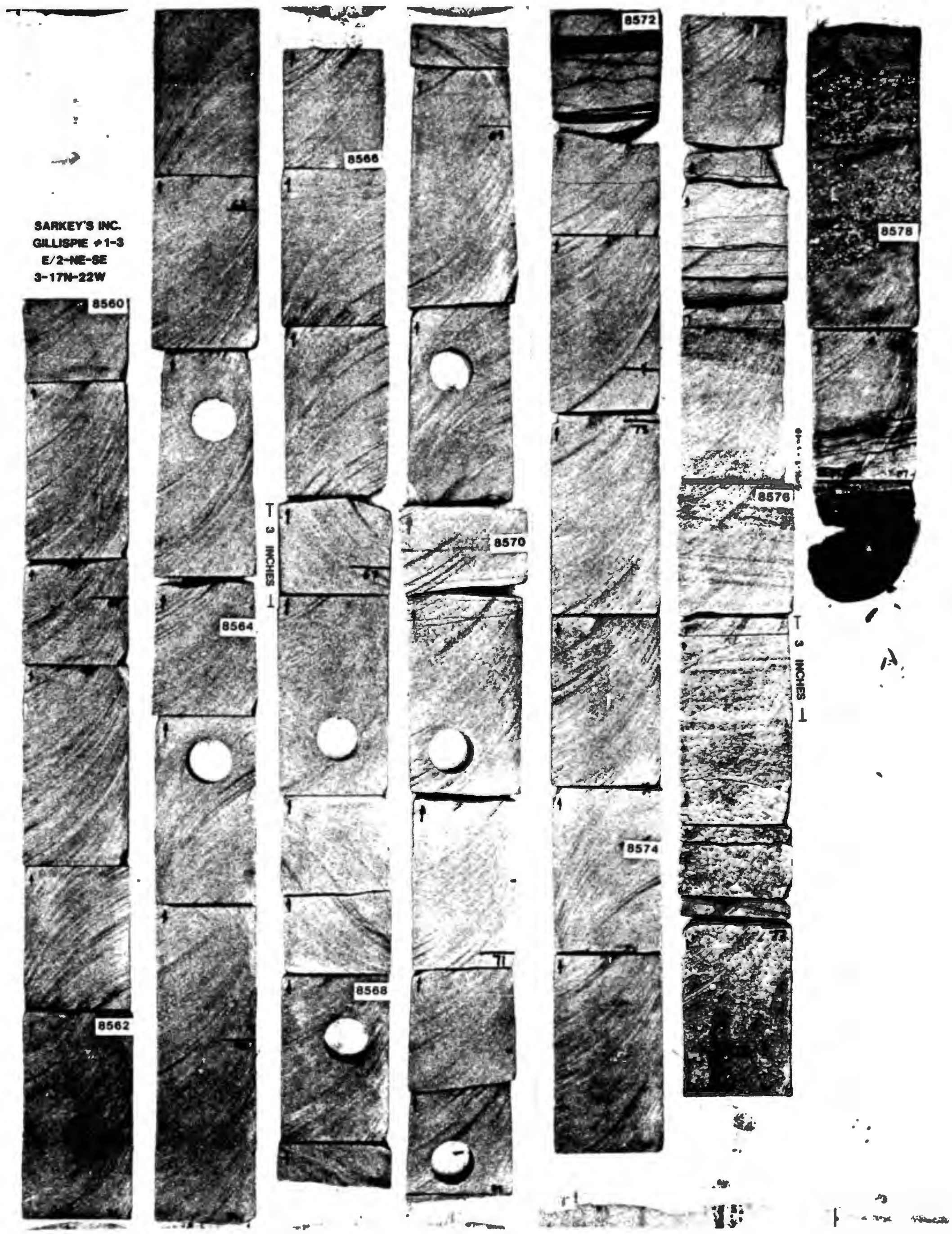


Figure 31. Sarkey's Inc., Gillispie No. 1-3 Core.


Figure 32. Graded Bioclastic Deposit near the Base of the Sandstone Facies; Sarkey's, Gillispie No. 1-3 (8578').

Petroleum Inc., Valentine No. 1

The Valentine No. 1 well (Figure 33) is located at SE NE, Sec. 1, T19N, R22W, in the East Harmon Field, Ellis Co, Oklahoma. The cored interval is approximately 44 feet long, from 7920' to 7965' core depths (-5595' to -5640' subsea). It is divisible into three units, a basal shale, in turn overlain by sandstone, and a bioturbated siltstone and shale.

The lowermost 10 feet of core (7954'-7964') predominantly are black shale with interbedded, thin lenses of very-fine grained sandstone and siltstone. Brachiopods, crinoids, and shale clasts are in chaotic layers within the shale.

The central portion of the core (7939.5' to 7954') is characterized by micaceous, tan to light gray, very-fine grained sandstone with a few thin interbedded shales. Sedimentary structures in this interval include small scale cross-bedding, horizontal laminae, inclined laminae, and massive bedding. Characteristic small scale, trough cross-bedding is at 7449' core depth (Figure 34).

The lower contact of the sandstone facies with the shale facies (at 7954') is distinct. The top of the sandstone facies abruptly fines upward from very-fine grained sandstone (at 7939') to interbedded siltstone and shale.

The uppermost facies (7920'-7939') is composed of interbedded, light gray siltstone and black shale. Bioturbated rock is common in this interval and most abundant in places with high proportions of relatively coarser clastics.

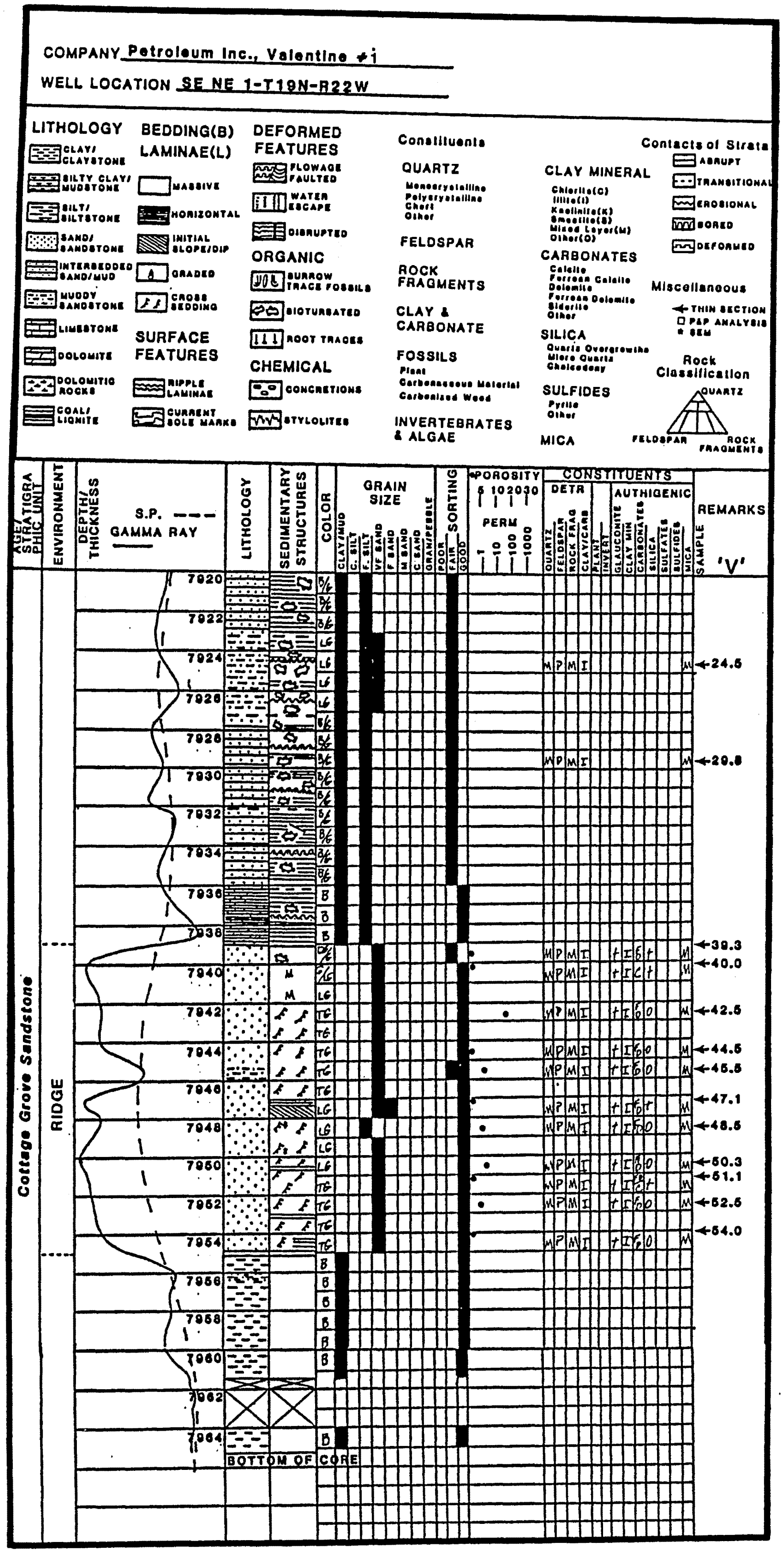


Figure 33. Petrolog of Petroleum Inc., Valentine No. 1 Core.

Other sedimentary structures include horizontal laminae, microfaults and ripple laminae.


Figure 34. Small Scale Cross-bedding (sample marred by saw marks); Petroleum Inc., Valentine No. 1, (7449').

Odessa Natural Corp., Wreath No. 1

The Wreath No. 1 well was drilled as a wildcat well just south of the SW Sharon field. It is located at C NW, Sec. 17, T20N, R21W, in Woodward Co., Oklahoma.

The cored interval is approximately 26 feet long, from 7774' to 7799.75' core depths (-5408' to -5433.75' subsea) (Figures 35 and 36). The core is divisible into three facies, a sandstone facies, a graded-sandstone facies, and a interbedded siltstone-and-shale facies. Although not logged, black, fissile marine shale was noted beneath the sandstone facies; the contact between the sandstone and shale was missing in the core.

The facies from 7799.75' to 7788' consists of fine to very-fine grained, tan to gray, well-sorted sandstone. Sedimentary structures in this interval include horizontal plane bedding, small scale cross-bedding, massive sandstone, and soft-sediment deformation. Figure 37 shows an example of the soft-sediment deformation observed at 7794'. Observable variations in cement range from brown (ferroan dolomite) to yellow (calcite). In this section of the core, calcite and ferroan dolomite appear to be mixed, as made evident by a "splotchy" appearance (Figure 38).

The graded-sandstone facies is present between the sandstone facies and the overlying interbedded siltstone-and-shale facies. An erosional contact is seen at the base of the graded-sandstone facies. This facies is characterized by a fining-upward sequence of strongly mixed fossiliferous

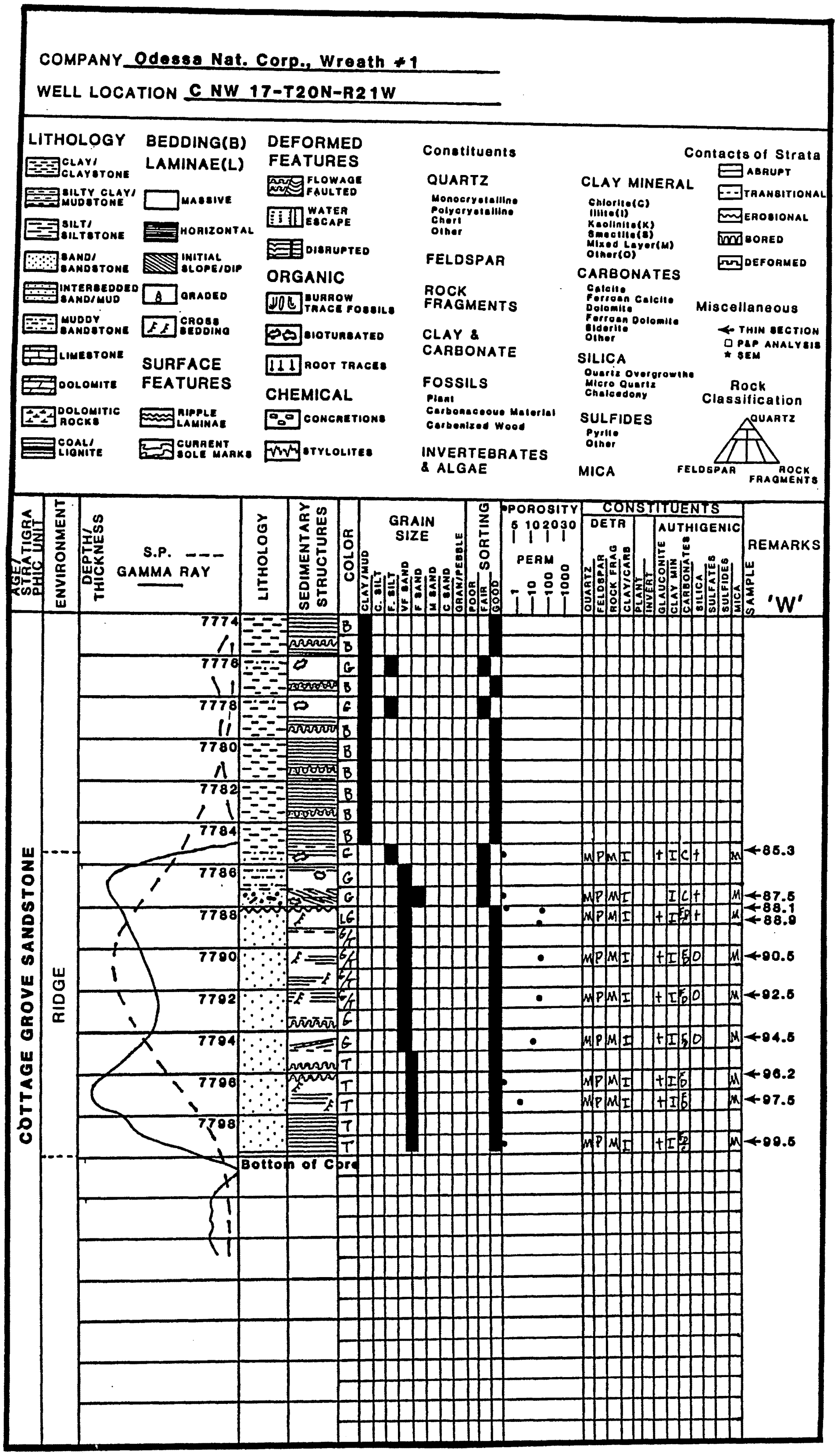


Figure 35. Petrolog of Odessa Natural Corp., Wreath No. 1 Core.

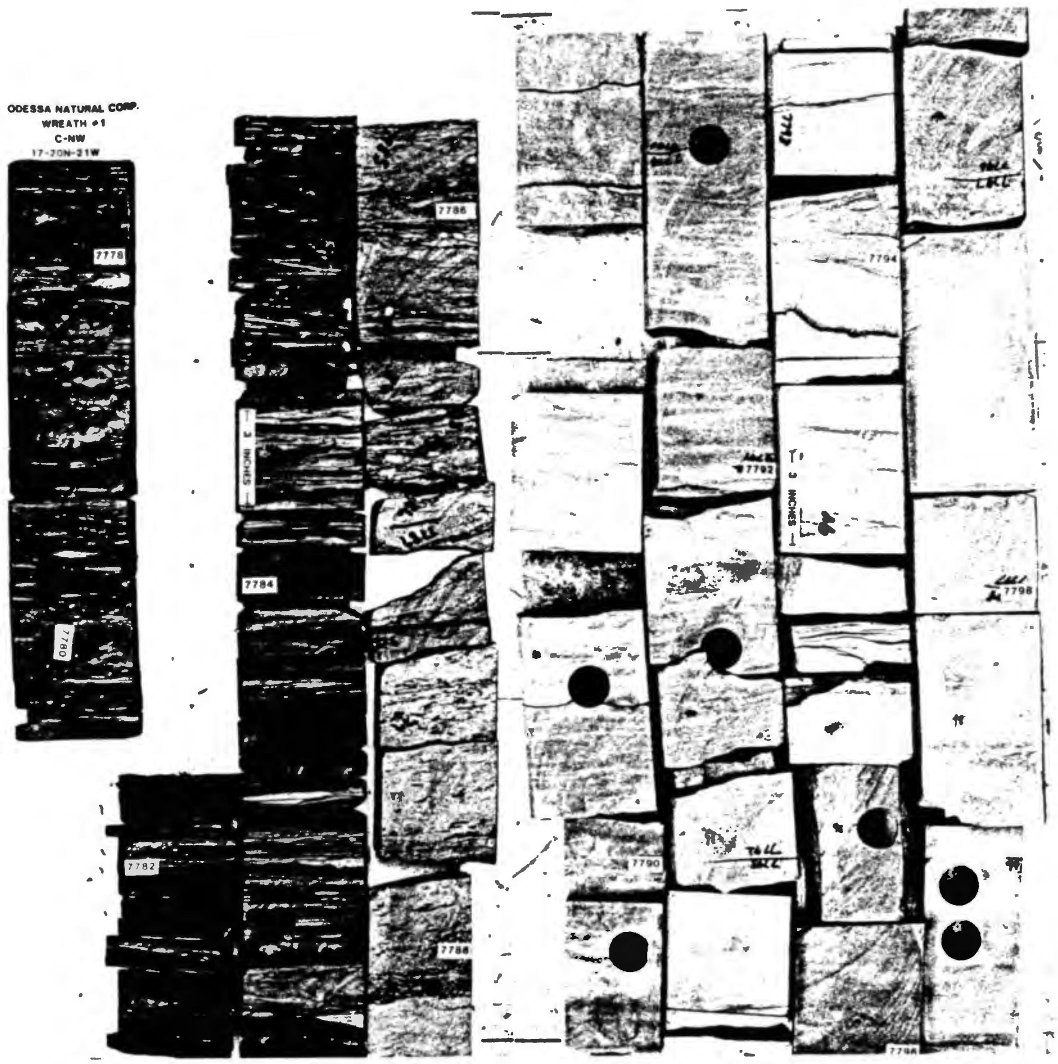


Figure 36. Odessa Natural Corp., Wreath No. 1 Core.

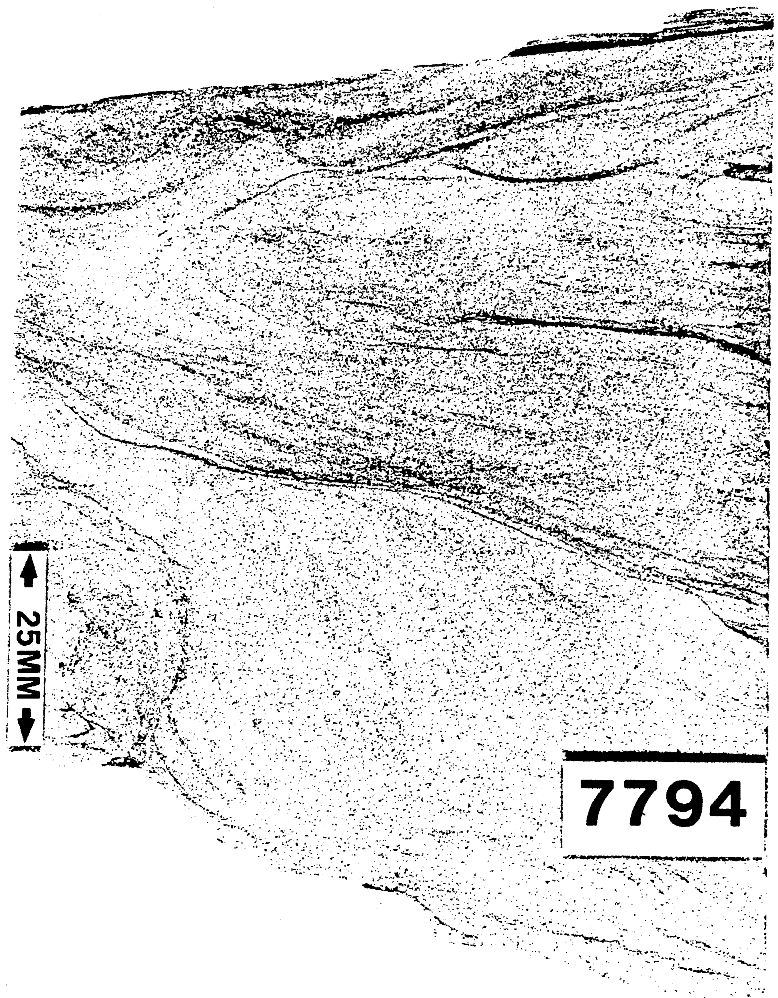


Figure 37. Soft-sediment Deformation in the Cottage Grove Sandstone; Odessa Natural Corp., Wreath No. 1 (7794').

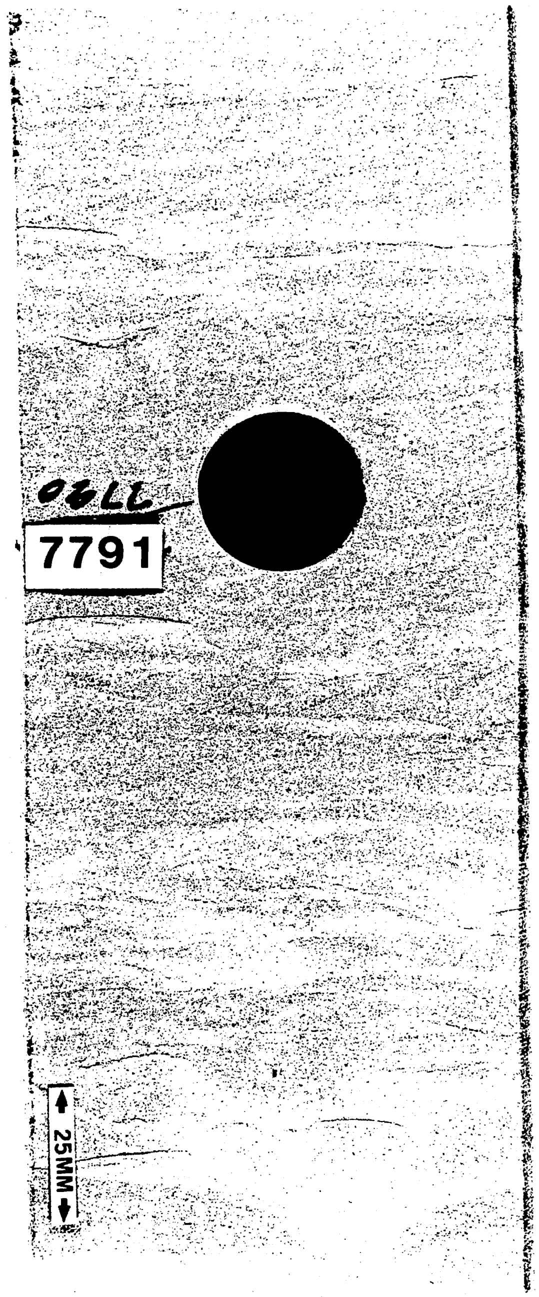


Figure 38. Sandstone Color Variations in Sandstone due to Changes in Diagenetic Cements (Ferroan-dolomite = Dark Gray, Calcite = Light Gray); Odessa Natural Corp., Wreath No. 1 (7791').

material, shale clasts and very-fine sandstone (Figure 39). This deposit is regarded as storm-washover deposit. The graded deposit fines upward to siltstone and clay laminae.

The upper facies (7774'-7787') is characterized by light gray siltstone interbedded with dark gray to black shale. Sedimentary structures include horizontal laminae, ripple laminae, and bioturbated rock.

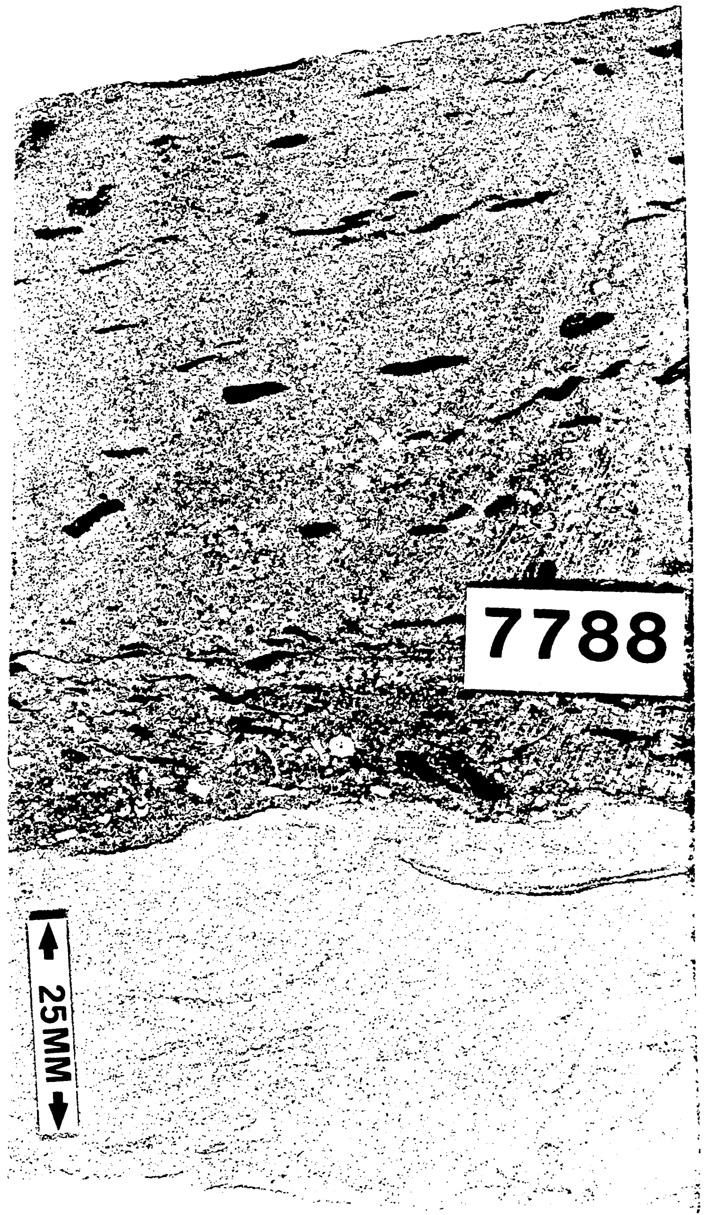


Figure 39. Erosional Contact and Graded Sequence near top of Sandstone Interval with Marine Fossil Material (Storm Wash-Over Deposit); Odessa Natural Corp., Wreath No. 1 (7788').

Ran Ricks Jr., Cole No. 28-A

The Cole No. 28-A well is located at C W2 NW, Sec. 28, T21N, R21W, in the West Sharon Field, Woodward Co., Oklahoma.

The cored interval is approximately 35 feet long, from 7418' to 7453' core depths (-5175' to -5210' subsea) (Figures 40 and 41). Three facies are present in this core; a basal fossiliferous, black marine shale, a middle sandstone, and a upper interbedded siltstone-and-shale facies. The contact between the sandstone and the underlying shale facies is not seen in the core.

Several pieces of core are missing from the sandstone facies. In addition, from 7444' to 7447.9', seven pieces of core were unmarked for footage and could only be described lithologically and not by position in the interval.

The lower facies (7449.9'-7453') is slightly bioturbated, fissile and fossiliferous marine shale. Abundant crinoidal fragments, brachiopods and shale clasts are concentrated within this deposit at 7450' (Figure 42).

The middle facies (7438.2'-7449.9') predominantly is very fine grained, well sorted sandstone. Common sedimentary structures include horizontal plane bedding, inclined plane bedding, small scale trough cross-bedding, and massive bedding. Figure 43 shows a segment of core from the unmarked interval that contains typical bedding structures. The sandstone facies includes several distinct contacts between diagenetic cements. The most obvious contact is at 7449.5' which marks the diagenetic boundary between calcite and

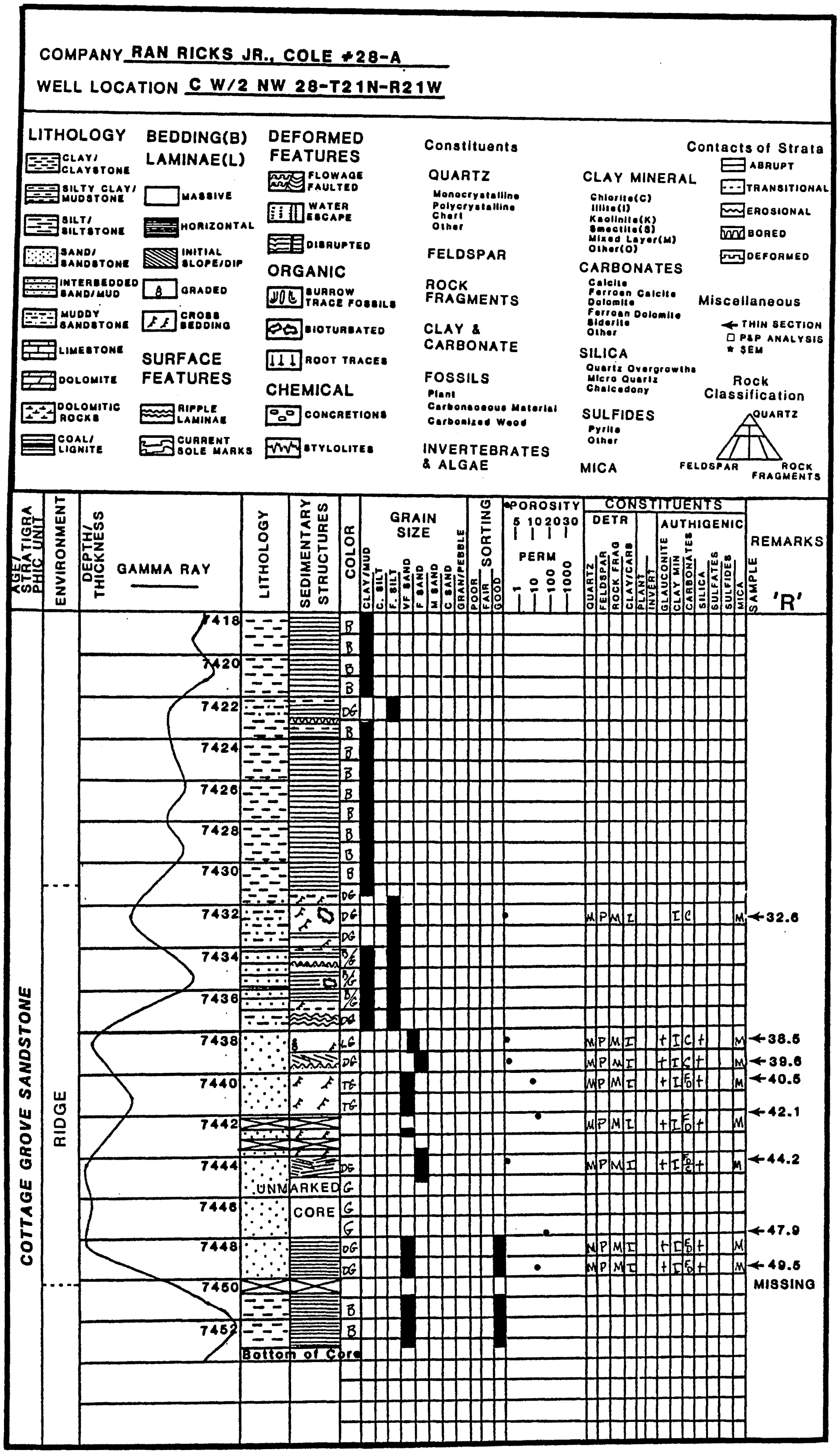


Figure 40. Petrolog of Ran Ricks Jr., Cole No. 28-A Core.

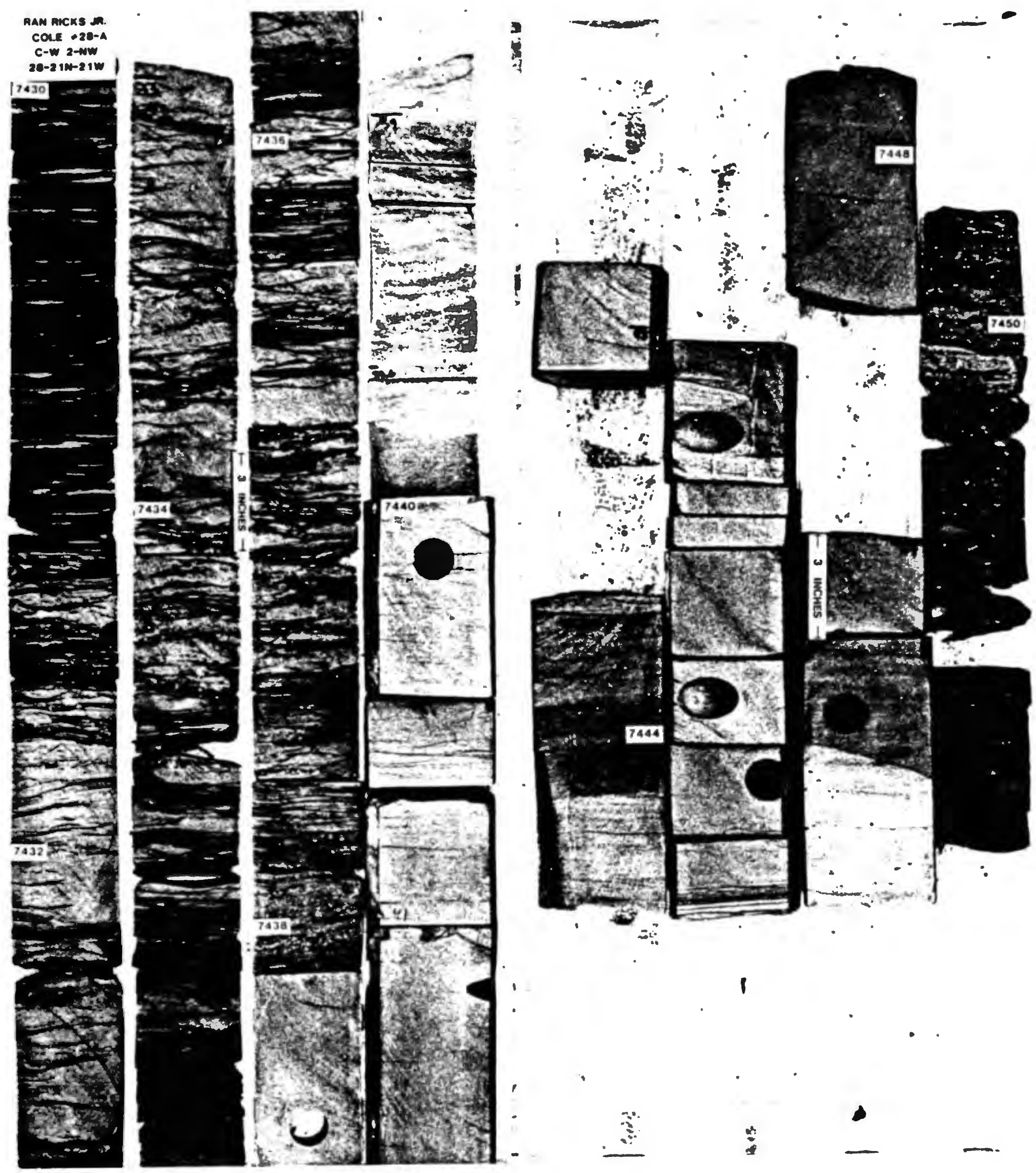


Figure 41. Ran Ricks Jr., Cole No. 28-A Core.

ferroan-dolomite cements (Figure 44). The source of the calcite cement almost certainly was carbonate fossil debris at the base of the sandstone, whereas the ferroan-dolomite is attributed to deep burial migrating ground waters. A similar diagenetic contact is at 7439.6', near the top of the sandstone facies (Figure 45).

The upper facies (7430'-7438.1') is interbedded fine-grained sandstone, siltstone and shale. Ripple laminae, small scale trough cross-bedding, horizontal laminae, evidence of soft-sediment deformation, and bioturbated rock are common. At the base of this interval, at 7438', is a concentration of fossil-fragments interbedded with siltstone and shale.

The upper facies fines upward to black shale. However, at 7434' to 7431.5' the overall fining sequence is interrupted by an interval of siltstone. This stratum probably represents the lateral extension of a sandstone deposit developed fully elsewhere in the study area.


Figure 42. Reworked Shale Deposit just below the Base of the Sandstone Facies; Ran Ricks Jr., Cole No. 28-A (7450').


Figure 43. Sedimentary Structures include (from top to bottom) Small Scale Trough Cross-Bedding, Inclined Planar (Medium Scale Cross-bedding), and Horizontal Planar Bedding; Ran Ricks Jr., Cole No. 28-A (7444').

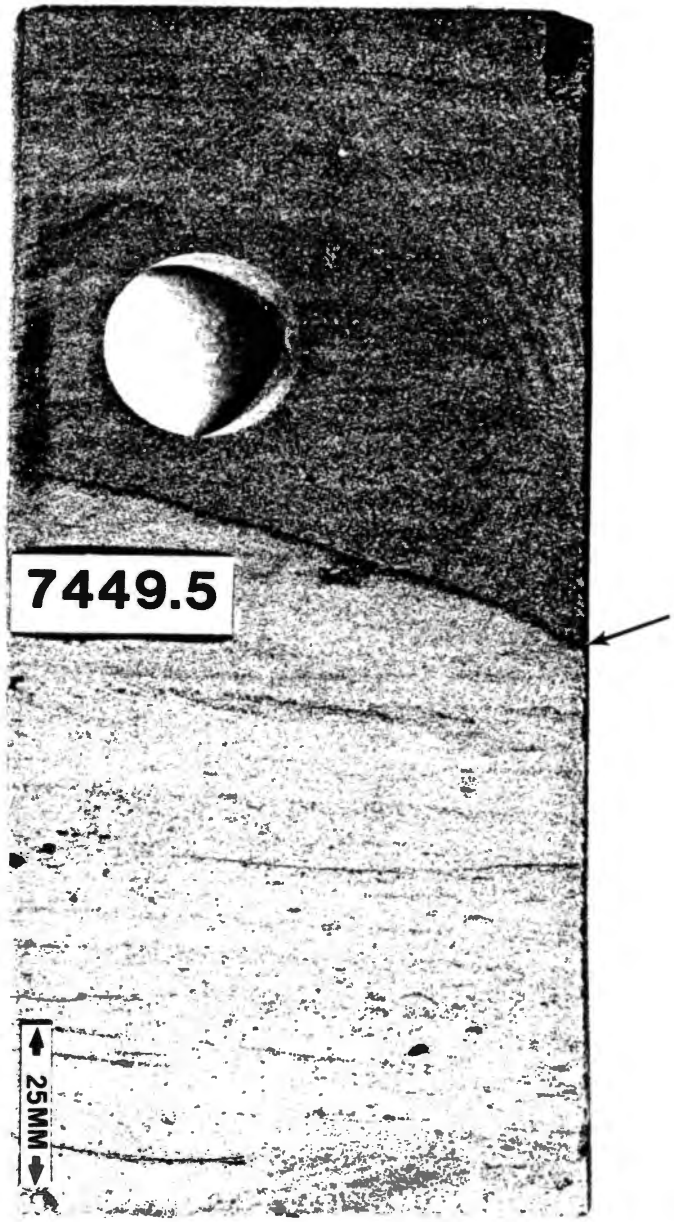


Figure 44. Sharp Diagenetic Contact between Rock Cemented by Ferroan-dolomite (Dark Gray) and Calcite (Light Gray) Ran Ricks Jr., Cole No. 28-A (7449.5').

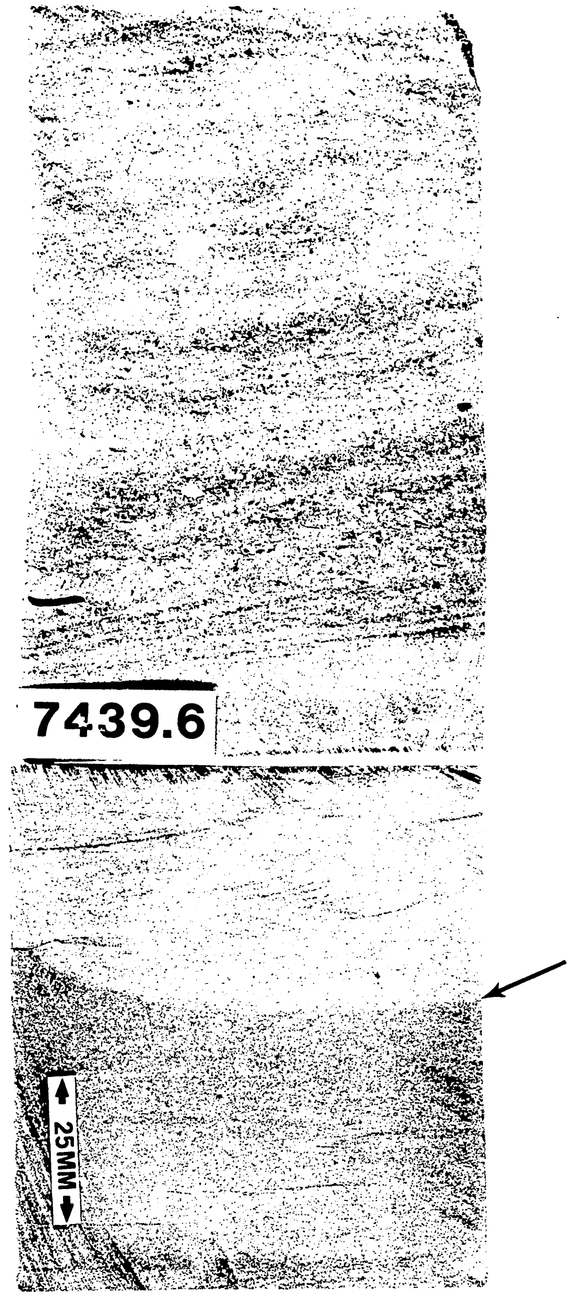


Figure 45. Diagenetic Contact between Rock Cemented by Ferroan-dolomite (Dark Gray) and Rock Cemented by Calcite (Light Gray), near the Top of the Cottage Grove Sandstone Facies, Note: White Specks in the Upper One-half of the Sample are Carbonate Fossil-fragments - the Probable Source of Calcite Cement; Ran Ricks Jr., Cole No. 28-A (7439.6).

## Summary

Several sedimentologic and diagenetic similarities exist among the cores studied. Resemblance between cores indicates that sandstones are of like depositional origin and their diagenetic histories are strongly similar. The primary difference recorded among the cores was in the overall thickness of the sandstone facies. These differences are attributable to (1) variations in stacking of the sandstone units (functions of current duration, sea level fluctuation, and subsidence rates), (2) positions of where the wells penetrated the sandstone bodies, and (3) some combination of (1) and (2). An outline of general characteristics observed in the Cottage Grove cores is shown in Figure 46.

## Outline of Characteristics of Cottage Grove Sandstone

I. CONTACTS

A. Upper contacts (gradational)

1. Sandstone facies grade upward to bioturbated and interbedded siltstone and shale deposits of marine origin.

a. This sequence is interrupted at some localities by storm wash-over deposits, as exhibited by the Odessa Natural Corp, Wreath No. 1 core.

B. Basal contacts (abrupt and tightly cemented)

1. Basal contact is abrupt with marine shales below.

a. Marine shales immediately below the contact show evidence of reworking (fossil-fragments and shale clasts).

2. Tightly cemented marine bioclastic deposits are near the base of the sandstone.

a. Deposits are tightly calcite-cemented.

(Cores with missing lower contacts indicated presence of bioclastic deposits by notable calcite-cemented zones near the bases of sandstone units and by low porosity on well logs.)

II. INTERNAL CHARACTERISTICS

A. Fining-upward Sequences

1. Intervals display overall, slight fining-upward sequences. Grain sizes commonly range from fine-grained sandstone near the base of the interval to very-fine grained sandstone and siltstone near the top.

2. Some fining-upward sequences contain fining-upward sequences that are the records of influxes of slightly coarser sediment.

a. Carbonate fossil-fragments and shale clasts commonly are associated with the coarser sediment.

B. Sedimentary Structures

1. Sedimentary structures predominantly are small in scale.

a. Sedimentary structures ordinarily noted in the cores include small scale trough, horizontal and ripple laminae, inclined planar cross-bedding, graded bedding, and massive bedding.

III. VISIBLE DIAGENETIC IMPRINTS

A. Variations in Color Ferroan-dolomite (tan) and Calcite (buff)

1. Abrupt contacts - are at bases and/or tops of the sandstones or near areas where fossil-material is concentrated.

2. Mixed contacts - occur mostly in the middle portions of the sandstone units. These contacts have a "splotchy" appearance.

Figure 46. Outline of Characteristics, Cottage Grove Sandstone.

# CHAPTER VI

# DIAGENESIS AND POROSITY

## Introduction

Post-depositional diagenetic changes have significantly altered the lithologic character of the Cottage Grove Sandstone. Its burial history is marked by a complex sequence of diagenetic events that includes physical compaction, cementation by silica, sulfate, and carbonate, authigenic clay precipitation, alteration, and dissolution of detrital and diagenetic constituents.

Physical compaction processes have reduced the primary rock volume, primary porosity, and permeability of the Cottage Grove Sandstone. Most of compaction occurred early as a result of overburden of sediments after burial. Porosity reduction by mechanical compaction is made evident in analysis of thin sections by stylolites, crenulated grain boundaries, flexed mica, and pseudomatrix (ductile grains deformed into matrix morphologies).

Chemical processes in the Cottage Grove Sandstone involved various stages of precipitation, dissolution, alteration, and replacement. Syntaxial quartz overgrowths, calcite, dolomite, ferroan dolomite, barite, feldspar overgrowths, illite, chlorite, and kaolinite all have been noted in thin-section as products of precipitation. The primary constituents affected by dissolution are carbonate cements and feldspars; however, metamorphic rock fragments, silica, and clay matrix also display signs of dissolution. Alteration is expressed by recrystallization of detrital matrix. Replacement occurred between ferroan dolomite and calcite cements. In addition, ferroan dolomite and calcite replaced quartz, feldspar, metamorphic rock fragments and detrital matrix.

## Paragenesis

The following is an analysis of the diagenetic history of the Cottage Grove Sandstone. The paragenetic sequence (Figure 47) is an interpretation based on information gathered from the five cores in the study area. The cores show evidence of very similar diagenetic histories; however, certain phases of the paragenetic sequence are not characterized well, or at all, in some cores (examples are barite cement and feldspar overgrowths). Therefore, the paragenetic sequence is a composite interpretation, and should not be considered as wholly applicable to any particular core.

Interpretations regarding the paragenetic sequence were derived largely from cross-cutting or other relationships of authigenic nature observed in thin-section. Literature that provided information useful for the identification and interpretation of authigenic constituents includes articles

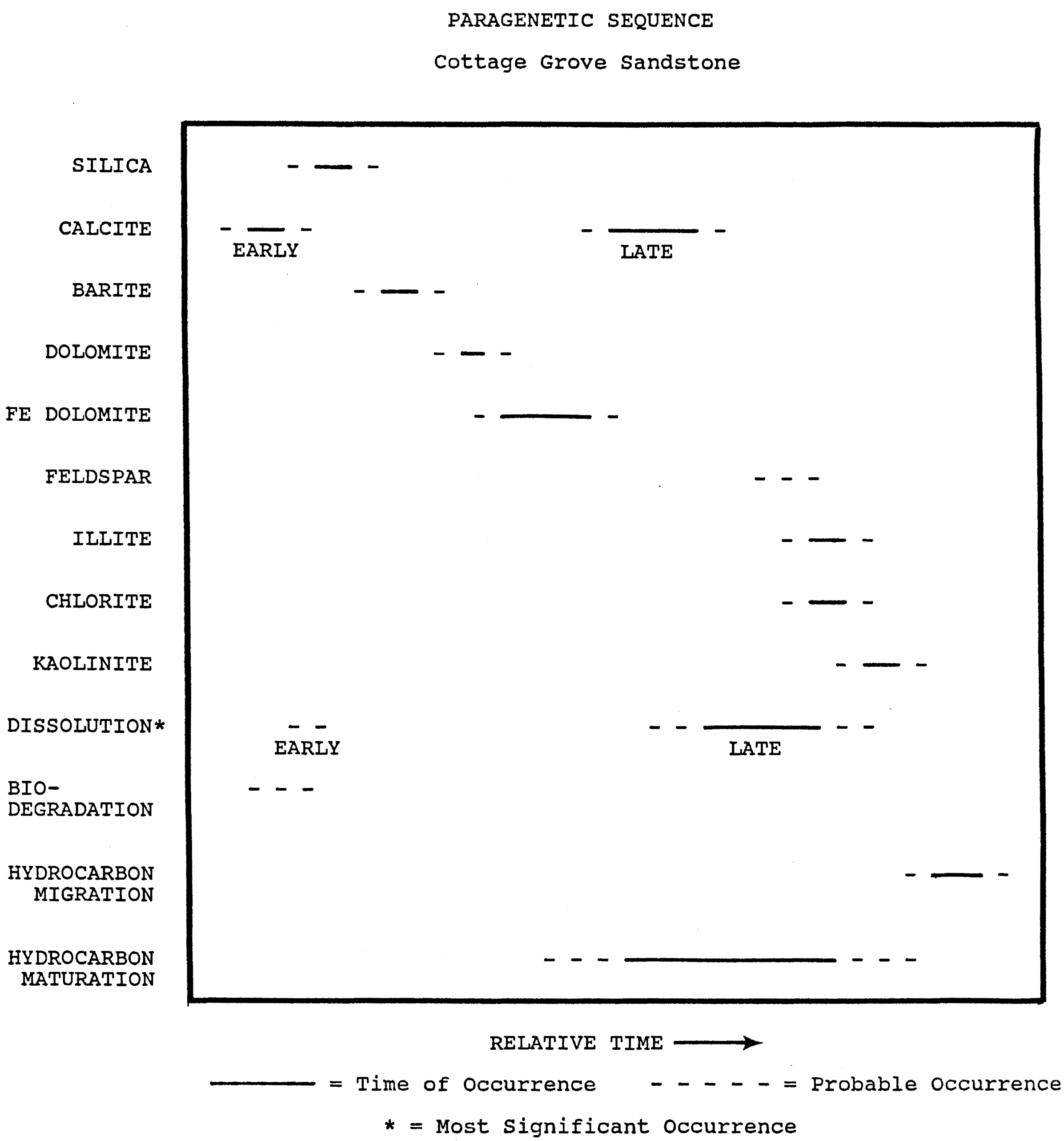


Figure 47. Cottage Grove Sandstone Paragenetic Sequence.

by Folk (1974) (detrital and authigenic minerals and cements), Wilson and Pittman (1977) (authigenic clay minerals), Land and Dutton (1978) (diagenesis), Schmidt and McDonald (1979), and Al-Shaieb and Shelton (1981) (secondary porosity and diagenesis).

The remainder of this section includes (1) a listing of individual diagenetic events, (2) a brief discussion of each constituent and related diagenesis, and (3) a series of photomicrographs showing typical paragenetic relationships. A section devoted to porosity development follows this section on paragenesis.

Although some overlap is inherent, the general order of diagenetic events in the Cottage Grove Sandstone is as follows:

1. Precipitation of calcite cement (early phase).
2. Dissolution (related to biodegradation and early carbonic acid formation).
3. Precipitation of syntaxial quartz overgrowths.
4. Precipitation of barite cement.
5. Precipitation of dolomite cement.
6. Precipitation of ferroan dolomite cement.
7. Precipitation of calcite (late phase) cement.
8. Dissolution of carbonate cements (calcite, ferroan dolomite, and dolomite), feldspars, rock fragments, and detrital matrix.
9. Precipitation of syntaxial feldspar overgrowths.
10. Precipitation of illite.

11. Precipitation of chlorite.
12. Precipitation of kaolinite.
13. Migration of hydrocarbons.

Calcite (Early Phase)

Calcite cement appears to have formed very early. It is commonly noted in intervals with detrital carbonate debris. Detrital carbonate material is most abundant in bioclastic deposits at or very near the bases of sandstone intervals. In these deposits, carbonate framework grains (skeletal grains, oolites, etc.) are regarded as having been the source for the calcite cement. Calcite cementation in bioclastic deposits is so complete that it seems to have partially isolated the sediments from the effects of subsequent diagenesis. The absence of later occurring diagenetic constituents in calcite cemented sediments (such as silica overgrowths) may help to distinguish the calcite as early. Early calcite occurs as interlocking mosaics of poikilotopic spar.

Silica

Precipitation of silica followed early calcite cementation. The formation of silicate minerals requires acidic ground water conditions. A shift in the pH of formation water from alkaline conditions (conducive to calcite precipitation) to acidic conditions (conducive to silica precipitation) is indicated by the precipitation of silica. Acidic conditions are generated when organic material in the sediment undergoes bacterial degradation. With biodegradation, $CO_2$ is released to solution, forming carbonic acid. Such a reaction may have been responsible for a pH shift in the Cottage Grove Sandstone. Quartz overgrowths commonly are surrounded and replaced by ferroan dolomite. Of course, this relationship indicates that precipitation of quartz was prior to dolomitization.

Barite

Precipitation of barite cement ($BaSO_4$) is timed as having been prior to formation of ferroan dolomite. This relationship is characterized by the replacement of barite by ferroan dolomite (Figure 48). A similar relationship exists between barite and late calcite (Figure 49).

Barite is observed as filling in voids of preserved or enhanced primary porosity. Presumably, these pores were not significantly affected during the precipitation of early calcite or silica. Some voids appeared to be enlarged, suggesting that an early phase of dissolution occurred prior to formation of barite. The barium needed to precipitate barite can originate from feldspar grains (Fuchtbauer, 1974). Sulfate probably was derived from migrating ground waters.

Dolomite

In most cases dolomite crystals are encased in ferroan dolomite cement; this indicates that a brief episode of non-

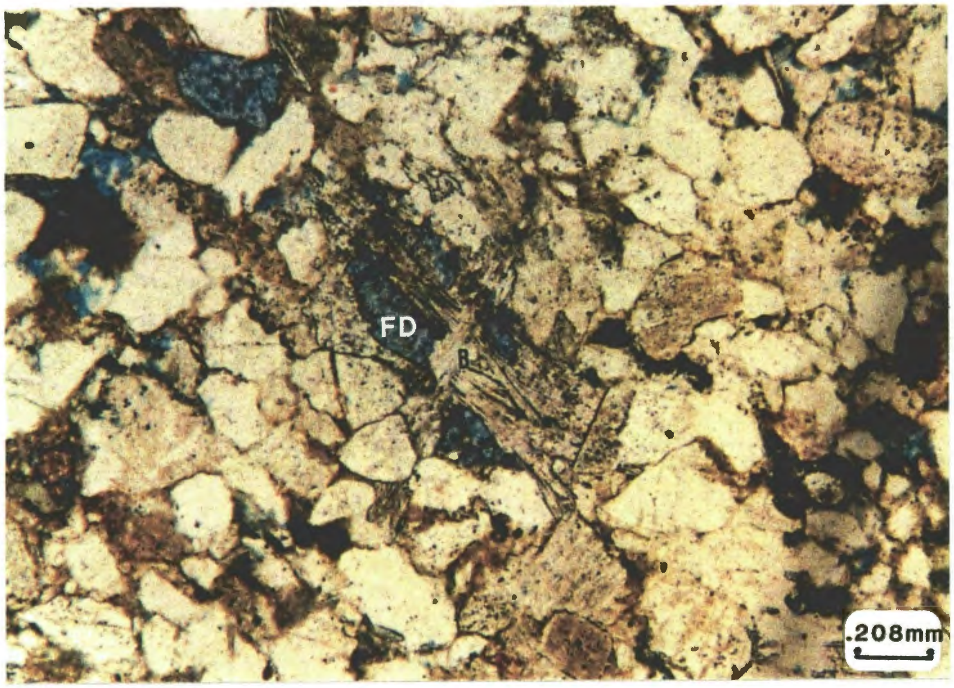


Figure 48. Crisscrossing Barite Cement (B) Partially Replaced by Ferroan Dolomite Cement (FD); Plane Polarized (40X).

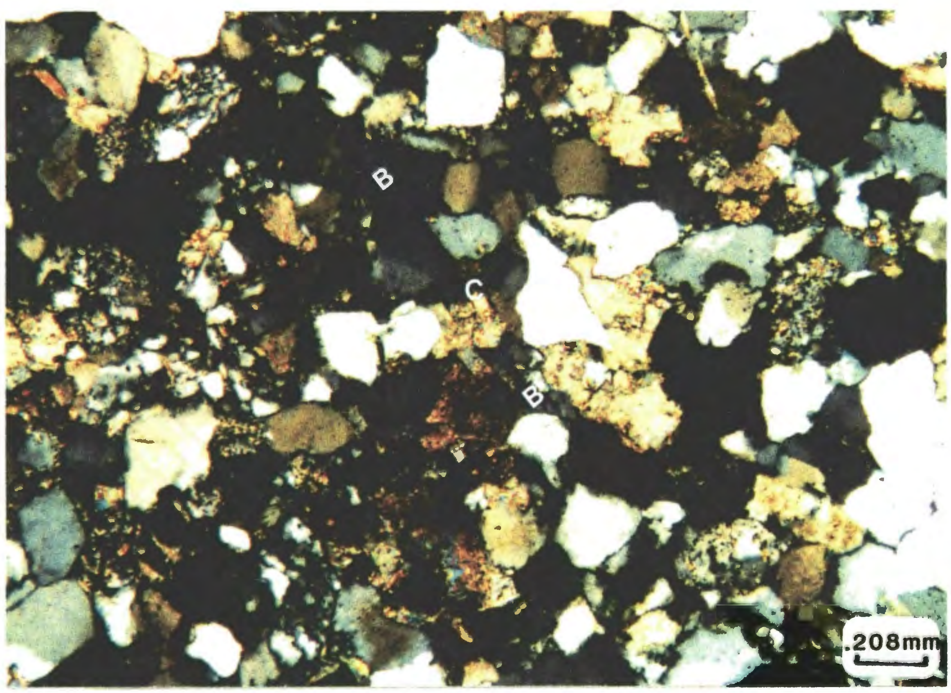


Figure 49. A Bladed Group of Barite Crystals (B) Partially Replaced by Late Calcite Cement; (Barite crosses the Photomicrograph Diagonally from NW to SE and is Etched by Calcite near Center of Photo); Plane Polarized (40X).

ferroan dolomitization preceded precipitation of ferroan dolomite. The relationship between the nonferroan dolomite and the other diagenetic constituents is difficult to determine, due to presence of the surrounding ferroan dolomite. Therefore, the relative timing of nonferroan dolomite to other diagenetic constituents is based on the diagenetic relationships of ferroan dolomite cement.

The formation of naturally occurring dolomite requires specific geochemical conditions. In a carbonate-forming environment, the precipitation of dolomite instead of calcite requires a groundwater $Mg^{++}/Ca^{++}$ ratio of at least 3 (Hanshaw, et al., 1971). According to Hardie (1987), at low temperatures (<$50^{0}$C), the formation of replacement dolomite requires long reaction times (approx. $10^4$ yrs.), and direct precipitation requires special conditions of highly supersaturated waters with high $Mg^{++}/Ca^{++}$ ratios and elevated $CO_3$-$HCO_3$ concentrations. In contrast, ordered dolomite can be made in a laboratory in a matter of days at $100^{0}$C. Furthermore, at temperatures above $60^{0}$C, Ca-rich waters become dolomitizing fluids, which makes most natural subsurface waters capable of dolomitization (Hardie, 1987).

In light of this information, a shallow dolomitization model seems unlikely for the Cottage Grove, especially since diagenetic relationships indicate that dolomite precipitation occurred after other early diagenetic events. The dolomite in the Cottage Grove Sandstone is thought to have formed under deep burial conditions and under the influence of regionally migrating marine ground waters. In order to precipitate dolomite the ground waters necessarily had high $Mg^{++}/Ca^{++}$ ratios.

Two mechanisms are believed to have been responsible for generation of favorable $Mg^{++}/Ca^{++}$ ratios in the Cottage Grove. The first mechanism involved early calcite precipitation; this process drives the $Mg^{++}/Ca^{++}$ ratio higher by removing $Ca^{++}$ ions from solution. The second mechanism involves dissolution of detrital illite; dissolution of illite increases the $Mg^{++}/Ca^{++}$ ratio by adding $Mg^{++}$ ions to solution.

Dolomite is difficult to crystallize because of the precise ordering required to form the alternating sheets of Ca and Mg. Thus it forms best when crystallization is slow, precipitating from dilute solutions (Folk, 1974). Slow precipitation forms euhedral and limpid dolomite crystals. Several examples of euhedral dolomite crystals were noted in the Cottage Grove Sandstone (Figure 50).

## Ferroan Dolomite

Formation of ferroan dolomite followed the precipitation of nonferroan dolomite and early calcite (Figures 51 and 52), and preceded the precipitation of late calcite (Figure 50).

Because in the dolomite crystal, $Fe^{2+}$ ions occupy sites of $Mg^{2+}$, an increased $Fe^{2+}:Mg^{2+}$ ratio in the solution is required in order to form ferroan dolomite. Such an increase cannot be attributed to a significant decrease of the


Figure 50. Example of a Euhedral Ferroan Dolomite Crystal (FD), Nucleated on Dolomite (D), and Surrounded by Late Calcite Cement (Stained Red); Also note selective replacement of Ooids by Ferroan Dolomite; Plane Polarized (100X).

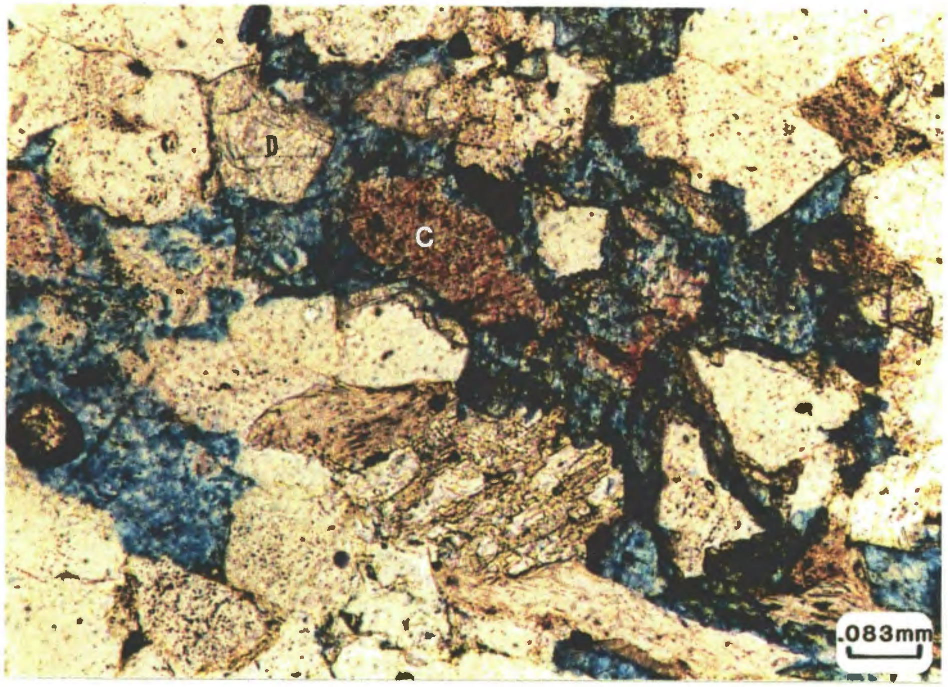


Figure 51. Ferroan Dolomite (lt. blue) has Partially Replaced Early Calcite (C) and Nonferroan Dolomite (D) in the Cottage Grove Sandstone; Plane Polarized (100X).

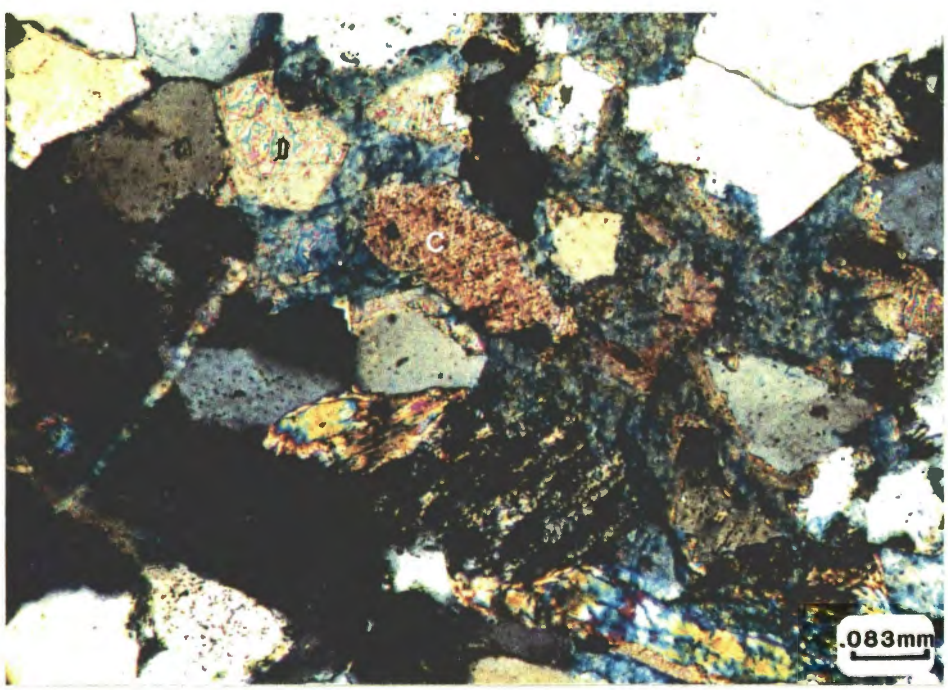


Figure 52. Same as Previous Photo; Cross Polarized (100X).

magnesium ion activity because this would prevent the formation of dolomite (Katz, 1971). Therefore, the increase in the $Fe^{2+}:Mg^{2+}$ ratio is attributed to increases of ferrous iron activity in solution. In the Cottage Grove Sandstone, $Fe^{++}$ ions may have been added to the system through dissolution of illite. Precipitation of nonferroan dolomite presumably indicates that ground-water conditions were conducive to formation of dolomite; the additional ferrous-ions in solution (perhaps introduced as a result of illite dissolution) would have forced a change in precipitation from nonferroan to ferroan dolomite.

Calcite (Late Phase)

Two phases of calcite cementation are observable in the Cottage Grove Sandstone; an early phase (previously discussed) and a late phase that occurred just prior to the main development of secondary porosity. Presumably, alkaline conditions persisted after the precipitation of ferroan dolomite. The formation of dolomite and ferroan dolomite almost certainly reduced the magnesium-ion activity in solution by absorbing Mg++ for precipitation. This is would have lowered the $Mg^{++}/Ca^{++}$ ratio, resulting in conditions more favorable to the precipitation of late (deep burial) calcite. Late calcite probably formed closely following the precipitation of ferroan dolomite, but prior to significant maturation of hydrocarbons.

Late calcite is different than early calcite in that it replaces ferroan dolomite and barite, rather than being replaced by these minerals. Texturally, late calcite appears similar to early calcite. Thus to distinguish late calcite in thin section requires examination for evidence suggesting that it is not early calcite. Sediments cemented by early calcite tend to be characterized by the absence of porosity, compaction features, or other, later-occurring authigenic constituents (such as silica overgrowths), that might otherwise be found in late calcite cemented zones (Figure 53).

Dissolution

A significant dissolution phase followed precipitation of late calcite. Most secondary porosity in the Cottage Grove was generated during this time. This dissolution phase is attributed to chemical changes in the ground water brought on by the maturation of hydrocarbons.

Dissolution is caused by the introduction of carbonic acids that form as a by-products during hydrocarbon generation (Schmidt and McDonald, 1979). When $CO_2$ is released to the system during the generation of hydrocarbons (known as decarboxylation) it reacts with formation water to form carbonic acid (equation 6-1). This acid may selectively leach out carbonates, feldspars, rock fragments and matrix. Carbonic-acid dissolution in the Cottage Grove involved mainly carbonate cements. Schmidt and McDonald (1979) refer to the dissolution of any textural and mineralogical type of

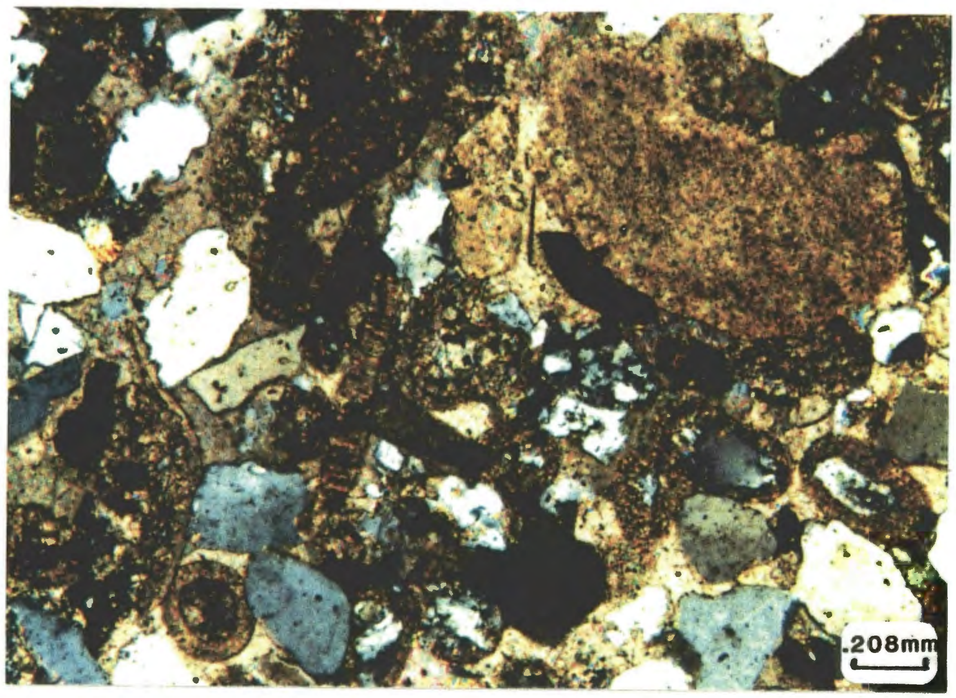


Figure 53. Carbonate Rich Deposit Completely Cemented by Interlocking (Early Phase) Calcite Crystals. Note: Lack of Quartz Overgrowths or Other Authigenic Constituents Indicating that Little Diagenesis has Influenced this Deposit Since Cementation; Cross Polarized (40X).

carbonate from sandstone or other rock as decarbonatization.

Equations 6-2, and 6-3 express the general alteration and dissolution reactions of carbonic acid with calcite (decarbonatization), and feldspar (Al-Shaieb and Shelton, 1981).

$$CO_{2g} + H_2O \rightleftharpoons \underset{\text{(Carbonic acid)}}{H_2CO_3{}^-{}_{aq}} \quad (6\text{-}1)$$

$$\underset{\text{(Calcite)}}{CaCO_3} + H_2CO_3{}^-{}_{aq} \rightleftharpoons 2HCO_3{}^-{}_{aq} + Ca^{++}{}_{aq} \quad (6\text{-}2)$$

$$\text{Feldspar} + H_2CO_3{}^-{}_{aq} + H_2O \rightleftharpoons \underset{\text{(Illite or Kaolinite)}}{\text{Clay}} + OH^-{}_{aq} + \underset{\text{(Free cation)}}{M^+{}_{aq}} \quad (6\text{-}3)$$

The premise behind these reactions is that $CO_2$ is increased as hydrocarbons mature; excess $CO_2$ results in formation of carbonic acid (equation 6-1) that must be utilized by the system in order to maintain equilibrium. This is accomplished through the dissolution of calcite (equation 6-2) and feldspar (equation 6-3).

Feldspar Overgrowths

Precipitation of feldspar overgrowths following dissolution is inferred. Due to the lack of other evidence, I hypothesize that feldspar ions and dissolved silica were made available through the dissolution of detrital feldspars. Logically, timing of this event would follow a major carbonic -acid dissolution phase. Once in solution the feldspar and silica ions could be redistributed; with a change to more basic conditions, they would precipitate as overgrowths.

## Authigenic Clays

Illite, chlorite and kaolinite were the latest diagenetic precipitants to form in the Cottage Grove Sandstone. Authigenic clays in the Cottage Grove have formed in secondary pore spaces created by the dissolution of carbonate and feldspar. Petrographic evidence suggests that illite and chlorite precipitated prior to kaolinite. This relationship is characterized by pores lined with mixed illite and chlorite clay and filled by kaolinite (Figure 54).

## Migration of Hydrocarbons

Migration of hydrocarbons was the final episode of the Cottage Grove's diagenetic history. Generation of the hydrocarbons extended as far back in time as the main development of secondary porosity. This type of scenario was discussed by Schmidt and McDonald (1979, p. 175)

> Primary migration of hydrocarbons commonly follows closely after the secondary porosity has been formed, because in the maturation of organic matter, the main phase of hydrocarbon generation follows after the culmination of decarboxylation. This close association of source and reservoir in time and space favors the accumulation of hydrocarbons in secondary porosity.

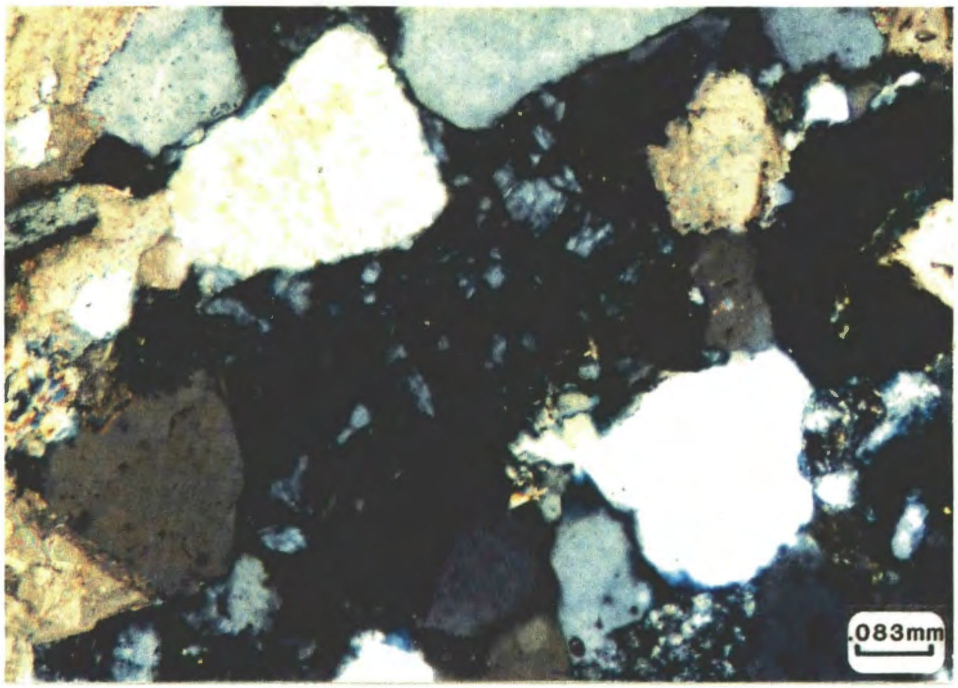


Figure 54. Dissolution Pore Space Lined with Authigenic Mixed Illite and Chlorite and Filled with Kaolinite; Cross Polarized (100X).

# Porosity

Porosity in the Cottage Grove Sandstone ranges from 0% to 16%, averages a modest 6%, and is almost entirely secondary. Primary porosity contributes as only an occasional trace amount.

The history of porosity development is marked by variety enhancement and reduction phases. Enhancement of porosity in the Cottage Grove occurred in two principle phases, a minor dissolution phase related to biodegradational release of $CO_2$, and a later, more significant phase associated with decarbonatization reactions and hydrocarbon maturation (Schmidt and McDonald, 1979). The carbonic acid that formed as product of biodegradational and hydrocarbon maturation reactions is thought to have controlled the development of secondary porosity in the Cottage Grove Sandstone. Reductions in porosity occurred as a result of compactional processes and from the replacement and precipitation of authigenic cements and clays.

## Evolution of Porosity

Diagenetic events that affected the evolution of porosity in the Cottage Grove Sandstone:

1. Reduction of primary porosity by compaction during burial.

2. Reduction in primary porosity by early calcite cementation.

3. Creation of secondary porosity (related to biodegradational formation of carbonic acids).

4. Reduction in porosity from continued compaction and precipitation of syntaxial quartz overgrowths.

5. Reduction in porosity from replacement and precipitation of barite.

6. Reduction in porosity from replacement and precipitation of dolomite.

7. Reduction in porosity from replacement and precipitation of ferroan dolomite.

8. Reduction in porosity from replacement and precipitation of calcite.

9. Main development of secondary porosity from dissolution of carbonate cements, feldspar, and detrital matrix (related to decarboxylation and decarbonatization)

10. Reduction in porosity from precipitation of authigenic clays (illite, chlorite, and kaolinite).

Discussion

Dissolution of carbonate cement, particularly ferroan dolomite and calcite, was responsible for most of the secondary porosity in the Cottage Grove Sandstone. This is indicated in thin section by a variety of dissolution textures. Figures 55 and 56 show that when porosity percentages are high, calcite and ferroan dolomite percentages are low. Calcite and ferroan dolomite are replacive cements and dissolution of these cements may open

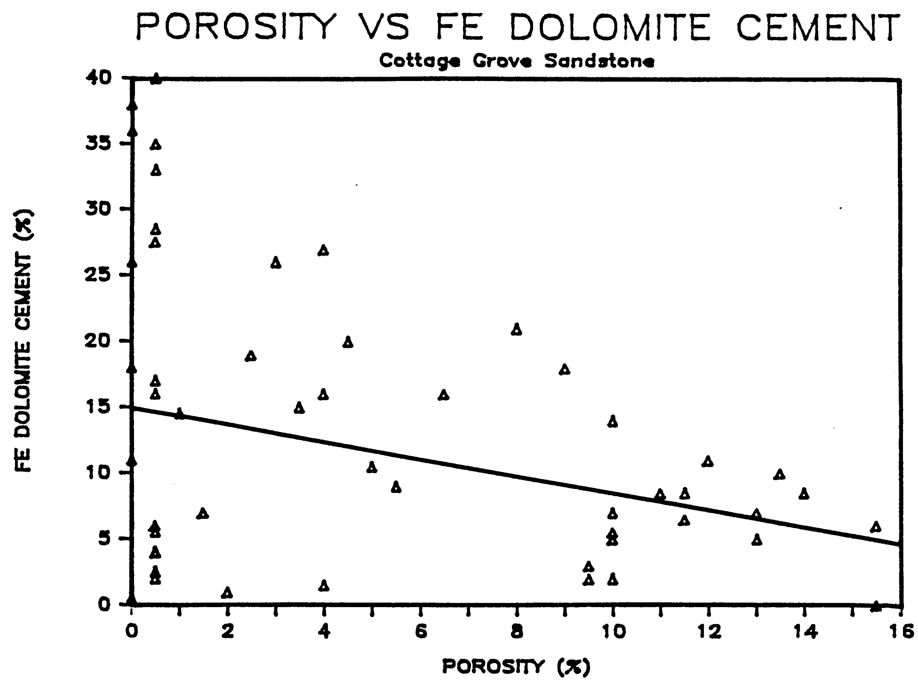


Figure 55. Plot of Porosity vs. Ferroan Dolomite Cement. Inverse Relationship Illustrates that when Porosity Percentages are High, Ferroan Dolomitization Percentages are Low.

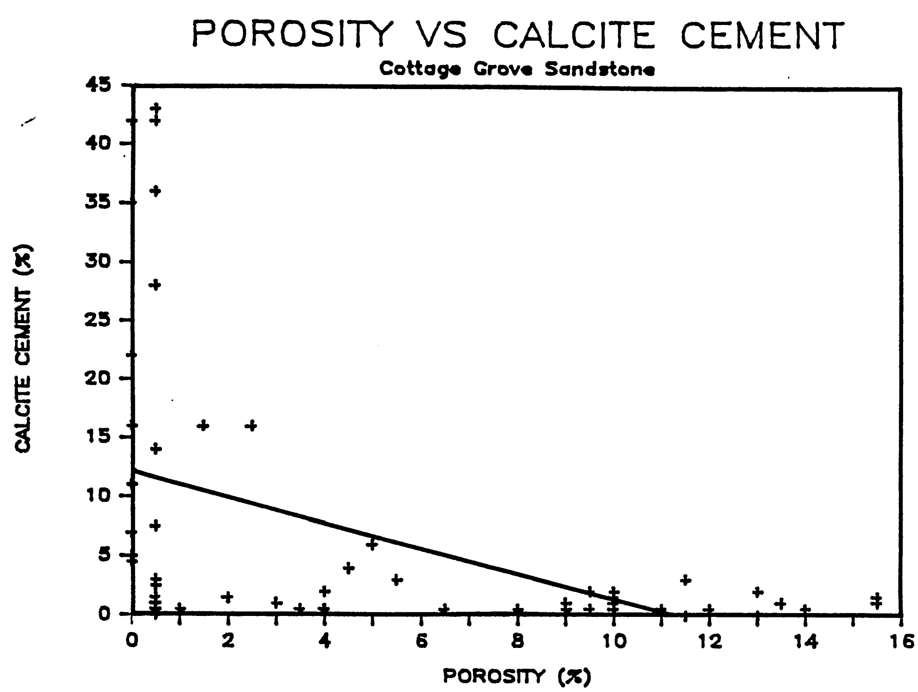


Figure 56. Plot of Porosity vs. Calcite Cement. Inverse Relationship Illustrates that when Porosity Percentages are High, Calcite Cementation is Low.

or reopen a variety of primary and secondary porosity textures. Textures that resulted from carbonate dissolution in the Cottage Grove include elongate pores, corroded grains, floating grains, partial dissolution, and oversized pores (Figure 57). Textures related to grain dissolution include honeycombed grains, grain molds, and corroded grains (Figures 58 and 59). Precipitation of kaolinite reduced secondary porosity and resulted in development of microporosity (Figure 60).

Shrinkage of silt and organic material in stylolites results in a hybrid type of secondary porosity in the Cottage Grove Sandstone (Figure 61). Overall, this type of porosity contributes very little to secondary porosity of the unit; however, in two thin sections shrinkage porosity is the only type of porosity present.

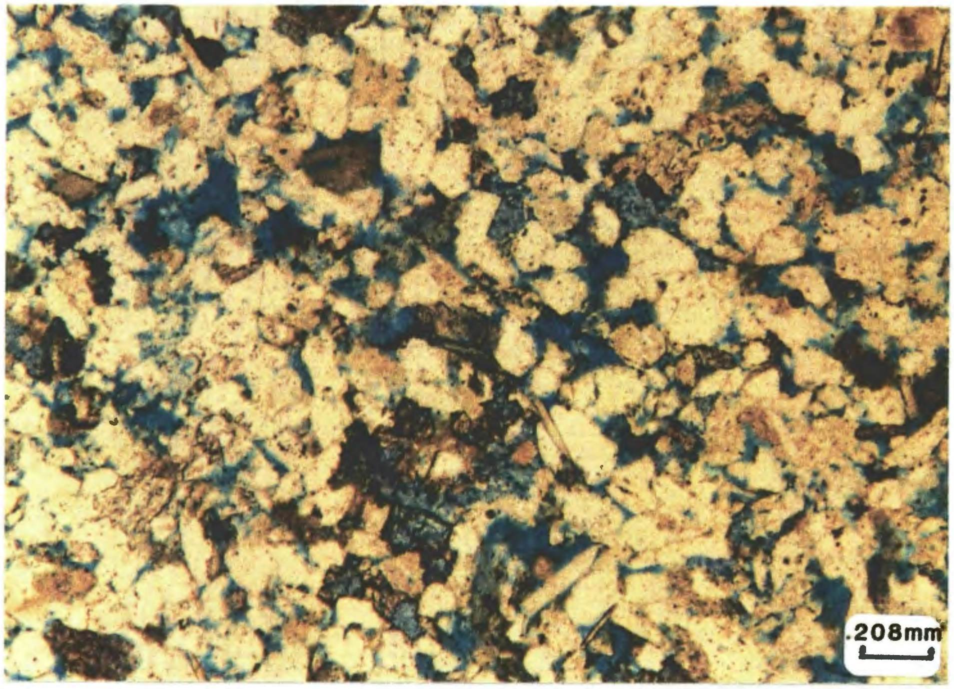


Figure 57. Examples of Porosity Textures in the Cottage Grove Sandstone, Including Elongate Pores, Corroded Grains, Floating Grains, Partial Dissolution, and Oversized Pores; Plane Polarized (40X).

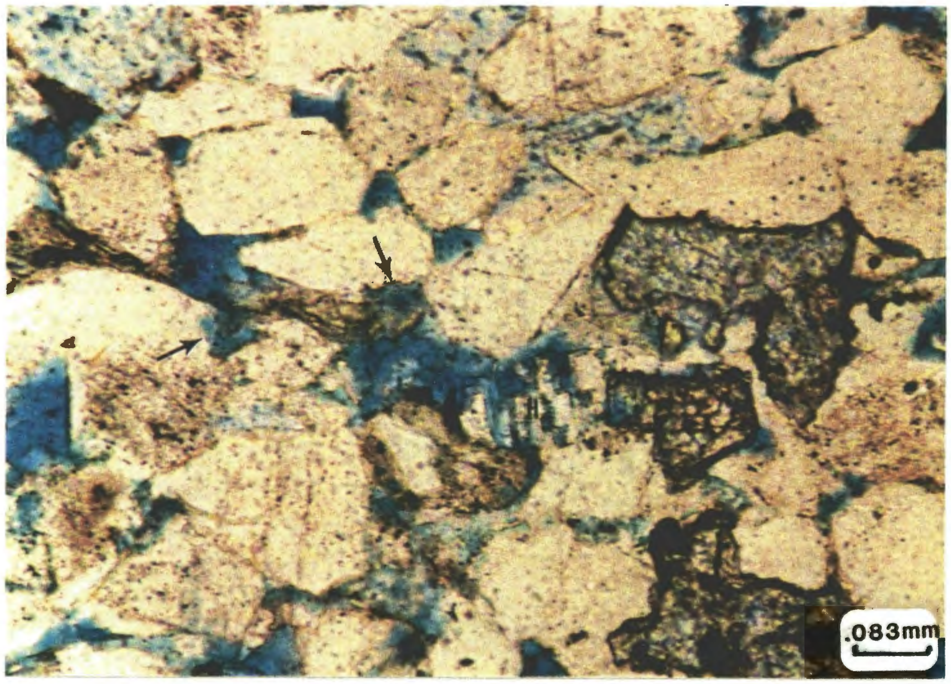


Figure 58. Grain-dissolution Textures, Including a Honeycombed Feldspar Grain (H) and Corroded Grains (arrowed); Plane Polarized (100X).

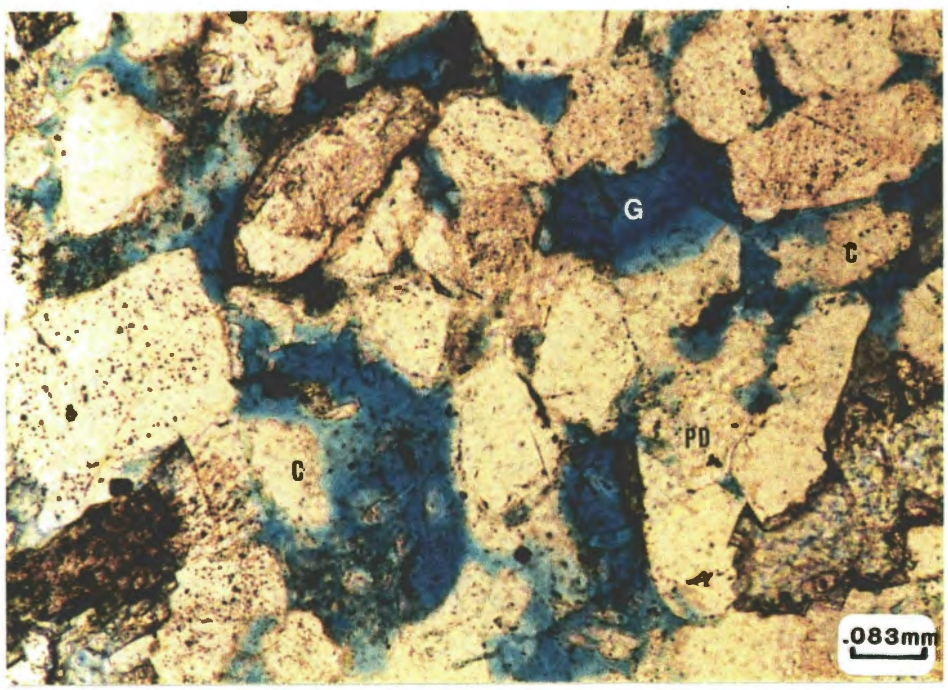


Figure 59. Dissolution Textures, Including Grain Molds (G), Corroded Grains (C), and Partial Dissolution (PD); Plane Polarized (100X).

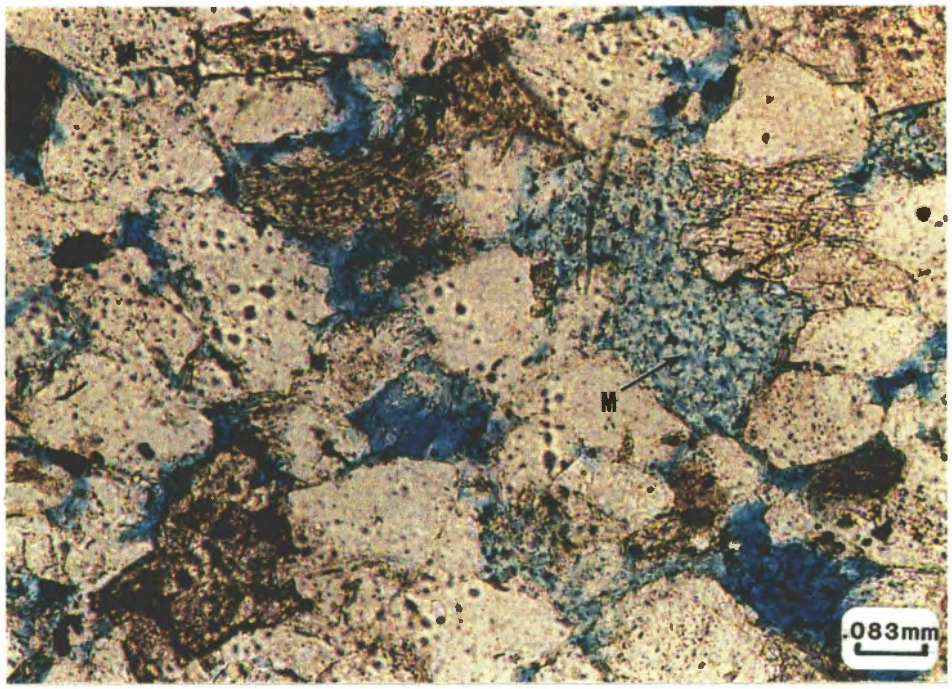


Figure 60. Dissolution Pore Space Filled by Kaolinite, Forming Microporosity (M); Also Pictured are examples of Corroded Grains, Grain Molds and Carbonate Dissolution; Plane Polarized (100X).

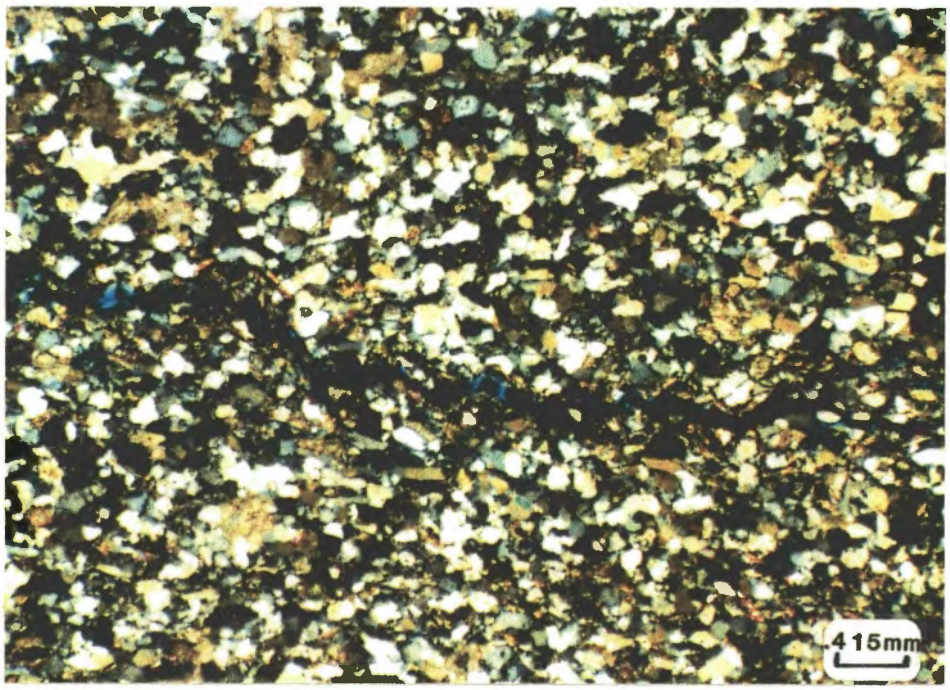


Figure 61. Hybrid Secondary Porosity Developed Along a Stylolite in the Cottage Grove Sandstone; Plane Polarized (100X).

# CHAPTER VII

## DEPOSITIONAL ENVIRONMENT

The Cottage Grove Sandstone in the study area was deposited on an epeiric shallow marine shelf, during transgression, under the influence of storm and tide dominated conditions. Mapping and petrographic evidence suggest that the principal form of deposition was as sub-parallel, east-northeast trending, linear sand ridges. A second mode of deposition is indicated by a narrow, north-trending sandstone body. This sandstone is interpreted as a shallow marine channel; however, some lines of evidence suggest submarine or shelf edge deposition.

Conclusions in this chapter are based on various lines of evidence from cores and logs of the Cottage Grove Sandstone from the study area, and from reasoning by analogy with other ancient and modern shelf sandstones. This evidence strongly supports the interpretation of a shallow marine depositional environment. Such evidence is shown in the study area; it has been described in the surrounding region by Towns (1978), Fruit (1976), Holmes (1966) and Rascoe and Adler (1983). Distal-delta, barrier-bar, or submarine-fan environments of deposition were considered -- as were other submarine geomorphic settings -- but these alternatives lack evidence sufficient to support their acceptance in lieu of a shallow marine model. Hence, it is considered highly probable that the basic depositional framework of the Cottage Grove Sandstone in the study area was that of a shallow marine environment or a variant thereof.

## Shelf Processes and Significance of Sedimentary Structures in the Cottage Grove Sandstone (Ridge Facies)

Transport and modification of shelf sediment are dominated by tides, waves, and currents. In the following paragraphs, shelf processes and their related formational and sedimentary characteristics are discussed briefly and a qualitative comparison is made to characteristics of the Cottage Grove Sandstone in the study area.

### Tides

Tidal currents have the capacity to transport shelf sediment and modify submarine landforms. Tidal influence on sediment transport is greatest on semi-enclosed and broad shallow shelves where tidal ranges tend to be amplified (Leeder, 1982). Missourian paleogeography suggests that the north-west limb of Anadarko basin was a broad shallow epicontinental shelf. Such a shelf may have had the characteristics conducive to formation of significant tidal ranges during deposition of the Cottage Grove Sandstone.

Two hypothesis that explain the relationship of tidal current flow direction to ridge orientation have been presented in the literature. In the first, tidal currents are proposed to maintain ridges that are parallel to current (Houboult, 1967). In the second, tidal currents are presumed to maintain linear sand bodies that are oriented sub-parallel to current flow (Huthnance, 1983). Both models were derived from studies of linear sand ridges in the North Sea. These ridges were described by Off (1963), and Swift et al., (1978). Since the conception of the Huthnance model, several authors have reconsidered interpretations of tidal bars. For example, Walker (1984) suggested that the Huthnance model be applied to the shoreface detached ridges in the Delaware-Maryland sector of the Middle Atlantic Bright, previously studied by Swift and Field (1981).

In the first hypothesis Houboult (1968) proposed that ridges of the North Sea form roughly parallel to tidal-current flow (Figure 62). Houboult described current patterns on the surface of the water which he interpreted as having arisen from spiral currents generated by differential velocities of tidal flows over ridges and swales of longitudinal sand ridges. The spiral flow of these currents presumedly pushes sand out of the swales and up the sides of the ridges. This would allow for maintenance of ridges parallel to flow. Houboult also notes that the sand ridges in the North Sea rest on a generally flat surface (as are sandstone bodies of the Cottage Grove (Fruit, 1986)).

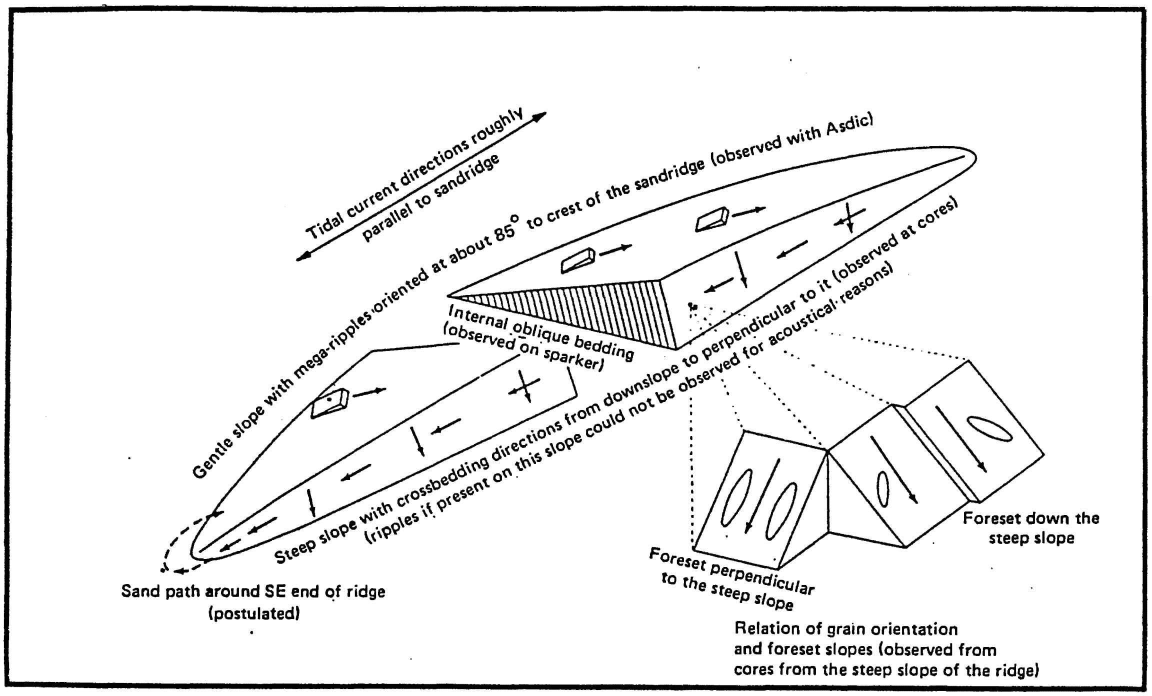


Figure 62. Schematic Diagram of the Morphology and Currents of a Large Sand Wave in the North Sea. (After Houboult, 1968).

An alternative hypothesis was formulated mathematically by Huthnance (1982) (Figure 63). Regarding the Huthnance model Parker et al. (1982) stated that

> ... an oblique orientation with respect to flow is essential because ridges parallel to flow can have no sand carried to their tops ... ridges normal to flow must experience an acceleration across the crests in order to satisfy continuity, hence cannot deposit sand there ... when flow is oblique with respect to the ridge crest, the cross-ridge component of flow must similarly accelerate. However, the along ridge components experience frictional retardation and the ensuing deceleration over the crestal area results in sand deposition.

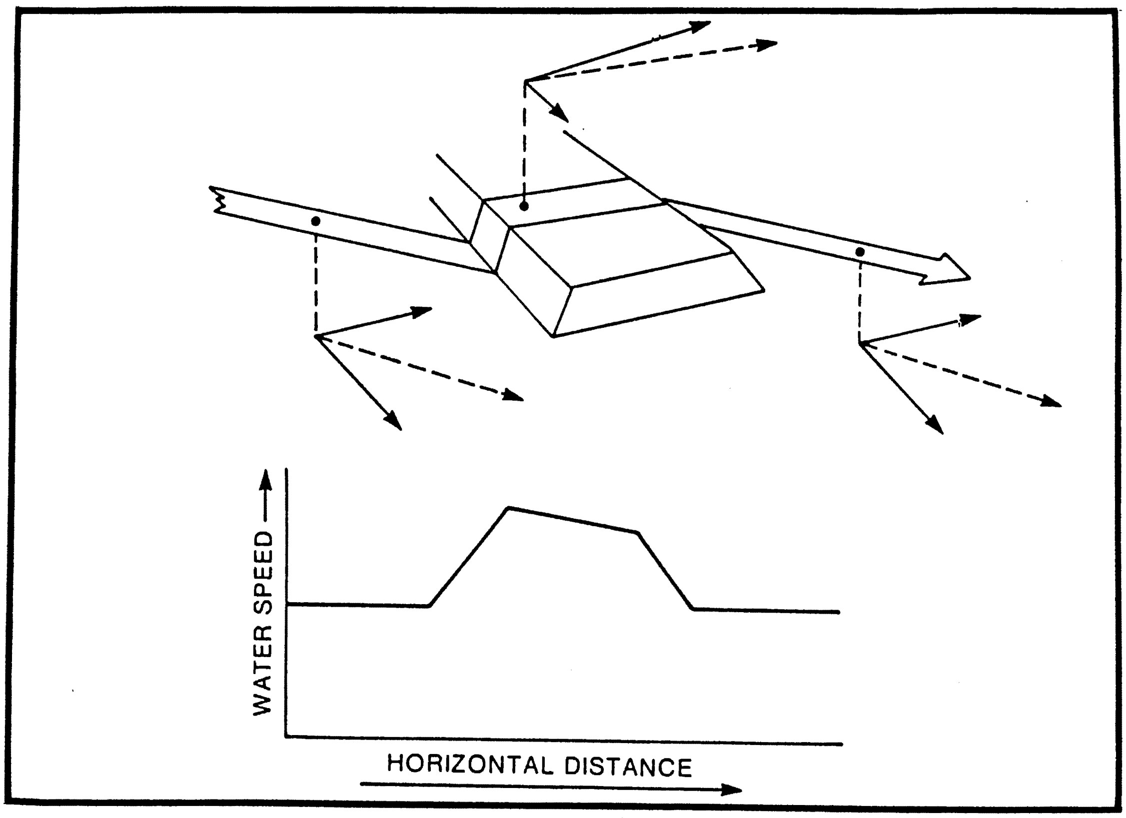


Figure 63. Huthnance Model of Flow-oblique Sand Ridge Formation. As Flow Moves Obliquely Up the Ridge Flank, the Cross-ridge Component of Velocity Accelerates Owing to Decreasing Cross-sectional Area. Over the Crest, the Along-ridge Component of Velocity is Reduced by Frictional Drag. The Cross-ridge Component Decreases to its Original Value. Changed Values for Two Flow Components Cause the Current to Veer as it Passes Over the Ridge.

In essence, according to Huthnance, tidal flows will favor the growth and maintenance of those sea floor irregularities oriented sub-parallel to current direction.

With the sparse amount of data available, the orientation of tidal currents with respect to Cottage Grove sand bodies is difficult to determine; however, what is important to point out is that sandstone deposits of the study area appear to have been maintained by some sort of process that remained relatively uniform in occurrence, in time and space, that resulted in a series of linear, parallel-trending ridges. Such a pattern of deposition can be explained by, and is likely the result of, shallow shelf tidal currents. According to Off (1963), the most characteristic feature of tidal-current ridges is their rhythmic pattern and the tendency of one ridge to parallel another.

Tidal currents typically produce herringbone cross-stratification (Davis, 1983). Herringbone cross-stratification was not identified in cores from the Cottage Grove in this study area. This missing evidence weakens the interpretation of deposition by tidal currents, but Houboult (1983) noted that in the offshore bars of the North Sea the dominant bedform is megaripples (Refer to Figure 62). Walker (1984) contends that megaripples may appear in the geological record as medium scale, angle-of-repose cross bedding. In Cottage Grove cores of the study area, inclined planar bedding (medium scale cross-bedding) is regarded as having originated as megaripples. Also, herringbone cross-stratification was documented by Fruit (1986) as a commonly occurring structure in cores from approximately 20 miles east of the study area. If the paleogeographic interpretation presented earlier is true, then the ridges of Fruit's area would have been closer to the paleoshoreline; accordingly, they may have been subjected to more intense tidal action than ridges in the study area. This inferred circumstance may account for the difference in herringbone cross-stratification between the two areas.

Waves

Waves generally do not transport sediment, but instead bring the sediment into the water column making it available for transport. Another function of waves is to rework sediment, such that even if no sediment is moved away by currents, the resettling of particles entrained by the wave may produce a texture or fabric different from the previous one. Under normal wave conditions the orbital motion of the passing wave will entrain sediment only to depths of about 10 meters or so. However, large storm waves may effect the entire shelf floor (This paragraph drawn from Davis, 1983).

As mentioned above, wave action may disrupt bedforms. Massive bedding may be the result of reworking by waves. In the Cottage Grove Sandstone indistinguishable bedding or massive bedding constitutes as much as 30% of the sedimentary column in some cores; this massive bedding may be the result of reworking by waves.

Currents

Current types vary depending on the type of driving mechanism. Three general categories of currents have been described in the literature. These are wind-induced currents, oceanic currents, and density currents (Stanley and Swift, 1976; Leeder, 1982; Davis, 1983). Although storm-generated currents are sometimes categorized as a fourth type, in effect they are amplified versions of wind induced currents.

Wind-forced currents drive water onshore, creating an elevation of the water surface referred to as "set up". A seaward pressure gradient results, which induces seaward bottom-water flow. On open shelves this flow may be deflected by Coriolis forces and evolve into a geostrophic flow that moves parallel to isobaths (Swift and Niedoroda, 1985).

Wind- and storm-induced currents are capable of transporting significant amounts of sediment transport on the shelf. Wind-driven currents can produce bottom flow velocities of as much as 60 cm/sec, as measured on the Atlantic shelf. Velocities of tens of cm/sec may result from storm generated currents (Swift and Field, 1981). Storm-induced currents are cited more often than any other type of current to explain the transport of sediment to the shelf.

Wind- and storm-induced currents may generate current ripples, megaripples, hummocky cross-stratification or graded bedding (Davis, 1983; Walker, 1984). Of these sedimentary structures, current ripples, megaripples and graded bedding have been identified in cores of the Cottage Grove from the study area. Hummocky cross stratification was not identified conclusively.

Current ripples are shown in the Cottage Grove as small-scale trough cross-bedding. This bedding probably is the result of waning storm flows. Megaripples, are manifest as inclined-planar bedding (medium scale cross-bedding) in the Cottage Grove. Turbidites are recorded in the Cottage Grove as graded bioclastic deposits near the bases of sandstone intervals (Refer to Figure 32). Walker (1984) proposed that turbidity currents occur as a result of storm-surge ebb flows that carry sediment below storm-wave base and deposit turbidites (graded bedding). Turbidites above storm-wave base may be reworked into hummocky cross-stratified sediment (Figure 64). Hummocky cross-stratification is difficult to identify in cores. Hummocky cross-stratification was not verified in any of the Cottage Grove cores from the study area. This bedform may not have been preserved, due to reworking by waves or to bioturbation. As previously mentioned, indistinguishable bedding or massive sandstone accounts for a large fraction of the sedimentary column in the Cottage Grove.

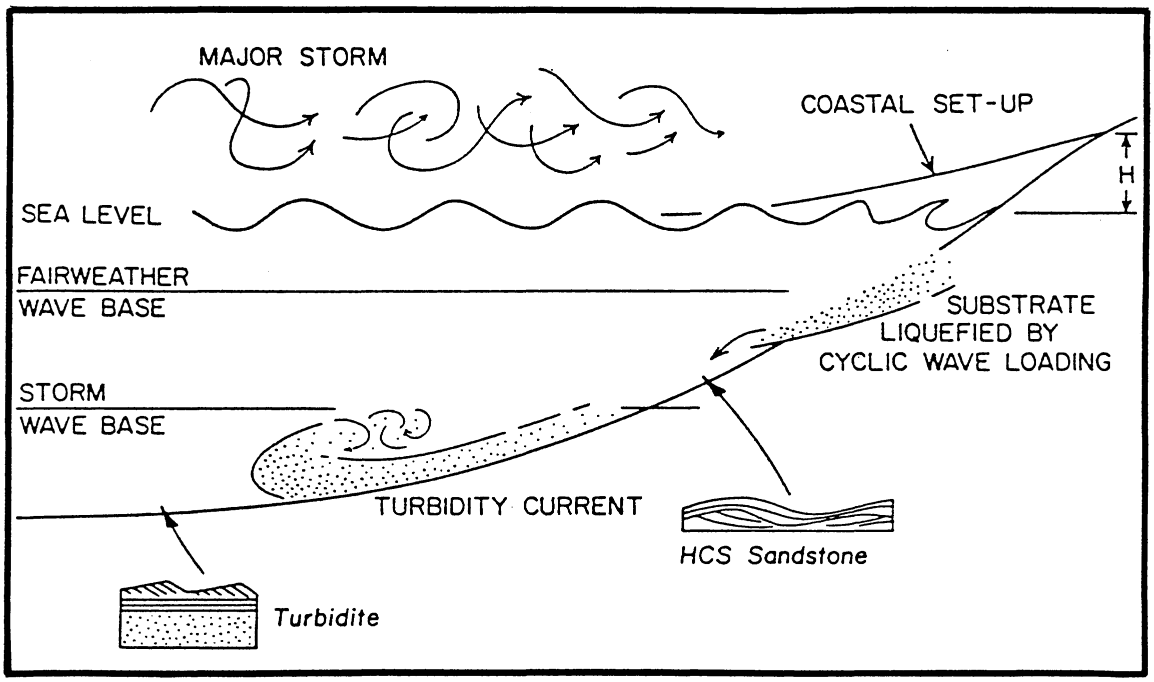


Figure 64. Schematic Diagram Illustrating Storm Wind Coastal Set up and Cyclic Loading of the Substrate by Storm Waves. The Liquefied Sediment may Flow and Accelerate Basinward, Transforming into a Turbidity Current. Above Storm Wave Base, Waves Feeling the Sea Floor may Rework the Turbidity Current Deposits into Hummocky Cross Stratification. After Walker (1984).

# Models of Deposition

## Ridge Facies

The conceptual model of deposition for Cottage Grove ridges is a variation of a model proposed by Fruit (1986). An outline of the model is as follows:

1. Coarse clastic sediment was brought to the shelf during a relatively sudden marine regression. Missourian tectonic activity and uplift of the Ouachita Mountains (probable main source of Cottage Grove sediments) may have spurred these events.

2. Wind- and storm-surge ebb currents episodically carried silt and sand from a deltaic complex to the east (mapped by Lalla, 1975). As currents moved across the shelf they entrained sediment, including ooids, shale clasts and skeletal carbonate material. This sediment was deposited in sand ridges on the shelf. Graded bedding, waning-flow current ripples and sharp-based sandstones record this event.

3. Tidal currents maintained and reworked sand ridges by scouring troughs, entraining sandy sediment from these areas, and by redepositing it on ridges in the form of megaripples and current ripples. These bedforms are recorded in cores by medium- and small-scale cross-bedding respectively.

4. Storm-induced waves reworked the outer layers of exposed ridges, resulting in destruction of bedforms. Evidence for wave-reworking is recorded in cores by massive or indistinguishable bedding.

5. Transgression followed and burial the ridges by shelf muds accelerated. The unburied portions of ridges were reworked by storm currents. Periodic influxes of silty sediment reached the ridges, marking the final input of coarse clastics. Silt and mud were bioturbated heavily as the ridges were inundated. Erosive-based, graded deposits (Refer to Figure 39) at the tops of sandstone intervals recorded storm deposits and interbedded siltstone and shale the reworking and inundation of the ridges.

This model accounts for a sharp based, overall slight fining upward sandstone that grades upward abruptly to interbedded siltstone and shale, then to shale as exhibited by the Cottage Grove.

Marine Channel Facies

More information, including at least one core, is needed to assess a detailed model of deposition for the channel facies. This facies trends northward, almost perpendicular to the ridge trends of the area. It appears to truncate and to be younger than a ridge complex in the North Ioland Field of T17N and T18N, R22W. It is separated from the bar facies in some areas by shale, and it appears to bifurcate above the ridge facies in cross-section. This arrangement of ridge and channel bears resemblance to two examples of ridge/channel couplets in the geologic record. The first is the Terry Sandstone Member, Pierre Shale in the Denver Basin, Colorado (Siemers and Ristow, 1986), and the second is the Cretaceous

Sussex Sandstone of Wyoming (Brenner, 1978).

Siemers and Ristow (1986) described a shingled couplet of shallow marine sandstones that are separated by a shale "notch" (very similar to the one in the Cottage Grove). The lower sandstone was interpreted as an offshore shallow marine bar, and the upper as a channelized deposit composed of active channel-fill sand, overlying inactive channel-fill sandy mudstone. They pointed out that the channel-like deposit may have been influenced strongly by the older sandbar, as dip-oriented currents could have been diverted in a pattern along the side of the marine sandbar (a relationship also suggested by the Cottage Grove channel/ridge couplet).

A second example is the Cretaceous, Sussex Sandstone of Wyoming (Brenner, 1978). Brenner proposed that the Sussex Sandstone was deposited as part of muddy sheet that prograded basinward. Sand ridges within this sheet were created and shaped by storm-generated and tidal currents. Brenner observed that offshore ridges of the Sussex Sandstone were breached periodically by intense storm-generated currents, which formed channels. These channels are approximately perpendicular to the long axes of ridges. The Cottage Grove Sandstone couplet has similar orientation; it may have formed under similar conditions.

An alternative depositional interpretation for the north trending sandstone may be that of an incised shelf margin channel. The position of the sandstone coincides with an increase of the Cottage Grove interval that may represent a slope break (see Plate II and discussion page 25).

## Summary

The following two lists summarize evidence supporting the depositional environments interpreted in this chapter. The lists show data collected from all aspects of this investigation. A summary is given for the east-northeast trending ridge sandstones and the northward-trending channel sandstone facies, respectively.

### Shallow Marine Ridge Sandstones

1. Late Pennsylvanian paleogeography and tectonic setting.
2. Linear geometry of the sand bodies.
3. Complete encasement of these sandstones by shallow marine shales.
4. Glauconite.
5. Marine fauna, including ooids, pelecypods, foraminifera, crinoids, brachiopods, and echinoderms.
6. Lateral rock-stratigraphic equivalence of ridges and carbonates.
7. Graded bedding, ripple cross-stratification, massive bedding, and inclined planar cross-bedding.
8. Sub-parallel trending sand bodies, with average lateral spacing of 3.5 to 4 miles.

Shallow Marine Channel Sandstone

1. Missourian paleogeography.
2. Sharp base and cylindrical well log profile.
3. Narrow, elongate geometry in map view.
4. Bifurcating pattern expressed in cross section.
5. Similarity to ridge/channel couplets documented in the geologic record.
6. Evidence of a sediment-bypassed channel path leading northward from the terrain of channel-fill sandstone, as indicated by the Avant structural contour map (See p. 16, and Plate I)

The preponderance of available evidence is judged to substantiate the above interpretations, at the expense of other reasonable alternatives.

# CHAPTER VIII

# LOG SIGNATURE EVALUATION

## Introduction

Well-log surveys in the study area were correlated to the various facies and vertical lithologic changes expressed by the Cottage Grove Sandstone. Instructive quantitative analyses were made of thin sections and well-log data from the core of Cottage Grove Sandstone in the Sarkey's, Gillispie No. 3-2 well, located in T17N, R22W, Ellis Co., Oklahoma.

Gamma-ray, compensated-density, spontaneous-potential and dual induction-laterlog well-log signatures were related to constituents of thin sections. From these analyses several generally dependable log-to-rock and log-to-log relationships were indicated.

Well-log signatures and certain associated lines of evidence can provide information useful for general assessments of depositional environments. Four categories of well-log signatures are described that characterize the major facies and combinations of facies recorded in the Cottage Grove.

## Methodology

Well-log, thin-section, and core-analyses data were entered into a computer spreadsheet. Graphs were prepared using Lotus software on an IBM personal computer.

Correlations coefficients and best-fit trend lines were calculated using Microstat software and a HP 41C calculator equipped with a statistics packet.

In the Sarkey's No. 3-2 Gillispie, thin sections were made of samples taken at approximately 2-foot intervals throughout the cored strata; well-log values were recorded from locations correlated as near as possible to positions of thin sections. For use in log-to-log analysis, additional well-log values were taken from below the cored interval, at even, two-foot spacings throughout the sandstone (as indicated by the gamma ray curve).

Correlation of well-log responses to facies was accomplished through analyses of cores, strip-logs, subsurface maps and cross-sections. Log signatures described as being "characteristic" where chosen from areas with the most geologic control.

## Classification of Well-log Signatures

Three basic facies are delineated in this study: ridge, channel, and interridge/interchannel facies. Three sets of characteristic gamma-ray log signatures have been chosen for each of these facies. In addition, log signatures of various stacked facies are included.

Characteristic log signatures of ridges are divided into sets typical of the northern and southern parts of the study area. This division is based on sizes of sandstone ridges. Ridges in the north tend to be composed of a thinner stratigraphic sequence than those in the south. However, the fundamental profile produced by ridges from the north and south is the same. Ridge sandstones of the Cottage Grove have sharp bases, fine upward slightly in grain size, and have upper contacts that grade abruptly to siltstone and shale. This configuration of sandstone results in bell-shaped to cylindrical well-log profiles (Figure 65). Under classical thought, an abrupt-based and cylindrically shaped profile, normally might be interpreted as a channel-fill deposit. In the area under study here, such an inference could lead to strongly erroneous mapping. The "sharp" bases of log profiles resulted from sands having been deposited by storm-surge ebb currents. The bell-shaped well-log signature reflects the overall fining-upward grain-size trend (a function of the overall marine transgressive conditions under which these ridges formed).

Channel-fill well-log signatures are shown by logs of several wells in T17N and T18N, R22W. These sandstones have barrel-shaped profiles (Figure 66). Typical of these signatures are extremely sharp lower and upper contacts. Between contacts the gamma-ray curve generally displays a relatively smooth profile. The inference that this deposit originated as channel-fill material is supported not only by

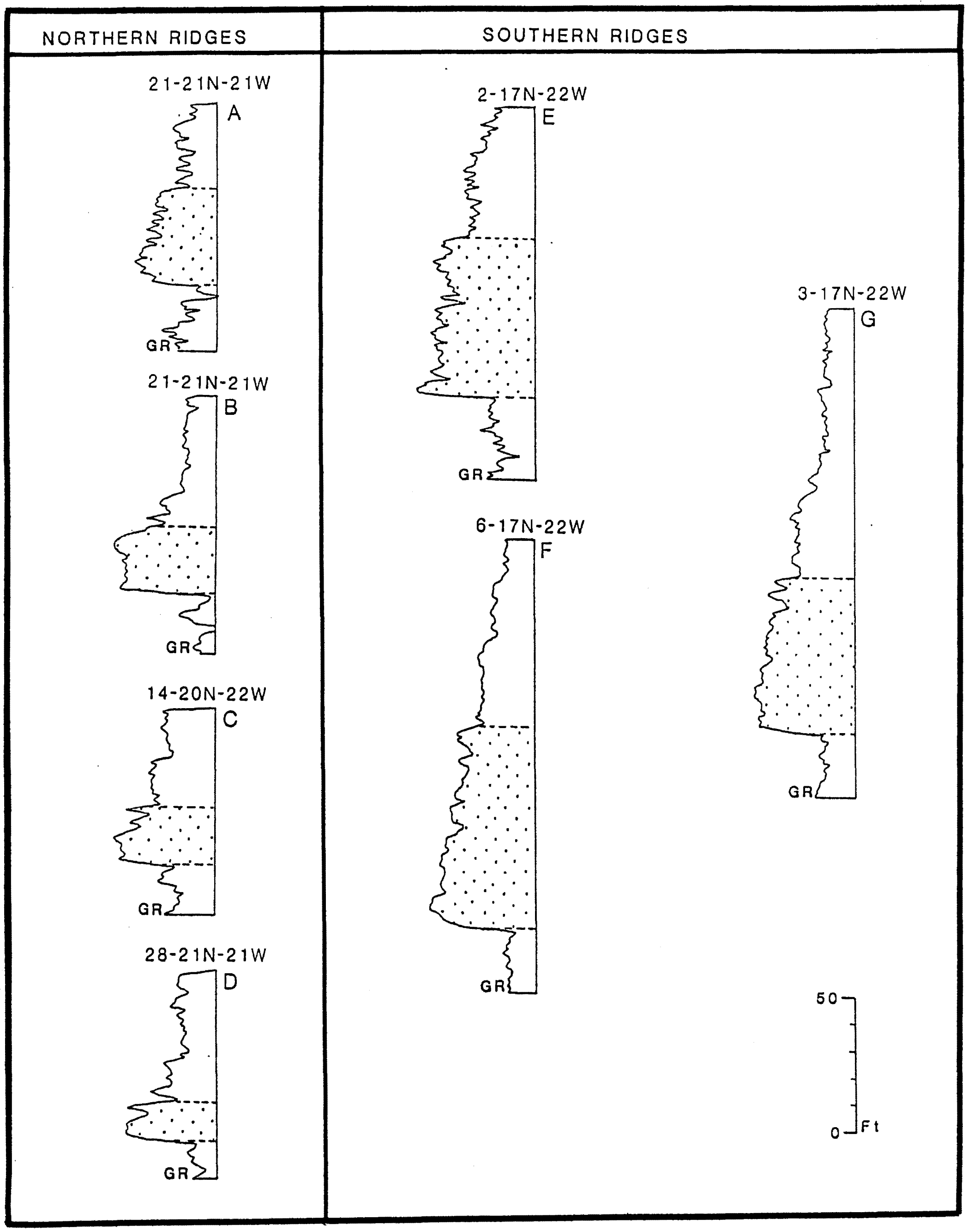


Figure 65. Typical Gamma-ray Log Signatures of Ridge Facies. Bell-Shaped and Cylindrical Profiles with Blunt Bases and Abruptly Graded Upper Contacts Characterize These Sandstones. Signatures A - D are from Northern Ridges, Whereas, E - G are of Southern Ridges. Signatures Corresponding to Cores Used in this Study Include D (Ran Ricks, Cole 28-A) and G (Sarkey's, Gillispie 3-2). In General, Northern and Southern Ridges Vary Conspicuously in Stratigraphic Thickness, but Share Overall Gamma-Ray Profile Characteristics.

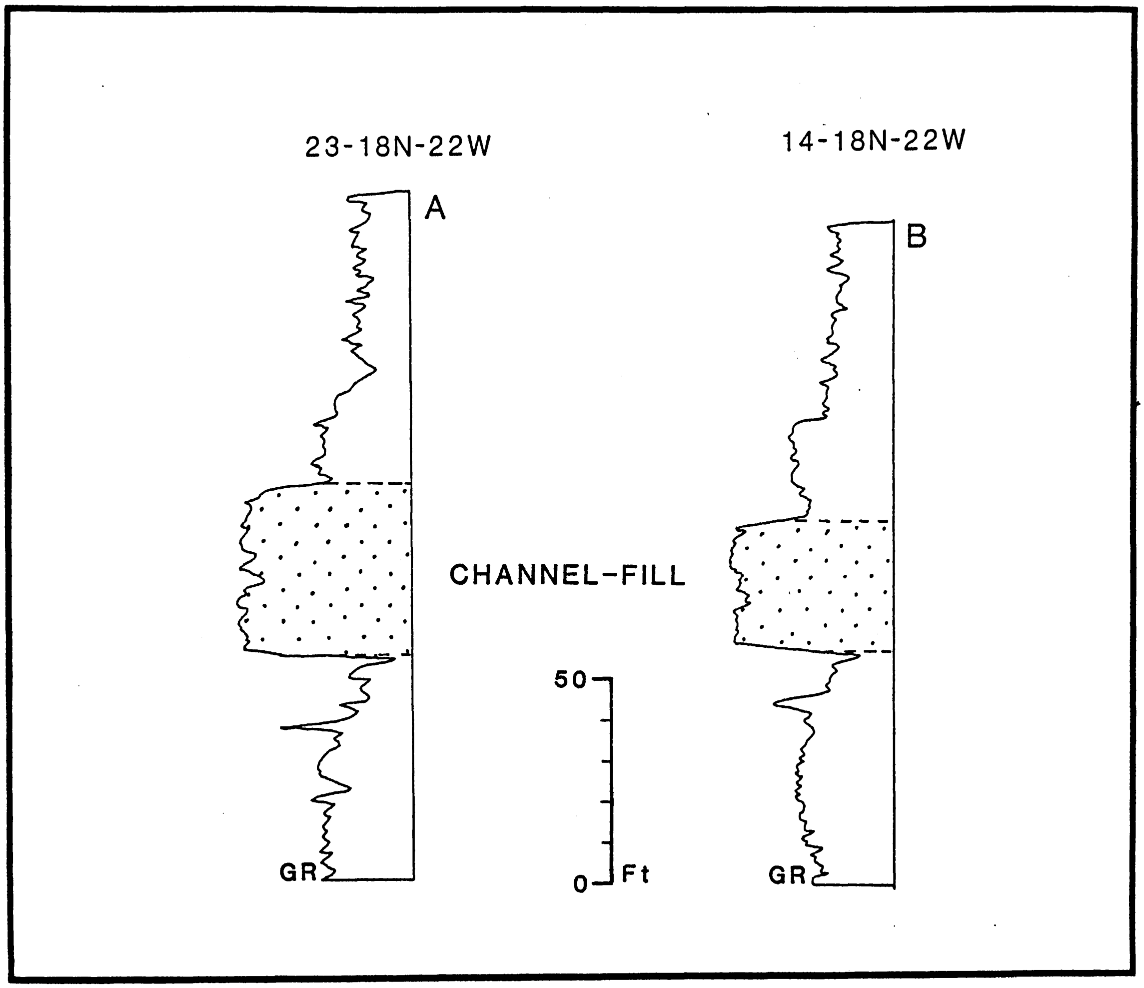


Figure 66. Typical Channel-Fill Well-Log Signatures. Profiles Tend to be Barrel-shaped with Very Abrupt Lower and Upper Contacts. Log Signature A Taken From Cross Section C-C' (Plate IV).

its log signature, but also by its narrow and elongate geometry in plan view and bifurcating pattern expressed in cross section. Additional evidence is cited in Chapter VII.

A third general type of log signature comes from regions between the tracts of sandstone facies in the Cottage Grove. In these areas strip-logs indicate the presence of thin, tightly carbonate-cemented sandstones and sandy limestones. These beds are at or very near the stratigraphic positions of adjacent sandstone facies. Gamma-ray profiles indicate that these carbonate units are composed of one or more thin beds separated by shales (Figure 67). Resistivity logs show invasion profiles suggestive of low-permeability rock. Cross-plots of nuetron-density logs indicate that the rock is limestone. Shaliness may affect the cross-plots somewhat.

Representative log-signatures of overlapping channel-margin/ridge and of stacked-ridge sequences are a fourth general type of log signature. The basic appearances of log signatures from zones where facies overlap or "stack" consists of two or more sandstone units separated by shale or interbedded siltstone and shale (Figure 68).

## Rock-to-log Correlations

### Response of Gamma Ray Log

The gamma ray log records the natural radioactivity of formations. In sedimentary rocks the gamma ray log generally reflects the amount of shale in the sequence of strata, because radioactive elements tend to be concentrated in

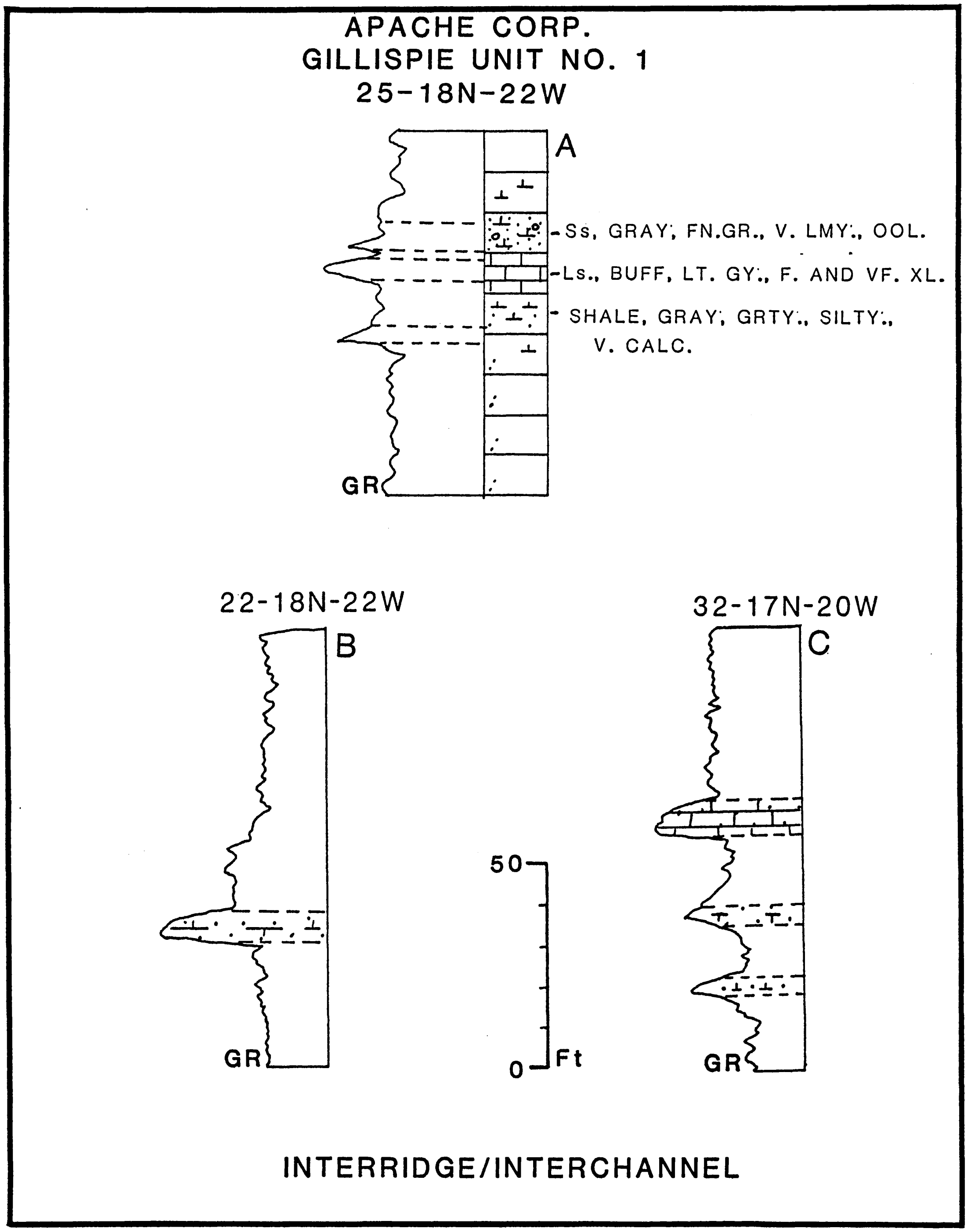


Figure 67. Interridge/Interchannel Well-Log Signatures. Gamma-ray Profiles May Delineate One or More Thin Units of Tightly Carbonate-Cemented Sandstone or Sandy Limestones Separated by Shale. Signature A is Correlated to a Strip-log Illustrating the Lithology Encountered within the Well.

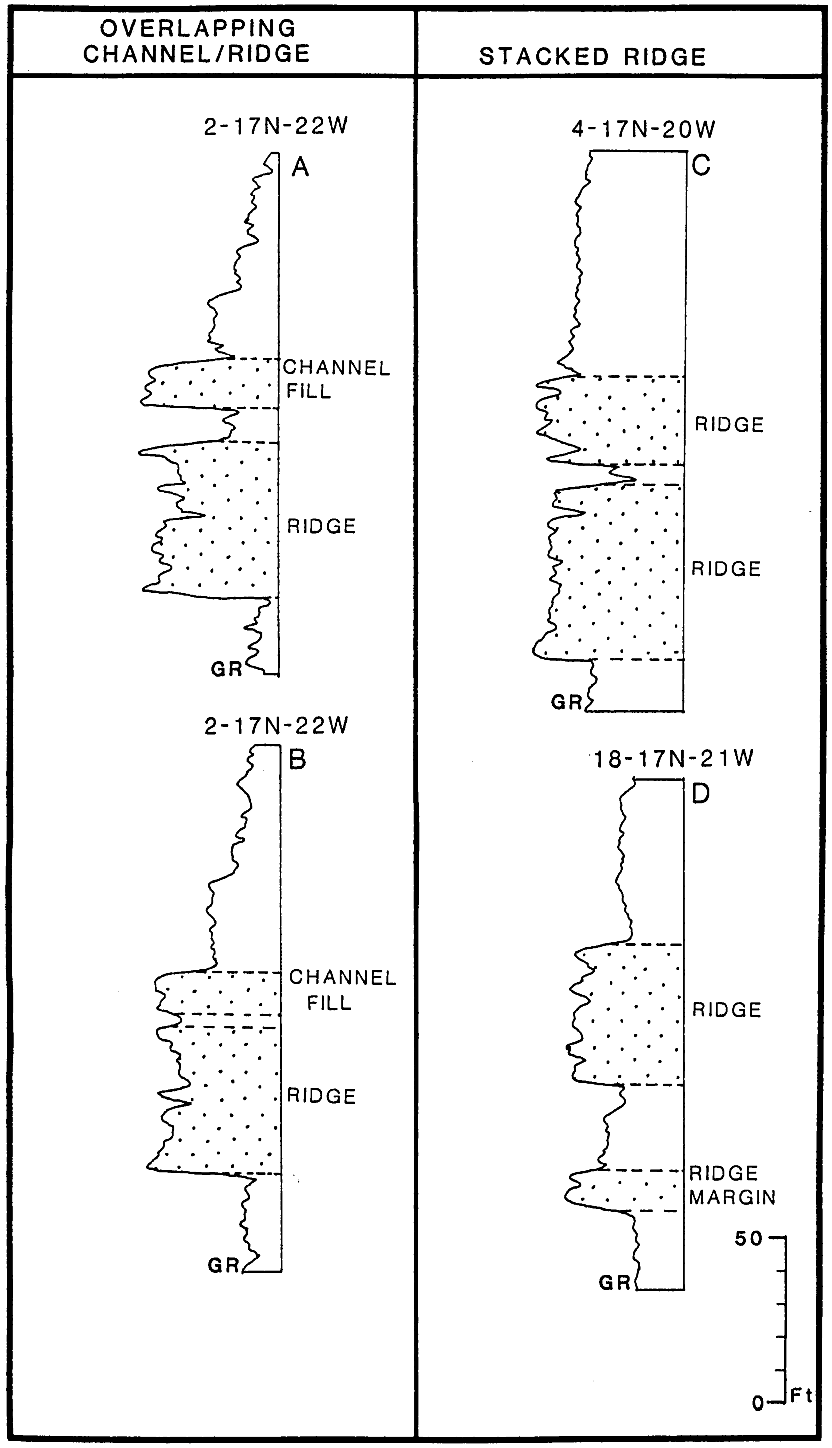


Figure 68. Gamma-ray Log Signatures of Stacked Sandstone Sequences. Sandstones may be Separated by Shale or Interbedded Siltstone and Shale. Signatures A and B (Taken from Cross-Section B-B' (Plate III)) are of Overlapping Channel and Ridge Sandstones. Signatures B and C are Interpreted as Stacked Ridge Sequences (Taken from T17N, R20W and R21W).

clays. However, sandstones with low shale content may be recorded by a large gamma-ray response if the sandstone contains potassium feldspars, micas, or glauconite (Asquith, 1982).

In general, the Cottage Grove Sandstone is fine to very-fine grained and contains potassium feldspar, glauconite, illite, muscovite and biotite. Samples from the Sarkey's 3-2 Gillispie provisionally were assumed to be representative of the Cottage Grove in the study area. (I recognize the likelihood of error, but this core is regarded as a reliable sample of the sandstone.) Data shown in Figures 69 through 76 were recorded from samples of the core of Sarkey's 3-2 Gillispie.

Plotted against the gamma-ray curve, samples comparatively rich in feldspar and glauconite failed to yield a distinguishable positive relationship. However, a linear relationship is suggested if total illite is plotted against the response of the gamma ray curve (Figure 69). As the percentage of total illite increases so does the gamma ray deflection in API units. A similar relationship is indicated by the plot of total mica verses the gamma ray curve (Figure 70). The loosely positive correlations set out in these plots suggest that the gamma ray curve dependably would indicate a "shalier" sandstone as the amounts of illite or mica increase. In the Cottage Grove, illite is chiefly of diagenetic origin. Thus, gamma-ray deflection might be useful as a criterion for mapping intensity of diagenetic

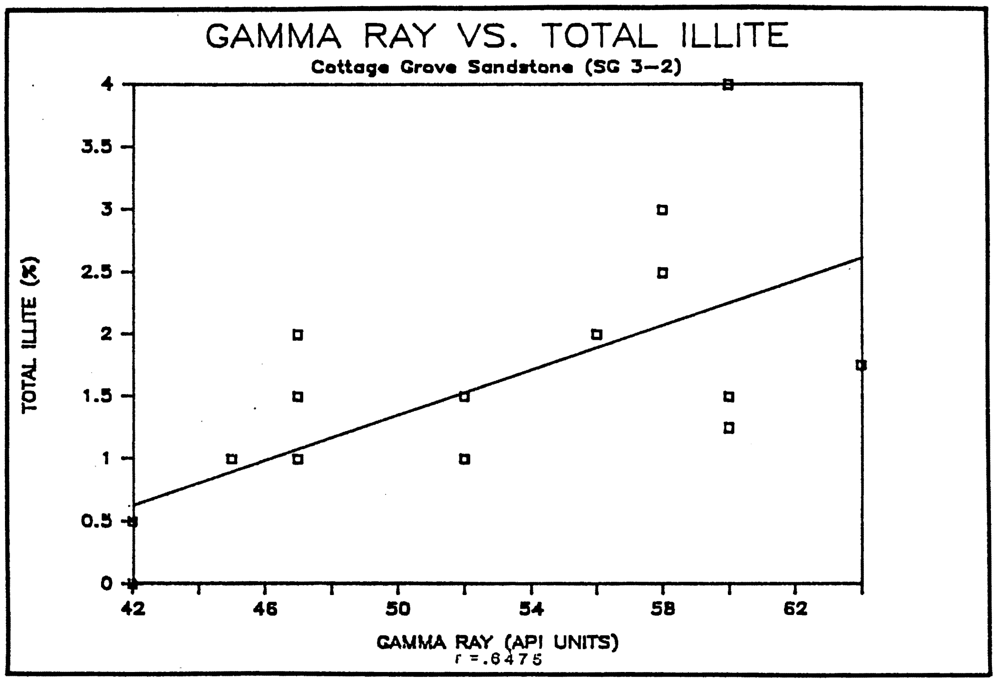


Figure 69. Graph of Total Illite versus Gamma Ray. As the Percentage of Illite Increases, so Does the Gamma Ray in API Units.

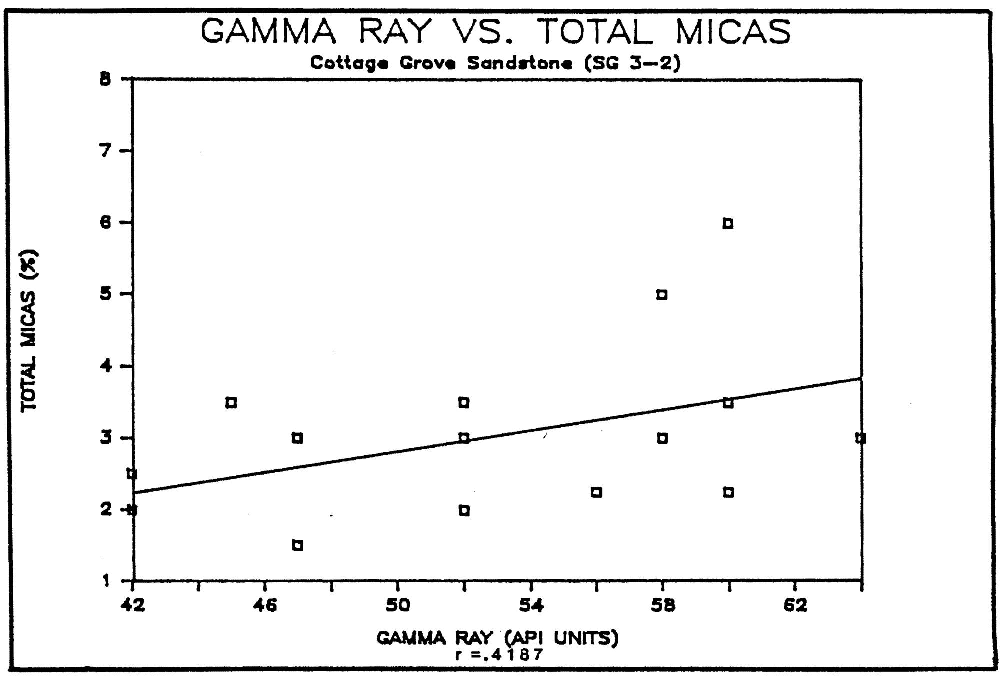


Figure 70. Graph of Total Mica versus Gamma Ray. As Total Mica Increases in Percent, the Gamma Ray Increases in API Units.

effects.

Gamma-ray deflection compared to average grain size shows negative correlation (Figure 71). As the average grain size of the sandstone decreases, the deflection of the gamma-ray increases. This arrangement is suggestive of the tendency of fine-grained sandstone to contain more detrital and/or authigenic clay.

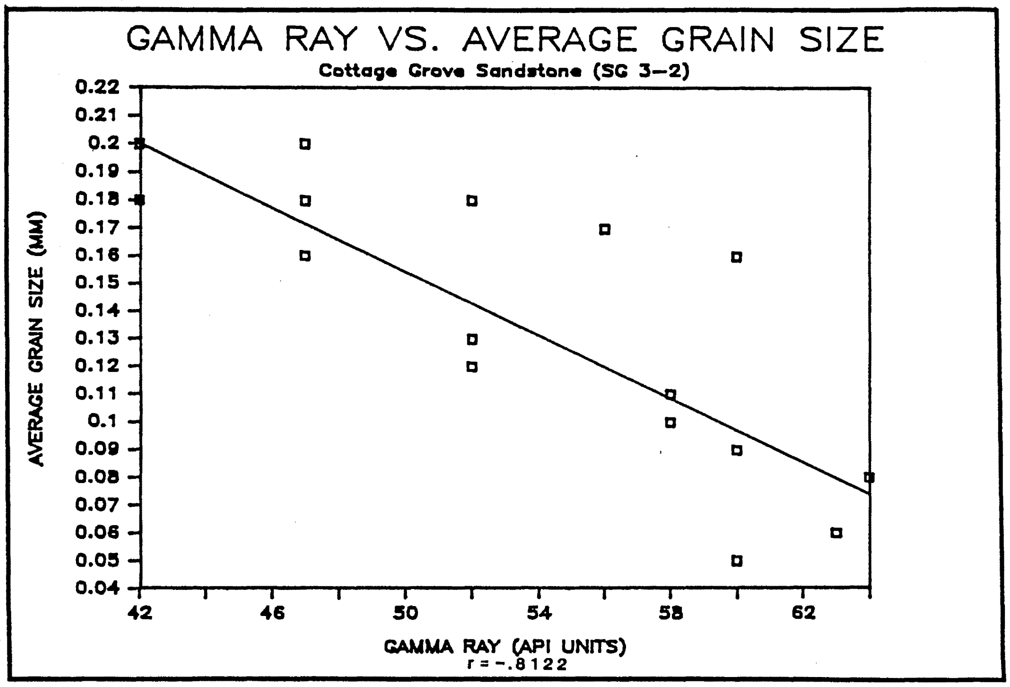


Figure 71. Graph of Average Grain Size versus Gamma Ray. Inverse Relationship Indicates that as Average Grain Size Decreases, the Gamma Ray Response Increases in API Units. This Suggests that Finer Grain Sedimentary Rocks Contain More Authigenic and/or Detrital Clays and Mica.

In the strict sense the gamma-ray relationships shown above might be expected to be almost one-to-one. However, the disparity of sampling-volumes between gamma-ray tool and thin sections undoubtedly has introduced much scatter in the cross-plots. Vertical resolution of the gamma-ray tool is approximately 2.5 ft (Hilchie, 1978) but measurements of constituents come from thin sections that are only 0.03 mm thick (roughly 1/25,000 of the vertical interval recorded by the gamma-ray). With this small amount of control, unless the rock were of uniform composition, the "ideal" one-to-one correlation between the gamma ray curve and petrographic data is highly unlikely to occur.

## Log-to-Log Relationships

Response of the bulk density curve (and related density porosity) was compared to responses of the laterolog, medium-induction, and deep-induction curves in order to test hypotheses about response-relationships among these curves.

### Bulk Density (and Density Porosity) Vs. Deep Induction

Figures 72 and 73 suggest some fundamental relationships among porosity, pore-fluids and resistivity. Density porosity (calculated from bulk density using an assumed matrix density of 2.68 gm/cc), plotted against deep induction resistivity, illustrates negative correlation (Figure 73) (an expected circumstance since bulk density and density porosity are inversely related).

Deep induction resistivity presumedly is a measured property of the uncontaminated zone -- i.e., rock and fluid-

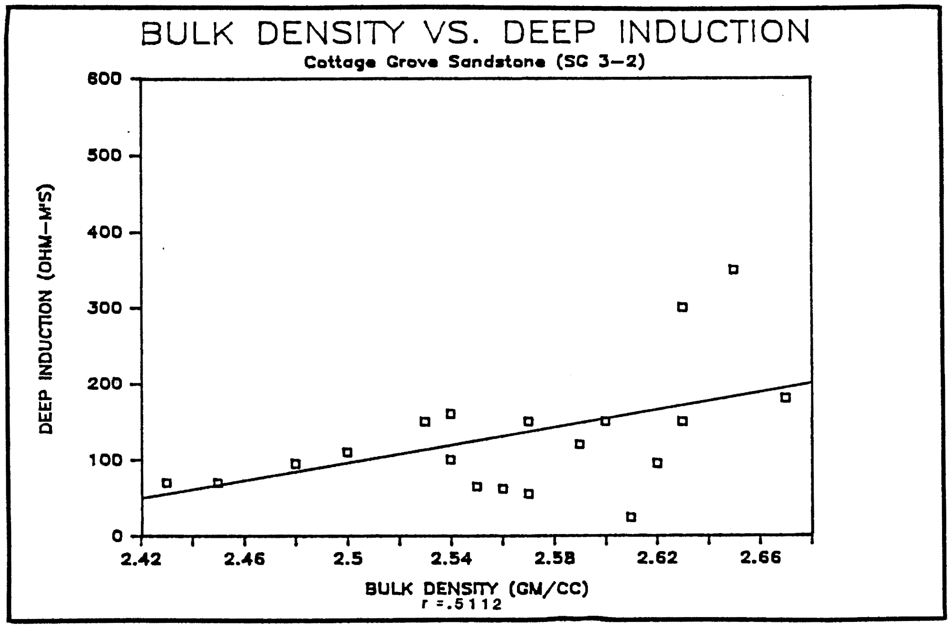


Figure 72. Bulk Density vs. Deep Induction. The Larger Amount of Scatter as Bulk Density Approaches 2.68 gm/cc Suggests that Porosity is More Variable in Finer Grained Rock and that Diagenetic Constituents Could be Relatively More Abundant.

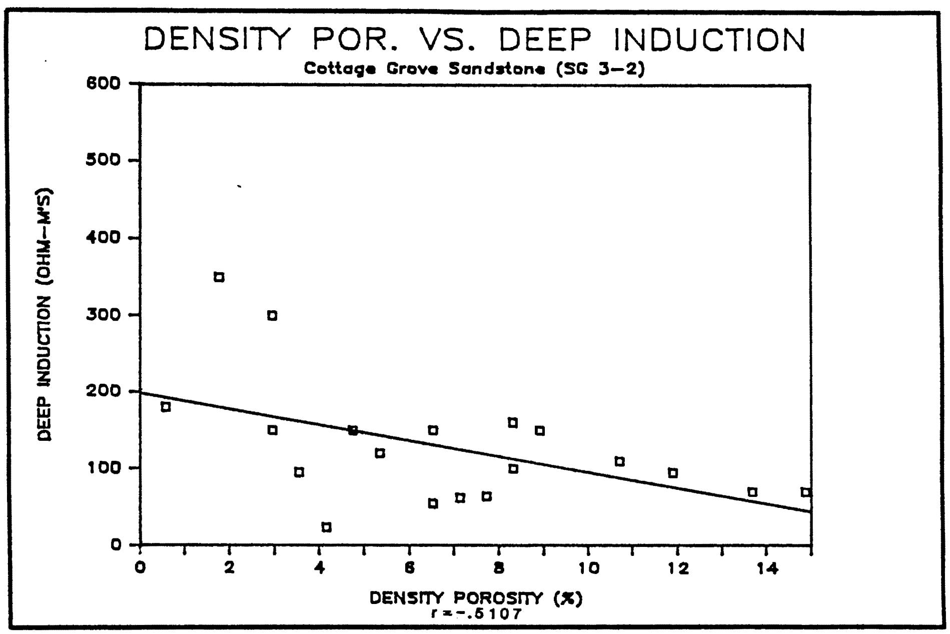


Figure 73. Density Porosity vs. Deep Induction. As Porosity Approaches 0 (or as Bulk Density Approaches 2.68 gm/cc, Above), Low Resistivity Shown by Some Samples Suggests a Relatively Large Amount of Water-binding Constituents.

filled porosity (mostly a measurement of the fluids). If Sw = 1, then smaller bulk density implies a larger amount of porosity, a larger amount of stored electrolyte, and therefore smaller resistivity. Such a general association should hold, even if Sw is less than 1 but is almost constant.

### Bulk Density Vs. Medium Induction

A positive slope of least-squares line results if bulk density is plotted against resistivity measured by the medium induction curve. In general, as medium-induction resistivity increases bulk density increases (Figure 74). This circumstance is to be expected, because decreased porosity (increased bulk density) implies decreased amount of electrolyte, and therefore overall larger resistivity of reservoir rock. In comparison to Figure 72, the trend line of Figure 74 is the steeper, which probably is evidence of the effect of mud filtrate in the invaded zone.

With respect to Figures 72, 73, and 74, some of the scatter in resistivity could be due to variation in amounts of oil and/or gas in the reservoir. Moreover, since the leftmost four points on Figures 72 and 74 (rightmost four points of Figure 73) are samples from the same strata, the strong similarity in bulk density (density porosity) and resistivity suggest that invasion was shallow -- so shallow as to have minimal effect on medium-induction tool.

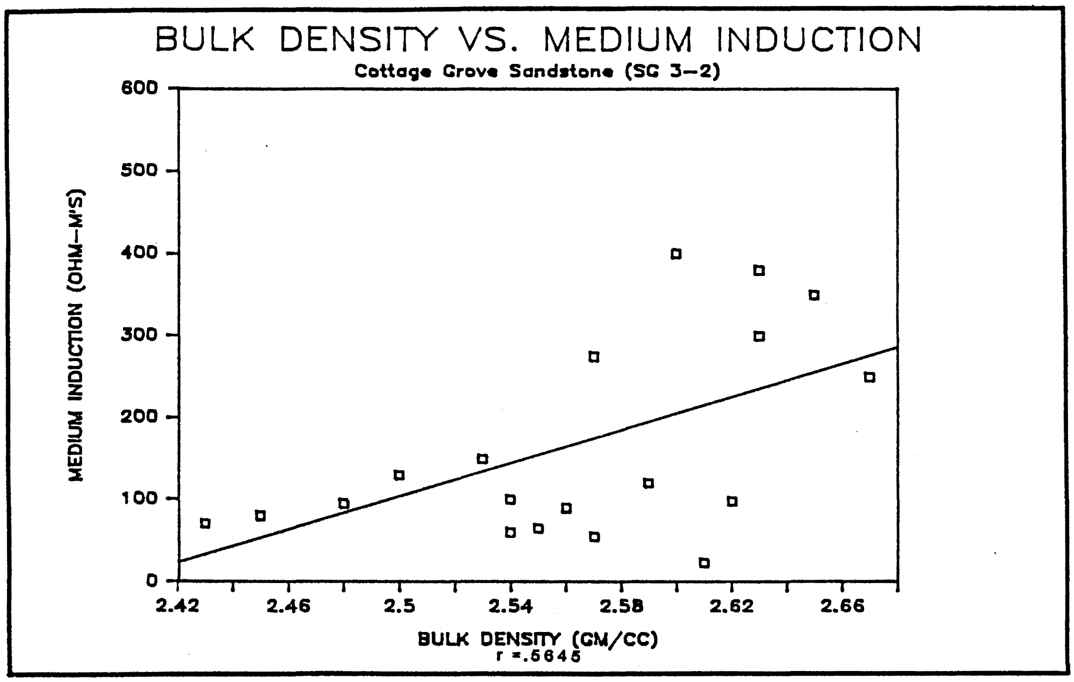


Figure 74. Bulk Density vs. Medium Induction. Clustering of Leftmost Four Points About the Trend Line Suggests That as Porosity Increases, Variation in Resistivity Diminishes. Resistivity of Samples in the Range of 2.5 to 2.68 gm/cc Suggests that Invasion of Mud Filtrate was Deeper in Some Low-porosity Rocks, Thereby Increasing Resistivity of Rock Within Range of the Medium-induction Tool.

<u>Bulk Density Vs. Laterolog Resistivity</u>

No apparent meaningful correlation exists between the bulk density (or density porosity) and laterolog resistivity (Figure 75). The nearly horizontal position of the trend line (i.e., closeness of slope to zero) suggests that the laterolog measures strongly invaded rock, that pore-fluid exerts strong influence on resistivity, and that pore-fluid mostly is mud filtrate no matter how large or small the porosity. This circumstance is expectable, for these are the conditions for which the laterolog was designed.

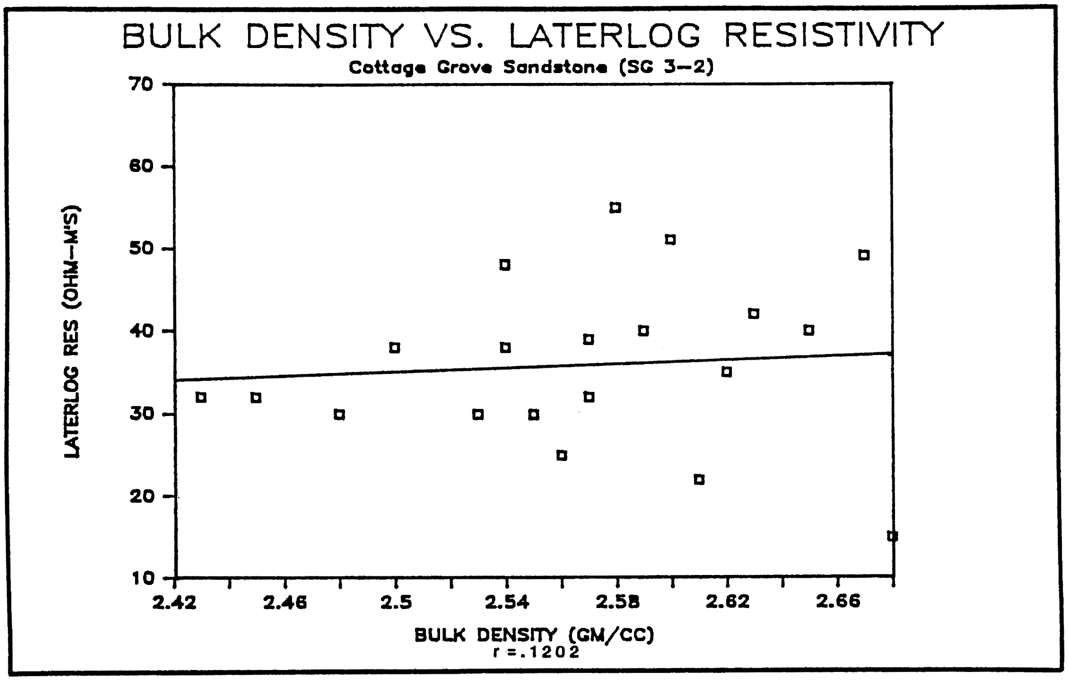


Figure 75. Bulk Density vs. Laterolog Resistivity.

Bulk Density Vs. The Difference Between Deep-induction and Laterolog Resistivity

Bulk density, plotted against the difference between deep-induction and laterolog resistivity, shows a positive slope of the best-fit line (Figure 76). This suggest a strong association: the smaller the amount of porosity (larger the bulk density), the deeper the invasion of rock and the greater the spread between deep induction and laterolog curves. This conclusion and those mentioned above are neither new nor unique. Such relationships can be expressed qualitatively, as the product of general study of wireline logs. However, these data indicate the robustness of the relationships when the sampling-differences of data from logs and thin sections are taken into account.

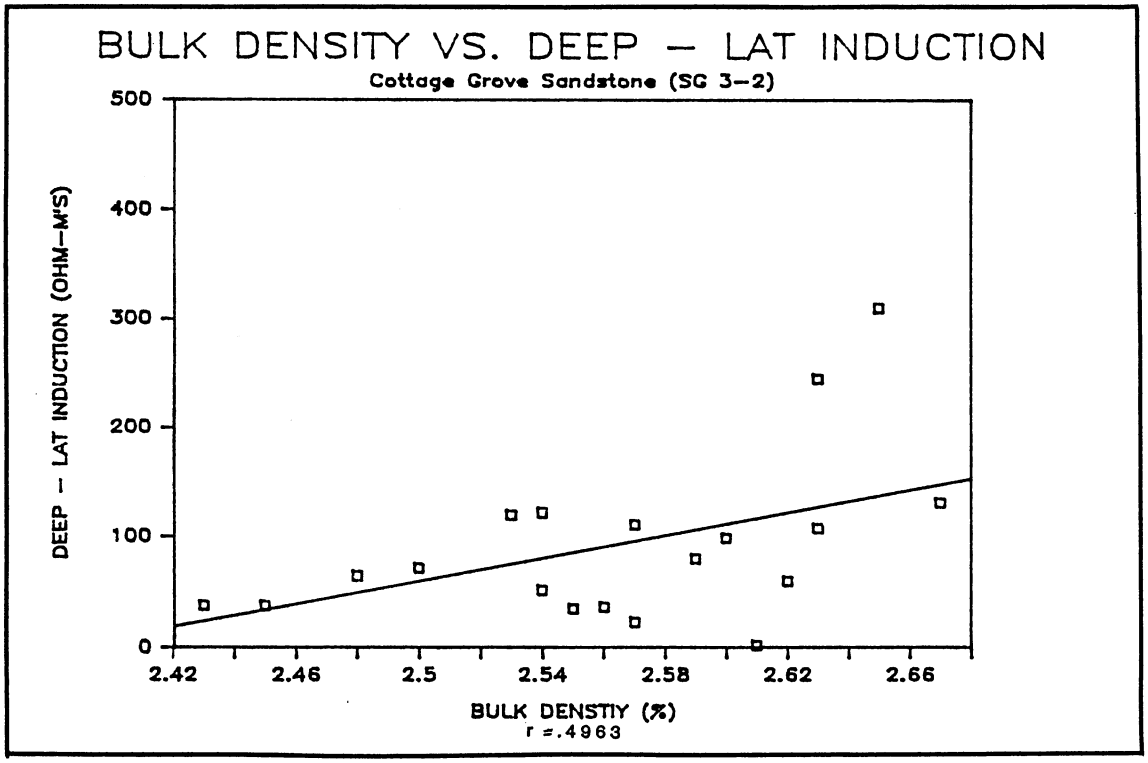


Figure 76. Bulk Density vs. Deep - Laterolog Resistivity. Samples that Approach Zero Probably are from Strata that are Shaly and Almost Impermeable (Which Probably is the Case in the Range of Bulk Density = 2.54 gm/cc and Greater).

## CHAPTER IX

## CONCLUSIONS

The principal conclusions of this study are as follows:

1. Structural features in the study area, as illustrated by the contour map of Avant "Hot" shale marker, consist of anticlinal and synclinal noses that are superimposed upon a southerly dipping homoclinal surface.

2. Some local anticlinal noses along the homocline are associated with linear trends of Cottage Grove Sandstone. These anticlines likely are the result of differential compaction and draping across sandstones.

3. The Cottage Grove Interval is defined as the stratigraphic section above the lowermost Hogshooter "hot" shale marker and below the lowermost Avant "hot" shale marker.

4. Regional correlations of the Cottage Grove Interval are facilitated by "hot" shale markers associated with the Avant and Hogshooter Limestone intervals. Detailed correlations in stacked sandstone sequences can be made through use of correlation markers that include: a) the lower Avant "hot" shale marker, b) nonporous strata shown by porosity-log curves and c) "shoulder-like" well-log signatures in sections of interbedded siltstone and shale, owing to variation in amount of shale in the interval above

the Cottage Grove Sandstone.

5. In cross section the Cottage Grove Interval increases in thickness southward; near the central part of T18N the rate of thickening changes from approximately 2 to 14 feet per mile. This increase generally is associated with thicker intervals of sandstone.

6. In the study area, the Cottage Grove Sandstone is very-fine to fine grained, well sorted, subrounded to rounded, mature litharenite to sublitharenite.

7. Detrital constituents of the Cottage Grove Sandstone are monocrystalline and polycrystalline quartz, feldspars, metamorphic-, plutonic-, and sedimentary-rock fragments, chert, muscovite, biotite, chlorite, phosphate, glauconite, zircon, tourmaline, fossil fragments, and ooids.

8. Authigenic constituents are ferroan dolomite, calcite, dolomite, quartz overgrowths, barite, feldspar overgrowths, illite, kaolinite, and chlorite.

9. Paleogeography, stratigraphic information, and the majority of petrographic data suggest that the Ouachita Mountains were the primary source of Cottage Grove sediments. However, granitic rock fragments, documented in cores from this study, suggest that a secondary source existed. This source may have been in the Wichita Mountains or Ancestral Rockies, because plutonic rocks have not been recorded in the Ouachita region.

10. Evidence from previous investigations, distribution of sandstones as based on subsurface maps and stratigraphic

cross sections constructed during this study, and internal sandstone features observed in cores, all indicate strongly that the Cottage Grove was deposited in a shallow marine setting.

11. The principal form of sandstone deposition in the study area was as sub-parallel, east-northeast-trending, linear ridges; a second mode of deposition is indicated by a narrow, north-trending sandstone that is interpreted as having been a shallow marine channel eroded by storm processes.

12. Dimensions of ridge sandstones are difficult to determine in the southern portion of the study area where the bodies of sandstones were stacked. However, in the north, sandstone ridges measure from 1 to 1.5 miles wide by 2 to 7 miles long. In the north, sandstone isolith thicknesses rarely exceed 35 feet; whereas, in the southern half thickness are as much as 96 feet. Maximal thickness recorded for the channel deposit is 45 ft.

13. Cottage Grove ridges were deposited under the influence of storm- and tide-dominated conditions during a marine transgression.

14. The "channel" sandstone overlies the ridge facies in T17N and T18N, R22W. In this region the sandstone appears to be within a channel that truncated the section above, and that bifurcated across the underlying ridge.

15. Several depositional characteristics exhibited by the channel/ridge couplet of the Cottage Grove resemble

characteristic shown by other channel/ridge couplets in the geologic record, including the Terry Sandstone Member, Pierre Shale in the Denver Basin, and the Cretaceous Sussex Sandstone of Wyoming.

16. Sedimentary structures apparent in cores of the Cottage Grove include massive bedding, medium-scale planar cross-bedding, small-scale trough cross-bedding, fining-upward sequences, and soft-sediment deformation. Bioturbated rock is confined largely to the interbedded siltstones and shales that overlie the sandstone facies.

17. Strip-logs suggest that interridge/interchannel areas of the Cottage Grove interval consist of limestone and thin, "tightly" carbonate-cemented sandstones and siltstones.

18. Carbonate fossil fragments, ooids, and shale clasts within the Cottage Grove likely were entrained by storm-surge ebb flows that deposited sandstone as ridges on the shelf. Detrital carbonaceous material was deposited (a) in shales immediately below the sandstones, (b) at the bases of sandstone intervals in fining-upward deposits, (c) as trace amounts within the sandstones, and (d) in fining-upward sequences that truncate the upper sandstone facies.

19. Numerous sandstone intervals containing abundant carbonate material are cemented completely by calcite.

20. Ridge sandstones of the Cottage Grove have abrupt lower contacts with shale, fine upward in grain size overall, and have upper contacts that grade over short distances to interbedded siltstone and shale. Ridges are enclosed

laterally by marine shale.

21. Major diagenetic events recorded in the Cottage Grove Sandstone include the mechanical process of compaction and chemical processes of dissolution, precipitation, alteration, and replacement.

22. The general paragenetic sequence of the Cottage Grove Sandstone is summarized as follows: (a) precipitation of calcite, (b) biogenic decarbonatization (b) precipitation of (in relative order of occurrence) quartz overgrowths, barite, dolomite, ferroan dolomite, and calcite, (c) dissolution of carbonate cements, feldspars, rock fragments and detrital matrix, (d) precipitation of feldspar overgrowths, illite, chlorite, and kaolinite. Migration of hydrocarbons followed precipitation of clay, although maturation likely began prior to dissolution of carbonate cements (stage c).

23. Porosity in the Cottage Grove Sandstone ranges from 0% to 16%, averages 6%, and is predominantly secondary. Primary porosity contributes only an occasional trace amount. Effective porosity is owing largely to dissolution of calcite and ferroan dolomite cements. Textures of secondary porosity consist of elongate pores, corroded grains, floating grains, partially dissolved grains, oversized pores, honeycombed grains, grain molds, shrinkage, and microporosity (associated with kaolinite).

24. In the Sarkey's, Gillispie 3-2 core, increase in the deflection of the gamma-ray log (API units) indicates

increases of total illite and total mica due to the presence of radioactive potassium ions contained in the matrices of these minerals. As the average grain size of the sandstone decreases, the deflection of the gamma ray increases. This arrangement reflects the tendency of fine-grained sandstone to contain more clay minerals and mica.

25. In logs of the Sarkey's Gillispie 3-2 well, deep- and medium-induction resistivity curves show positive correlation to the bulk density curve: increased bulk density implies decreased porosity, which implies a decreased amount of electrolyte; accordingly, this results in overall larger resistivity of the reservoir rock. Hence, a general assessments of reservoir porosity may be made from evaluation of deep- and medium-induction resistivity curves.

26. Gamma-ray well log signatures of the Cottage Grove can be categorized into sets "characteristic" of ridge, channel, interridge/interchannel, and stacked sandstone facies. This information should contribute to improved prediction of depositional environments from well logs.

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# APPENDIX A

# WELL-LOG DATA SHEETS

# LIST OF SYMBOLS

| | |
|---|---|
| SPOT | - Well location |
| SEC | - Section |
| STAT | - Well status (LOC = Location only, Ghst = Ghost point) |
| NUMB | - Assigned well number per Township |
| ELEV | - Elevation (KB, DF, etc.) |
| AVANT | - Avant structural top (lowermost Avant "hot" shale marker) recorded as subsea |
| HGSH | - Hogshooter Limestone structural top (lowermost Hogshooter "hot" shale marker) recorded as subsea |
| CGNSS | - Cottage Grove Net Sandstone (represents net gamma-ray 2.5 chart divisions from shale base line) -- some values may record limestone |
| CGPHI | - Cottage Grove Sandstone Net Porosity greater than 8 percent |
| CGSS | - Cottage Grove Net Sandstone Isolith value (value represents only those CGNSS values with porosity (CGPHI)) |

17N-20W

| SPOT | SEC | STAT | NUMB | ELEV | AVANT | HGSH | CGNSS | CGPHI | CGSS |
|---|---|---|---|---|---|---|---|---|---|
| 2640E 1440N | 1 | LOC | 37 | 1878 | 6278 | 6660 | 68 | MS | 68 |
| 3600E 330N | 2 | LOC | 38 | 1919 | 6297 | 6681 | 68 | MS | 68 |
| 2980E 1980N | 2 | LOC | 39 | 1923 | 6285 | 6663 | 56 | MS | 56 |
| SW SW SW | 2 | LOC | 40 | 1996 | 6345 | 6724 | 48 | MS | 48 |
| 3300E 1400N | 4 | LOC | 1 | 2094 | 6340 | 6726 | 70 | 56 | 70 |
| C | 6 | LOC | 36 | 2128 | 6361 | 6736 | 68 | 64 | 68 |
| SE SE | 8 | LOC | 2 | 2095 | 6407 | 6791 | 54 | MS | 54 |
| S2 SE NE | 9 | LOC | 3 | 2055 | 6381 | 6751 | 68 | MS | 68 |
| C SE SW | 9 | LOC | 4 | 2094 | 6398 | 6778 | 54 | 26 | 54 |
| 2230E 3300N | 9 | LOC | 5 | 2030 | 6382 | 6770 | 60 | 34 | 60 |
| 1875E 2970N | 9 | LOC | 6 | 2066 | 6392 | 6779 | 52 | 40 | 52 |
| SE NW SE | 9 | LOC | 41 | 2105 | 6399 | 6785 | 57 | 26 | 57 |
| C SE | 10 | LOC | 7 | 1997 | 6360 | 6748 | 55 | 24 | 55 |
| C SE NE | 10 | LOC | 42 | 2057 | 6347 | 6733 | 80 | MS | 80 |
| C SE NW | 10 | LOC | 45 | 2068 | 6362 | 6748 | 59 | 38 | 59 |
| C NW SE | 10 | LOC | 46 | 2021 | 6364 | 6749 | 76 | MS | 76 |
| S2 SW SW | 10 | LOC | 43 | 2078 | 6398 | 6784 | 58 | 20 | 58 |
| C SE | 11 | LOC | 8 | 1915 | 6358 | 6741 | 28 | 4 | 28 |
| C SE SW NE | 11 | LOC | 9 | 1925 | 6343 | 6722 | 50 | 10 | 50 |
| 1650E 3180N | 11 | LOC | 47 | 2024 | 6336 | 6721 | 68 | MS | 68 |
| E2 NW SE | 12 | LOC | 10 | 1885 | 6329 | 6703 | 30 | MS | 30 |
| C SE NW | 12 | LOC | 11 | 1887 | 6321 | 6698 | 56 | 44 | 56 |
| SW NW | 12 | LOC | 12 | 1889 | 6316 | 6691 | 60 | 34 | 60 |
| 4950E 1067N | 12 | LOC | 13 | 1865 | 6300 | 6675 | 58 | 46 | 58 |
| 3520E 3520N | 12 | LOC | 14 | 1880 | 6312 | 6690 | 60 | 48 | 60 |
| C NE SW | 12 | LOC | 48 | 1885 | 6343 | MS | 34 | MS | 34 |
| C NW NW | 13 | LOC | 15 | 1889 | 6391 | 6775 | 17 | 9 | 17 |
| NW NW NW | 14 | LOC | 16 | 1966 | 6394 | 6784 | 46 | 26 | 46 |
| NW NW NE | 14 | LOC | 17 | 1935 | 6378 | 6775 | 33 | 4 | 33 |
| E2 W2 NE NW | 16 | LOC | 18 | 2124 | 6408 | 6790 | 0 | MS | MS |
| SW SW NE | 16 | LOC | 19 | 2152 | MS | MS | MS | MS | MS |
| NW NW | 16 | LOC | 49 | 2147 | MS | 6786 | 66 | MS | 66 |
| 3300E 3710N | 17 | LOC | 20 | 2069 | 6415 | 6799 | MS | MS | MS |
| 2970E 2210N | 17 | LOC | 21 | 2070 | 6444 | 6820 | MS | MS | MS |
| 2121E 3111N | 17 | LOC | 22 | 2044 | 6429 | 6816 | MS | MS | MS |
| N2 NW SW | 17 | LOC | 50 | 2011 | 6437 | 6819 | 61 | 17 | 61 |
| 4570E 3460N | 17 | LOC | 51 | 2127 | 6421 | 6805 | 68 | MS | 68 |
| 460E 3111N | 18 | LOC | 23 | 2153 | 6447 | 6833 | MS | MS | MS |
| C SE | 18 | LOC | 24 | 2087 | 6459 | 6843 | 80 | MS | MS |
| NW NW NW | 18 | LOC | 25 | 2122 | 6440 | 6820 | MS | MS | MS |
| 1980E 2280N | 18 | LOC | 54 | 2084 | MS | 6826 | 64 | MS | 64 |
| C N2 SW SW | 18 | LOC | 55 | 2091 | 6469 | 6855 | 64 | MS | 64 |
| C SW NE | 18 | LOC | 56 | 2040 | 6430 | 6812 | 66 | MS | 66 |
| 3230E 2300N | 18 | LOC | 57 | 2020 | 6438 | 6820 | 60 | MS | 60 |
| 2120E 2980N | 18 | LOC | 53 | 2068 | 6442 | 6824 | 66 | MS | 66 |
| 1540E 1320N | 25 | LOC | 26 | 1889 | 6535 | 6931 | 31 | 0 | 0 |
| 1170E 1320N | 26 | LOC | 27 | 1994 | 6578 | 6978 | MS | MS | MS |
| C SW | 27 | LOC | 28 | 2011 | 6599 | 7001 | 26 | MS | MS |
| SE | 27 | LOC | 58 | 2019 | 6587 | 6992 | 12 | 0 | 12 |
| 1770E 3960N | 28 | LOC | 29 | 2057 | 6571 | 6963 | 18 | 0 | 18 |
| C SE | 28 | LOC | 59 | 2007 | 6594 | 6987 | 16 | 0 | 12 |
| SE | 29 | LOC | 30 | 2149 | 6597 | 7005 | 16 | 4 | 16 |
| NE NE | 29 | LOC | 31 | 2115 | 6555 | 6955 | 18 | 0 | 18 |
| C SE | 33 | LOC | 33 | 2098 | 6654 | 7064 | 15 | 0 | 0 |
| NW | 34 | LOC | 3 | 2042 | 6616 | 7021 | 12 | 0 | 0 |
| C NE | 35 | LOC | 35 | 2043 | 6569 | 6969 | 10 | 0 | 0 |

17N-21W

| SPOT | SEC | STAT | NUMB | ELEV | AVANT | HGSH | CGNSS | CGPHI | CGSS |
|---|---|---|---|---|---|---|---|---|---|
| C NW SE | 3 | LOC | 3 | 2101 | 6379 | 6743 | 22 | 4 | 22 |
| NW | 3 | LOC | 32 | 2101 | 6319 | 6685 | 64 | 34 | 64 |
| C W2 SW | 4 | LOC | 4 | 2078 | 6360 | 6737 | 58 | MS | 58 |
| C SE SE | 5 | LOC | 5 | 2065 | 6355 | 6727 | 56 | 16 | 56 |
| C NE SW | 5 | LOC | 6 | 2045 | 6343 | 6713 | 54 | 35 | 54 |
| NW NE SW | 6 | LOC | 7 | 1922 | 6350 | 6723 | 76 | 17 | 76 |
| 2755E 3300N | 6 | LOC | 8 | 1938 | 6366 | MS | 38 | 20 | 38 |
| SE NW SE | 7 | LOC | 11 | 2071 | 6411 | 6797 | 66 | 34 | 66 |
| NE SE | 7 | LOC | 12 | 2043 | 6385 | 6776 | 74 | 35 | 74 |
| SW NE | 8 | LOC | 13 | 2068 | 6346 | 6718 | 40 | 17 | 40 |
| C NW | 9 | LOC | 16 | 2112 | 6383 | 6755 | 34 | 13 | 34 |
| NW SW | 10 | LOC | 17 | 2137 | 6431 | 6834 | 80 | 18 | 80 |
| 4080E 900N | 10 | LOC | 33 | 2164 | 6432 | 6819 | 90 | 24 | 90 |
| C S2 SW | 11 | LOC | 34 | 2160 | 6413 | 6796 | 96 | 42 | 96 |
| S2 SW NW | 13 | LOC | 18 | 2066 | 6448 | 6781 | 78 | MS | 78 |
| SW SW | 13 | LOC | 19 | 2137 | 6455 | 6841 | 60 | 6 | 60 |
| NE SE | 13 | LOC | 20 | 2153 | 6453 | MS | 80 | MS | 80 |
| C NE SW | 13 | LOC | 31 | 2098 | 6450 | 6834 | 66 | MS | 66 |
| 3300E 1780N | 13 | LOC | 36 | 2123 | 6456 | 6841 | 82 | MS | 82 |
| C SW SW NE | 13 | LOC | 37 | 2113 | 6461 | 6842 | 58 | 43 | 58 |
| SW SE | 14 | LOC | 21 | 2097 | 6437 | 6819 | 84 | MS | 84 |
| SW SW | 14 | LOC | 22 | 2104 | 6432 | 6818 | 82 | 8 | 82 |
| S2 SE NW | 14 | LOC | 38 | 2107 | 6420 | 6801 | 75 | 56 | 75 |
| E2 SW NW | 14 | LOC | 39 | 2141 | 6413 | 6793 | 82 | 22 | 82 |
| C S2 SW NW | 15 | LOC | 23 | 2152 | 6467 | 6856 | 82 | MS | 82 |
| C SE NE | 15 | LOC | 40 | 2166 | 6427 | 6807 | 75 | 16 | 75 |
| NW | 17 | LOC | 24 | 2019 | 6471 | 6865 | 68 | 8 | 68 |
| NE | 18 | LOC | 25 | 2088 | 6480 | 6868 | 54 | 12 | 54 |
| 1320E 3810N | 19 | LOC | 41 | 2174 | 6522 | 6916 | 58 | MS | 58 |
| C NW | 20 | LOC | 27 | 2071 | 6515 | 6905 | 74 | 56 | 74 |
| NE SW NE | 22 | LOC | 42 | 2152 | 6507 | 6892 | 42 | 11 | 42 |
| 630E 4690N | 23 | LOC | 43 | 2124 | 6469 | 6853 | 56 | 10 | 56 |
| NE SW NE | 25 | LOC | 28 | 2218 | 6536 | 6962 | 10 | 0 | 0 |
| 4130E 1320N | 29 | LOC | 29 | 2230 | 6558 | 6959 | 18 | 0 | 0 |
| E2 E2 NW | 29 | LOC | 30 | 2141 | 6558 | 6947 | 14 | 0 | 0 |
| C | 34 | Ghst | 501 | MS | 6600 | 7000 | MS | MS | MS |

17N-22W

| SPOT | SEC | STAT | NUMB | ELEV | AVANT | HGSH | CGNSS | CGPHI | CGSS |
|---|---|---|---|---|---|---|---|---|---|
| C SE NW | 1 | LOC | 1 | 1959 | 6347 | 6718 | 89 | 40 | 89 |
| C NW NE | 1 | LOC | 2 | 1968 | 6356 | MS | 46 | 11 | 46 |
| W2 W2 NW | 1 | LOC | 3 | 2079 | 6357 | MS | 10 | 0 | 10 |
| N2 NW SE | 2 | LOC | 4 | 2075 | 6373 | MS | 60 | 32 | 60 |
| C SE NW | 2 | LOC | 5 | 2097 | 6343 | MS | 64 | 14 | 64 |
| N2 SE SW | 2 | LOC | 6 | 2071 | 6399 | MS | 59 | 26 | 59 |
| C NE | 2 | LOC | 7 | 2134 | 6329 | 6690 | 76 | 67 | 76 |
| C E2 SE | 2 | LOC | 8 | 2050 | 6377 | 6740 | 73 | 17 | 73 |
| 960E 1980N | 2 | LOC | 9 | 2081 | 6383 | MS | 59 | 40 | 59 |
| E2 NE SE | 3 | LOC | 12 | 2040 | 6377 | MS | 58 | 22 | 58 |
| S2 NW SE | 3 | LOC | 13 | 2040 | 6393 | MS | MS | MS | MS |
| NW NW | 3 | LOC | 14 | 2118 | 6336 | 6672 | 24 | MS | 24 |
| S2 SW NE | 4 | LOC | 16 | 2170 | 6366 | MS | 34 | 22 | 34 |
| W2 SW | 4 | LOC | 17 | 2095 | 6361 | MS | 36 | 8 | 36 |
| N2 NE SW | 4 | LOC | 18 | 2162 | 6360 | MS | 38 | 22 | 38 |
| SW NE | 6 | LOC | 19 | 2144 | 6302 | 6614 | 20 | 8 | 20 |
| C | 7 | Ghst | 502 | MS | 6300 | 6650 | MS | MS | MS |
| NE NE NE | 10 | LOC | 21 | 2070 | 6440 | MS | 30 | 18 | 30 |
| C NE NW | 11 | LOC | 22 | 2050 | 6420 | MS | 50 | 20 | 50 |
| SE SE SE | 12 | LOC | 23 | 2063 | 6431 | 6821 | 68 | MS | 68 |
| S2 S2 NE | 13 | LOC | 24 | 2149 | 6506 | 6889 | 46 | 25 | 46 |
| NE NE | 15 | LOC | 25 | 2008 | 6506 | MS | 29 | 12 | 29 |
| W2 SE | 18 | LOC | 26 | 2147 | 6434 | MS | 10 | 0 | 10 |
| S2 SE SW | 18 | LOC | 28 | 2184 | 6450 | MS | 14 | 4 | 14 |
| SW NE SW | 19 | LOC | 30 | 2314 | 6480 | MS | 6 | 0 | 6 |
| C SE | 23 | LOC | 31 | 2304 | 6542 | 6922 | 38 | 16 | 38 |
| C NE | 24 | LOC | 32 | 2156 | 6538 | 6928 | 63 | 24 | 63 |
| C | 28 | Ghst | 503 | MS | 6550 | 6900 | MS | MS | MS |
| C | 32 | Ghst | 504 | 0 | 6600 | 6950 | MS | MS | MS |
| 3530E 1470N | 36 | LOC | 33 | 2064 | 6688 | 7078 | 14 | 0 | 14 |

| SPOT | SEC | STAT | NUMB | 18N-20W ELEV | AVANT | HGSH | CGNSS | CGPHI | CGSS |
|---|---|---|---|---|---|---|---|---|---|
| C NW | 3 | LOC | 1 | 2134 | 5716 | 6028 | 13 | 0 | 0 |
| S2 S2 NW | 3 | LOC | 2 | 2148 | 5708 | 6024 | 13 | 0 | 0 |
| 1320E 3080N | 4 | LOC | 3 | 2005 | 5761 | 6079 | 13 | 0 | 0 |
| C NE | 5 | LOC | 4 | 1972 | 5770 | 6085 | 12 | 0 | 0 |
| SW NE SW | 6 | LOC | 5 | 2126 | 5867 | 6184 | 13 | 0 | 0 |
| N2 S2 SE | 8 | LOC | 6 | 2096 | 5907 | 6234 | 17 | 0 | 0 |
| C NE | 8 | LOC | 18 | 2077 | 5863 | 6190 | 19 | MS | MS |
| C SE NW SE | 9 | LOC | 19 | 1925 | 5850 | 6179 | MS | MS | MS |
| C NW | 10 | LOC | 7 | 1975 | 5786 | 6111 | 13 | 0 | 0 |
| C S2 NE SW | 10 | LOC | 20 | 2004 | 5847 | 6255 | 12 | 0 | 0 |
| NW | 12 | LOC | 8 | 2044 | 5906 | 6234 | 12 | 0 | 0 |
| C W2 NE | 13 | LOC | 21 | 2073 | 5920 | 6272 | 84 | 70 | 84 |
| C NW | 16 | LOC | 9 | 2071 | 5899 | 6258 | 8 | 0 | 0 |
| W2 W2 W2 NE | 16 | LOC | 22 | 1992 | 5882 | 6214 | 22 | 0 | 0 |
| C SE | 17 | LOC | 10 | 1956 | 5954 | 6290 | 9 | 0 | 0 |
| SE NW | 21 | LOC | 11 | 1890 | 6012 | 6357 | 34 | 0 | 0 |
| C NE | 21 | LOC | 12 | 1896 | 6006 | 6354 | 52 | 12 | 12 |
| C NE SW | 22 | LOC | 13 | 1876 | 6056 | 6413 | 62 | 27 | 62 |
| NW SE | 25 | LOC | 14 | 1867 | 6116 | 6481 | 50 | 28 | 50 |
| C NE | 25 | LOC | 23 | 1931 | 6061 | 6429 | 54 | 42 | 54 |
| 1350E 2780N | 33 | LOC | 24 | 1896 | 6268 | 6640 | 29 | 24 | 29 |
| NE NE SW NE | 34 | LOC | 15 | 1913 | 6215 | 6592 | 88 | MS | 88 |
| C NE | 35 | LOC | 16 | 1846 | 6201 | 6563 | 83 | 54 | 83 |
| C NE | 36 | LOC | 17 | 1828 | 6178 | 6548 | 63 | 50 | 63 |

| SPOT | SEC | STAT | NUMB | 18N-21W ELEV | AVANT | HGSH | CGNSS | CGPHI | CGSS |
|---|---|---|---|---|---|---|---|---|---|
| C NW | 1 | LOC | 18 | 2080 | 5861 | 6173 | 16 | 0 | 0 |
| 1930E 1700N | 2 | LOC | 19 | 2156 | 5919 | 6229 | 14 | 0 | 0 |
| SW SW SW | 2 | LOC | 20 | 2131 | 5951 | 6269 | 15 | 0 | 0 |
| 4280E 4280N | 3 | LOC | 1 | 2157 | 5871 | 6179 | 20 | 0 | 0 |
| SW | 4 | LOC | 21 | 2150 | 5898 | 6234 | 12 | 0 | 0 |
| C NE | 5 | LOC | 2 | 2277 | 5883 | 6183 | 15 | 0 | 0 |
| C NW | 7 | LOC | 3 | 2249 | 5933 | 6243 | 12 | 0 | 0 |
| C E2 SW | 9 | LOC | 4 | 2140 | 5981 | 6314 | 16 | 0 | 0 |
| S2 NE NE | 9 | LOC | 22 | 2144 | 5961 | 6282 | 10 | 0 | 0 |
| 4620E 1960N | 9 | LOC | 23 | 2141 | 5982 | 6304 | 13 | 0 | 0 |
| NE NE SW NE | 9 | LOC | 24 | 2127 | 5964 | 6286 | 12 | 0 | 0 |
| 3300E 4470N | 10 | LOC | 25 | 2074 | 5960 | 6278 | 16 | 0 | 0 |
| SE SE NW | 10 | LOC | 26 | 1985 | 5979 | 6301 | 14 | 0 | 0 |
| E2 SW | 10 | LOC | 27 | 2049 | 6007 | 6330 | 12 | 0 | 0 |
| SE NW SE | 10 | LOC | 28 | 1993 | 5995 | 6320 | 14 | 0 | 0 |
| C SE SE | 10 | LOC | 29 | 2011 | 6014 | 6341 | 16 | 0 | 0 |
| NW SW | 10 | LOC | 30 | 2133 | 5986 | 6310 | 12 | 0 | 0 |
| SE NE | 10 | LOC | 31 | 2105 | 5982 | 6301 | 12 | 0 | 0 |
| W2 E2 NW | 11 | LOC | 5 | 2085 | 5951 | 6269 | 14 | 0 | 0 |
| C NW NW | 11 | LOC | 32 | 2114 | 5943 | 6260 | 14 | 0 | 0 |
| C NW SW | 11 | LOC | 33 | 2023 | 5993 | 6313 | 14 | 0 | 0 |
| NW SE | 12 | LOC | 6 | 2029 | 5974 | 6298 | 15 | 0 | 0 |
| C NE | 14 | LOC | 7 | 1925 | 6025 | 6350 | 16 | 0 | 0 |
| 560E 4950N | 14 | LOC | 34 | 1962 | 6012 | 6338 | 14 | 0 | 0 |
| 1955E 3790N | 15 | LOC | 35 | 1980 | 6027 | 6354 | 15 | 0 | 0 |
| C NE | 16 | LOC | 8 | 2098 | 6028 | 6360 | 12 | 0 | 0 |
| C NE | 19 | LOC | 9 | 2098 | 6123 | 6466 | 9 | 0 | 0 |
| C NE NW | 21 | LOC | 36 | 2172 | 6078 | 6411 | 6 | 0 | 0 |
| N2 SW SW | 22 | LOC | 10 | 2122 | 6174 | 6515 | 14 | 0 | 0 |
| 2980E 3960N | 22 | LOC | 11 | 2010 | 6090 | 6425 | 11 | 0 | 0 |
| C SE | 23 | LOC | 12 | 1967 | 6131 | 6474 | 9 | 0 | 0 |
| 1622E 3538N | 30 | LOC | 14 | 2139 | 6225 | 6550 | 7 | 0 | 0 |
| C SE SW | 32 | LOC | 15 | 1943 | 6301 | 6655 | 6 | 0 | 0 |
| C SE | 33 | LOC | 16 | 2080 | 6281 | 6635 | 5 | 0 | 0 |
| SW | 34 | LOC | 17 | 2047 | 6297 | 6654 | 34 | 17 | 34 |

18N-22W

| SPOT | SEC | STAT | NUMB | ELEV | AVANT | HGSH | CGNSS | CGPHI | CGSS |
|---|---|---|---|---|---|---|---|---|---|
| C N2 SW | 2 | LOC | 1 | 2288 | 5951 | 6212 | 12 | 0 | 0 |
| C SW | 3 | LOC | 2 | 2378 | 5992 | 6269 | 0 | 0 | 0 |
| C SE | 4 | LOC | 46 | 2380 | 6025 | 6307 | 4 | 0 | 0 |
| C SW | 5 | LOC | 3 | 2407 | 6039 | 6308 | 0 | 0 | 0 |
| C SW | 6 | LOC | 3 | 2348 | 6054 | 6279 | 0 | 0 | 0 |
| NE | 7 | LOC | 4 | 2368 | 6074 | 6366 | 3 | 0 | 0 |
| 3760E 1320N | 8 | LOC | 5 | 2359 | 6081 | 6357 | 3 | 0 | 0 |
| NW | 8 | LOC | 6 | 2390 | 6052 | 6322 | 12 | MS | 0 |
| C SW NE | 9 | LOC | 7 | 2386 | 6051 | 6324 | 8 | 0 | 0 |
| C NW SW | 14 | LOC | 8 | 2326 | 6082 | MS | 32 | 0 | 32 |
| C NW | 16 | LOC | 9 | 2376 | 6116 | 6391 | 0 | 0 | 0 |
| C SW SE NW | 17 | LOC | 10 | 2321 | 6123 | 6401 | 0 | MS | 0 |
| C SE | 18 | LOC | 11 | 2308 | 6134 | 6414 | 8 | MS | 0 |
| C NE | 18 | LOC | 12 | 2335 | 6115 | 6395 | 8 | 0 | 0 |
| C NE | 20 | LOC | 13 | 2301 | 6179 | 6413 | 0 | 0 | 0 |
| C SE | 20 | LOC | 14 | 2264 | 6196 | 6478 | 0 | MS | MS |
| C NE | 21 | LOC | 15 | 2352 | 6159 | 6440 | 0 | 0 | 0 |
| SE SE | 22 | LOC | 16 | 2323 | 6153 | MS | 7 | 0 | 0 |
| C NE SE | 22 | LOC | 17 | 2299 | 6149 | 6446 | 18 | MS | MS |
| C SE | 23 | LOC | 18 | 2210 | 6162 | 6472 | 15 | 0 | 0 |
| W2 NW NW | 23 | LOC | 19 | 2288 | 6128 | 6425 | 30 | 13 | 30 |
| 760E 660N | 23 | LOC | 20 | 2299 | 6141 | MS | 41 | 27 | 41 |
| SW NW | 23 | LOC | 21 | 2283 | 6138 | 6445 | 45 | 22 | 45 |
| SW NE SW | 23 | LOC | 22 | 2303 | 6145 | MS | 29 | 15 | 29 |
| C NW SE | 25 | LOC | 23 | 2126 | 6221 | 6544 | 8 | 0 | 0 |
| C | 25 | LOC | 24 | 2091 | 6209 | 6451 | 12 | 0 | 0 |
| SW NE | 26 | LOC | 25 | 2143 | 6203 | MS | 13 | 0 | 0 |
| C NW | 26 | LOC | 26 | 2272 | 6182 | 6492 | 27 | 15 | 27 |
| NW NE SW | 26 | LOC | 27 | 2178 | 6204 | MS | 15 | 8 | 15 |
| SE NE NE | 27 | LOC | 28 | 2264 | 6162 | MS | 5 | 0 | 0 |
| SW NW SW NE | 27 | LOC | 29 | 2248 | 6191 | 6488 | 10 | 0 | 0 |
| NW SE SE | 27 | LOC | 30 | 2147 | 6224 | MS | 34 | 4 | 34 |
| 1320E 1330N | 29 | LOC | 31 | 2142 | 6232 | 6526 | 11 | 0 | 0 |
| W2 SE SE | 30 | LOC | 32 | 2160 | 6227 | 6533 | 11 | 0 | 0 |
| 1320E 3760N | 32 | LOC | 33 | 2142 | 6250 | 6551 | 16 | 4 | 16 |
| 1320E 3380N | 33 | LOC | 34 | 2205 | 6237 | 6535 | 11 | 0 | 0 |
| S2 NW | 34 | LOC | 35 | 2126 | 6264 | 6574 | 11 | 2 | 11 |
| NE NE | 34 | LOC | 36 | 2112 | 6236 | MS | 25 | 10 | 25 |
| SW NE | 34 | LOC | 37 | 2151 | 6261 | MS | 12 | 8 | 12 |
| C NE SW | 34 | LOC | 38 | 2147 | 6269 | 6597 | MS | MS | MS |
| W2 NE SE | 34 | LOC | 39 | 2096 | 6275 | MS | 13 | 0 | 13 |
| SW NW | 35 | LOC | 40 | 2143 | 6270 | MS | 22 | 9 | 22 |
| SE NW SW | 35 | LOC | 41 | 2052 | 6330 | MS | 15 | 0 | 15 |
| NE NW | 35 | LOC | 42 | 2107 | 6251 | MS | 23 | 17 | 23 |
| E2 SW SW SE | 35 | LOC | 43 | 2080 | 6320 | MS | 48 | 17 | 48 |
| C NW SE | 35 | LOC | 44 | 2104 | 6303 | 6636 | 8 | 0 | 0 |
| SW SW SW | 36 | LOC | 45 | 2082 | 6352 | MS | 10 | 0 | 0 |

19N-20W

| SPOT | SEC | STAT | NUMB | ELEV | AVANT | HGSH | CGNSS | CGPHI | CGSS |
|---|---|---|---|---|---|---|---|---|---|
| SW SW | 1 | LOC | 24 | 2265 | 5471 | 5754 | 12 | 0 | 0 |
| NE NW | 2 | LOC | 1 | 2249 | 5429 | 5704 | 6 | 0 | 0 |
| SE NW | 3 | LOC | 2 | 2286 | 5414 | 5710 | 13 | MS | MS |
| NW | 5 | LOC | 25 | 2306 | 5455 | 5720 | 14 | 0 | 0 |
| SE | 6 | LOC | 27 | 2316 | 5502 | MS | 17 | 0 | 0 |
| NE | 7 | LOC | 28 | 2351 | 5528 | 5802 | 10 | 0 | 0 |
| 1320E 2825N | 7 | LOC | 29 | 2332 | 5568 | 5842 | 20 | 0 | 0 |
| NW | 8 | LOC | 3 | 2322 | 5519 | 5798 | 24 | 0 | 0 |
| SW NE | 9 | LOC | 4 | 2245 | 5495 | 5771 | 10 | 0 | 0 |
| SE | 9 | LOC | 5 | 2251 | 5513 | 5793 | 8 | MS | MS |
| NE | 10 | LOC | 6 | 2209 | 5460 | 5741 | 25 | 0 | 0 |
| SW | 10 | LOC | 30 | 2220 | 5514 | 5796 | 16 | 0 | 0 |
| NW SE | 11 | LOC | 7 | 2251 | 5489 | 5777 | 12 | 0 | 0 |
| SE SW NE | 11 | LOC | 31 | 2226 | 5502 | 5789 | 22 | 0 | 0 |
| SE NW | 12 | LOC | 8 | 2273 | 5497 | 5787 | 31 | 0 | 0 |
| 1380E 1920N | 13 | LOC | 32 | 2188 | 5580 | 5881 | 12 | 0 | 0 |
| SW SW NE SW | 14 | LOC | 33 | 2161 | MS | MS | 10 | 0 | 0 |
| S2 N2 SE | 15 | LOC | 34 | 2196 | 5522 | 5812 | 11 | 0 | 0 |
| 1220E 3960N | 16 | LOC | 35 | 2276 | 5538 | 5822 | 15 | 0 | 0 |
| N2 SE | 17 | LOC | 9 | 2303 | 5584 | 5876 | 22 | 6 | 22 |
| E2 NE SW | 17 | LOC | 36 | 2265 | MS | 5881 | 23 | 0 | 0 |
| 4570E 3630N | 17 | LOC | 37 | 2296 | 5564 | 5848 | 17 | 0 | 0 |
| 4530E 4620N | 18 | LOC | 38 | 2295 | MS | 5868 | 20 | 0 | 0 |
| NE SW | 18 | LOC | 39 | 2272 | 5613 | 5894 | 16 | 0 | 0 |
| 2970E 2560N | 19 | LOC | 10 | 2209 | 5641 | 5929 | 8 | 0 | 0 |
| SW | 20 | Ghst | 11 | 2259 | 5610 | 5910 | 14 | 0 | 0 |
| NW SW SE | 21 | LOC | 12 | 2185 | 5623 | 5915 | 10 | 0 | 0 |
| SW NE SW | 22 | LOC | 15 | 2202 | 5589 | 5882 | 8 | 0 | 0 |
| S2 | 23 | LOC | 40 | 2127 | 5621 | 5921 | MS | MS | MS |
| E2 NW | 26 | LOC | 16 | 2093 | 5661 | 5959 | 10 | 0 | 0 |
| NW | 27 | LOC | 41 | 2210 | 5594 | 5884 | 8 | 0 | 0 |
| SW SW NE | 28 | LOC | 17 | 2173 | 5603 | 5899 | 6 | MS | MS |
| SW | 29 | LOC | 18 | 2052 | 5682 | 5984 | 5 | MS | MS |
| NE | 30 | LOC | 19 | 2203 | 5680 | 5978 | 10 | 0 | 0 |
| NE NE | 31 | LOC | 20 | 2099 | 5743 | 6047 | 7 | 0 | 0 |
| E2 E2 W2 NE | 32 | LOC | 21 | 2111 | 5697 | 6004 | 12 | 0 | 0 |
| E2 W2 SW | 33 | LOC | 22 | 2080 | 5706 | 6015 | 12 | 0 | 0 |
| NW | 33 | LOC | 23 | 2121 | 5671 | 5975 | 15 | 0 | 0 |
| NW | 34 | LOC | 42 | 2101 | 5640 | 5940 | 11 | 0 | 0 |
| NW | 35 | LOC | 43 | 2107 | 5761 | 6073 | MS | MS | MS |

19N-21W

| SPOT | SEC | STAT | NUMB | ELEV | AVANT | HGSH | CGNSS | CGPHI | CGSS |
|---|---|---|---|---|---|---|---|---|---|
| 1420E 1320N | 1 | LOC | 1 | 2358 | 5538 | 5797 | 20 | 0 | 0 |
| S2 NE | 1 | LOC | 2 | 2336 | 5510 | 5770 | 20 | 0 | 0 |
| C SW | 2 | LOC | 3 | 2328 | 5565 | 5804 | 20 | 0 | 0 |
| NE NE | 2 | LOC | 28 | 2300 | 5532 | 5772 | 20 | 0 | 0 |
| SW | 3 | LOC | 4 | 2333 | 5531 | 5775 | 16 | 0 | 0 |
| 1320E 1445N | 4 | LOC | 5 | 2369 | 5537 | 5783 | 15 | 0 | 0 |
| C SE | 5 | LOC | 6 | 2357 | 5563 | 5807 | MS | MS | MS |
| C NW SW | 6 | LOC | 7 | 2342 | 5568 | 5814 | 7 | 0 | 0 |
| C SE SE | 6 | LOC | 8 | 2333 | 5603 | MS | 22 | 0 | 0 |
| C NE | 6 | LOC | 29 | 2373 | 5539 | 5785 | 18 | 0 | 0 |
| 3400E 3300N | 8 | LOC | 30 | 2367 | 5620 | 5859 | 17 | 0 | 0 |
| C NE | 9 | LOC | 9 | 2363 | 5573 | 5817 | 15 | 0 | 0 |
| NE SE NW | 10 | LOC | 10 | 2332 | 5568 | 5814 | MS | MS | MS |
| SW SE NW | 11 | LOC | 11 | 2370 | 5594 | 5852 | MS | MS | MS |
| 1470E 1320N | 11 | LOC | 31 | 2348 | 5599 | 5863 | 16 | 0 | 0 |
| C NE | 12 | LOC | 32 | 2373 | 5556 | 5822 | 18 | 0 | 0 |
| NE SW SE | 13 | LOC | 13 | 2309 | 5620 | 5904 | 12 | MS | MS |
| C NE | 14 | LOC | 33 | MS | MS | MS | 16 | 0 | 0 |
| 3750E 3960N | 15 | LOC | 34 | 2319 | 5643 | 5908 | 15 | 0 | 0 |
| C NE | 16 | LOC | 35 | 2347 | 5662 | 5920 | 20 | 0 | 0 |
| SW NE | 17 | LOC | 12 | 2280 | 5669 | 5920 | 14 | 0 | 0 |
| 1820E 1470N | 17 | LOC | 36 | 2216 | 5684 | 5934 | 12 | 0 | 0 |
| W2 W2 E2 SW | 18 | LOC | 37 | 2315 | 5705 | 5947 | 14 | 0 | 0 |
| C SW | 19 | LOC | 14 | 2379 | 5759 | 6015 | 18 | 0 | 0 |
| SW SW | 20 | LOC | 38 | 2287 | 5741 | 6002 | 14 | 0 | 0 |
| C SW | 21 | LOC | 39 | 2168 | 5752 | 6012 | 16 | 0 | 0 |
| 4620E 1135N | 24 | LOC | 15 | 2248 | 5710 | 6002 | 18 | 0 | 0 |
| NE | 24 | LOC | 40 | 2319 | 5646 | 5931 | MS | MS | MS |
| 1673E 660N | 24 | LOC | 41 | 2241 | 5699 | 5988 | 10 | 0 | 0 |
| NE | 25 | LOC | 16 | 2223 | 5722 | 6017 | 15 | 0 | 0 |
| C SW | 25 | LOC | 42 | 2195 | 5755 | 6050 | 10 | 0 | 0 |
| C SE | 26 | LOC | 43 | 2190 | 5782 | 6079 | 14 | 0 | 0 |
| C W2 | 28 | LOC | 17 | 2221 | 5775 | 6047 | 14 | 0 | 0 |
| N2 S2 NW | 29 | LOC | 18 | 2265 | 5787 | 6050 | 13 | 0 | 0 |
| C NW | 30 | LOC | 19 | 2375 | 5795 | 6051 | 17 | 0 | 0 |
| NE NE | 31 | LOC | 20 | 2353 | 5841 | 6107 | 8 | MS | MS |
| C SW | 32 | LOC | 44 | 2334 | 5858 | 6142 | 12 | 0 | 0 |
| 1320E 3607N | 32 | LOC | 45 | 2254 | 5863 | 6138 | 10 | 0 | 0 |
| N2 N2 S2 NW | 33 | LOC | 21 | 2255 | 5826 | 6113 | 9 | 0 | 0 |
| C N2 S2 SW | 33 | LOC | 46 | 2178 | 5856 | 6152 | 12 | 0 | 0 |
| S2 N2 SE | 34 | LOC | 22 | 2192 | 5845 | 6151 | 21 | 0 | 0 |
| C NE | 35 | LOC | 24 | 2143 | 5797 | 6103 | 3 | 0 | 0 |
| 1550E 1550N | 35 | LOC | 25 | 2155 | 5838 | 6141 | 17 | 0 | 0 |
| C NE NE SW | 35 | LOC | 26 | 2104 | 5820 | 6125 | 21 | 0 | 0 |
| C S2 NW | 36 | LOC | 47 | 2147 | 5803 | 6105 | 12 | 0 | 0 |

19N-22W

| SPOT | SEC | STAT | NUMB | ELEV | AVANT | HGSH | CGNSS | CGPHI | CGSS |
|---|---|---|---|---|---|---|---|---|---|
| SE NW | 1 | LOC | 1 | 2238 | 5584 | MS | 18 | 0 | 18 |
| SE NE | 1 | LOC | 2 | 2325 | 5565 | MS | 19 | MS | 19 |
| SW NE | 1 | LOC | 3 | 2313 | 5565 | 5815 | 16 | 14 | 16 |
| SE SW | 1 | LOC | 4 | 2325 | 5617 | MS | 18 | MS | MS |
| NW SW | 1 | LOC | 5 | 2396 | 5606 | MS | 20 | 12 | 20 |
| SE SE | 2 | LOC | 6 | 2388 | 5623 | MS | 21 | 10 | 21 |
| SE SW | 2 | LOC | 7 | 2317 | 5635 | MS | 22 | MS | 22 |
| SE NW | 2 | LOC | 8 | 2374 | 5613 | MS | 20 | 12 | 20 |
| SE NE | 2 | LOC | 9 | 2374 | 5597 | MS | 18 | MS | 18 |
| NW SE | 2 | LOC | 44 | 2323 | 5617 | MS | 22 | 18 | 22 |
| C NW SW | 2 | LOC | 45 | 2346 | 5618 | MS | 24 | 18 | 24 |
| SE NE | 3 | LOC | 10 | 2400 | 5612 | MS | 21 | 14 | 21 |
| SE NW | 3 | LOC | 11 | 2366 | 5616 | MS | 18 | 6 | 18 |
| NW SE | 3 | LOC | 12 | 2389 | 5636 | MS | 23 | MS | 23 |
| NW SW | 3 | LOC | 13 | 2358 | 5634 | MS | 21 | 12 | 21 |
| NW SE | 4 | LOC | 14 | 2470 | 5631 | MS | 16 | 6 | 16 |
| N2 SW | 5 | LOC | 15 | 2510 | 5587 | 5838 | 0 | 0 | 0 |
| C SW | 7 | LOC | 16 | 2520 | 5700 | 5978 | 25 | MS | MS |
| W2 SE | 7 | LOC | 17 | 2495 | 5715 | MS | 24 | 0 | 24 |
| C NW | 7 | LOC | 18 | 2521 | 5663 | 5923 | 12 | MS | MS |
| NW SE | 8 | LOC | 20 | 2442 | 5678 | MS | 24 | 16 | 24 |
| NW NE | 9 | LOC | 21 | 2473 | 5651 | MS | 30 | 7 | 30 |
| NW SE | 10 | LOC | 22 | 2435 | 5682 | MS | 33 | 8 | 33 |
| NW NE | 10 | LOC | 23 | 2358 | 5650 | MS | 24 | 14 | 24 |
| NW NW | 10 | LOC | 24 | 2448 | 5658 | MS | 25 | 13 | 25 |
| NW NW | 11 | LOC | 25 | 2348 | 5646 | MS | 24 | 12 | 24 |
| NW NE | 11 | LOC | 26 | 2318 | 5648 | MS | 43 | 15 | 43 |
| SE NE | 12 | LOC | 27 | 2263 | 5630 | MS | 16 | 3 | 16 |
| 3200E 1980N | 12 | LOC | 28 | 2299 | 5685 | MS | 14 | 0 | 14 |
| SE NW | 12 | LOC | 29 | 2271 | 5655 | 5911 | 15 | 10 | 15 |
| C NE | 13 | LOC | 30 | 2428 | 5700 | 5938 | 12 | 0 | 12 |
| SW NE | 17 | LOC | 31 | 2378 | 5739 | 6012 | 20 | 5 | 20 |
| C NW NW | 17 | LOC | 46 | 2422 | 5724 | MS | 36 | 24 | 36 |
| NW NE | 18 | LOC | 47 | 2456 | 5726 | MS | 37 | 32 | 37 |
| C NW | 18 | LOC | 48 | 2510 | 5712 | MS | 45 | 36 | 45 |
| C NW SW | 18 | LOC | 49 | 2446 | 5733 | MS | 24 | 16 | 24 |
| 3860E 1335N | 19 | LOC | 32 | 2452 | 5840 | 6100 | 2 | 0 | 0 |
| NW SE | 20 | LOC | 33 | 2445 | 5838 | 6098 | 13 | 4 | 13 |
| NE NW | 20 | LOC | 50 | 2367 | 5825 | MS | 0 | MS | MS |
| NE SW | 21 | LOC | 34 | 2364 | 5816 | 6066 | 0 | 0 | 0 |
| E2 NW | 21 | LOC | 51 | 2358 | 5798 | 6050 | 4 | 0 | 0 |
| C NE | 23 | LOC | 35 | 2424 | 5780 | 6028 | 2 | 0 | 0 |
| C NE | 25 | LOC | 36 | 2376 | 5822 | 6078 | 16 | 0 | 0 |
| C NW | 26 | LOC | 37 | 2373 | 5863 | 6110 | 6 | 0 | 0 |
| SW SW | 27 | LOC | 38 | 2308 | 5884 | 6142 | 4 | 0 | 0 |
| C NE | 28 | LOC | 52 | 2335 | 5873 | 6121 | 0 | 0 | 0 |
| C SW | 29 | LOC | 39 | 2399 | 5917 | 6143 | 14 | 0 | 0 |
| C W2 NE | 29 | LOC | 40 | 2413 | 5875 | MS | MS | MS | MS |
| 3960E 1520N | 30 | LOC | 53 | 2419 | 5907 | 6166 | 4 | 0 | 0 |
| C NE | 31 | LOC | 41 | 2410 | 5954 | 6217 | 10 | 0 | 0 |
| C SW | 32 | LOC | 42 | 2402 | 5982 | 6250 | 13 | 0 | 0 |
| 1520E 1320N | 33 | LOC | 43 | 2385 | 5953 | 6217 | 10 | 0 | 0 |
| C NE | 35 | LOC | 54 | 2346 | 5883 | 6140 | 12 | 0 | 0 |
| C SW | 36 | LOC | 55 | 2340 | 5942 | 6200 | 17 | 0 | 0 |

| SPOT | SEC | STAT | NUMB | 20N-20W ELEV | AVANT | HGSH | CGNSS | CGPHI | CGSS |
|---|---|---|---|---|---|---|---|---|---|
| 1461E 1461N | 2 | LOC | 1 | 2060 | 5162 | 5379 | 12 | 0 | 0 |
| 3300E 3004N | 2 | LOC | 21 | 2049 | 5159 | 5379 | 12 | 0 | 0 |
| C SW | 4 | LOC | 2 | 2106 | 5188 | 5401 | MS | MS | MS |
| C NW | 5 | LOC | 3 | 2185 | 5219 | 5427 | MS | MS | MS |
| C SE NW | 6 | LOC | 22 | 2221 | 5221 | 5435 | MS | MS | MS |
| C SE NW | 7 | LOC | 4 | 2182 | 5260 | 5482 | MS | MS | MS |
| C NW NW | 7 | LOC | 23 | 2205 | 5249 | 5463 | 14 | MS | MS |
| C NE | 8 | LOC | 5 | 2142 | 5213 | 5430 | MS | MS | MS |
| SE SW NE | 9 | LOC | 24 | 2083 | 5195 | 5415 | 16 | 0 | 0 |
| C NE SW | 13 | LOC | 6 | 2107 | 5271 | 5513 | MS | MS | MS |
| 1020E 800N | 14 | LOC | 7 | 2164 | 5207 | 5444 | 18 | 0 | 0 |
| E2 E2 SW | 15 | LOC | 8 | 2175 | 5220 | 5453 | 24 | 0 | 0 |
| E2 | 15 | LOC | 25 | 2149 | 5190 | 5419 | 18 | 0 | 0 |
| C SW NW SE | 17 | LOC | 9 | 2169 | 5255 | 5481 | MS | MS | MS |
| C NW NW | 19 | LOC | 10 | 2159 | 5315 | 5550 | MS | MS | MS |
| C SE | 20 | LOC | 11 | 2216 | 5314 | 5558 | MS | MS | MS |
| C SW NE | 21 | LOC | 12 | 2198 | 5264 | 5506 | 16 | 0 | 0 |
| 3301E 3300N | 22 | LOC | 13 | 2164 | 5235 | 5484 | MS | MS | MS |
| C SE NW | 23 | LOC | 14 | 2152 | 5231 | 5483 | MS | MS | MS |
| C SW NE | 24 | LOC | 15 | 2089 | 5273 | 5529 | 17 | 0 | 0 |
| NW SE | 27 | LOC | 17 | 2180 | 5328 | 5588 | 15 | 0 | 0 |
| E2 W2 SW | 27 | LOC | 26 | 2200 | MS | 5597 | 13 | 0 | 0 |
| 2840E 2340N | 28 | LOC | 18 | 2237 | 5331 | 5589 | 26 | 0 | 0 |
| NW SE | 29 | LOC | 19 | 2283 | 5350 | 5607 | MS | MS | MS |
| C SW NE SW | 30 | LOC | 27 | 2317 | 5389 | 5629 | 16 | 0 | 0 |
| 1230E 1260N | 31 | LOC | 28 | 2339 | 5455 | 5713 | 18 | 0 | 0 |
| NE SW NW | 34 | LOC | 20 | 2221 | 5384 | 5652 | MS | MS | MS |

20N-21W

| SPOT | SEC | STAT | NUMB | ELEV | AVANT | HGSH | CGNSS | CGPHI | CGSS |
|---|---|---|---|---|---|---|---|---|---|
| C NE | 1 | LOC | 1 | 2187 | 5216 | 5418 | 16 | 0 | 0 |
| SE NW | 3 | LOC | 21 | 2250 | 5212 | MS | 16 | 0 | 0 |
| NW NE SW | 4 | LOC | 2 | 2249 | 5271 | 5489 | 32 | MS | MS |
| C SW | 5 | LOC | 22 | 2206 | 5299 | 5519 | 12 | 6 | 12 |
| NW NW | 5 | LOC | 23 | 2224 | 5250 | 5466 | 8 | MS | MS |
| C S2 | 6 | LOC | 3 | 2280 | 5295 | 5514 | MS | MS | MS |
| SE NW | 6 | LOC | 24 | 2296 | 5270 | 5489 | 8 | 0 | 0 |
| C NE | 6 | LOC | 25 | 2288 | 5264 | 5484 | 20 | 14 | 20 |
| SE | 7 | LOC | 4 | 2289 | 5319 | 5545 | 20 | 18 | 20 |
| W2 SE | 7 | LOC | 5 | 2272 | 5326 | MS | 26 | 12 | 26 |
| SW NE SW | 8 | LOC | 6 | 2319 | 5331 | 5553 | MS | MS | MS |
| NW NW SE NW | 9 | LOC | 7 | 2280 | 5314 | 5538 | 20 | 0 | 0 |
| C SW | 9 | LOC | 26 | 2290 | 5339 | 5559 | 13 | 0 | 0 |
| C NE | 10 | LOC | 8 | 2284 | 5290 | 5510 | MS | MS | MS |
| C SW | 12 | LOC | 27 | 2236 | 5297 | 5517 | 16 | 0 | 0 |
| SW NE | 13 | LOC | 28 | 2248 | 5294 | 5514 | 15 | MS | MS |
| C NE SW | 13 | LOC | 29 | 2257 | 5329 | 5551 | 16 | 0 | 0 |
| C NW | 13 | LOC | 30 | 2218 | 5320 | 5532 | 16 | MS | MS |
| NW SE | 14 | LOC | 9 | 2272 | 5344 | 5571 | MS | MS | MS |
| C NE NE | 14 | LOC | 31 | 2257 | 5335 | 5555 | 16 | 0 | 0 |
| C SE SE | 14 | LOC | 32 | 2261 | 5351 | 5575 | 18 | 0 | 0 |
| C NW | 15 | LOC | 10 | 2285 | 5351 | 5575 | 12 | 0 | 0 |
| C SW | 16 | LOC | 11 | 2328 | 5379 | 5600 | 0 | MS | MS |
| C NW | 17 | LOC | 12 | 2366 | 5370 | 5588 | 13 | 4 | 13 |
| C NW NE | 18 | LOC | 33 | 2274 | 5352 | MS | 18 | 8 | 18 |
| 3330E 1980N | 18 | LOC | 34 | 2281 | 5387 | 5614 | 18 | 8 | 18 |
| C NE NE | 18 | LOC | 35 | 2234 | 5358 | 5578 | 14 | 6 | 14 |
| C SE | 19 | LOC | 36 | 2392 | 5443 | 5676 | MS | MS | MS |
| W2 SE | 20 | LOC | 13 | 2359 | 5442 | 5659 | MS | MS | MS |
| NE SW | 21 | LOC | 14 | 2338 | 5408 | 5636 | 23 | 0 | 0 |
| C SE | 21 | LOC | 37 | 2318 | 5424 | 5650 | 20 | 0 | 0 |
| C NW SE | 22 | LOC | 38 | 2326 | 5400 | 5624 | 16 | 0 | 0 |
| C W2 SE | 23 | LOC | 39 | 2221 | 5383 | 5612 | 11 | MS | MS |
| E2 W2 W2 NE | 24 | LOC | 40 | 2232 | 5351 | 5581 | 16 | 0 | 0 |
| C SW | 25 | LOC | 41 | 2248 | 5441 | 5680 | 4 | 0 | 0 |
| E2 SW NW SE | 25 | LOC | 42 | 2173 | 5462 | 5695 | 18 | 0 | 0 |
| 1820E 1320N | 26 | LOC | 15 | 2242 | 5462 | 5693 | MS | MS | MS |
| C SW | 27 | LOC | 43 | 2297 | 5488 | 5720 | 16 | 0 | 0 |
| C E2 | 28 | LOC | 44 | MS | MS | MS | 16 | 0 | 0 |
| 1420E 1420N | 29 | LOC | 45 | 2371 | 5447 | 5684 | 14 | 0 | 0 |
| C SE | 30 | LOC | 16 | 2400 | 5444 | 5684 | MS | MS | MS |
| NE NW | 30 | LOC | 46 | 2427 | 5456 | MS | 23 | 0 | 23 |
| NE SW | 30 | LOC | 47 | MS | MS | MS | 18 | MS | MS |
| NE | 30 | LOC | 48 | 2415 | 5445 | 5685 | 22 | 13 | 22 |
| C SE | 31 | LOC | 17 | 2394 | 5491 | 5732 | MS | MS | MS |
| C SE | 32 | LOC | 18 | 2358 | 5502 | 5746 | 18 | 0 | 0 |
| 1360E 1360N | 33 | LOC | 19 | 2365 | 5507 | 5752 | 24 | 0 | 0 |
| 4620E 1500N | 33 | LOC | 49 | 2347 | 5504 | 5748 | 16 | MS | MS |
| 1520E 1320N | 34 | LOC | 50 | 2301 | 5493 | 5733 | MS | MS | MS |
| C W2 NW | 34 | LOC | 51 | 2303 | 5484 | 5722 | 18 | MS | MS |
| C SW | 35 | LOC | 52 | 2295 | 5517 | 5755 | MS | MS | MS |
| N2 SE SE | 35 | LOC | 53 | 2300 | 5508 | 5747 | 18 | MS | MS |
| SW SW | 36 | LOC | 20 | 2299 | 5503 | 5744 | 22 | 0 | 0 |

20N-22W

| SPOT | SEC | STAT | NUMB | ELEV | AVANT | HGSH | CGNSS | CGPHI | CGSS |
|---|---|---|---|---|---|---|---|---|---|
| NE SW | 1 | LOC | 1 | 2361 | 5264 | 5486 | 0 | 0 | 0 |
| C NW | 1 | LOC | 2 | 2364 | 5261 | 5476 | 6 | 0 | 0 |
| NW | 2 | LOC | 3 | 2427 | 5266 | 5500 | 8 | 0 | 0 |
| NE NE | 2 | LOC | 20 | 2388 | MS | 5480 | 8 | 1 | 8 |
| SE NW | 3 | LOC | 4 | 2411 | 5290 | 5529 | 6 | 0 | 0 |
| E2 NW NW | 3 | LOC | 21 | 2408 | 5253 | 5488 | 11 | 2 | 11 |
| 3347E 3347N | 4 | LOC | 5 | 2370 | 5260 | 5509 | MS | MS | MS |
| S2 NE NE | 4 | LOC | 22 | 2423 | 5251 | 5482 | 9 | 2 | 9 |
| SW | 6 | LOC | 23 | 2405 | 5250 | 5488 | 2 | 0 | 0 |
| NW SE | 7 | LOC | 6 | 2415 | 5301 | 5541 | 2 | 0 | 0 |
| SE | 8 | LOC | 7 | 2394 | 5350 | 5592 | 4 | 0 | 0 |
| E2 SW | 9 | LOC | 24 | 2400 | 5342 | 5581 | 4 | 0 | 0 |
| NW NW SE NW | 10 | LOC | 25 | 2428 | 5308 | 5546 | 7 | 0 | 0 |
| NE SW | 11 | LOC | 8 | 2387 | 5346 | 5567 | MS | MS | MS |
| NE | 12 | LOC | 26 | 2344 | 5308 | 5534 | 12 | 1 | 12 |
| SE SE | 12 | LOC | 27 | 2230 | 5326 | MS | 21 | 12 | 21 |
| N2 SW NE | 13 | LOC | 28 | 2228 | 5390 | MS | 21 | 13 | 21 |
| NW NW | 13 | LOC | 29 | 2254 | 5355 | 5591 | 21 | 14 | 21 |
| NE NE | 14 | LOC | 30 | 2282 | 5362 | 5596 | 17 | 10 | 17 |
| 1460E 1570N | 15 | LOC | 31 | 2390 | 5385 | MS | 16 | 3 | 16 |
| SW NE | 16 | LOC | 9 | 2408 | 5374 | 5603 | 4 | 0 | 0 |
| 1875E 1320N | 16 | LOC | 32 | 2458 | 5381 | 5619 | 9 | 0 | 0 |
| SE NW | 16 | LOC | 33 | 2443 | 5356 | 5591 | 2 | 0 | 0 |
| 3960E 3810N | 17 | LOC | 10 | 2447 | 5349 | 5592 | 6 | 0 | 0 |
| SW | 19 | LOC | 34 | 2484 | 5456 | 5708 | 0 | 0 | 0 |
| NE | 20 | LOC | 35 | 2465 | 5425 | 5671 | 4 | 0 | 0 |
| E2 W2 NW | 21 | LOC | 36 | 2380 | 5403 | 5648 | 15 | 0 | 0 |
| NW | 22 | LOC | 11 | 2301 | 5407 | 5647 | 14 | 4 | 14 |
| 3460E 1320N | 23 | LOC | 37 | 2348 | 5423 | 5666 | 18 | 9 | 18 |
| 1520E 3910N | 23 | LOC | 38 | 2273 | 5418 | 5657 | 17 | 7 | 17 |
| SW | 24 | LOC | 12 | 2248 | 5418 | 5657 | 19 | 7 | 19 |
| SW NE | 24 | LOC | 13 | 2296 | 5422 | 5658 | 6 | 0 | 0 |
| SW | 25 | LOC | 14 | 2281 | 5491 | 5735 | MS | MS | MS |
| NE | 26 | LOC | 39 | 2263 | 5465 | 5705 | MS | MS | MS |
| C SW NE | 27 | LOC | 15 | 2306 | 5482 | 5751 | 14 | 6 | 14 |
| SW NE | 28 | LOC | 16 | 2353 | 5482 | 5729 | 22 | 4 | 22 |
| E2 SW | 29 | LOC | 40 | 2494 | 5518 | 5765 | 14 | 2 | 14 |
| SW | 30 | LOC | 17 | 2501 | 5508 | 5749 | MS | MS | MS |
| NW | 31 | LOC | 41 | 2501 | 5529 | 5779 | 7 | 0 | 0 |
| NW | 32 | LOC | 18 | 2505 | 5500 | 5753 | 8 | MS | MS |
| NE SE SW | 35 | LOC | 19 | 2335 | 5578 | 5823 | 6 | 0 | 0 |
| NE | 36 | LOC | 42 | 2383 | 5485 | 5723 | 13 | 0 | 0 |

21N-20W

| SPOT | SEC | STAT | NUMB | ELEV | AVANT | HGSH | CGNSS | CGPHI | CGSS |
|---|---|---|---|---|---|---|---|---|---|
| SE NW | 1 | LOC | 1 | 2004 | 4872 | 5057 | 22 | 2 | 0 |
| NW SE | 6 | LOC | 2 | 2112 | 4932 | 5122 | 15 | 0 | 0 |
| 1320E 1331N | 7 | LOC | 3 | 2200 | 5000 | 5198 | 16 | 0 | 0 |
| C NW | 8 | LOC | 4 | 2149 | 4956 | 5151 | 22 | 0 | 0 |
| 3660E 1320N | 10 | LOC | 5 | 2117 | 4979 | 5177 | 24 | 0 | 0 |
| NE SW | 10 | LOC | 6 | 2126 | 4962 | 5156 | 23 | 0 | 0 |
| 2310E 1420N | 13 | LOC | 7 | 2050 | 4993 | 5198 | 16 | 0 | 0 |
| SW SE NW | 14 | LOC | 8 | 2051 | 5037 | 5243 | MS | MS | MS |
| C E2 SE | 15 | LOC | 9 | 2109 | 5041 | 5247 | 30 | 4 | 0 |
| NW SE | 15 | LOC | 10 | 2117 | 5037 | 5249 | MS | MS | MS |
| NW SE NW | 17 | LOC | 11 | MS | MS | MS | MS | MS | MS |
| NE SW | 18 | LOC | 12 | 2230 | 5035 | 5234 | 17 | 0 | 0 |
| C E2 SW NW | 19 | LOC | 13 | 2208 | 5056 | 5268 | 16 | 0 | 0 |
| 795E 2750N | 20 | LOC | 14 | 2114 | 5052 | 5255 | 21 | 0 | 0 |
| 3960E 3860N | 22 | LOC | 15 | 2105 | 5043 | 5249 | 8 | 0 | 0 |
| 1370E 3960N | 23 | LOC | 16 | 2107 | 5019 | 5223 | 13 | 0 | 0 |
| NW | 24 | LOC | 17 | 2093 | 5002 | 5209 | MS | MS | MS |
| NE SW NE | 25 | LOC | 18 | 1998 | 5054 | 5264 | 13 | 0 | 0 |
| NE SW | 26 | LOC | 19 | 2006 | 5080 | 5286 | 12 | MS | MS |
| SE NW | 29 | LOC | 20 | 2094 | 5100 | 5306 | 20 | MS | MS |
| SW SW | 29 | LOC | 21 | 2135 | 5128 | 5353 | 24 | 0 | 0 |
| 1332E 3948N | 30 | LOC | 22 | 2094 | 5092 | 5297 | 20 | MS | MS |
| SE SW | 31 | LOC | 23 | 2186 | 5204 | 5414 | 16 | MS | MS |
| NW SE | 33 | LOC | 24 | 2113 | 5137 | 5341 | 14 | 0 | 0 |
| C W2 | 35 | LOC | 25 | 2052 | 5107 | 5317 | 10 | 0 | 0 |

21N-21W

| SPOT | SEC | STAT | NUMB | ELEV | AVANT | HGSH | CGNSS | CGPHI | CGSS |
|---|---|---|---|---|---|---|---|---|---|
| C SE | 1 | LOC | 1 | 2082 | 4944 | 5144 | 13 | 0 | 0 |
| NW NW SE NW | 1 | LOC | 42 | 2110 | 4908 | 5100 | 22 | 0 | 0 |
| C NW | 2 | LOC | 43 | 2147 | 4894 | 5085 | 7 | 0 | 0 |
| E2 E2 SW | 2 | LOC | 44 | 2114 | 4951 | 5144 | 21 | 0 | 0 |
| C SW NE | 3 | LOC | 2 | 2187 | 4875 | 5076 | MS | MS | MS |
| C SW SW | 3 | LOC | 45 | 2163 | 4935 | 5135 | 8 | MS | MS |
| NW | 4 | LOC | 3 | 2274 | 4904 | 5116 | 10 | 0 | 0 |
| C SW | 5 | LOC | 4 | 2340 | 4890 | 5161 | 8 | MS | MS |
| C NW | 5 | LOC | 46 | 2344 | 4894 | 5108 | 25 | 0 | 0 |
| C NW SE | 7 | LOC | 47 | 2374 | 4992 | 5206 | 0 | 0 | 0 |
| NE SW | 8 | LOC | 5 | 2305 | 5003 | 5215 | 0 | 0 | 0 |
| N2 SE | 8 | LOC | 48 | 2288 | 4999 | 5213 | 7 | 0 | 0 |
| SE | 9 | LOC | 6 | 2260 | 4987 | 5196 | MS | MS | MS |
| C NE | 9 | LOC | 49 | 2190 | 4967 | 5177 | 11 | 0 | 0 |
| W2 W2 W2 SE | 10 | LOC | 7 | 2224 | 5002 | 5206 | 8 | 0 | 0 |
| C NE | 10 | LOC | 50 | MS | MS | MS | 3 | 0 | 0 |
| SW | 11 | LOC | 9 | 2120 | 5007 | 5202 | 16 | 0 | 0 |
| W2 W2 NE NW | 11 | LOC | 51 | 2150 | 4953 | 5149 | 33 | 0 | 0 |
| SE | 11 | LOC | 52 | 2160 | 4975 | 5172 | 19 | 0 | 0 |
| C SW SW | 11 | LOC | 53 | 2132 | 5018 | 5214 | 16 | 0 | 0 |
| C NE | 12 | LOC | 10 | 2111 | 4963 | 5157 | 13 | 0 | 0 |
| NE SW | 12 | LOC | 11 | 2147 | 4979 | 5179 | MS | MS | MS |
| E2 E2 W2 SE | 12 | LOC | 54 | 2133 | 4991 | 5187 | 11 | 0 | 0 |
| NE SW | 13 | LOC | 12 | 2230 | 5033 | 5236 | 12 | 0 | 0 |
| NW SE | 14 | LOC | 13 | 2231 | 5036 | 5242 | 10 | 0 | 0 |
| NW SE | 15 | LOC | 14 | 2166 | 5046 | 5249 | 26 | MS | MS |
| SW SE NE | 16 | LOC | 15 | 2262 | 5040 | 5246 | 20 | 0 | 0 |
| NW SE | 17 | LOC | 16 | 2245 | 5053 | 5266 | 2 | 0 | 0 |
| C NW | 17 | LOC | 55 | 2297 | 5044 | 5260 | 0 | 0 | 0 |
| C SW | 19 | LOC | 17 | 2323 | 5111 | 5327 | 5 | 0 | 0 |
| NW NW | 19 | LOC | 56 | 2323 | 5079 | 5301 | 3 | 0 | 0 |
| SW SE SE | 20 | LOC | 57 | 2301 | 5125 | MS | 10 | 0 | 0 |
| C S2 NW | 20 | LOC | 18 | 2306 | 5086 | 5304 | 6 | 0 | 0 |
| NE SW NE | 21 | LOC | 58 | 2184 | 5081 | 5291 | MS | MS | MS |
| SE NW SE | 21 | LOC | 59 | 2210 | 5100 | MS | 20 | 0 | 20 |
| SE SE | 21 | LOC | 60 | 2223 | 5123 | MS | 26 | 17 | 26 |
| SE SW SE | 21 | LOC | 61 | 2214 | 5120 | MS | 26 | 0 | 26 |
| SW SW | 21 | LOC | 62 | 2241 | 5129 | MS | 15 | 7 | 15 |
| SW SE | 22 | LOC | 63 | 2272 | 5109 | 5326 | 20 | 2 | 20 |
| SW NW SW | 22 | LOC | 64 | 2250 | 5123 | MS | 18 | 0 | 18 |
| SW SW SW | 22 | LOC | 65 | 2264 | 5126 | MS | 20 | 14 | 20 |
| C SE SW | 22 | LOC | 66 | 2278 | 5130 | 5347 | 28 | 7 | 28 |
| C NE | 22 | LOC | 19 | 2196 | 5065 | 5288 | MS | MS | MS |
| C NE | 23 | LOC | 20 | 2241 | 5063 | 5271 | 13 | 0 | 0 |
| SE | 23 | LOC | 67 | 2208 | 5092 | 5296 | 12 | 0 | 0 |
| SW NE | 24 | LOC | 22 | 2172 | 5074 | 5281 | 20 | 0 | 0 |
| 2790E 4490N | 25 | LOC | 23 | 2118 | 5102 | 5308 | 11 | 0 | 0 |
| C SE | 25 | LOC | 68 | 2176 | 5117 | 5322 | 17 | 0 | 0 |
| 2220E 1370N | 25 | LOC | 69 | 2127 | 5145 | 5357 | 21 | 0 | 0 |
| C NE | 26 | LOC | 24 | 2185 | 5123 | 5331 | 17 | 0 | 0 |
| C SE | 26 | LOC | 70 | 2158 | 5136 | 5346 | 14 | 0 | 0 |
| C NW NW | 27 | LOC | 25 | 2284 | 5126 | MS | 23 | 14 | 23 |
| C NW NE | 27 | LOC | 41 | 2276 | 5120 | MS | 22 | 4 | 22 |
| NW NE SE | 27 | LOC | 71 | 2192 | 5145 | 5360 | 22 | 0 | 22 |
| E2 W2 SE NW | 27 | LOC | 73 | 2288 | 5145 | MS | 26 | 7 | 26 |
| C W2 NW | 28 | LOC | 26 | 2243 | 5147 | MS | 27 | 7 | 27 |
| S2 SE NE | 28 | LOC | 27 | 2290 | 5130 | MS | 25 | 11 | 25 |
| C N2 NE SW | 28 | LOC | 28 | 2282 | 5182 | MS | 24 | 2 | 24 |
| S2 SE NW | 28 | LOC | 74 | 2270 | 5171 | MS | 20 | 13 | 20 |
| C SE NW SW | 29 | LOC | 29 | 2321 | 5169 | MS | 17 | 11 | 17 |
| C S2 NW NE | 29 | LOC | 30 | 2263 | 5170 | MS | 17 | 5 | 17 |
| C N2 SE SW | 29 | LOC | 31 | 2331 | 5175 | MS | 17 | 12 | 17 |
| C S2 NW SE | 29 | LOC | 75 | 2281 | 5187 | MS | 20 | 12 | 20 |
| C SE SE | 29 | LOC | 76 | 2316 | 5182 | 5410 | MS | MS | MS |
| C SE NE | 29 | LOC | 77 | 2275 | 5171 | MS | 16 | MS | 16 |
| SE SE | 30 | LOC | 78 | 2357 | 5146 | MS | 15 | 9 | 15 |
| C NW SE | 30 | LOC | 79 | 2360 | 5189 | 5416 | 7 | 0 | 0 |
| C NW NE | 31 | LOC | 32 | 2354 | 5197 | MS | 26 | 5 | 26 |
| SE NE NE | 31 | LOC | 34 | 2367 | 5238 | MS | 24 | 13 | 24 |
| N2 NW SW | 31 | LOC | 35 | 2338 | 5234 | MS | 26 | 8 | 26 |
| NW NW | 32 | LOC | 36 | 2329 | 5174 | 5401 | 0 | 0 | 0 |
| NW NW NE | 32 | LOC | 80 | 2289 | 5193 | 5422 | 8 | 1 | 8 |
| N2 NE NE | 32 | LOC | 81 | 2319 | 5201 | MS | 17 | 6 | 17 |
| NW NW NW NW | 33 | LOC | 37 | MS | MS | MS | 25 | 6 | 25 |
| C NW NE | 33 | LOC | 38 | 2250 | 5200 | MS | 24 | 8 | 24 |
| C NE SW | 34 | LOC | 39 | 2156 | 5216 | 5429 | 18 | 0 | 0 |
| NE NE SW NE | 35 | LOC | 82 | 2140 | 5184 | 5396 | 18 | 0 | 0 |
| C E2 NW | 36 | LOC | 40 | 2140 | 5170 | 5393 | 20 | 0 | 0 |
| C NE SE | 36 | LOC | 83 | 2172 | 5191 | 5400 | 7 | 0 | 0 |
| C NE | 36 | LOC | 84 | 2214 | 5158 | 5366 | MS | MS | MS |

21N-22W

| SPOT | SEC | STAT | NUMB | ELEV | AVANT | HGSH | CGNSS | CGPHI | CGSS |
|---|---|---|---|---|---|---|---|---|---|
| C NE | 1 | LOC | 1 | 2327 | 4903 | 5137 | 22 | 9 | 22 |
| 1320E 1495N | 1 | LOC | 31 | 2330 | 4934 | 5168 | 31 | 11 | 31 |
| C NW | 2 | LOC | 32 | 2323 | 4909 | 5138 | 20 | 1 | 20 |
| C SW | 4 | LOC | 33 | 2295 | 4901 | 5138 | 0 | 0 | 0 |
| C NW | 5 | LOC | 2 | 2227 | 4879 | 5117 | MS | 2 | MS |
| C S2 NW | 6 | LOC | 3 | 2192 | 4852 | 5100 | 7 | 4 | 7 |
| C SE | 6 | LOC | 34 | 2269 | 4867 | 5112 | 2 | 0 | 0 |
| S2 N2 NW | 7 | LOC | 4 | 2191 | 4923 | 5164 | 0 | 0 | 0 |
| C NE | 8 | LOC | 5 | 2303 | 4925 | 5170 | 26 | 13 | 26 |
| NE SW | 8 | LOC | 6 | 2315 | 4945 | 5187 | 18 | 10 | 18 |
| C NW NW | 8 | LOC | 35 | 2302 | 4916 | 5154 | 1 | 0 | 0 |
| C NW | 9 | LOC | 7 | 2313 | 4927 | 5171 | 48 | 28 | 48 |
| C SE SE SW | 9 | LOC | 36 | 2330 | 5010 | 5249 | 3 | 0 | 0 |
| S2 S2 NE | 10 | LOC | 8 | 2294 | 4983 | 5218 | MS | MS | MS |
| C NE | 10 | LOC | 37 | 2290 | 4963 | 5202 | 25 | 14 | 25 |
| 1620E 2640N | 10 | LOC | 39 | 2271 | 4985 | 5230 | 39 | 17 | 39 |
| 1475E 2390N | 11 | LOC | 9 | 2321 | 4991 | 5219 | 10 | 0 | 0 |
| C SW SE | 13 | LOC | 40 | 2375 | 5085 | 5271 | 3 | 0 | 0 |
| C SW | 13 | LOC | 41 | 2368 | 5048 | 5275 | 0 | 0 | 0 |
| C SW | 14 | LOC | 42 | 2350 | 5065 | 5295 | 0 | 0 | 0 |
| 768E 3849N | 14 | LOC | 43 | 2336 | 5039 | 5274 | 22 | 0 | 22 |
| NE SW SW | 15 | LOC | 10 | 2317 | 5062 | 5291 | 13 | 0 | 0 |
| SE NW | 15 | LOC | 11 | 2321 | 5004 | 5274 | MS | MS | MS |
| C W2 NE | 15 | LOC | 44 | 2332 | 5030 | 5265 | 28 | 7 | 28 |
| SE | 15 | LOC | 45 | 2338 | 5062 | 5295 | 3 | 0 | 0 |
| 1990E 1320N | 16 | LOC | 12 | 2342 | 5038 | 5268 | 7 | 0 | 0 |
| C NE | 16 | LOC | 46 | 2331 | 5034 | 5266 | 0 | 0 | 0 |
| C SE | 17 | LOC | 13 | 2305 | 4998 | 5223 | 6 | 0 | 0 |
| C N2 SW | 17 | LOC | 47 | 2271 | 4980 | 5210 | 6 | 0 | 0 |
| NW SW SE | 18 | LOC | 14 | 2243 | 4996 | 5227 | 0 | 0 | 0 |
| SE NW SE | 19 | LOC | 15 | 2277 | 5030 | 5258 | MS | MS | MS |
| C NE | 20 | LOC | 48 | 2282 | 5042 | 5274 | 6 | 0 | 0 |
| C NW SE | 21 | LOC | 16 | 2347 | MS | MS | MS | MS | MS |
| W2 E2 NE | 21 | LOC | 17 | 2343 | 5075 | 5309 | 0 | 0 | 0 |
| C SE SE | 21 | LOC | 49 | 2353 | 5107 | 5339 | 2 | 0 | 0 |
| SW NE SW | 22 | LOC | 18 | 2338 | 5102 | 5332 | 2 | 0 | 0 |
| NE SW | 23 | LOC | 50 | 2373 | 5105 | 5333 | 2 | 0 | 0 |
| C SW NE | 24 | LOC | 51 | 2380 | 5115 | 5342 | 0 | 0 | 0 |
| 3820E 3960N | 25 | LOC | 19 | 2362 | 5157 | 5385 | 6 | 2 | 6 |
| E2 SW | 25 | LOC | 52 | MS | MS | MS | 12 | 4 | 12 |
| SE NW | 26 | LOC | 20 | 2385 | 5143 | 5373 | 10 | MS | MS |
| C SW SW | 26 | LOC | 21 | 2393 | 5167 | 5392 | MS | MS | MS |
| SE SE | 26 | LOC | 53 | 2415 | 5153 | 5382 | 8 | 4 | 8 |
| C NW SE | 27 | LOC | 22 | 2383 | 5147 | 5379 | 10 | 5 | 10 |
| 1980E 2130N | 28 | LOC | 23 | 2330 | 5125 | 5362 | 19 | 8 | 19 |
| SE SW NW | 29 | LOC | 24 | 2302 | 5115 | 5350 | 6 | 0 | 0 |
| C SE SE | 30 | LOC | 54 | 2317 | 5147 | MS | 12 | 8 | 12 |
| 3660E 3820N | 30 | LOC | 55 | 2317 | 5093 | 5331 | 10 | 1 | 10 |
| C NW SE | 31 | LOC | 25 | 2351 | 5202 | MS | 3 | 0 | 0 |
| NW SE NW | 31 | LOC | 56 | 2369 | 5176 | 5414 | 10 | 0 | 0 |
| NE NW NE | 32 | LOC | 26 | 2346 | 5162 | MS | 14 | 0 | 0 |
| NE SE | 32 | LOC | 57 | 2319 | 5189 | MS | 13 | 0 | 0 |
| 1370E 3850N | 32 | LOC | 58 | 2355 | 5173 | 5407 | 12 | 0 | 0 |
| SE SE | 33 | LOC | 27 | 2363 | 5219 | 5472 | 9 | 0 | 0 |
| NW SE | 33 | LOC | 59 | 2342 | 5211 | MS | 9 | 0 | 0 |
| C NW | 33 | LOC | 60 | 2317 | 5176 | MS | 11 | 5 | 11 |
| 2960E 3280N | 33 | LOC | 61 | 2360 | 5197 | 5434 | 16 | 10 | 16 |
| C SW NE | 34 | LOC | 28 | 2421 | 5191 | 5425 | 13 | 3 | 13 |
| NW NW | 34 | LOC | 62 | 2376 | 5175 | MS | 16 | 11 | 16 |
| 1320E 2460N | 35 | LOC | 29 | 2396 | 5206 | 5429 | MS | MS | MS |
| C SW | 36 | LOC | 30 | 2410 | 5242 | 5473 | 12 | 6 | 12 |
| SE NW SE | 36 | LOC | 63 | 2370 | 5230 | MS | 12 | 3 | 12 |
| NE SW NE | 36 | LOC | 64 | 2382 | 5247 | MS | 18 | 9 | 18 |
| C NE NE | 36 | LOC | 65 | 2375 | 5231 | MS | 19 | 6 | 19 |

# APPENDIX B

# THIN SECTION ANALYSIS DATA SHEETS

SARKEY'S INC.
GILLISPIE #3-2
SE-NW-SE-NW
SEC 2 T17N R22W
ELLIS CO., OKLA.

| NUMBER | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TH. SECT. G (8500')- | 50.5 | 52.5 | 54.1 | 56.1 | 58.0 | 59.3 | 62.5 | 64.2 | 66.5 | 68.5 | 70.5 | 72.5 | 74.3 | 76.4 | 78.1 | 80.5 | 81.9 | AVG. (%) |
| DETRITAL CONSTITUENTS | 71.0 | 54.5 | 54.5 | 80.0 | 51.5 | 53.0 | 86.0 | 83.0 | 87.0 | 77.0 | 83.5 | 79.0 | 72.0 | 73.0 | 65.0 | 72.0 | 62.0 | 70.8 |
| QUARTZ | 43.0 | 39.0 | 31.0 | 61.0 | 30.0 | 37.5 | 66.5 | 64.0 | 69.0 | 59.0 | 60.0 | 62.0 | 53.0 | 58.0 | 49.0 | 48.0 | 46.0 | 51.5 |
| MONOCRYSTALLINE | 39.0 | 35.0 | 28.0 | 58.0 | 27.0 | 35.0 | 65.0 | 62.0 | 65.0 | 56.0 | 56.0 | 58.0 | 50.0 | 55.0 | 47.0 | 47.0 | 44.0 | 48.6 |
| POLYCRYSTALLINE | 4.0 | 4.0 | 3.0 | 3.0 | 3.0 | 2.5 | 1.5 | 2.0 | 4.0 | 3.0 | 4.0 | 4.0 | 3.0 | 3.0 | 2.0 | 1.0 | 2.0 | 2.9 |
| FELDSPAR | 4.0 | 4.0 | 5.0 | 4.5 | 5.0 | 4.0 | 2.5 | 2.0 | 3.0 | 3.5 | 3.5 | 4.5 | 4.0 | 3.0 | 1.5 | 5.0 | 3.0 | 3.6 |
| MICROCLINE | 1.0 | 1.0 | 2.0 | 0.5 | 1.0 | 1.0 | 0.5 | 1.0 | 1.0 | 0.5 | 0.5 | 0.5 | 1.0 | 1.0 | 0.5 | 2.0 | 1.0 | 0.9 |
| PLAGIOCLASE | 3.0 | 3.0 | 3.0 | 4.0 | 4.0 | 3.0 | 2.0 | 1.0 | 2.0 | 3.0 | 3.0 | 4.0 | 3.0 | 2.0 | 1.0 | 3.0 | 2.0 | 2.7 |
| ROCK FRAGMENTS | 9.0 | 6.5 | 11.5 | 8.0 | 10.0 | 7.0 | 8.5 | 7.5 | 8.0 | 8.0 | 10.0 | 6.0 | 9.5 | 6.5 | 9.0 | 12.5 | 7.5 | 8.5 |
| SHALE | 0.5 | 0.5 | 0.5 | | 0.5 | | | 0.5 | 0.5 | | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.0 | 1.0 | 0.4 |
| CHERT | 2.0 | 2.0 | 3.0 | 2.0 | 3.0 | 2.0 | 1.5 | 3.0 | 0.5 | 1.0 | 2.5 | 1.5 | 3.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.1 |
| CARBONATE | 0.5 | | 0.5 | | | | | | | | | | | | | 0.5 | | 0.5 |
| SILTSTONE | 0.5 | | | | 0.5 | | | | | | | | | | 0.5 | 0.5 | 0.5 | 0.1 |
| METAMORPHIC | 5.0 | 4.0 | 7.0 | 5.5 | 5.0 | 4.0 | 7.0 | 4.0 | 7.0 | 7.0 | 7.0 | 4.0 | 6.0 | 4.0 | 6.0 | 8.5 | 4.0 | 5.6 |
| PLUTONIC | 0.5 | | 0.5 | 0.5 | 1.0 | 1.0 | | | | | | | | | | | | 0.2 |
| OTHER GRAINS | 15.0 | 5.0 | 7.0 | 6.5 | 6.5 | 4.5 | 8.5 | 9.5 | 7.0 | 6.5 | 10.0 | 6.5 | 5.5 | 5.5 | 5.5 | 6.5 | 5.5 | 7.1 |
| DETR. CHLORITE | 0.5 | 0.5 | 0.5 | 1.0 | 0.5 | 0.5 | 1.5 | 2.0 | 1.0 | 1.0 | 2.0 | 1.0 | 1.0 | 0.5 | 0.5 | 0.5 | 0.5 | 0.9 |
| GLAUCONITE | | | | 0.5 | | | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.4 |
| PHOSPHATE | | 0.5 | 0.5 | 0.5 | 0.5 | | 0.5 | 0.5 | 0.5 | | | | | | 0.5 | | | 0.2 |
| MUSCOVITE | 10.0 | 1.0 | 3.0 | 2.0 | 2.0 | 1.0 | 4.0 | 4.0 | 3.0 | 2.0 | 4.0 | 3.0 | 1.0 | 2.0 | 1.0 | 2.0 | 2.5 | 2.8 |
| BIOTITE | 3.0 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.0 | 0.5 | 1.0 | 2.0 | | 0.5 | 1.0 | 0.5 | 1.0 | 0.5 | 0.8 |
| ZIRCON | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| TOURMALINE | 0.5 | 0.5 | 0.5 | 0.5 | 1.0 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.0 | 0.5 | 0.5 | 0.5 | 0.5 | 0.6 |
| LEUCOXENE | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.0 | 0.5 | 1.0 | 1.0 | 0.5 | 1.0 | 1.5 | 0.5 | 0.7 |
| FOSSIL FRAGS. | | 1.0 | 1.0 | 0.5 | 1.0 | 1.0 | | | | | | | | | 0.5 | | | 0.8 |
| DETRITAL MATRIX | 20.0 | 0.5 | 0.5 | 0.5 | 0.0 | 0.0 | 1.0 | 2.5 | 4.5 | 0.5 | 1.5 | 2.0 | 2.0 | 1.5 | 0.5 | 1.5 | 2.0 | 2.4 |
| ILLITE | 20.0 | 0.5 | 0.5 | 0.5 | | | 0.5 | 2.0 | 4.0 | 0.5 | 1.0 | 1.5 | 1.5 | 1.0 | 0.5 | 1.0 | 1.5 | 2.1 |
| CHLORITE | | | | | | | 0.5 | 0.5 | 0.5 | | 0.5 | 0.5 | 0.5 | 0.5 | | 0.5 | 0.5 | 0.3 |
| DIAGENETIC CONSTS. | 9.0 | 45.0 | 45.0 | 19.5 | 48.5 | 47.0 | 13.0 | 14.5 | 8.5 | 22.5 | 15.0 | 19.0 | 26.0 | 25.5 | 34.5 | 26.5 | 36.0 | 26.8 |
| CEMENTS | 3.0 | 44.5 | 44.0 | 18.0 | 48.0 | 45.5 | 11.0 | 11.5 | 7.0 | 10.0 | 12.5 | 7.0 | 15.0 | 12.5 | 29.0 | 13.0 | 29.0 | 21.2 |
| QUARTZ | 0.5 | 0.5 | 0.5 | 6.0 | 0.5 | 0.5 | 6.0 | 6.0 | 2.0 | 5.0 | 7.0 | 4.0 | 3.0 | 5.0 | 1.0 | 3.0 | 3.0 | 3.1 |
| FELDSPAR | | | | | | | | | | | | 0.5 | | 0.5 | | 0.5 | | 0.5 |
| CALCITE | 1.5 | 5.0 | 0.5 | 7.5 | 43.0 | 42.0 | | 1.5 | 1.0 | 2.0 | 2.5 | 0.5 | 3.0 | 1.0 | 1.0 | 0.5 | 4.0 | 6.9 |
| DOLOMITE | | 1.0 | 39.0 | 0.5 | 0.5 | 0.5 | 1.0 | | | | 0.5 | | | 0.5 | 1.0 | 0.5 | 2.0 | 2.8 |
| FE DOLOMITE | 1.0 | 38.0 | 4.0 | 4.0 | 4.0 | 2.5 | 4.0 | 4.0 | 4.0 | 3.0 | 2.5 | 2.0 | 9.0 | 5.5 | 26.0 | 8.5 | 20.0 | 8.4 |
| BARITE | | | | | | | | | | | | | | | | | | 0.0 |
| AUTHIGENIC CLAYS | 4.0 | 0.5 | 0.0 | 1.0 | 0.0 | 1.0 | 1.5 | 2.0 | 1.0 | 2.5 | 1.5 | 2.0 | 5.0 | 2.0 | 2.0 | 2.0 | 2.0 | 1.8 |
| KAOLINITE | | | | 1.0 | | | 0.5 | 0.5 | 0.5 | 1.0 | 0.5 | 0.5 | 4.0 | 1.0 | 1.0 | 1.0 | 1.0 | 0.7 |
| ILLITE | 4.0 | 0.5 | | | | 1.0 | 0.5 | 1.0 | 0.5 | 0.8 | 0.5 | 1.0 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.7 |
| CHLORITE | | | | | | | 0.5 | 0.5 | | 0.8 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| HYDROCARBON | | | 0.5 | | | | | 0.5 | | 0.5 | 0.5 | 0.5 | 0.5 | 1.0 | 0.5 | 0.5 | 0.5 | 0.3 |
| POROSITY | 2.0 | 0.0 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 9.5 | 0.5 | 9.5 | 5.5 | 10.0 | 3.0 | 11.0 | 4.5 | 3.5 |
| PRIMARY | | | | | | | | | | 0.5 | | 0.5 | 0.5 | | 0.5 | | 0.5 | 0.4 |
| SECONDARY | 2.0 | | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 9.0 | 0.5 | 9.0 | 5.0 | 10.0 | 2.5 | 11.0 | 4.0 | 3.3 |
| AVE. GRAIN SIZE (MM) | 0.06 | 0.16 | 0.18 | 0.18 | 0.20 | 0.20 | 0.06 | 0.10 | 0.05 | 0.08 | 0.09 | 0.11 | 0.17 | 0.12 | 0.13 | 0.16 | 0.18 | 0.13 |
| QRF NORMALIZED (%) | | | | | | | | | | | | | | | | | | |
| QUARTZ | 60.6 | 71.6 | 56.9 | 76.3 | 58.3 | 70.8 | 77.3 | 77.1 | 79.3 | 76.6 | 71.9 | 78.5 | 73.6 | 79.5 | 75.4 | 66.7 | 74.2 | 72.0 |
| ROCK FRAGMENTS | 33.8 | 21.1 | 33.9 | 18.1 | 32.0 | 21.7 | 19.8 | 20.5 | 17.2 | 18.8 | 24.0 | 15.8 | 20.8 | 16.4 | 22.3 | 26.4 | 21.0 | 22.6 |
| FELDSPAR | 5.6 | 7.3 | 9.2 | 5.6 | 9.7 | 7.5 | 2.9 | 2.4 | 3.4 | 4.5 | 4.2 | 5.7 | 5.6 | 4.1 | 2.3 | 6.9 | 4.8 | 5.4 |
| CORE LAB DATA: | | | | | | | | | | | | | | | | | | |
| PERM. N-S | | 3.5 | 0.1 | 0.1 | 5.4 | 0.1 | 3600.0 | 0.1 | 0.1 | 0.1 | 0.2 | 0.1 | 1.1 | 0.1 | 0.1 | 0.9 | 0.1 | 212.5 |
| PERM. E-W | 0.1 | 2.7 | 0.1 | 1.8 | 2.7 | 0.1 | 0.3 | 0.1 | 0.3 | 0.1 | 0.6 | 0.1 | 0.1 | 0.1 | 0.1 | 0.8 | 0.1 | 0.6 |
| PLUG PERM | | | | | | | | | | 0.1 | 0.1 | 0.1 | | 0.4 | | 1.3 | | 0.3 |
| POROSITY | 3.5 | 2.3 | 2.1 | 4.8 | 2.2 | 3.3 | 5.5 | 7.1 | 6.9 | 9.2 | 9.3 | 9.5 | 4.5 | 8.4 | 4.5 | 9.6 | 3.5 | 5.7 |
| FLUID OIL | 9.1 | 6.0 | 6.4 | 9.7 | 6.7 | 8.7 | 11.3 | 12.4 | 12.6 | 11.1 | 11.3 | 14.0 | 9.6 | 13.2 | 9.4 | 13.9 | 8.5 | 10.2 |
| WTR. SAT. | 60.1 | 67.9 | 68.4 | 59.2 | 67.6 | 61.4 | 54.5 | 52.5 | 52.8 | 41.7 | 40.7 | 40.3 | 52.2 | 45.3 | 53.6 | 41.3 | 57.4 | 53.9 |
| GRAIN DEN. | 2.70 | 2.71 | 2.71 | 2.71 | 2.72 | 2.71 | 2.68 | 2.67 | 2.67 | 2.67 | 2.67 | 2.66 | 2.66 | 2.66 | 2.73 | 2.66 | 2.66 | 2.7 |
| LOG DATA: | | | | | | | | | | | | | | | | | | |
| GAMMA RAY (API) | 63.0 | 60.0 | 52.0 | 42.0 | 42.0 | 47.0 | 45.0 | 58.0 | 60.0 | 64.0 | 60.0 | 58.0 | 56.0 | 52.0 | 52.0 | 47.0 | 47.0 | 53.2 |
| SP (MV) | 10.0 | 11.0 | 12.0 | 13.0 | 14.0 | 15.0 | 16.0 | 17.0 | 18.0 | 19.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 19.0 | 19.0 | 16.6 |
| LATEROLOG (OHM-M'S) | 40.0 | 40.0 | 42.0 | 51.0 | 42.0 | 39.0 | 49.0 | 35.0 | 32.0 | 25.0 | 30.0 | 32.0 | 32.0 | 30.0 | 30.0 | 55.0 | 40.0 | 37.9 |
| MED RES (OHM-M'S) | 40.0 | 55.0 | 100.0 | 400.0 | 300.0 | 275.0 | 250.0 | 98.0 | 55.0 | 90.0 | 65.0 | 70.0 | 80.0 | 95.0 | 150.0 | 380.0 | 350.0 | 167.8 |
| DEEP RES (OHM-M'S) | 40.0 | 55.0 | 80.0 | 150.0 | 150.0 | 150.0 | 180.0 | 95.0 | 55.0 | 62.0 | 65.0 | 70.0 | 70.0 | 95.0 | 150.0 | 380.0 | 350.0 | 129.2 |
| DENS POR (%) | 13.7 | 13.7 | 4.8 | 4.8 | 3.0 | 6.5 | 0.6 | 3.6 | 6.5 | 7.1 | 7.7 | 14.9 | 13.7 | 11.9 | 8.9 | 6.0 | 1.8 | 7.6 |
| BULK DENS. (GM/CC) | 2.45 | 2.45 | 2.60 | 2.60 | 2.63 | 2.57 | 2.67 | 2.62 | 2.57 | 2.56 | 2.55 | 2.43 | 2.45 | 2.48 | 2.53 | 2.58 | 2.65 | 2.6 |
| DEEP - LAT (OHM-M'S) | 0.0 | 15.0 | 38.0 | 99.0 | 108.0 | 111.0 | 131.0 | 60.0 | 23.0 | 37.0 | 35.0 | 38.0 | 38.0 | 65.0 | 120.0 | 325.0 | 310.0 | |
| TH. SECT. G (8500')- | 50.5 | 52.5 | 54.1 | 56.1 | 58.0 | 59.3 | 62.5 | 64.2 | 66.5 | 68.5 | 70.5 | 72.5 | 74.3 | 76.4 | 78.1 | 80.5 | 81.9 | AVG. (%) |

SARKEY'S INC.
GILLISPIE #1-3
E/2 NE SE
SEC 3 T17N R22W
ELLIS CO., OKLA.

| NUMBER | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| THIN SECTION (S)- | 60.5 | 62.5 | 64.5 | 66.5 | 68.5 | 70.5 | 72.5 | 74.5 | 75.7 | 76.5 | 77.3 | 78.3 | AVG. (%) |
| DETRITAL CONSTITUENTS | 74.0 | 68.0 | 59.5 | 74.0 | 62.0 | 72.0 | 73.0 | 78.5 | 50.0 | 57.0 | 57.5 | 58.0 | 65.3 |
| QUARTZ | 56.0 | 50.0 | 44.0 | 55.0 | 45.0 | 51.0 | 56.0 | 57.0 | 40.0 | 44.0 | 7.0 | 42.0 | 45.6 |
| MONOCRYSTALLINE | 53.0 | 48.0 | 42.0 | 54.0 | 44.0 | 49.0 | 54.0 | 56.0 | 39.0 | 43.0 | 5.0 | 40.0 | 43.9 |
| POLYCRYSTALLINE | 3.0 | 2.0 | 2.0 | 1.0 | 1.0 | 2.0 | 2.0 | 1.0 | 1.0 | 1.0 | 2.0 | 2.0 | 1.7 |
| FELDSPAR | 2.0 | 4.0 | 3.0 | 4.0 | 3.0 | 4.0 | 5.0 | 5.5 | 3.0 | 3.0 | 2.0 | 4.0 | 3.5 |
| MICROCLINE | 1.0 | 2.0 | 1.0 | 2.0 | 2.0 | 1.0 | 2.0 | 2.0 | 1.0 | 1.0 | 0.5 | 1.0 | 1.4 |
| PLAGIOCLASE | 1.0 | 2.0 | 2.0 | 2.0 | 1.0 | 3.0 | 3.0 | 3.5 | 2.0 | 2.0 | 1.5 | 3.0 | 2.2 |
| ROCK FRAGMENTS | 9.0 | 8.0 | 7.0 | 10.0 | 9.0 | 10.5 | 6.0 | 9.5 | 5.0 | 4.0 | 4.5 | 5.5 | 7.3 |
| SHALE | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.5 | | 0.5 | | 0.5 | 2.0 | 1.0 | 0.8 |
| CHERT | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.0 | 1.0 | 2.0 | 1.0 | 1.0 | 0.5 | 1.0 | 0.8 |
| CARBONATE | | | | | | | 0.5 | 0.5 | 0.5 | 0.5 | 1.0 | | 0.6 |
| SILTSTONE | | | | | | | 0.5 | 0.5 | 0.5 | | 0.5 | 0.5 | 0.4 |
| METAMORPHIC | 8.0 | 7.0 | 6.0 | 9.0 | 8.0 | 8.0 | 4.0 | 6.0 | 3.0 | 2.0 | 0.5 | 3.0 | 5.4 |
| PLUTONIC | | | | | | | | | | | | | 0.0 |
| OTHER GRAINS | 7.0 | 6.0 | 5.5 | 5.0 | 5.0 | 6.5 | 6.0 | 6.5 | 2.0 | 6.0 | 44.0 | 6.5 | 8.8 |
| DETR. CHLORITE | 0.5 | | 0.5 | | | 0.5 | 0.5 | 1.0 | | | 0.5 | | 0.6 |
| GLAUCONITE | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| PHOSPHATE | 0.5 | 1.0 | 0.5 | 0.5 | 0.5 | 0.5 | | | | 0.5 | 0.5 | 0.5 | 0.6 |
| MUSCOVITE | 3.0 | 2.0 | 2.0 | 2.0 | 1.5 | 3.0 | 3.0 | 3.0 | | 1.0 | 0.5 | 0.5 | 2.0 |
| BIOTITE | 1.0 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | | | | | 1.0 | 0.6 |
| ZIRCON | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | | 0.5 | | | 0.5 |
| TOURMALINE | 0.5 | 0.5 | 0.5 | 0.5 | 1.0 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | | 1.0 | 0.5 |
| LEUCOXENE | 0.5 | 1.0 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.0 | 0.5 | 1.0 | | 0.5 | 0.6 |
| FOSSIL FRAGS. | | | | | | | | | 0.5 | 2.0 | 42.0 | 2.5 | 11.8 |
| DETRITAL MATRIX | 2.0 | 1.5 | 2.5 | 1.0 | 1.5 | 4.0 | 4.0 | 3.5 | 1.0 | 1.0 | 0.5 | 4.0 | 2.2 |
| ILLITE | 2.0 | 1.0 | 2.0 | 0.5 | 1.0 | 3.0 | 3.5 | 3.0 | 0.5 | 0.5 | 0.5 | 3.0 | 1.7 |
| CHLORITE | | 0.5 | 0.5 | 0.5 | 0.5 | 1.0 | 0.5 | 0.5 | 0.5 | 0.5 | | 1.0 | 0.5 |
| DIAGENETIC CONSTS. | 24.0 | 30.5 | 38.0 | 25.0 | 36.5 | 24.0 | 23.0 | 18.0 | 49.0 | 42.0 | 42.0 | 38.0 | 32.5 |
| CEMENTS | 21.5 | 16.0 | 27.5 | 13.0 | 24.0 | 9.5 | 9.5 | 12.0 | 47.0 | 41.5 | 42.0 | 37.0 | 25.0 |
| QUARTZ | 3.0 | 4.0 | 4.0 | 5.0 | 4.0 | 6.0 | 6.0 | 8.0 | 3.0 | 3.0 | | 2.0 | 4.4 |
| FELDSPAR | | | | | | | | | | | | | ERR |
| CALCITE | 0.5 | 0.5 | 0.5 | 0.5 | 1.0 | 0.5 | 0.5 | 2.0 | 3.0 | 36.0 | 42.0 | 35.0 | 10.2 |
| DOLOMITE | 1.0 | 0.5 | 2.0 | 0.5 | 1.0 | 1.0 | 3.0 | 0.5 | 1.0 | 0.5 | | | 1.1 |
| FE DOLOMITE | 17.0 | 11.0 | 21.0 | 7.0 | 18.0 | 2.0 | | 1.5 | 40.0 | 2.0 | | | 13.3 |
| BARITE | | | | | | | | | | | | | ERR |
| AUTHIGENIC CLAYS | 1.5 | 2.0 | 2.0 | 2.0 | 3.5 | 4.5 | 4.5 | 2.0 | 1.5 | 0.0 | 0.0 | 1.0 | 2.0 |
| KAOLINITE | 1.0 | 1.0 | 1.0 | 1.0 | 2.0 | 3.0 | 3.0 | 1.0 | 0.5 | | | 0.5 | 1.4 |
| ILLITE | 0.5 | 0.5 | 0.5 | 0.5 | 1.0 | 1.0 | 1.0 | 0.5 | 0.5 | | | | 0.7 |
| CHLORITE | | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | | | 0.5 | 0.5 |
| HYDROCARBON | 0.5 | 0.5 | 0.5 | | | | | | | | | | 0.5 |
| POROSITY | 0.5 | 12.0 | 8.0 | 10.0 | 9.0 | 10.0 | 9.0 | 4.0 | 0.5 | 0.5 | 0.0 | 0.0 | 5.3 |
| PRIMARY | | | | | | | | | | | | | 0.0 |
| SECONDARY | 0.5 | 12.0 | 8.0 | 10.0 | 9.0 | 10.0 | 9.0 | 4.0 | 0.5 | 0.5 | | | 6.4 |
| AVE. GRAIN SIZE (MM) | 0.10 | 0.12 | 0.11 | 0.12 | 0.12 | 0.10 | 0.10 | 0.11 | 0.11 | 0.18 | 0.15 | 0.13 | 0.12 |
| QRF NORMALIZED (%) | | | | | | | | | | | | | |
| QUARTZ | 75.7 | 73.5 | 73.9 | 74.3 | 72.6 | 70.8 | 76.7 | 72.6 | 80.0 | 77.2 | 12.2 | 72.4 | 69.33 |
| ROCK FRAGMENTS | 21.6 | 20.6 | 21.0 | 20.3 | 22.6 | 23.6 | 16.4 | 20.4 | 14.0 | 17.5 | 84.3 | 20.7 | 25.26 |
| FELDSPAR | 2.7 | 5.9 | 5.0 | 5.4 | 4.8 | 5.6 | 6.8 | 7.0 | 6.0 | 5.3 | 3.5 | 6.9 | 5.41 |
| CORE LAB DATA: | | | | | | | | | | | | | |
| PERM. N-S | 0.1 | 1.7 | 0.4 | 0.3 | 0.1 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.28 |
| PERM. E-W | 0.1 | 2304.0 | 0.4 | 0.3 | 0.1 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 192.14 |
| POROSITY | 8.5 | 9.7 | 9.3 | 8.3 | 8.8 | 9.4 | 9.0 | 8.6 | 3.4 | 3.4 | 2.1 | 2.0 | 6.88 |
| FLUID OIL | 10.2 | 11.9 | 12.2 | 14.3 | 15.2 | 10.7 | 14.8 | 13.9 | 4.1 | 6.7 | 6.3 | 0.0 | 10.03 |
| WTR. SAT. | 37.3 | 39.4 | 41.3 | 34.8 | 40.9 | 39.1 | 36.3 | 37.0 | 66.6 | 64.0 | 61.9 | 62.2 | 46.73 |
| GRAIN DENS. | 2.70 | 2.70 | 2.71 | 2.68 | 2.67 | 2.66 | 2.66 | 2.67 | 2.68 | 2.72 | 2.72 | 2.72 | 2.69 |
| LOG DATA: | | | | | | | | | | | | | |
| GAMMA RAY (API) | 37.0 | 37.0 | 39.0 | 37.0 | 46.0 | 45.0 | 45.0 | 47.0 | 60.0 | 80.0 | 95.0 | 105.0 | 56.08 |
| SP (MV) | 43.0 | 43.0 | 43.0 | 43.0 | 42.0 | 41.0 | 40.0 | 38.0 | 37.0 | 35.0 | 33.0 | 32.0 | 39.17 |
| SHORT RES (OHM-M'S) | 45.0 | 40.0 | 47.0 | 40.0 | 39.0 | 35.0 | 39.0 | 40.0 | 60.0 | 150.0 | 100.0 | 17.0 | 54.33 |
| MED. RES. (OHM-M'S) | 800.0 | 600.0 | 100.0 | 50.0 | 80.0 | 100.0 | 200.0 | 200.0 | 175.0 | 150.0 | 140.0 | 15.0 | 217.50 |
| DEEP RES. (OHM-M'S) | 1000.0 | 700.0 | 800.0 | 500.0 | 200.0 | 200.0 | 500.0 | 900.0 | 500.0 | 150.0 | 140.0 | 15.0 | 467.08 |
| *DENSITY POR. (%) | 7.7 | 8.9 | 8.3 | 8.9 | 8.3 | 10.7 | 8.9 | 6.6 | 4.8 | 1.8 | 1.8 | 1.8 | 6.55 |
| BULK DENS. (GM/CC) | 2.55 | 2.53 | 2.54 | 2.53 | 2.54 | 2.50 | 2.53 | 2.57 | 2.60 | 2.65 | 2.65 | 2.65 | 2.57 |
| THIN SECTION (S)- | 60.5 | 62.5 | 64.5 | 66.5 | 68.5 | 70.5 | 72.5 | 74.5 | 75.7 | 76.5 | 77.3 | 78.3 | |

PETROLEUM INC.
VALENTINE #1
SE NE
SEC 1 19N 22W
ELLIS CO., OKLA.

| NUMBER / THIN SEC. (V) (7900') | 1<br>24.5 | 2<br>39.3 | 3<br>40.0 | 4<br>42.5 | 5<br>44.5 | 6<br>45.5 | 7<br>47.1 | 8<br>48.5 | 9<br>50.3 | 10<br>51.1 | 11<br>52.5 | 12<br>54.0 | AVE (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DETRITAL CONSTITUENTS | 55.0 | 56.0 | 57.0 | 67.5 | 61.0 | 64.0 | 59.0 | 68.0 | 62.0 | 54.0 | 68.0 | 69.0 | 61.7 |
| QUARTZ | 42.0 | 35.0 | 40.0 | 48.0 | 43.0 | 45.0 | 38.0 | 42.0 | 46.0 | 36.0 | 50.0 | 54.0 | 43.3 |
| MONOCRYSTALLINE | 41.0 | 34.0 | 39.0 | 47.0 | 42.0 | 42.0 | 35.0 | 39.0 | 42.0 | 33.0 | 46.0 | 50.0 | 40.8 |
| POLYCRYSTALLINE | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 3.0 | 3.0 | 3.0 | 4.0 | 3.0 | 4.0 | 4.0 | 2.4 |
| FELDSPAR | 2.0 | 4.0 | 3.0 | 3.0 | 2.0 | 4.0 | 3.0 | 3.0 | 4.0 | 3.0 | 2.0 | 2.0 | 2.9 |
| MICROCLINE | | 0.5 | 1.0 | 0.5 | | 1.0 | 0.5 | | 1.0 | 0.5 | | 0.5 | 0.5 |
| PLAGIOCLASE | 2.0 | 3.5 | 2.0 | 2.5 | 2.0 | 3.0 | 2.5 | 3.0 | 3.0 | 2.5 | 2.0 | 1.5 | 2.5 |
| ROCK FRAGMENTS | 5.0 | 7.0 | 7.0 | 7.5 | 8.0 | 7.0 | 6.5 | 4.0 | 6.5 | 5.5 | 6.5 | 5.0 | 6.3 |
| SHALE | 0.5 | 0.5 | 1.0 | 2.0 | 0.5 | | | | | 0.5 | 1.5 | | 0.5 |
| CHERT | 1.0 | 0.5 | 1.0 | 1.0 | 0.5 | 2.0 | 1.0 | 1.0 | 1.5 | 1.0 | 0.5 | 1.0 | 1.0 |
| CARBONATE | | 1.0 | 0.5 | | 0.5 | 0.5 | | 0.5 | | | | | 0.6 |
| SILTSTONE | | 1.0 | 1.0 | 0.5 | 0.5 | | 0.5 | | | | 0.5 | | 0.3 |
| METAMORPHIC | 3.5 | 4.0 | 3.5 | 4.0 | 6.0 | 4.0 | 5.0 | 2.5 | 5.0 | 4.0 | 4.0 | 4.0 | 4.1 |
| PLUTONIC | | | | | | 0.5 | | | | | | | .0 |
| OTHER GRAINS | 6.0 | 10.0 | 7.0 | 9.0 | 8.0 | 8.0 | 11.5 | 19.0 | 5.5 | 9.5 | 9.5 | 8.0 | 9.3 |
| DETR. CHLORITE | 1.0 | 1.0 | 0.5 | 0.5 | 1.0 | 0.5 | 1.0 | 2.0 | 0.5 | 1.0 | 1.0 | 1.0 | 0.9 |
| GLAUCONITE | | 0.5 | 0.5 | 0.5 | | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.4 |
| PHOSPHATE | | | 0.5 | 0.5 | 0.5 | 0.5 | 1.0 | | | 0.5 | | 0.5 | 0.3 |
| MUSCOVITE | 3.5 | 6.0 | 2.5 | 5.0 | 4.0 | 4.0 | 4.0 | 12.0 | 1.5 | 4.0 | 4.0 | 4.0 | 4.5 |
| BIOTITE | | 0.5 | 0.5 | 1.0 | 1.0 | 1.0 | 1.0 | 2.0 | 0.5 | 2.0 | 1.0 | 0.5 | 0.9 |
| ZIRCON | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| TOURMALINE | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.0 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| LUECOXENE | 0.5 | 0.5 | 1.5 | 0.5 | 0.5 | 0.5 | 1.0 | 1.0 | 1.0 | 0.5 | 1.0 | 0.5 | 0.8 |
| FOSSIL FRAGS. # | | 0.5 | | | | | 2.0 | | 0.5 | | 1.0 | | 1.0 |
| DETRITAL MATRIX | 16.0 | 6.0 | 1.0 | 4.5 | 4.0 | 4.5 | 1.5 | 8.0 | 2.0 | 2.5 | 4.0 | 6.0 | 5.0 |
| ILLITE | 15.0 | 5.0 | 1.0 | 4.0 | 3.5 | 4.0 | 1.0 | 6.0 | 1.5 | 2.0 | 3.0 | 5.0 | 4.3 |
| CHLORITE | 1.0 | 1.0 | | 0.5 | 0.5 | 0.5 | 0.5 | 2.0 | 0.5 | 0.5 | 1.0 | 1.0 | 0.8 |
| DIAGENETIC CONST.'S | 29.0 | 38.0 | 42.0 | 28.0 | 35.0 | 31.5 | 39.5 | 24.0 | 36.0 | 43.5 | 28.0 | 25.0 | 33.3 |
| CEMENTS | 28.5 | 35.0 | 41.5 | 12.5 | 31.0 | 21.5 | 36.5 | 19.5 | 29.5 | 42.0 | 21.5 | 23.5 | 28.5 |
| QUARTZ | | 0.5 | 0.5 | 2.0 | 1.5 | 1.5 | 0.5 | 2.0 | 1.5 | 1.0 | 4.0 | 6.0 | 1.8 |
| FELDSPAR | | | | | | | | | | | | | 0.0 |
| CALCITE | 1.0 | 7.0 | 22.0 | | 0.5 | 6.0 | 1.0 | 0.5 | 0.5 | 4.5 | 0.5 | 0.5 | 3.7 |
| DOLOMITE | | 1.5 | 1.0 | 0.5 | | 0.5 | | 1.0 | | | | 2.0 | 0.5 |
| FE DOLOMITE | 27.5 | 26.0 | 18.0 | 7.0 | 28.5 | 10.5 | 35.0 | 16.0 | 27.0 | 36.0 | 15.0 | 14.5 | 21.8 |
| BARITE | | | | 3.0 | 0.5 | 3.0 | | | 0.5 | 0.5 | 2.0 | 0.5 | 1.4 |
| AUTHEGENIC CLAYS | 0.0 | 2.5 | 0.5 | 2.0 | 3.0 | 4.5 | 2.0 | 0.0 | 2.0 | 1.5 | 2.5 | 0.0 | 1.7 |
| KAOLINITE | | 0.5 | | 0.5 | 0.5 | 3.0 | 1.5 | | 1.0 | 0.5 | 0.5 | | 0.7 |
| ILLITE | * | 2.0 | 0.5 | 1.0 | 2.0 | 1.0 | 0.5 | * | 0.5 | 0.5 | 1.5 | * | 0.8 |
| CHLORITE | * | | | 0.5 | 0.5 | 0.5 | | * | 0.5 | 0.5 | 0.5 | * | 0.3 |
| HYDROCARBON | | 0.5 | | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | | 0.5 | 0.5 | 0.4 |
| POROSITY | 0.5 | 0.0 | 0.0 | 13.0 | 0.5 | 5.0 | 0.5 | 4.0 | 4.0 | 0.0 | 3.5 | 1.0 | 2.7 |
| PRIMARY | 0.5 | | | | | | | | | | 0.5 | | 0.5 |
| SECONDARY | | | | 13.0 | 0.5 | 5.0 | 0.5 | 4.0 | 4.0 | | 3.0 | 1.0 | 2.6 |
| AVE. GRAIN SIZE (MM) | 0.05 | 0.05 | 0.11 | 0.07 | 0.09 | 0.18 | 0.14 | 0.04 | 0.10 | | 0.08 | 0.07 | 0.08 |
| QRF NORMALIZED (%) | | | | | | | | | | | | | |
| QUARTZ | 76.4 | 62.5 | 70.2 | 71.1 | 70.5 | 70.3 | 64.4 | 61.8 | 74.2 | 66.7 | 73.5 | 78.3 | 70.0 |
| ROCK FRAGMENTS | 20.0 | 30.4 | 24.6 | 24.4 | 26.2 | 23.4 | 30.5 | 33.8 | 19.4 | 27.8 | 23.5 | 18.8 | 25.2 |
| FELDSPAR | 3.6 | 7.1 | 5.3 | 4.4 | 3.3 | 6.3 | 5.1 | 4.4 | 6.5 | 5.6 | 2.9 | 2.9 | 4.8 |

* = recrystallized detrital matrix
# = commonly includes: echinoderms, crinoids, brachiopods, pelecypods; may also include: ooids, intraclasts

ODESSA NATURAL CORP.
WREATH #1
C NW
SEC 17 20N 21W
WOODWARD CO., OKLA.

| NUMBER<br>THIN SEC. (W) (7700') | 1<br>85.3 | 2<br>87.5 | A<br>3<br>88.1 | B<br>3<br>88.1 | 4<br>88.9 | 5<br>90.5 | 6<br>92.5 | 7<br>94.5 | 8<br>96.2 | 9<br>97.5 | 10<br>99.5 | AVG. (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DETRITAL CONSTITUENTS | 74.0 | 60.0 | 55.5 | 66.5 | 72.5 | 68.0 | 68.0 | 65.0 | 58.0 | 65.0 | 67.0 | 65.4 |
| QUARTZ | 40.0 | 34.0 | 17.0 | 46.0 | 50.0 | 46.0 | 44.0 | 45.0 | 37.0 | 43.0 | 46.0 | 40.7 |
| MONOCRYSTALLINE | 38.0 | 32.0 | 16.0 | 44.0 | 49.0 | 45.0 | 43.0 | 44.0 | 35.0 | 41.0 | 44.0 | 39.2 |
| POLYCRYSTALLINE | 2.0 | 2.0 | 1.0 | 2.0 | 1.0 | 1.0 | 1.0 | 1.0 | 2.0 | 2.0 | 2.0 | 1.5 |
| FELDSPAR | 3.5 | 4.0 | 2.0 | 3.5 | 3.0 | 4.0 | 4.0 | 3.0 | 3.0 | 4.0 | 4.0 | 3.5 |
| MICROCLINE | 0.5 | | | 0.5 | 0.5 | 1.0 | 0.5 | 0.5 | | 0.5 | 0.5 | 0.4 |
| PLAGIOCLASE | 3.0 | 4.0 | 2.0 | 3.0 | 2.5 | 3.0 | 3.5 | 2.5 | 3.0 | 3.5 | 3.5 | 3.0 |
| ROCK FRAGMENTS | 7.5 | 10.5 | 6.0 | 9.0 | 7.5 | 9.5 | 9.5 | 7.5 | 8.0 | 9.5 | 9.5 | 8.5 |
| SHALE | 0.5 | 2.0 | 0.5 | 1.0 | 0.5 | 0.5 | 1.0 | 1.0 | | 0.5 | 0.5 | 0.7 |
| CHERT | 2.0 | 3.0 | 1.0 | 2.0 | 1.0 | 2.0 | 1.0 | 2.0 | 2.0 | 1.0 | 1.0 | 1.6 |
| CARBONATE | | | | | | | | | | | 0.5 | 0.3 |
| SILTSTONE | 0.5 | | 0.5 | | | | | | | | | 0.1 |
| METAMORPHIC | 4.0 | 5.0 | 4.0 | 6.0 | 6.0 | 7.0 | 7.5 | 4.5 | 6.0 | 8.0 | 7.5 | 6.0 |
| PLUTONIC | 0.5 | 0.5 | | | | | | | | | | 0.1 |
| OTHER GRAINS | 23.0 | 11.5 | 30.5 | 8.0 | 12.0 | 8.5 | 10.5 | 9.5 | 10.0 | 8.5 | 7.5 | 12.7 |
| DETR. CHLORITE | 3.0 | 0.5 | 0.5 | 0.5 | 0.5 | 1.0 | 2.0 | 1.0 | 2.0 | 1.5 | 1.0 | 1.2 |
| GLAUCONITE | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | | 0.5 |
| PHOSPHATE | 0.5 | | 0.5 | 0.5 | | 0.5 | | | | 0.5 | 0.5 | 0.3 |
| MUSCOVITE | 13.0 | 2.0 | 2.0 | 4.0 | 6.0 | 4.0 | 4.0 | 5.0 | 5.0 | 4.0 | 4.0 | 4.8 |
| BIOTITE | 3.0 | 0.5 | 0.5 | 0.5 | 1.0 | 1.0 | 0.5 | 1.0 | 0.5 | 0.5 | 0.5 | 0.9 |
| ZIRCON | 0.5 | 0.5 | 0.5 | 1.0 | 1.0 | 0.5 | 2.0 | 0.5 | 0.5 | 0.5 | 0.5 | 0.7 |
| TOURMALINE | 0.5 | 0.5 | 0.5 | 0.5 | 1.0 | 0.5 | 1.0 | 0.5 | 0.5 | 0.5 | 0.5 | 0.6 |
| LUECOXENE | 1.0 | 1.0 | 0.5 | 0.5 | 2.0 | 0.5 | 0.5 | 1.0 | 0.5 | 0.5 | 0.5 | 0.8 |
| FOSSIL FRAGS. # | 1.0 | 6.0 | 25.0 | | | | | | 0.5 | | | 5.4 |
| DETRITAL MATRIX | 8.5 | 1.0 | 1.0 | 1.0 | 2.0 | 1.5 | 2.5 | 1.5 | 0.5 | 2.0 | 1.0 | 2.0 |
| ILLITE | 7.5 | 0.5 | 0.5 | 0.5 | 1.5 | 1.0 | 1.5 | 1.5 | 0.5 | 2.0 | 1.0 | 1.6 |
| CHLORITE | 1.0 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.0 | | | | | 0.4 |
| DIAGENETIC CONST.'S | 17.5 | 39.0 | 43.5 | 32.5 | 25.5 | 30.5 | 29.5 | 33.5 | 41.5 | 33.0 | 32.0 | 32.5 |
| CEMENTS | 17.0 | 35.0 | 38.0 | 13.0 | 10.5 | 13.0 | 13.0 | 21.0 | 39.5 | 25.0 | 30.0 | 23.2 |
| QUARTZ | 0.5 | 0.5 | 0.5 | 2.5 | 2.0 | 3.0 | 2.5 | 2.0 | 2.0 | 3.5 | 4.0 | 2.1 |
| FELDSPAR | | | | | | | | | | | | 0.0 |
| CALCITE | 16.0 | 28.0 | 16.0 | 1.5 | 2.0 | 1.0 | 0.5 | 2.0 | 0.5 | 0.5 | 11.0 | 7.2 |
| DOLOMITE | | 0.5 | 2.0 | 7.5 | 0.5 | 1.0 | | 2.0 | 1.0 | | 2.0 | 1.5 |
| FE DOLOMITE | 0.5 | 6.0 | 19.0 | | 5.0 | 6.0 | 8.5 | 14.0 | 33.0 | 16.0 | 11.0 | 10.8 |
| BARITE | | | 0.5 | 1.5 | 1.0 | 2.0 | 1.5 | 1.0 | 3.0 | 5.0 | 2.0 | 1.9 |
| AUTHEGENIC CLAYS | 0.0 | 3.0 | 2.5 | 3.0 | 1.5 | 1.5 | 2.0 | 2.0 | 1.0 | 1.5 | 2.0 | 1.8 |
| KAOLINITE | | 0.5 | | 0.5 | 0.5 | 1.0 | 1.0 | 1.0 | 0.5 | 1.0 | 1.0 | 0.6 |
| ILLITE | * | 2.0 | 2.0 | 2.0 | 1.0 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.0 | 1.0 |
| CHLORITE | * | 0.5 | 0.5 | 0.5 | | | 0.5 | 0.5 | | | | 0.3 |
| HYDROCARBON | 0.5 | 0.5 | 0.5 | 1.0 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | | | 0.5 |
| POROSITY | 0.0 | 0.5 | 2.5 | 15.5 | 13.0 | 15.5 | 14.0 | 10.0 | 0.5 | 6.5 | 0.0 | 7.1 |
| PRIMARY | | | 0.5 | 0.5 | | 0.5 | | | | 0.5 | | 0.3 |
| SECONDARY | | 0.5 | 2.0 | 15.0 | 13.0 | 15.0 | 14.0 | 10.0 | 0.5 | 6.0 | | 6.9 |
| AVE. GRAIN SIZE (MM) | 0.04 | 0.14 | 0.15 | 0.08 | 0.10 | 0.09 | 0.10 | 0.11 | 0.13 | 0.10 | 0.11 | 0.1 |
| QRF NORMALIZED (%) | | | | | | | | | | | | |
| QUARTZ | 54.1 | 56.7 | 30.6 | 69.2 | 69.0 | 67.6 | 64.7 | 69.2 | 63.8 | 66.2 | 68.7 | 61.8 |
| ROCK FRAGMENTS | 41.2 | 36.7 | 65.8 | 25.6 | 26.9 | 26.5 | 29.4 | 26.2 | 31.0 | 27.7 | 25.4 | 32.9 |
| FELDSPAR | 4.7 | 6.7 | 3.6 | 5.3 | 4.1 | 5.9 | 5.9 | 4.6 | 5.2 | 6.2 | 6.0 | 5.3 |

* = recrystallized
detrital matrix

\# = commonly includes:
Echinoderms
Crinoids
Brachiopods
Bryozoans
Pelycepods
may also include:
ooids
intraclasts

RAN RICKS JR.
COLE #28-A
C W/2 NW
SEC 28 T21N R21W
WOODWARD CO., OKLA.

| NUMBER | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| THIN SEC. (R) (7400') | 38.5 | 39.6 | 40.5 | 42.1 | 44.2 | 47.9 | 49.5 | AVG. (%) |
| DETRITAL CONSTITUENTS | 63.0 | 70.0 | 75.5 | 73.5 | 68.5 | 66.0 | 68.5 | 69.3 |
| QUARTZ | 41.0 | 48.0 | 51.0 | 50.0 | 50.0 | 45.0 | 45.0 | 47.1 |
| MONOCRYSTALLINE | 37.0 | 45.0 | 48.0 | 46.0 | 46.0 | 43.0 | 42.0 | 43.9 |
| POLYCRYSTALLINE | 4.0 | 3.0 | 3.0 | 4.0 | 4.0 | 2.0 | 3.0 | 3.3 |
| FELDSPAR | 4.0 | 3.0 | 3.0 | 3.5 | 4.5 | 4.0 | 4.5 | 3.8 |
| MICROCLINE | 0.5 | 0.5 | | 0.5 | 0.5 | | 0.5 | 0.4 |
| PLAGIOCLASE | 3.5 | 2.5 | 3.0 | 3.0 | 4.0 | 4.0 | 4.0 | 3.4 |
| ROCK FRAGMENTS | 10.0 | 9.0 | 5.5 | 7.0 | 7.0 | 10.5 | 9.5 | 8.4 |
| SHALE | 0.5 | 1.0 | 0.5 | 0.5 | | 1.0 | 2.0 | 0.8 |
| CHERT | 2.0 | 2.0 | 1.0 | 1.0 | 1.0 | 1.5 | 1.0 | 1.4 |
| CARBONATE | 0.5 | 1.0 | | 0.5 | 1.0 | | | 0.6 |
| SILTSTONE | | | | | | | | 0.0 |
| METAMORPHIC | 7.0 | 4.5 | 4.0 | 5.0 | 5.0 | 8.0 | 6.5 | 5.7 |
| PLUTONIC | | 0.5 | | | | | | 0.1 |
| OTHER GRAINS | 8.0 | 10.0 | 16.0 | 13.0 | 7.0 | 6.5 | 9.5 | 10.0 |
| DETR. CHLORITE | 0.5 | 1.0 | 2.0 | 2.0 | 1.0 | 1.5 | 2.0 | 1.4 |
| GLAUCONITE | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | | 0.4 |
| PHOSPHATE | 0.5 | | 0.5 | 0.5 | 0.5 | | | 0.3 |
| MUSCOVITE | 2.5 | 4.0 | 10.0 | 8.0 | 2.0 | 2.0 | 4.0 | 4.6 |
| BIOTITE | 1.0 | 0.5 | 1.0 | 0.5 | 0.5 | 0.5 | 0.5 | 0.6 |
| ZIRCON | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.0 | 0.6 |
| TOURMALINE | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| LUECOXENE | 1.5 | 1.0 | 1.0 | 0.5 | 1.0 | 1.0 | 1.5 | 1.1 |
| FOSSIL FRAGS. # | 0.5 | 2.0 | | | 0.5 | | | 0.8 |
| DETRITAL MATRIX | 1.0 | 2.0 | 5.0 | 5.5 | 0.0 | 3.0 | 4.0 | 2.9 |
| ILLITE | 0.5 | 2.0 | 4.5 | 5.0 | | 2.0 | 3.0 | 2.4 |
| CHLORITE | 0.5 | | 0.5 | 0.5 | | 1.0 | 1.0 | 0.5 |
| DIAGENETIC CONST.'S | 36.0 | 28.0 | 19.5 | 21.0 | 31.5 | 31.0 | 27.5 | 27.8 |
| CEMENTS | 34.0 | 24.0 | 8.0 | 8.0 | 30.0 | 13.5 | 13.0 | 18.6 |
| QUARTZ | 0.5 | 0.5 | 1.5 | 1.0 | | 1.0 | 1.0 | 0.8 |
| FELDSPAR | | | | | | | | 0.0 |
| CALCITE | 28.0 | 16.0 | 1.5 | | 14.0 | 1.0 | 3.0 | 9.1 |
| DOLOMITE | | | | 0.5 | | | 0.5 | 0.1 |
| FE DOLOMITE | 5.5 | 7.0 | 5.0 | 6.5 | 16.0 | 10.0 | 8.5 | 8.4 |
| BARITE | | 0.5 | | | | 1.5 | | 1.0 |
| AUTHEGENIC CLAYS | 1.0 | 2.5 | 1.0 | 1.0 | 1.0 | 3.5 | 2.5 | 1.8 |
| KAOLINITE | | | 0.5 | 0.5 | 0.5 | 0.5 | | 0.3 |
| ILLITE | 0.5 | 2.0 | * | * | 0.5 | 2.5 | 2.0 | 1.1 |
| CHLORITE | 0.5 | 0.5 | 0.5 | 0.5 | | 0.5 | 0.5 | 0.5 |
| HYDROCARBON | 0.5 | | 0.5 | 0.5 | | 0.5 | 0.5 | 0.4 |
| POROSITY | 0.5 | 1.5 | 10.0 | 11.5 | 0.5 | 13.5 | 11.5 | 7.0 |
| PRIMARY | | | | 0.5 | | 0.5 | 0.5 | 0.4 |
| SECONDARY | 0.5 | 1.5 | 10.0 | 11.0 | 0.5 | 13.0 | 11.0 | 6.8 |
| AVE. GRAIN SIZE (MM) | 0.13 | 0.11 | 0.08 | 0.07 | 0.15 | 0.12 | 0.11 | 0.1 |
| QRF NORMALIZED (%) | | | | | | | | |
| QUARTZ | 65.1 | 68.6 | 67.5 | 68.0 | 73.0 | 68.2 | 65.7 | 68.0 |
| ROCK FRAGMENTS | 28.6 | 27.1 | 28.5 | 27.2 | 20.4 | 25.8 | 27.7 | 26.5 |
| FELDSPAR | 6.3 | 4.3 | 4.0 | 4.8 | 6.6 | 6.1 | 6.6 | 5.5 |

\# = commonly includes:
Echinoderms
Crinoids
Brachipods
Bryozoans
may also include:
ooids
intraclasts
algae

* = recrystallized detrital matrix

2

# VITA

Bruce Jerome Wade

Candidate for the Degree of

Master of Science

Thesis: THE PETROGRAPHY, DIAGENESIS, AND DEPOSITIONAL SETTING OF THE PENNSYLVANIAN COTTAGE GROVE SANDSTONE IN DEWEY, ELLIS, ROGER MILLS AND WOODWARD COUNTIES, OKLAHOMA

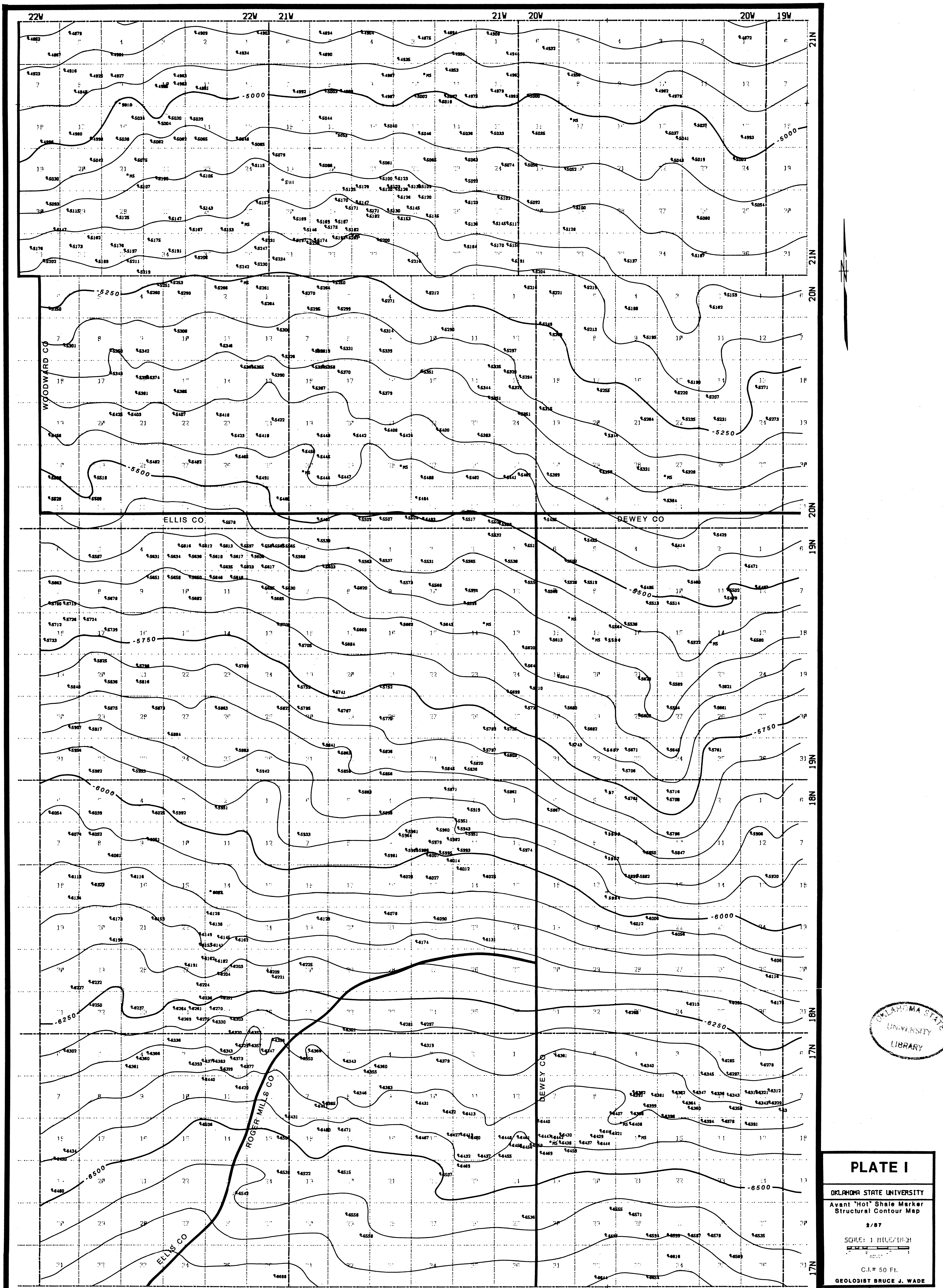
Major Field: Geology

Biographical:

Personal: Born in San Jose, California, July 16, 1962, the son of Guy A. and Aida L. Wade.

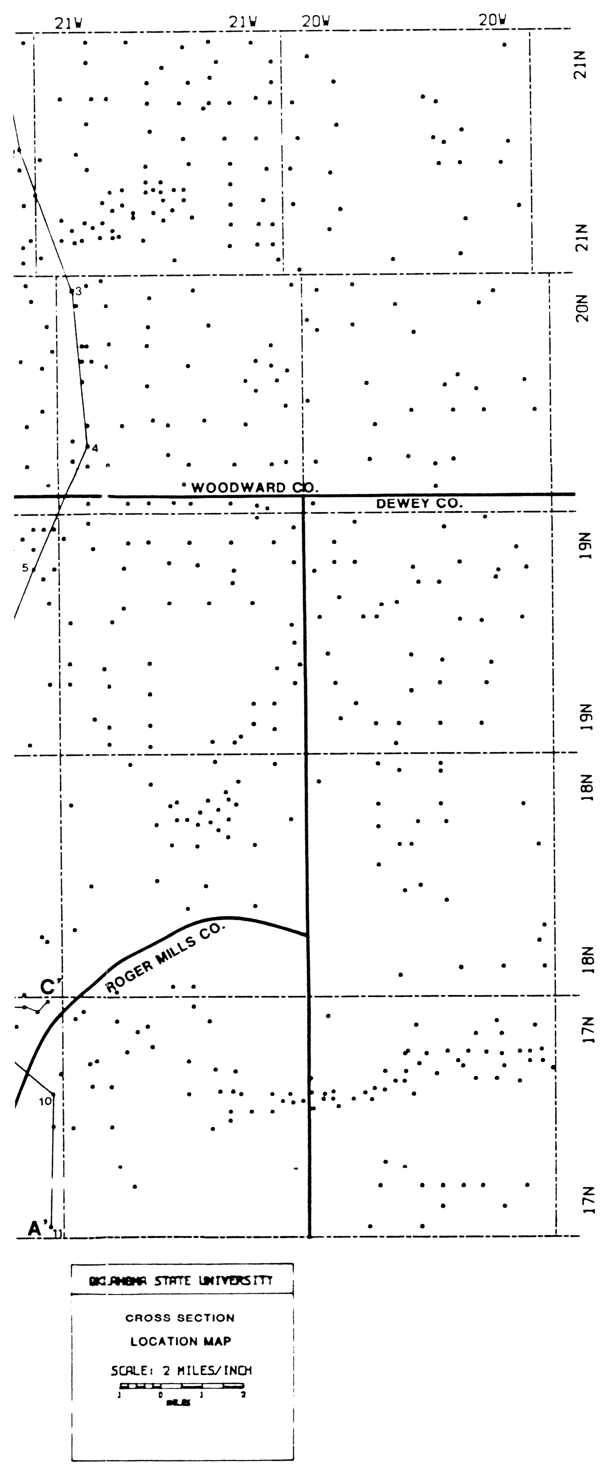
Education: Graduated from Graham High School, near Weleetka, Oklahoma, in May, 1980; received Bachelor of Science degree in Arts and Sciences from Oklahoma State University in December, 1984; completed requirements for Master of Science degree at Oklahoma State University in December, 1987.

Professional Experience: Summer Geologist, Hadson Exploration Company, Oklahoma City, Oklahoma, May to August, 1985; Summer Geophysicist, Exxon Company U.S.A., Houston, Texas, May to August 1986; Graduate Teaching Assistant, Geology Department, Oklahoma State University, January 1985 to May 1987.



22W
21W
20W
19W
21N
20N
19N
18N
17N
WOODWARD CO
ELLIS CO
DEWEY CO
ROGER MILLS CO
ELLIS CO
DEWEY CO
-5000
-5250
-5500
-5750
-6000
-6250
-6500
PLATE I
OKLAHOMA STATE UNIVERSITY
Avant "Hot" Shale Marker
Structural Contour Map
2/87
SCALE: 1 MILE/INCH
C.I.= 50 Ft.
GEOLOGIST BRUCE J. WADE

# REGIONAL NORTH-SOUTH STRATIGRAPHIC CROSS-SECTION A - A'


VERTICAL SCALE

1" = 100'

HORIZONTAL SCALE

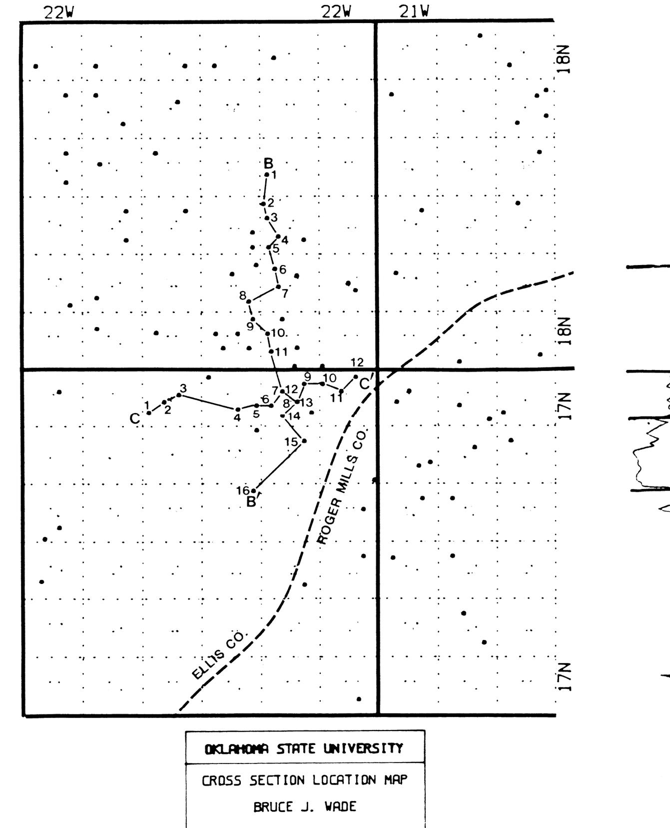
1" = 3960'

**PLATE II**

**REGIONAL NORTH -SOUTH STRATAGRAPHIC CROSS SECTION**

2/87

GEOLOGIST : BRUCE J. WADE




OKLAHOMA STATE UNIVERSITY

CROSS SECTION LOCATION MAP

BRUCE J. WADE

JULY 24, 1987


VERTICAL SCALE

1" = 50'

HORIZONTAL SCALE

1" = 375'



**PLATE III**

**NORTH-SOUTH STRATAGRAPHIC CROSS SECTION B-B'**

2/87

GEOLOGIST BRUCE J. WADE

# EAST-WEST STRATIGRAPHIC CROSS-SECTION C - C'

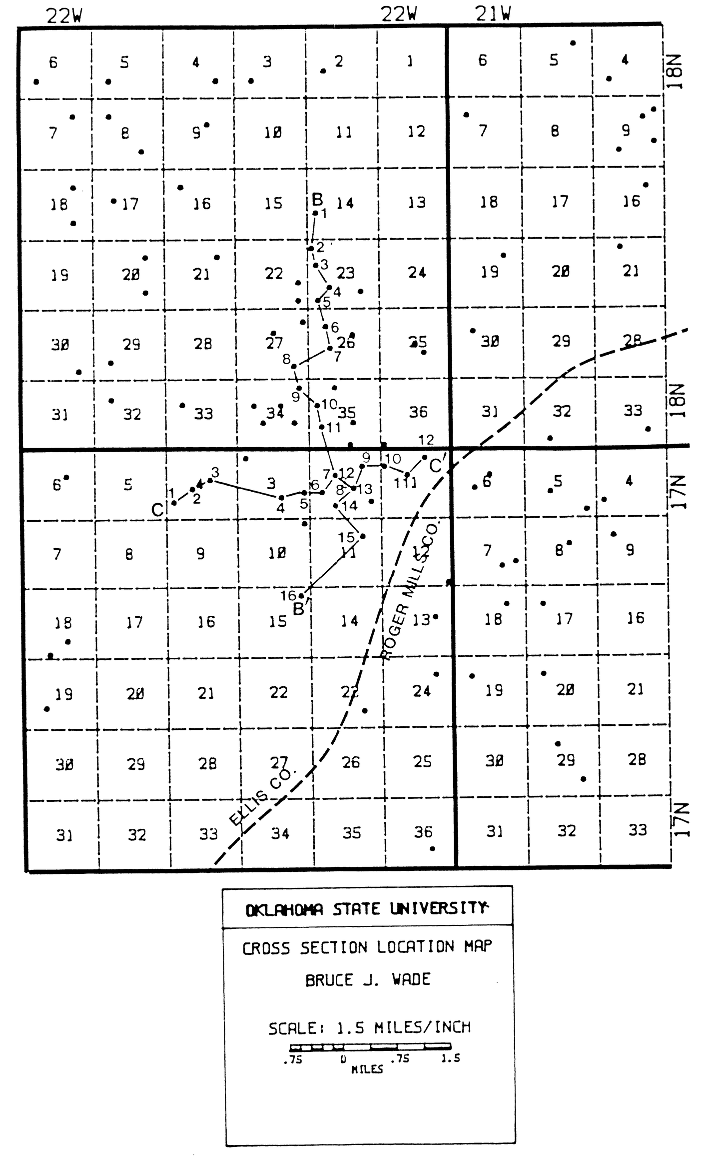




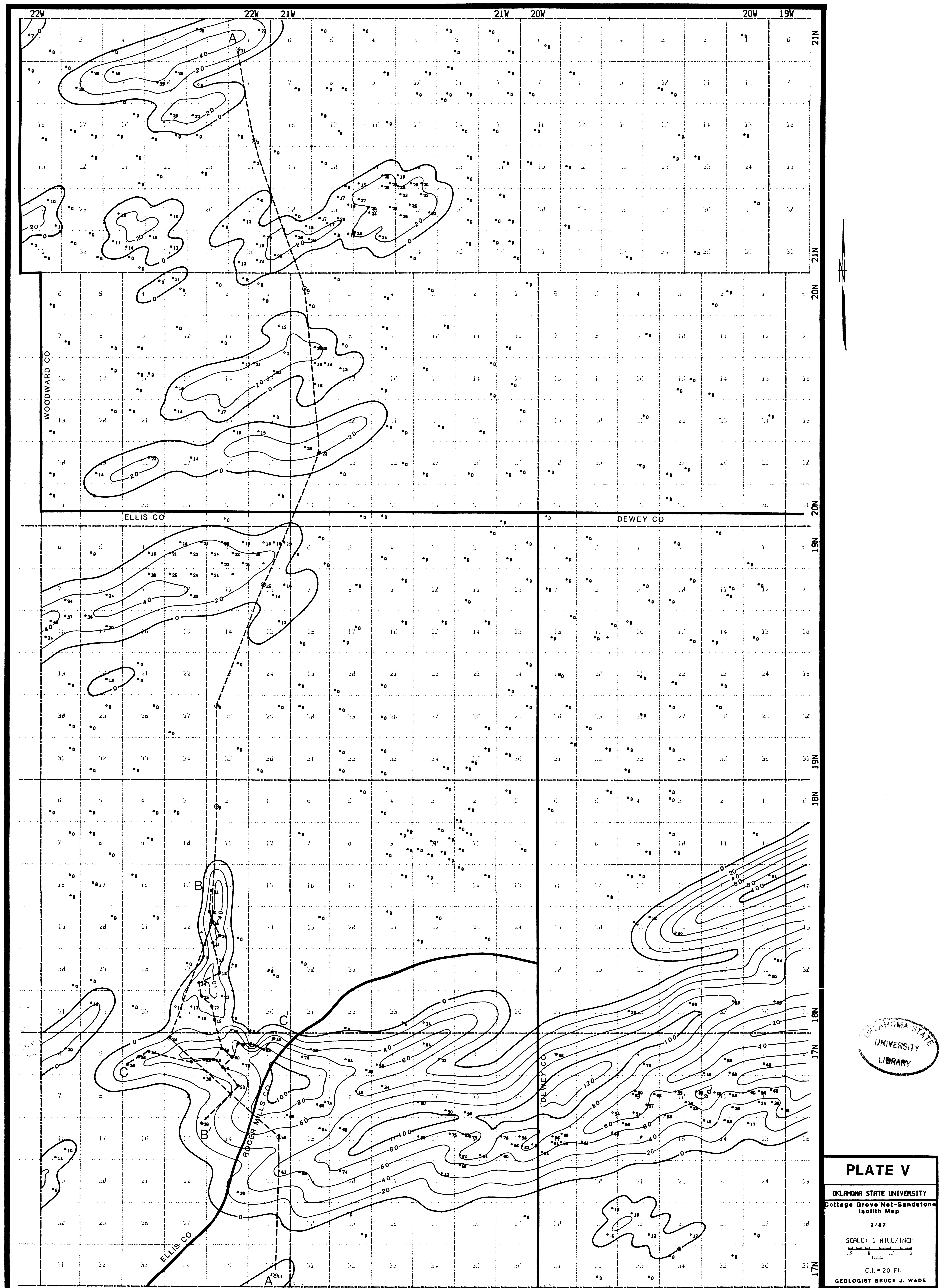


**PLATE IV**

**EAST-WEST STRATAGRAPHIC CROSS SECTION C-C'**

2/87

GEOLOGIST BRUCE J. WADE



22W
21W
20W
19W
21N
20N
19N
18N
17N
A
A'
B
B'
C
C'
WOODWARD CO
ELLIS CO
DEWEY CO
ROGER MILLS CO
PLATE V
OKLAHOMA STATE UNIVERSITY
Cottage Grove Net-Sandstone Isolith Map
2/87
SCALE: 1 MILE/INCH
C.I. = 20 Ft.
GEOLOGIST BRUCE J. WADE