

**KANSAS GEOLOGICAL SURVEY**  
**OPEN-FILE REPORT 78-6**

A Geologic Study of the Sallyards Field Area,  
Greenwood County, Kansas

by

William J. Hulse

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**KANSAS GEOLOGICAL SURVEY**

1930 Constant Avenue  
University of Kansas  
Lawrence, KS 66047

A GEOLOGIC STUDY  
OF THE SALLYARDS FIELD AREA  
GREENWOOD COUNTY, KANSAS

by

William J. Hulse  
B. S. Purdue University, 1973

Submitted to the Department of  
Geology and the Faculty of the  
Graduate School of the University  
of Kansas in partial fulfillment  
of the requirements for the degree  
of Master of Science.

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For the Department

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## ABSTRACT

Facies models of the subsurface Skinner, Burbank, and Bartlesville Sandstones in the Sallyards Field Area, Greenwood County, Kansas, were developed from descriptions of well cores, examination of electric logs, and construction of maps and cross sections. Comparison with process-response models of modern depositional environments indicates that these three sandstones were deposited in fluvial environments.

Studies of cores reveal similar ideal vertical sequences for the three sandstones: a sharp basal contact, above which are large-scale cross bedding or massive bedding, asymmetrical unidirectional current ripples, and a gradational or sharp upper contact with overlying siltstone. Grain size within the sandstones decreases upward as does the scale of sedimentary structures. Rocks which are laterally equivalent to the Burbank and Bartlesville Sandstones probably were deposited in a delta plain to shallow marine shelf environment.

Cross sections through the Sallyards Field area show vertical separation between each sandstone. All three sandstones are discontinuous elongate bodies having convex-down bases. The Bartlesville and Skinner Sandstones are distinctly lenticular and straight along their axes. The Burbank Sandstone, on the other hand, is more uniform in thickness than the other two sandstones and displays a branching pattern.

The sandstones in the three zones are litharenites or feldspathic litharenites whose average composition is 65% quartz, 20% rock fragments, and 15% feldspars.

The sources for the sandstones were probably the nearby Nemaha Uplift to the west, metasediments in northern Greenwood County, and the more distant Canadian Shield to the north. The Bartlesville Sandstone was deposited in a stream flowing from the northeast to the southwest along a low area in the pre-Pennsylvanian surface. Following a marine transgression which inundated the area, the Burbank Sandstone was deposited by southward flowing streams. The net sandstone map of the Burbank zone indicates that the trend of the sandstones does not follow the structure on the Mississippian surface and that the sandstone was deposited over the entire study area. After a subsequent regressive episode, the Skinner Sandstone was deposited in a similar fashion as the Burbank Sandstone. Enclosure of the sandstone bodies in oil-rich shale, draping of the sandstone over the pre-Pennsylvanian surface, and later structural movement of the Cherokee basin led to favorable conditions for the development of combination structure-stratigraphic traps.

Previous regional work, checked by log correlations across Kansas, suggest that the Bartlesville Sandstone in Sallyards Field is laterally equivalent to the surface Bluejacket Sandstone; the Burbank Sandstone occurs above the Bartlesville interval but below the Weir Coal; and the Skinner Sandstone is correlative to the Chelsea Sandstone.

A study of reservoir parameters revealed that permeability may be related to grain size, sedimentary structures, and to the effects of later diagenesis. Vertical sequences of sedimentary structures may be deduced from values of permeability. This may diminish the need for additional coring prior to the initiation of an enhanced recovery process. Porosity shows a general, but ill defined, increase with increasing permeability.

Micellar enhanced recovery methods may have the most applicability in the Sallyards Field Area, however, pore-filling carbonate cements, clay adsorption of chemicals or plugging of pores by clays, lateral discontinuities within the sandstones, and unfavorable salinities of connate waters may adversely affect chemicals injected into the sandstones. Further studies on the effects of mineralogy to the injected chemicals are needed. In-situ combustion may also be feasible in the Sallyards Field Area, but only in that portion of the sandstones with greater than 20 md-ft./cp. transmissibility.

## INTRODUCTION

### Purpose of Investigation

Subsurface "shoestring sandstones" (Rich, 1923) in Greenwood and Butler Counties, Kansas have long been important oil reservoirs. The origin of these sandstones continues to be debated, however, and the geologic characteristics which may influence the feasibility of applying enhanced oil recovery processes to these reservoirs have not been established. The objectives of this research, then, are:

1. To determine and describe the depositional environments of the reservoir sandstones in one field area, using models of sediment deposition.

2. To document geologic characteristics of these sandstones which may improve the understanding of fluid movement through the reservoir.

### Location of the Area of Study

The area of study (Fig. 1) occurs within one of five related systems or trends referred to as the "Golden Lanes" (Bass, 1934). Each trend consists of numerous individual narrow, elongate, lenticular, discontinuous sandstone bodies. Two extend in a northeast-southwest direction, two in a northwest-southeast direction, and a fifth is north-south. The trends extend as much as 75 km and are remarkably straight. The specific area of study includes the present limits of Sallyards Field, Teichgraber Field to the northwest and Jackson Field to the southwest (Fig. 1).

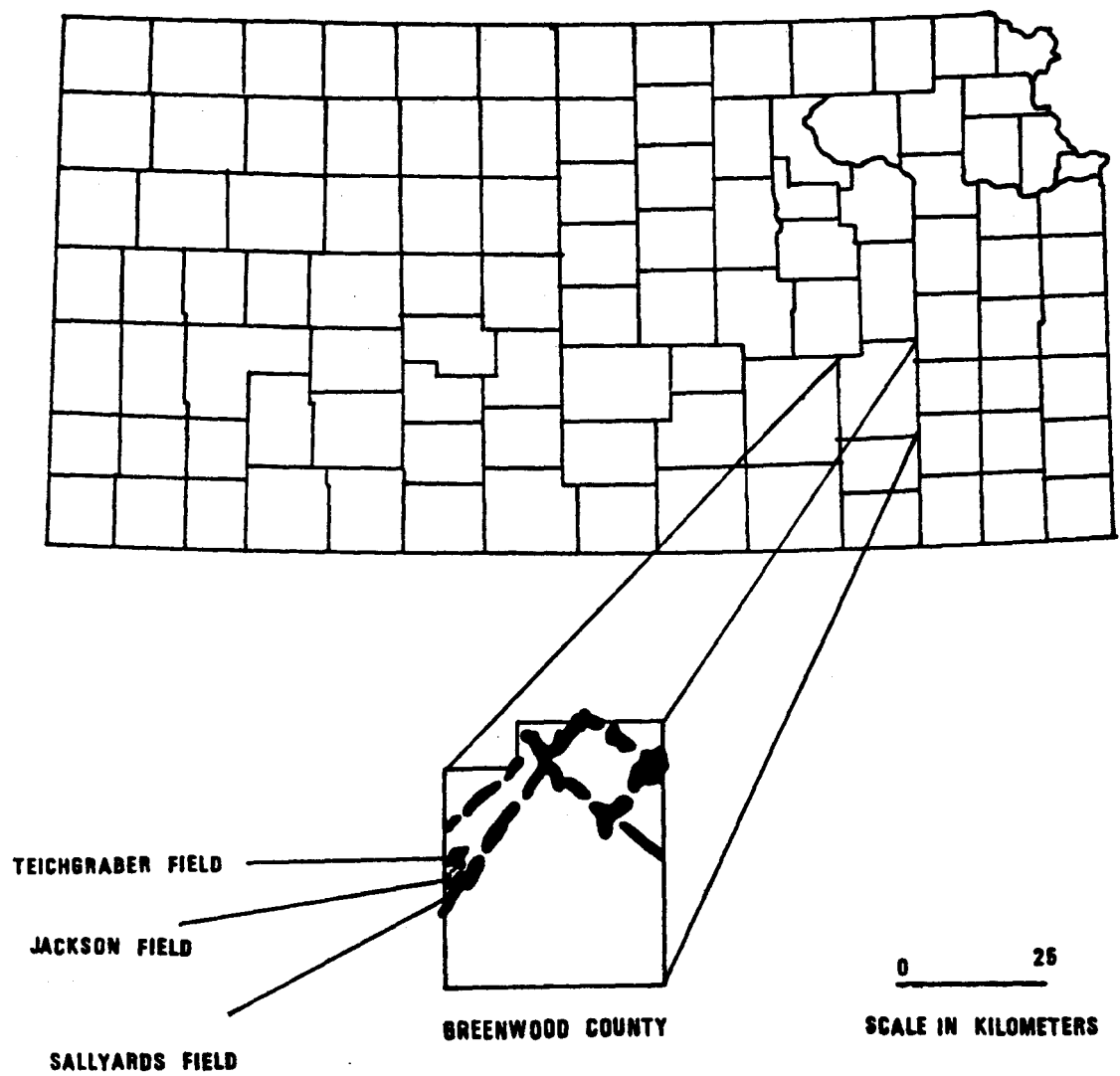


Fig. 1-Location of the area of study. After Bass (1934).

## Previous Investigations

Stratigraphy and petroleum geology of the Cherokee Group in southeastern Kansas and northeastern Oklahoma have been the subject of studies by Moore, et al. (1951), Searight, et al. (1953), Weirich (1953), Howe (1956), Jordan (1957), Branson (1957, 1962), Zeller (1968), Baker (1962, 1969), and Ebanks and James (1974).

The subsurface sandstones in the "Golden Lanes" area have been a subject of considerable controversy since the inception of drilling some sixty years ago. Conflicting theories have been advanced to explain their origin.

Bass (1934, 1936), Bass, et al. (1937), Leatherock (1937), and Cheyney (1929) favored the theory that these sandstones are buried offshore barrier bars because of: 1. the cross-sectional geometry of the sandstone bodies (Fig. 2); 2. the straightness and the "offset" relation of the sandstone bodies with each other (Fig 3); and 3. the supposed similarity of the "shoestring" sandstone bodies in areal distribution and in form to present day barriers forming off the New Jersey coast (Fig. 3).

Cadman (1927), in contrast, cited features in some sandstone bodies which are characteristic of stream channel deposits. His study concentrated on the sandstone of the Teeter Field, which he suggested originated as a river channel deposit because of: 1. the lack of a definite lagoonal facies; 2. a coarse-to-fine sequence of grain size from the base of the sandstone to the top; 3. a curving pattern typical of sands along river meanders,

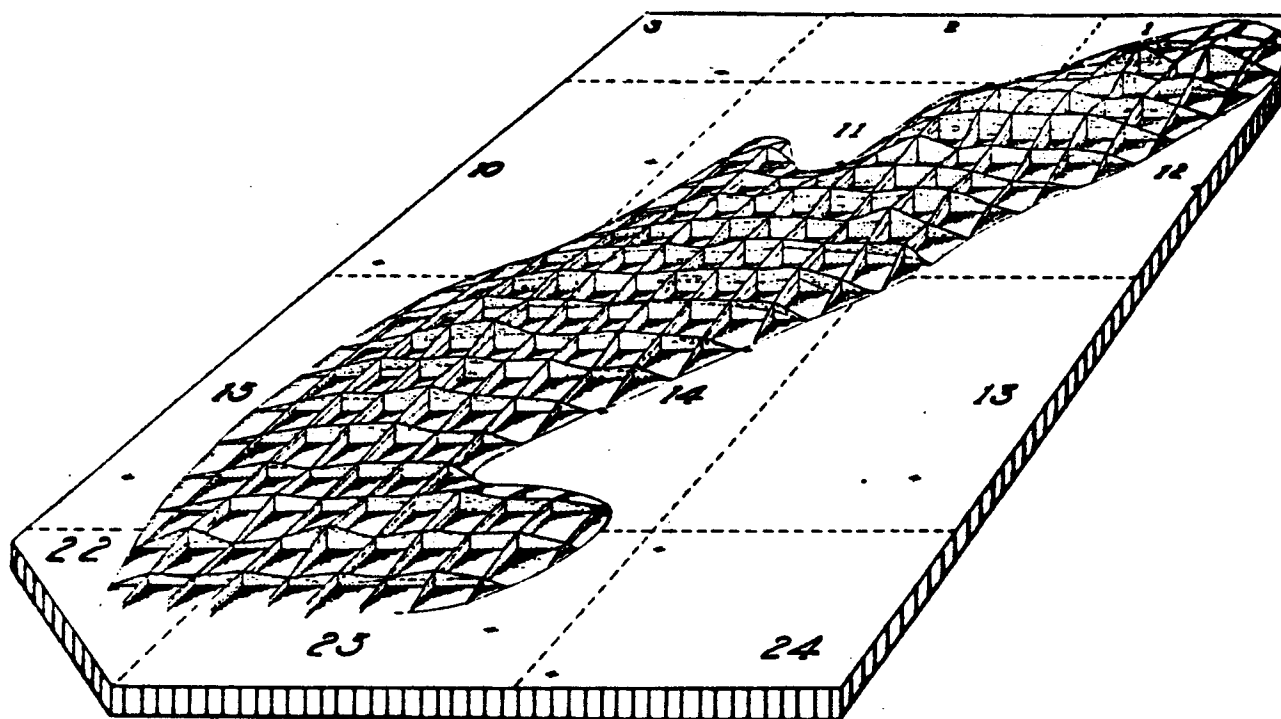


Fig. 2-Fence diagram of a field in the Sallyards Trend showing the convex-up top and sloping planar base. This illustration was constructed from driller's logs. After Bass (1936).

and 4. the scour-and fill contact at the base of the sandstone. MacKenzie (1972) maintains, based on reasoning similar to that of Cadman cited above, that the sandstones in the Burbank trend are an extension of the "Golden Lanes" Trends of southeastern Kansas and that these are channel sandstones. Rich (1923) recognized the possibility of multiple origins for the various trends, such as: 1. off-shore barrier bars; 2. stream channels; 3. beach deposits; and 4. tidal channel deposits.

Busch (1959) proposed that the sandstone bodies are strike-valley sandstones. These deposits are formed in low areas between cuestas during transgression of a shallow sea (Fig. 4). Berger (1921) proposed a similar mode of origin, the deposition occurring between the Nemaha Anticline and a high area to the east which had been produced by folding.

The only recent studies of "shoestring sands" in Kansas are by Maderak (1960), McQuillan (1968), and Hudson (1969). Shoestring sands in northeastern Oklahoma have been the most studied; included are the works of Clements (1961), Clayton (1965), Hawisa (1965), Visher (1968, 1971), Saitta (1968), Dogan (1969), Phares (1969), Scott (1970), and Valderrama (1974).

## Conclusions

Based on the data presented in the paper, the following conclusions have been reached: 1. The Bartlesville, Burbank and Skinner Sandstones were deposited as meandering alluvial systems subsequent to delta progradation through the area;

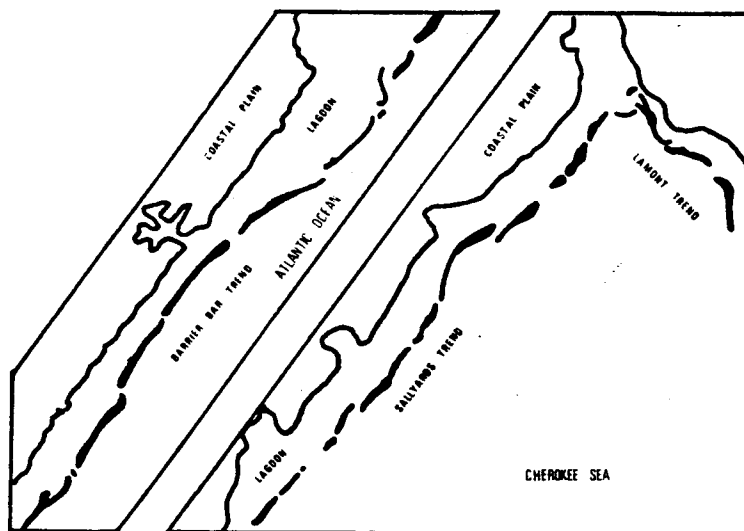


Fig. 3-Comparison of the New Jersey coastline to a hypotheticalal model of the Sallyards Trend showing the similarity in straightness and the en echelon arrangement of sandstone bodies. After Bass (1936).

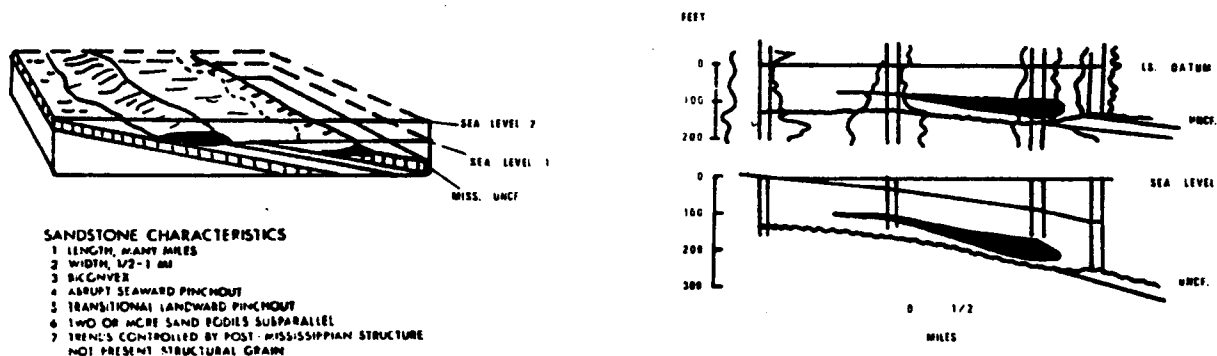


Fig. 4-Characteristics of a strike-valley sandstone. After Busch (1974).

2. The compositions of the sandstones are similar, consisting of 65% quartz, 25% rock fragments, and 10% feldspar; 3. The sandstones are porous bodies enclosed by impermeable Cherokee shales and form combination structural-stratigraphic traps for oil and gas; 4. The subsurface Bartlesville Sandstone in the Sallyards Field Area is laterally equivalent to the surface Bluejacket Sandstone in southeastern Kansas; 5. The source area for the sandstones was the Nemaha Anticline to the north and west, metasediments in northern Greenwood County, and possibly the Canadian Shield Area to the north; 6. Permeability of the sandstones can be directly related to grain size, sedimentary structures and later diagenetic changes; 7. A graph relating permeability values to specific groups of sedimentary structures found in the reservoir sandstones has been developed which allows prediction of a vertical sequence of dominant sedimentary structures from core analyses; 8. Porosity shows an ill-defined increase with increasing permeability; 9. Micellar flooding or in-situ combustion may be the most feasible enhanced recovery methods in the Sallyards Field Area; 10. Cementation, lateral discontinuities, adsorption of chemicals, plugging of pores by clays, connate water composition may adversely affect chemical fluids used in enhanced recovery operations.

## Acknowledgements

This project was supported by the Tertiary Oil Recovery Project of the University of Kansas, Lawrence, and was supervised by Dr. W. J. Ebanks, Jr. of the Kansas Geological Survey. The Geological Survey provided facilities and numerous services for the study.

I would like to thank Drs. M. J. Brady (Chairman), W. J. Ebanks, Jr., and M. E. Bickford for serving as Master's thesis advisors and Drs. A. W. Walton, J. H. Doveton, E. F. McBride and G. W. James for their helpful suggestions. Much appreciation goes to Drs. Don Green and G. Paul Willhite for their help in the engineering section. Thanks also to Abdul Jarjur and Dan Muhs for their labor and Kaye Long, Donna Saile and Debbi Oehler for typing the manuscript. Appreciation also goes to Bill Thetford and Charles Thomas for drafting all the plates.

Finally, thanks go to George Jackson, Jackson Brothers Oil Company, to Lyle English of Beard, English and Martin Oil Company, to R. R. Abderhalden, to R. K. Taylor of Nadel Gussman, and to Harold Russell of White and Ellis Drilling Company for supplying the necessary materials for this study.

## GEOLOGY OF THE CHEROKEE GROUP

### Nomenclature

The Cherokee Group was first described in Cherokee County, Kansas by Haworth and Kirk in 1894 (Jordan, 1957). It is defined as the lowest division of the Desmoinesian Stage, Middle Pennsylvanian Series. It is bounded at the top by the basal member of the Marmaton Group, the Fort Scott Limestone, and at the base by an unconformable contact with the underlying pre-Pennsylvanian surface. In 1953, the name "Cherokee" was pre-empted because of prior use and replaced by the Krebs and Cabaniss Groups. Due to widespread acceptance, the term "Cherokee" was re-adopted in 1955 and the names Krebs and Cabaniss were reduced to subgroups (Howe, 1956). Jewett (1959) changed the status of Krebs and Cabaniss to formations, retaining the named sandstones, coals, and limestones as subdivisions.

### Stratigraphy

The first Pennsylvanian cyclic deposits in southeastern Kansas are those of the Cherokee Group. Interbedding resulted from periodic subsidence and variable rates of sediment supply as the Cherokee sea encroached from the south onto the land. The Cherokee in southeastern Kansas is composed of an abundance of shale and sandstone, with minor coal, underclay and a few thin limestones. Howe (1956) recognized 15 member units outcropping in Cherokee County, Kansas, each containing an incomplete cyclic sequence (Fig. 5). Some of the surface

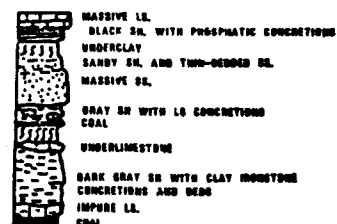
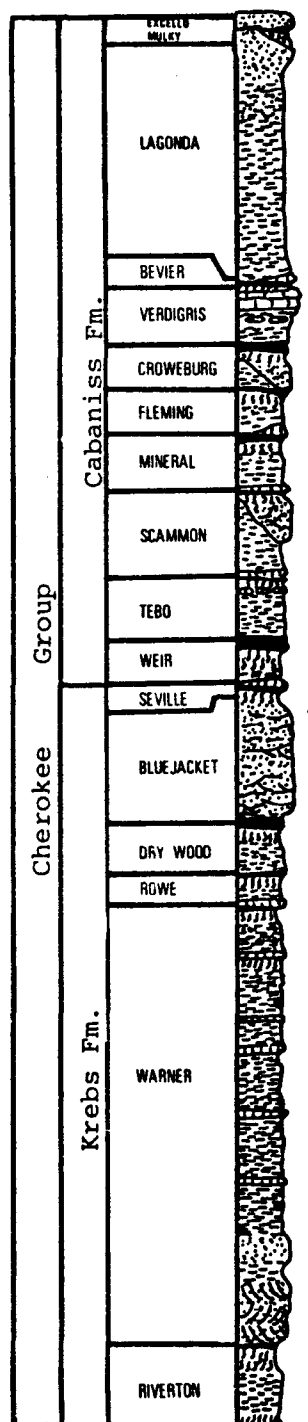


Fig. 5-Generalized rock column of the Cherokee Group outcropping in southeastern Kansas. After Howe (1956).

formations thin drastically or change lithologic character in the subsurface making concise correlations of individual units difficult. In order to correlate the discontinuous sandstones, geologists have resorted to dealing with larger stratigraphic units. Busch (1974) explained the significance of "zones of sedimentation" based on the concept of a Genetic Sequence of Strata. He states,

" A Genetic Increment of Strata is an interval of strata representing one cycle of sedimentation in which each lithologic component is related genetically to all the others; the upper boundary must be a lithologic time marker and the lower boundary may be either a lithologic time marker, an unconformity, or a facies change from marine to non-marine. A genetic sequence of strata is two or more contiguous genetic increments representing more or less continuous sedimentation."  
(Fig. 6)

The boundaries must represent contemporaneous deposition for the concept to be valid.

Cole (1969) reconstructed the paleodepositional configuration of the Arkoma Basin in Oklahoma using six genetic increments of strata based on five continuous limestones or coals in the Cherokee Group. However, attempts to correlate between Kansas and Oklahoma have proven difficult.

The earliest attempts at correlation were by Bass (1936) and Bass et al. (1937). He equated the lowermost sandstone in the Golden Lanes trends to the Red Fork sandstone of the Oklahoma subsurface, based on a cross section through Osage and Kay Counties, Oklahoma (Fig. 7).

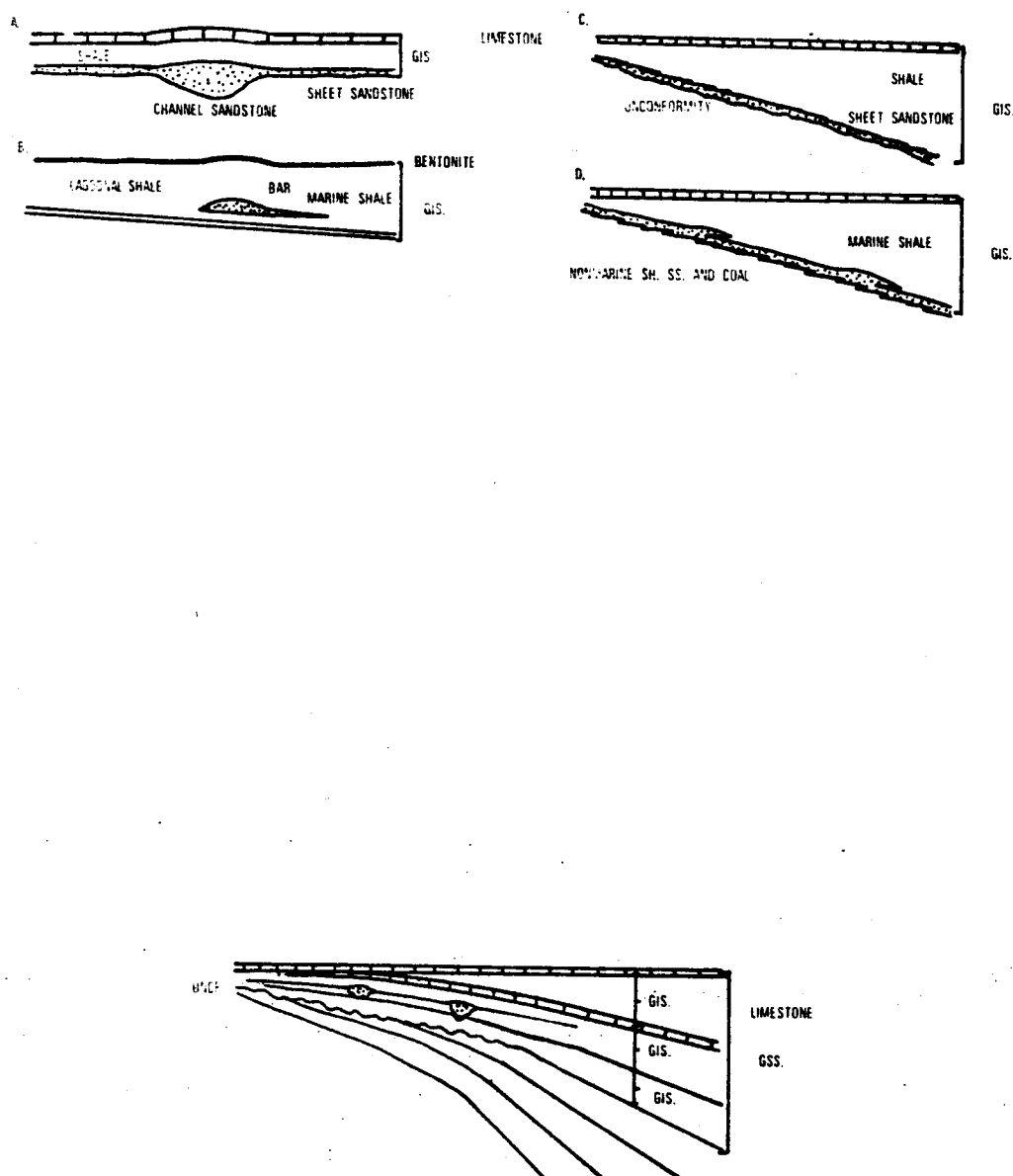


Fig. 6-Examples of the concept of "A Genetic Sequence of Strata". Examples A through D are examples of individual genetic increments of strata which might be a part of a genetic sequence (lower picture). After Busch (1974).

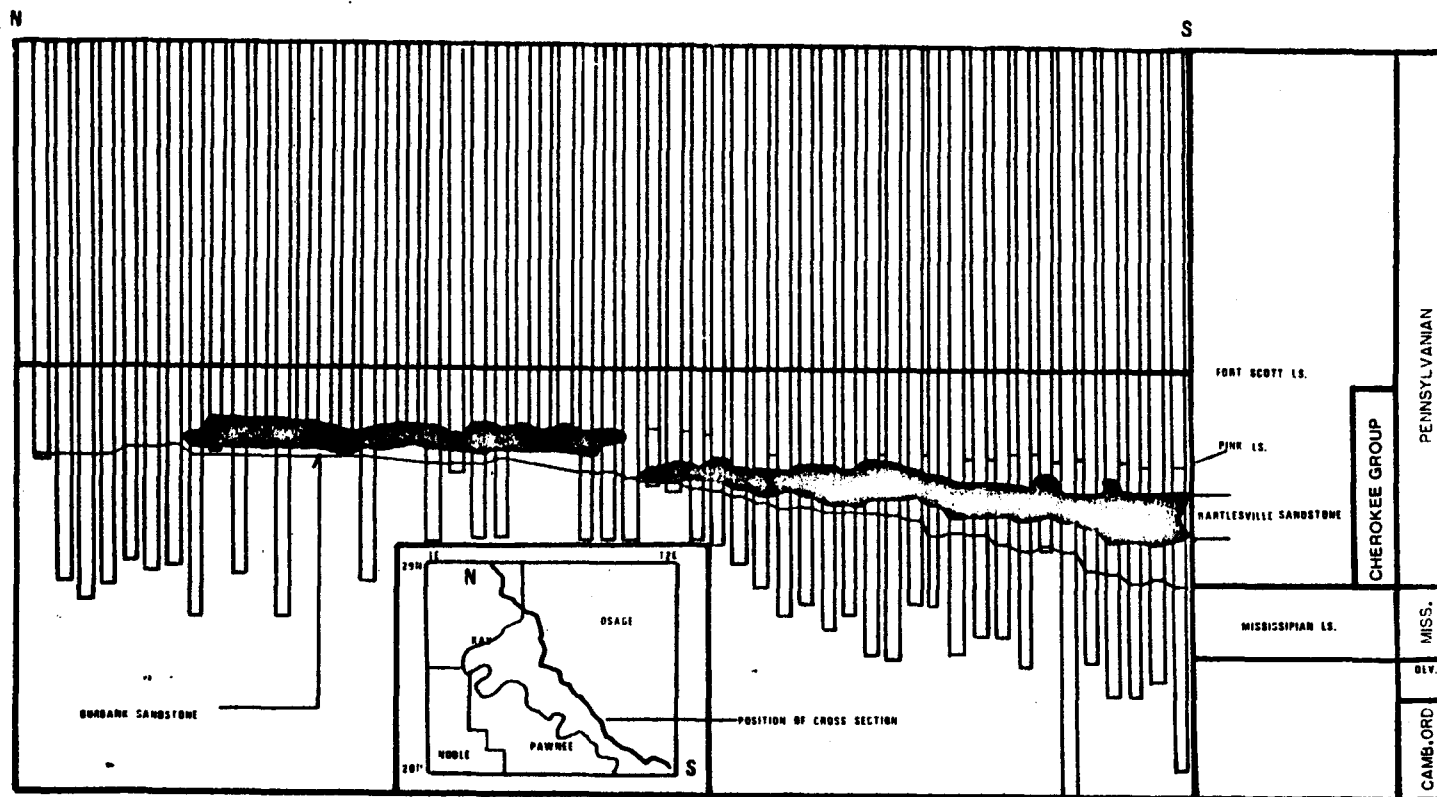


Fig. 7-Cross section by Bass (1937) through Osage and Kay Counties, Oklahoma showing separation between the Burbank and Bartlesville Sandstones.

The cross section showed the Burbank Sandstone to be stratigraphically higher and separated from the Bartlesville Sandstone by shale. Both sandstones also occupied similar positions with respect to the underlying pre-Pennsylvanian surface. Assuming that the sandstones were laid down on a southward dipping eroded surface as off-shore bars during a northward transgression of the sea, Bass suggested that the Bartlesville Sandstone was buried prior to the deposition of the Burbank trend and its extension into Greenwood County, Kansas. Hudson (1969) developed a cross section from Sallyards Field to Osage County, Oklahoma (Fig. 8). From this he correlated all of the Cherokee producing formations below the Verdigris Limestone to the Red Fork (Burbank) zone. His interpretation was based on the onlap of the Inola and Pink limestones onto a pre-Pennsylvanian high in Chautauqua County, Kansas (Fig. 8). He further stated that the sandstone in the Sallyards Trend was younger than "true Bartlesville" sandstones in the northwest-southeast trends based on the conclusions of Bass (1936). Finally, Visher et al. (1971) suggested that the time stratigraphic framework in Kansas could not be re-constructed because of a lack of data and non-deposition of recognizable time-marker units.

Bass (1936), though, does not state conclusively that the trends are of different age. In an attempt in this study to resolve the problem, correlations were made to logs of wells near the surface outcrops in eastern-most Kansas.

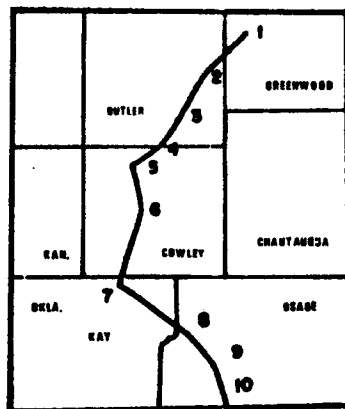
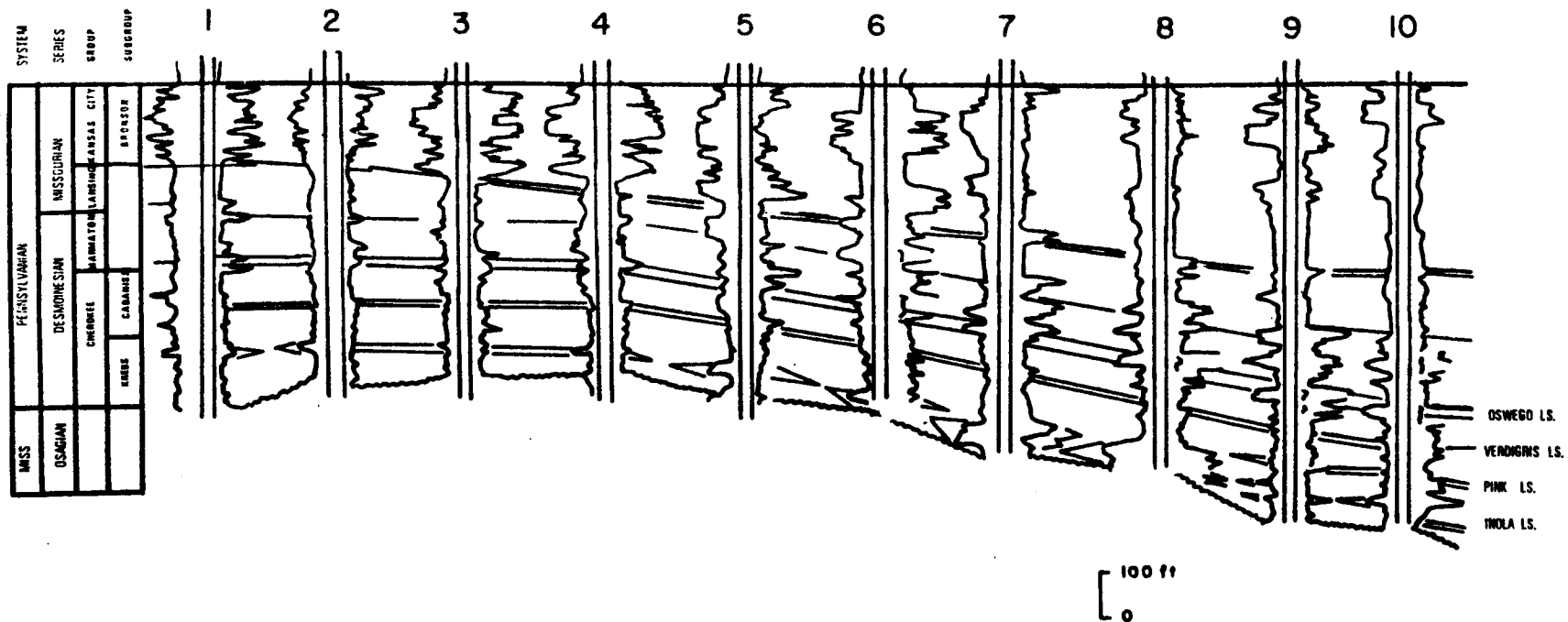


Fig. 8-A north to south cross section showing onlap of the Cherokee Group on a pre-Pennsylvanian high in Cowley County, Kansas. After Hudson (1969).

An east-west cross-section from the Sallyards Field area to the Missouri state line along Township 26 South (Plate 1) suggests that marker units are present and that the lowest producing sandstone in Sallyards Field is equivalent to the Bluejacket Sandstone in outcrop. The lowermost sandstone in the Sallyards Field Area may indeed be equivalent to the Bartlesville Sandstone in Northeastern Oklahoma; however, the scarcity of data and ambiguities in surface and subsurface correlations between Kansas and Oklahoma obscure the relationships between genetic increments of strata present in the two states. The Oklahoma zone boundaries by Cole (1969) and their proposed Kansas equivalents are given in Figure 9.

Lithologic descriptions of the relevant marker units and Sandstone zones of the Cherokee Group in the Sallyards Field Area are given in Appendix A.

The term "zone", as used here, has no significance as a paleontological unit in the usual sense, but, rather, is used to designate a group of beds or correlatable stratigraphic units, without regard to formational boundaries. "Zone" is used informally to discuss intervals which include important oil-producing sandstones.

Fig. 9-Comparison of zone boundaries used by Cole (1969) and those used in this thesis. Modified from Baker (1962).

| SOUTHEASTERN KANSAS                          |                    |                     |                   | NORTHEASTERN OKLAHOMA                                                           |                   |                   |                                                                 |                   |                                      |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |
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| FORMATION                                    |                    | MEMBER              |                   | FORMATION                                                                       |                   | MEMBER            |                                                                 |                   |                                      |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |
| MIDDLE PENNSYLVANIAN<br>DESYNCHRONOUS SERIES | CYGANA SUBSTAGE    | INFORMATION GROUP   | Fort Scott        | Holmesville Lm.<br>Little Osage Sh.<br>Blackjack Creek Lm.                      | SCOTIA            | Fort Scott        | Holmesville Lm.<br>Little Osage Shale<br>Blackjack Creek Lm.    |                   |                                      |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |
|                                              |                    |                     | Excelsio          | Excelsio Sh.                                                                    |                   | Excelsio Sh.      |                                                                 |                   |                                      |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |
|                                              |                    | CARANESS SUBGROUP   | Mulky             | Mulky Coal<br>Breezy Hill Lm.                                                   |                   | SUBSURFACE        | PRUE-CALVIN ZONE                                                | Mulky             | Breezy Hill Lm.<br>Kinnison Sh.      |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |
|                                              |                    |                     | Lagonda           |                                                                                 |                   |                   |                                                                 | Lagonda           | Iron Post Coal<br>Lagonda Ss.        |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |
|                                              |                    |                     | Bevier            | Bevier Coal                                                                     |                   |                   |                                                                 | Bevier            | Bevier Coal                          |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |
|                                              |                    |                     | Verdigris         | Verdigris Lm.                                                                   |                   |                   |                                                                 | Verdigris         | Verdigris Lm.<br>Verdigris Black Sh. |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |
|                                              |                    |                     | Croweburg         | Croweburg Coal                                                                  |                   |                   |                                                                 | Croweburg         | Croweburg Coal                       |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |
|                                              |                    |                     | Fleming           | Fleming Coal                                                                    |                   |                   |                                                                 | Fleming           | Fleming Coal                         |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |
|                                              |                    |                     | Robinson Branch   | Robinson Branch Coal                                                            |                   |                   |                                                                 | Robinson Branch   | Russell Creek Lm.                    |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |
|                                              |                    |                     | Mineral           | Mineral Coal                                                                    |                   |                   |                                                                 | Mineral           | Mineral Coal                         |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |
|                                              |                    |                     | Scammon           | Chelsea Ss.<br>Tlawah Lm.                                                       |                   |                   |                                                                 | Scammon           | Chelsea Ss.<br>Tlawah Lm.            |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |
|                                              |                    |                     | Tobo              | Tobo Coal                                                                       |                   |                   |                                                                 | Tobo              | Upper Taft Ss.                       |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |
|                                              | Wier               | Wier-Pittsburg Coal | Wier              | Wier-Pittsburg Coal<br>Taft Ss.<br>Verdigris Lm.<br>(Inola ss. l.)<br>Inola Lm. |                   |                   |                                                                 |                   |                                      |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |
|                                              | VENTERIAN SUBSTAGE | KANSAS SUBGROUP     | Seville           | Seville Lm.                                                                     | SKINNER ZONE      | Seville           | Seville Lm.                                                     |                   |                                      |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |
|                                              |                    |                     | Blue Jacket       | Blue Jacket Coal<br>Blue Jacket Ss.                                             |                   | Blue Jacket       | Blue Jacket Coal<br>Blue Jacket Ss.                             |                   |                                      |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |
|                                              |                    |                     | Dry Wood          | Dry Wood Coal                                                                   |                   | Dry Wood          | Coal<br>Doreley Lm.                                             |                   |                                      |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |
|                                              |                    |                     | Roue              | Roue Coal                                                                       |                   | Roue              | Roue Coal<br>San Creek and<br>Shanley Lm.                       |                   |                                      |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |
|                                              |                    |                     | Warner            | Neutral Coal<br>Warner Ss.                                                      |                   | Warner            | Warner Ss.                                                      |                   |                                      |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |
|                                              |                    |                     | Wentworth         | Wentworth Coal                                                                  |                   | Wentworth         | Wentworth Coal<br>San Creek Lm.<br>Tawanna Lm.<br>Ss. and Cong. |                   |                                      |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |
|                                              |                    |                     | BEECHY            | BARTLESVILLE ZONE                                                               |                   | BARTLESVILLE ZONE | BARTLESVILLE ZONE                                               | BARTLESVILLE ZONE | BARTLESVILLE ZONE                    | BARTLESVILLE ZONE |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |
|                                              |                    |                     |                   |                                                                                 |                   |                   |                                                                 |                   |                                      |                   | BEECHY            | BARTLESVILLE ZONE | BARTLESVILLE ZONE | BARTLESVILLE ZONE | BARTLESVILLE ZONE | BARTLESVILLE ZONE |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |
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| BEECHY                                       |                    |                     |                   |                                                                                 |                   |                   |                                                                 |                   |                                      |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |
|                                              | BEECHY             | BARTLESVILLE ZONE   | BARTLESVILLE ZONE | BARTLESVILLE ZONE                                                               | BARTLESVILLE ZONE | BARTLESVILLE ZONE |                                                                 |                   |                                      |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |
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| BEECHY                                       |                    |                     |                   |                                                                                 |                   |                   |                                                                 |                   |                                      |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   | BARTLESVILLE ZONE | BARTLESVILLE ZONE | BARTLESVILLE ZONE |
|                                              | BEECHY             | BARTLESVILLE ZONE   | BARTLESVILLE ZONE | BARTLESVILLE ZONE                                                               | BARTLESVILLE ZONE | BARTLESVILLE ZONE |                                                                 |                   |                                      |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |
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| BEECHY                                       |                    |                     |                   |                                                                                 |                   |                   |                                                                 |                   |                                      |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   | BARTLESVILLE ZONE | BARTLESVILLE ZONE | BARTLESVILLE ZONE |
|                                              | BEECHY             | BARTLESVILLE ZONE   | BARTLESVILLE ZONE | BARTLESVILLE ZONE                                                               | BARTLESVILLE ZONE | BARTLESVILLE ZONE |                                                                 |                   |                                      |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |
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|                                              | BEECHY             | BARTLESVILLE ZONE   | BARTLESVILLE ZONE | BARTLESVILLE ZONE                                                               | BARTLESVILLE ZONE | BARTLESVILLE ZONE |                                                                 |                   |                                      |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |
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| BEECHY                                       |                    |                     |                   |                                                                                 |                   |                   |                                                                 |                   |                                      |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   | BARTLESVILLE ZONE | BARTLESVILLE ZONE | BARTLESVILLE ZONE |
|                                              | BEECHY             | BARTLESVILLE ZONE   | BARTLESVILLE ZONE | BARTLESVILLE ZONE                                                               | BARTLESVILLE ZONE | BARTLESVILLE ZONE |                                                                 |                   |                                      |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |
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| BEECHY                                       |                    |                     |                   |                                                                                 |                   |                   |                                                                 |                   |                                      |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   | BARTLESVILLE ZONE | BARTLESVILLE ZONE | BARTLESVILLE ZONE |
|                                              | BEECHY             | BARTLESVILLE ZONE   | BARTLESVILLE ZONE | BARTLESVILLE ZONE                                                               | BARTLESVILLE ZONE | BARTLESVILLE ZONE |                                                                 |                   |                                      |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |
|                                              |                    |                     |                   |                                                                                 |                   |                   | BEECHY                                                          | BARTLESVILLE ZONE | BARTLESVILLE ZONE                    | BARTLESVILLE ZONE | BARTLESVILLE ZONE | BARTLESVILLE ZONE |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |
|                                              |                    |                     |                   |                                                                                 |                   |                   |                                                                 |                   |                                      |                   |                   |                   | BEECHY            | BARTLESVILLE ZONE | BARTLESVILLE ZONE | BARTLESVILLE ZONE | BARTLESVILLE ZONE | BARTLESVILLE ZONE |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |
|                                              |                    |                     |                   |                                                                                 |                   |                   |                                                                 |                   |                                      |                   |                   |                   |                   |                   |                   |                   |                   |                   | BEECHY            | BARTLESVILLE ZONE | BARTLESVILLE ZONE | BARTLESVILLE ZONE | BARTLESVILLE ZONE | BARTLESVILLE ZONE |                   |                   |                   |                   |                   |                   |                   |                   |                   |
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| BEECHY                                       |                    |                     |                   |                                                                                 |                   |                   |                                                                 |                   |                                      |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   | BARTLESVILLE ZONE | BARTLESVILLE ZONE | BARTLESVILLE ZONE |
|                                              | BEECHY             | BARTLESVILLE ZONE   | BARTLESVILLE ZONE | BARTLESVILLE ZONE                                                               | BARTLESVILLE ZONE |                   |                                                                 |                   |                                      |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |

## Structural Setting and Regional Tectonics

The Cherokee Basin (Fig. 10), a shelf-like extension of the Arkoma Basin in Oklahoma, extends from the Ozark Uplift westward to the eastern flank of the Nemaha Uplift. Low relief on the pre-Pennsylvanian surface partially isolates the Cherokee Basin from the Forest City Basin to the north. The Desmoinesian stratigraphic section in the Cherokee Basin varies from 110 to 275 m in thickness and dips west-northwest at a rate of 3-5 m/km from western Missouri to the Nemaha Anticline (Ebanks and James, 1974).

The Cherokee Basin developed by gentle downwarp to the south after rising of the Nemaha Uplift (Ebanks and James, 1974). Folding, faulting and erosion upon the pre-Pennsylvanian surface created an irregular topography with considerable relief. To the south the Arkoma Basin was actively subsiding while the Ouachita Mountains were undergoing deformation. Periodic movements and down to the east faulting along the Nemaha Uplift continued through Desmoinesian time to the Permian (Weirich, 1953). It was in this setting that seas advanced from the south.

Pennsylvanian sediments were deposited during an overall transgression, as indicated by onlap of progressively younger sediments (Fig. 11) on the eroded pre-Pennsylvanian surface and an overall change in sediment character from clastics to carbonates within the Desmoinesian Stage (Weirich, 1953; Visher, et al., 1971; Ebanks and James,

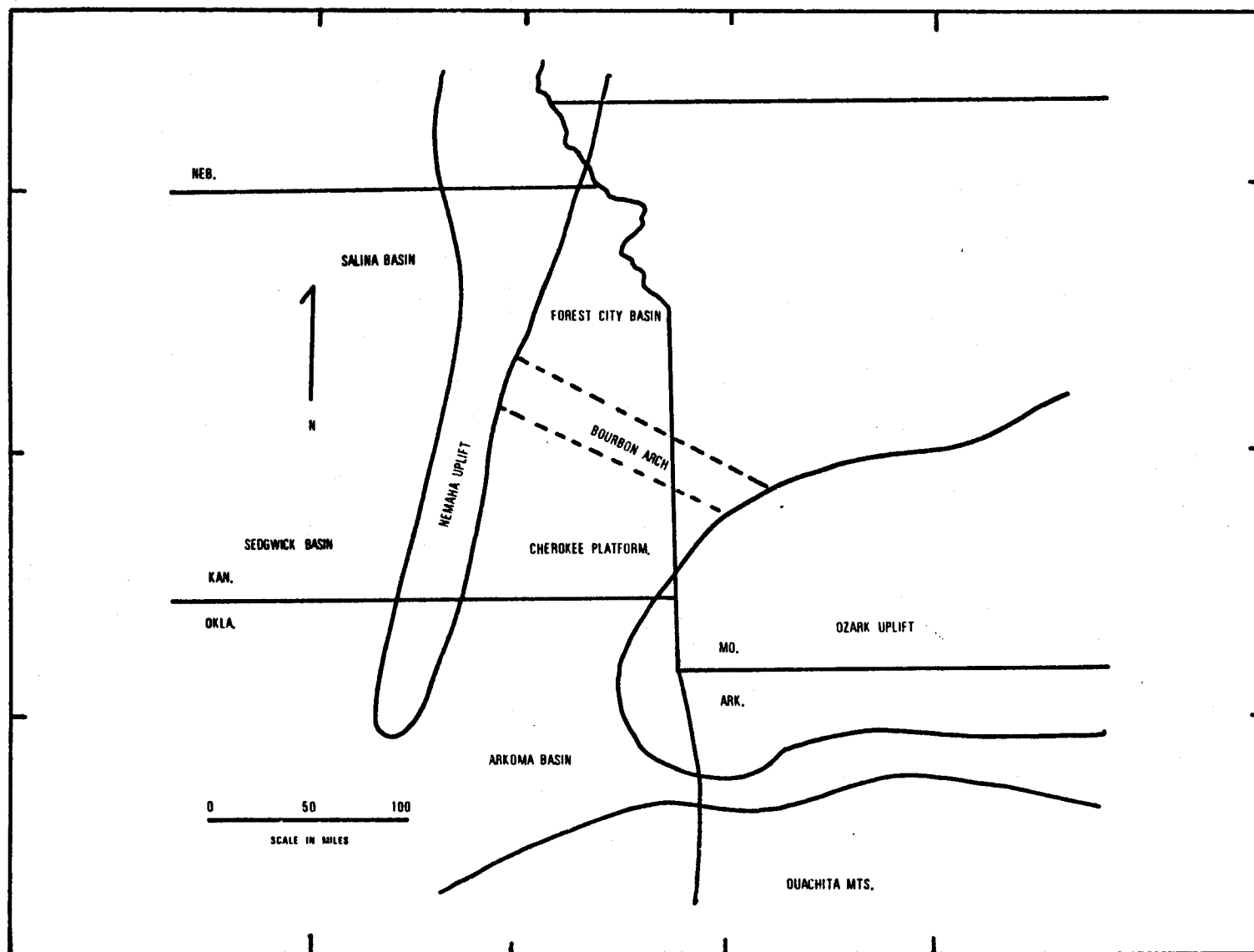


Fig. 10-Structural setting during Middle Pennsylvanian time.  
After Van Dyke (1975).



Fig. 11-North to south cross section through southeastern Kansas showing transgressive onlap of the Cherokee Group. After Ebanks and James (1974).

1974). Branson (1968), however, suggests that the water was never greater than 60 m deep and that portions of the shelf were exposed at least 20 times during deposition of the Cherokee Group. The transgression was interrupted by several regressive episodes which were deposited as widespread, locally lenticular sandstone sheets and coal deposits covering thousands of kilometers. Deltaic complexes formed in the Arkoma Basin while coastal delta plains and alluvial deposits formed on the platform in Oklahoma, Kansas and Missouri (Visher, et al., 1971). In mid-to-late Cherokee time, the Bourbon Arch was inundated, and the Cherokee and Forest City Basins were joined. Late Permian movement along the Ozark Uplift resulted in north-westward tilting of the Cherokee Basin Strata.

## Geology Of The Sallyards Field Area

### Stratigraphy and Areal Distribution of the Reservoir Rocks

Oil is produced from four sandstones within the Cherokee Group in Sallyards Field: the Bartlesville, Burbank, Skinner and Cattleman Sandstones. The Bartlesville, Burbank and Skinner Sandstones trend in a northeast-southwest direction and are as thick as 30 meters, 12 meters, and 15 meters, respectively. The Bartlesville Sandstone extends 11 km in this area, varies from 1 to 1.6 km in width, and is remarkably straight along its axis. The Burbank zone consists of a number of laterally equivalent discontinuous sandstones covering an area of approximately 80 km<sup>2</sup> northwest of the Bartlesville trend in the area of study (Plate 9). The distribution of the Skinner Sandstones is obscured by incomplete well control but they appear as elongate, narrow, discontinuous sandstones with widths of 0.5 km or less in Sections 23, 24, and 35, T-25-S, R-8-E; Sections 18 and 19, T-25-S, R-9-E; and Sections 1, 2, 3, 9, 10, 11, T-26-S, R-8-E. The upper horizon of the Burbank zone, the Cattleman zone, and the Squirrel zone were not mapped because a study of the scout tickets for wells in the Sallyards Field Area revealed that these sandstones were unproductive.

The Bartlesville Sandstone continues northeast-southwest in the Sallyards trend and oil is produced from this reservoir in the Blankenship, Polhamus, Seeley-Wick, and Thrall-Aagard Fields. The Skinner zone is laterally

equivalent to an important north-south trend further east in Anderson and Allen Counties, Kansas where it occurs in Kincaid, Selma, Centerville, Davis-Bronson, and Elsmore Fields (Van Dyke, 1975). Laterally, the sandstones cut down into greenish gray or dark gray shales which contain but do not produce hydrocarbons. The extent of the Burbank Sandstone is unknown.

#### Geometry of the Sandstones

Over 500 driller's and electric logs were used to develop stratigraphic cross-sections, structural cross-sections and subsurface maps. The major sources of possible error were lack of elevations for most of the gamma ray and driller's logs and the use of driller's logs in areas with no electric logs. Elevations were estimated from topographic maps and presented no serious problem. Only those driller's logs whose sandstone horizons could be interpreted clearly were used. It is felt that both sources of error were minor and that reliable data was used. The Verdigris Limestone was used as a datum for stratigraphic measurement based on the assumption that it was deposited contemporaneously over the whole area of study (Busch, 1974). It was used in preference to Fort Scott Limestone because of its stratigraphic proximity to the sandstone deposits.

#### Shape of the Sandstone Bodies

Stratigraphic cross-sections (Plates 2-5) and maps of sediment thickness are used here to depict the shape

of important sandstones within the study area. Locations of the cross-sections are given in Plate 6.

Bartlesville Sandstone - The net sand map of the Bartlesville zone (Plate 7) indicates that the sandstone, is distinctly lenticular; that is, it thickens in the middle and abruptly thins on the edges. The sandstone which trends northeast-southwest, has a straight trend overall but is highly irregular in thickness. The isopach map from the base of the sandstone to the Verdigris Limestone shows that the sandstone base was convex downward during deposition (Plate 8). Stratigraphic cross sections A-A', C-C', D-D' show that the Bartlesville sandstone is in actuality a number of laterally interconnected, "stacked" sandstone bodies separated by continuous or discontinuous shales. Cross sections D-D' and A-A' indicate that the Bartlesville thickens at the expense of the underlying shales (line A on both cross-sections). Self potential logs usually show an abrupt change at the base and a blocky or a gradually reducing deflection from the shale line upward toward the top of the sandstone. Cross sections C-C' and D-D' both show an asymmetrical cross-sectional shape with the thicker sandstone interval to the west.

Burbank Sandstone - The net sandstone map of the lower horizon (Plate 9) indicates that the Burbank Sandstone exhibits a branching pattern (follow arrows on Plate 9), is discontinuous but more uniform in thickness

or less distinctly lenticular than the Bartlesville Sandstone, has a widespread distribution and follows or cuts across the Bartlesville Sandstone in certain areas. In fact, the pattern of arrows suggests more than one episode of deposition and will be discussed in the "History of Deposition of the Sandstones" section. Correlations of shale units within the Burbank and Bartlesville intervals in all stratigraphic cross sections (Plates 2-5; line B) show a distinct separation between the the Bartlesville and Burbank Sandstones. For this reason it is believed that the Burbank Sandstone was deposited later than the Bartlesville Sandstone. A map of thickness from the base of the sandstone to the Verdigris Limestone (Plate 8) shows that this sandstone has an irregular, flattened base in Teichgraber Field and a convex downward base in Jackson Field. On cross sections A-A' and C-C' (line B) the sandstone cuts down into underlying shales indicating a channel morphology. Self potential logs show an abrupt base with a blocky curve-shape or a gradually decreasing deflection from the shale base line toward the top of the sandstone.

Skinner Sandstone - The net sandstone map (Plate 10) indicates that the Skinner Sandstone thickens in the middle and abruptly thins on the edges. The distribution is obscured by incomplete well control; however, the Skinner seems to be widespread, occurring in narrow straight channels. Cross section D-D' demonstrates that the Skinner Sandstone thickens at the expense of the underlying shales. Electric log patterns are similar to those in the Bartlesville zone.

## Attitude of the Reservoir Sandstones

Stratigraphic cross sections A-A' and D-D' reveal that the Bartlesville Sandstone was deposited over a low in the pre-Pennsylvanian surface. Hudson (1969) suggests that deposition of the Bartlesville Sandstone was influenced by faults and folds in the pre-Pennsylvanian terrane because of the similarity in direction of the faults paralleling the Nemaha Uplift and the NE-SW trend of the sandstones (Fig. 46). Cole (1969) suggests that the Cherokee sandstones in Oklahoma follow topographic lows on the pre-Pennsylvanian surface. To find the influence of the underlying structure on the sandstones, a structure map at the top of the pre-Pennsylvanian surface was constructed (Plate 11). Comparison of the map with the net sandstone map of the Bartlesville interval shows that the trend of the Bartlesville Sandstone generally corresponds well with an underlying low. A high in the pre-Pennsylvanian surface in Section 3-26S-8E corresponds with a thinning of the Bartlesville Sandstone. This development may be explained by McCoy and Keyte (1934), who suggest that further deformation of the pre-Pennsylvanian surface occurred during Cherokee time. The underlying surface undoubtedly influenced deposition of the Bartlesville Sandstone. While topographic relief due to erosion cannot be discounted, the striking parallelism between faults and the trends of the "Golden Lanes" Sandstones suggests that the conclusion by Hudson (1969) offers the most likely interpretation for the straight-line pattern of the "Golden Lanes" trends. The Burbank

and Skinner Sandstones show no correlation to the underlying topography and have a less confined pattern of occurrence. Therefore, their deposition was probably not influenced by the underlying structure.

The structure map of the base of the Verdigris Limestone (Plate 12) shows the limestone draping over the sandstones. This effect may be attributed to differential compaction over the sandstones (Rich, 1938), and to the underlying structure of the pre-Pennsylvanian surface. Structural cross sections A-A', B-B' and D-D' indicate that the Bartlesville Sandstone dips to the east, to the west, or in both directions. Comparison of the structural cross sections with the pre-Pennsylvanian structure map indicates that both sandstones drape over underlying topographic highs. Stratigraphic cross sections A-A' and D-D', however, show the Bartlesville Sandstone deposited in low areas on the underlying surface. This suggests that the underlying surface underwent further movement after deposition of the sandstones.

In summary, the Bartlesville Sandstone was laid down over a pre-Pennsylvanian low which constricted deposition to a narrow area. The straight trend of the sandstone and the similarity in direction between the sandstones and faults paralleling the Nemaha Uplift suggests that the major influence on deposition of the Bartlesville Sandstone was the underlying structure deformed by folding and faulting, however, topographic relief cannot be discounted. The widespread distribution of the Burbank and Skinner

Sandstones suggests that the underlying structure did little to influence their deposition. Later structural movement of the underlying surface and differential compaction caused the draping seen in the structural cross sections. Movement during Permian time along the Ozark Uplift imparted a slight westward dip to the area.

### Petrography

Results of point counts from 10 thin sections divided equally from samples among the three sandstones is shown in Table 1. The point-counts indicate a remarkable similarity among the three sandstones. Mineralogy petrofabric of the sandstones has been determined by the study of 50 thin sections taken from cores which are thought to be representative of the three zones.

Quartz - Silica grain-types dominate the framework fraction of the reservoir rocks. Monocrystalline quartz comprises 50-75% of the detrital portion. The single grains are fine to very fine in size, subangular, and subequant to elongate in shape. The boundaries are commonly corroded (Figs. 12, 23) and extinction varies from straight to strongly undulose. Vacuoles occur in most grains either in random fashion or in trains (Fig. 12). Greenish needle-like inclusions are present. The greenish inclusions are probably apatite (Van Dyke, 1975). The angular nature of many of the single grains is due in part to the presence of overgrowths. Euhedral outlines are the most common indicators of overgrowths, but in

|                        | 1  | 2  | 3  | 4  | 5   | 6  | 7  | 8  | 9  | 10 |
|------------------------|----|----|----|----|-----|----|----|----|----|----|
| <u>Quartz Types</u>    |    |    |    |    |     |    |    |    |    |    |
| Monocrystalline        | 86 | 62 | 80 | 99 | 102 | 98 | 78 | 91 | 96 | 93 |
| Polycrystalline        | 8  | 11 | 9  | 4  | 5   | 10 | 15 | 5  | 7  | 8  |
| Stretch Quartz         | 0  | 0  | 0  | 0  | 0   | 0  | 0  | 0  | 0  | 1  |
| Schistose Quartz       | 16 | 14 | 15 | 9  | 14  | 5  | 12 | 19 | 20 | 11 |
| Chert                  | 1  | 2  | 1  | 0  | 0   | 0  | 3  | 0  | 1  | 3  |
| <u>Feldspars</u>       |    |    |    |    |     |    |    |    |    |    |
| Untwinned              | 9  | 16 | 13 | 8  | 7   | 11 | 21 | 9  | 10 | 10 |
| Plagioclase            | 2  | 4  | 3  | 4  | 1   | 2  | 9  | 8  | 5  | 2  |
| <u>Rock Fragments</u>  |    |    |    |    |     |    |    |    |    |    |
| Phyllitic              | 10 | 17 | 17 | 12 | 8   | 8  | 9  | 6  | 13 | 15 |
| Clay Ironstone         | 5  | 10 | 3  | 5  | 0   | 2  | 7  | 3  | 5  | 8  |
| <u>Micas and Clays</u> |    |    |    |    |     |    |    |    |    |    |
| Muscovite-Illite       | 0  | 1  | 6  | 7  | 4   | 2  | 0  | 1  | 2  | 2  |
| Sericite               | 0  | 1  | 0  | 2  | 3   | 1  | 5  | 2  | 5  | 0  |
| Biotite                | 0  | 0  | 1  | 5  | 2   | 0  | 0  | 0  | 0  | 0  |
| Chlorite               | 3  | 1  | 6  | 1  | 3   | 3  | 2  | 0  | 0  | 4  |
| Kaolinite              | 1  | 2  | 1  | 5  | 2   | 5  | 1  | 8  | 3  | 3  |
| <u>Cements</u>         |    |    |    |    |     |    |    |    |    |    |
| Silica overgrowths     | 6  | 3  | 8  | 2  | 7   | 1  | 4  | 7  | 9  | 14 |
| Dolomite               | 13 | 10 | 1  | 4  | 2   | 6  | 3  | 14 | 0  | 0  |
| Siderite               | 5  | 8  | 0  | 0  | 0   | 0  | 0  | 0  | 4  | 12 |
| Feldspar overgrowths   | 0  | 0  | 0  | 0  | 0   | 1  | 2  | 0  | 0  | 0  |
| <u>Heavy Minerals</u>  |    |    |    |    |     |    |    |    |    |    |
| Iron Opaques           | 3  | 5  | 2  | 0  | 2   | 3  | 0  | 1  | 0  | 3  |
| Zircon                 | 0  | 0  | 0  | 2  | 0   | 0  | 1  | 1  | 0  | 0  |
| Tourmaline             | 0  | 0  | 1  | 0  | 0   | 0  | 0  | 0  | 0  | 0  |
| <u>Organics</u>        | 2  | 0  | 0  | 2  | 0   | 0  | 0  | 0  | 0  | 0  |
| <u>Porosity</u>        | 26 | 29 | 33 | 24 | 39  | 39 | 21 | 22 | 20 | 21 |
| <u>Unidentified</u>    | 1  | 6  | 3  | 5  | 0   | 3  | 10 | 2  | 6  | 5  |

Table 1-Point count results from 10 thin sections. These were equally selected from the three sandstone zones.

some instances, partings (Fig. 13) located on the perimeter of the nucleus grain separate the detrital part from the cement. The nuclei generally are subrounded to rounded (Figs. 12, 13). The size of the monocrystalline quartz grains decreases gradually from the base to the top of the sandstones (Figs. 53, 54).

Polycrystalline quartz is present in numerous varieties. The first type, shear quartz, contains sub-parallel crystals with strongly undulose extinction having sutured contacts between one another. The second variety, recrystallized metaquartz (Fig. 14) is composed of a mosaic of subequant grains with straight to slightly undulose extinction and straight boundaries. Schistose metaquartz crystals (Fig. 16) are generally elongate, sub-parallel to the mica flakes and have straight to slightly sutured boundaries.

Microquartz or chert (Fig. 21) comprises less than 1% of the total composition of the sandstones.

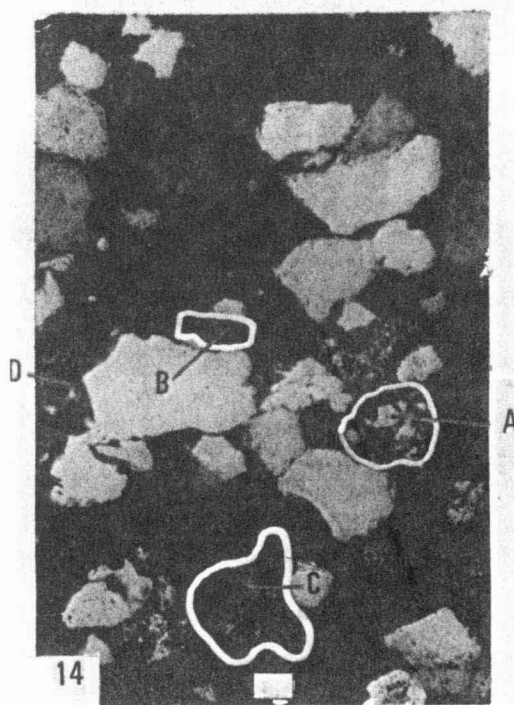
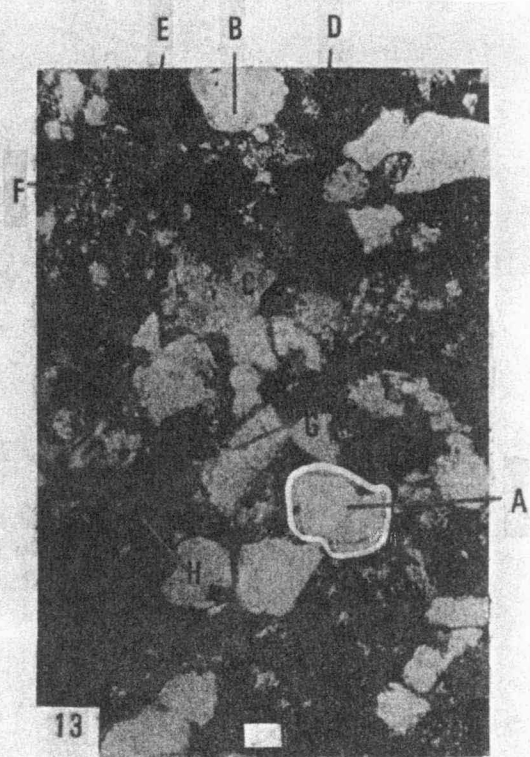
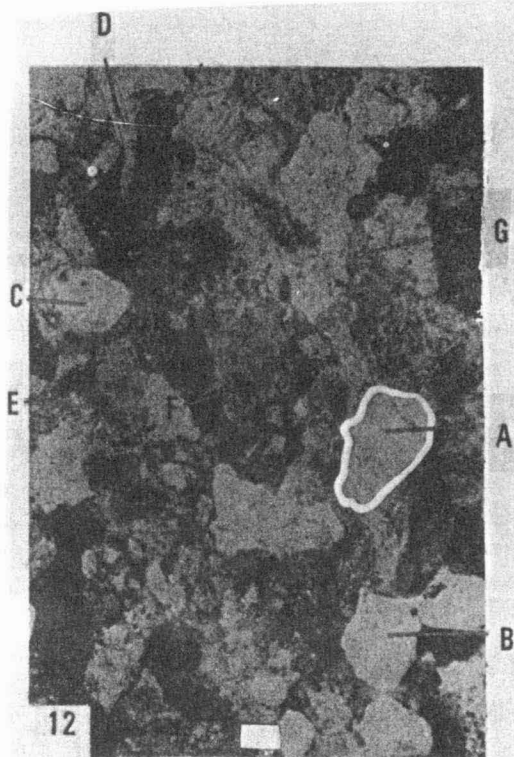
Feldspars - The feldspars comprise 5-15% of the total rock and consist of a 2:1 ratio of untwinned feldspars to plagioclase (Figs. 14, 15). Untwinned varieties (Figs. 12, 13, 16, 21) are believed to be potassium rich although one untwinned plagioclase was found. Both types include slightly to strongly altered grains with angular to rounded shapes, and fresh to corroded boundaries (Figs. 13, 15). Kaolinite, appearing as small dark specks and sericite, a bright yellow birefringent hydromica, are common alteration products of feldspar. Cleavage traces are common in untwinned feldspar

Figure 12.- A train of vacuoles in a quartz grain (A). Also in slide are quartz grains with randomly spaced vacuoles (B). Quartz grain with a subrounded nucleus and anhedral overgrowth (C). Bent muscovite grain showing effects of compaction (D). Quartz grain with corroded boundaries (E). Untwinned feldspar showing alteration to kaolinite (F). Lighter colored areas around grain are porosity (G). (un-x nicols; 50x); scale= .05 mm. Taken from Jackson Bros. Teichgraber #4-7 slide. (Burbank Sandstone)

Figure 13.- Subrounded quartz grain with anhedral overgrowth (A). Minute particles outlining subrounded quartz nuclei and separating it from an anhedral quartz overgrowth (B). Glauconite grain (C). Siderite cement with spherulitic habit (D). Iron opaque (E). Psuedo-matrix probably derived from a metamorphic rock fragment (F). Untwinned feldspar showing alteration to both sericite and kaolinite (G). Compare that grain with its more angular boundaries with (H) where the grain is subrounded. This may indicate that one feldspar was angular and relatively unweathered when deposited while the other grain was already weathered. (x-nicols; 50x); scale= .05 mm. Taken from Jackson Bros. Teichgraber #4-7 slide. (Burbank Sandstone)

Figure 14.- Polycrystalline quartz grain (A). Also note the albite twinning of plagioclase (B). Kaolinite with its distinctive "book-like" form is present in the lower center of the slide (C). Siderite is seen wrapping around a quartz grain and is replacing the overgrowth (D). (x-nicols; 50x); scale= .05 mm. Taken from an unknown slide.

Figure 15.- Plagioclase with albite twinning (A). The grain is angular and the boundaries are uncorroded. Iron opaque (B). Many iron opaques are pyrite or altered leucoxene. (x-nicols; 50x); scale =.05 mm. Taken from Jackson Bros. Teichgraber #4-10 slide. (Burbank Sandstone)



grains, whereas some plagioclase grains show bent and strained lamellae. Rarely, microcline, with the distinctive crosshatch twinning was found. Rare overgrowths were found on a few grains.

Metamorphic Rock Fragments - Metamorphic rock fragments make up an average of 20% of the framework grains in the sandstones. Phyllitic fragments with included muscovite, biotite and chlorite is the dominant variety (Figs. 17, 21). Dark gray to black foliated rock fragments are also present (Fig. 18) (Walton, 1976, personal communication). Parallel orientation of the micas and the included quartz are the distinguishing characteristics for identification. Many of these ductile grains have been compacted forming psuedomatrix around other detrital grains (Fig. 17).

Accessory Minerals - Accessory minerals constitute up to 2% of the total rock. Opaques were identified in reflected light as leucoxene, which appears milky white, and pyrite which replaces organic material and quartz. Leucoxene may be an alteration product of ilmenite (Figs. 15, 16), while pyrite diagenetically formed from the sulfur present in the carbonaceous matter (Fig. 24).

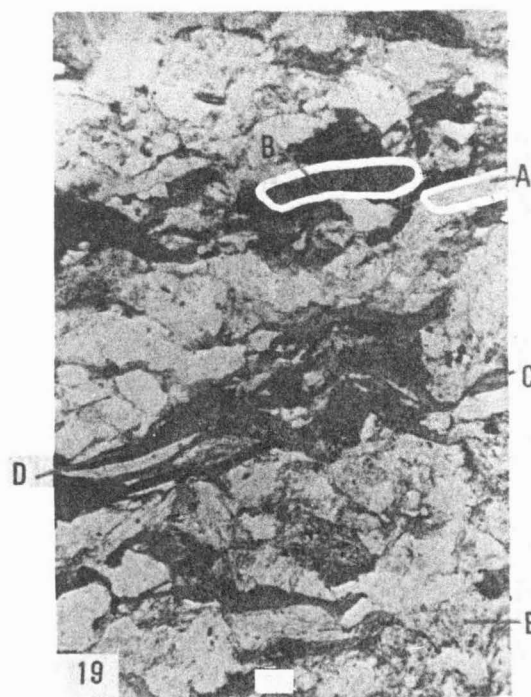
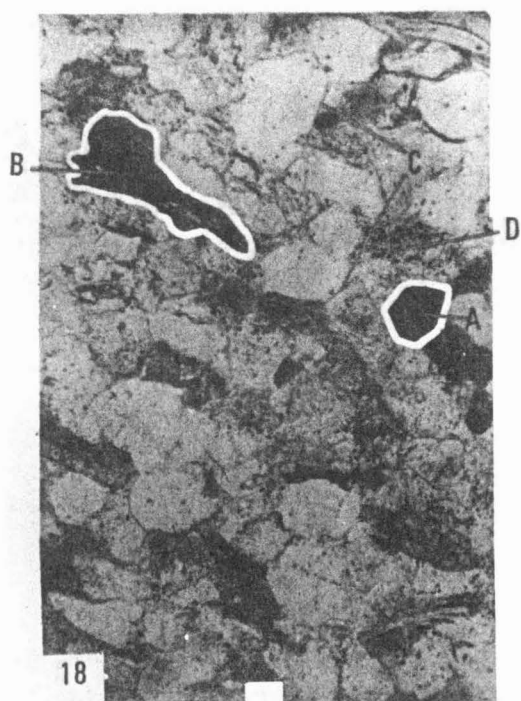
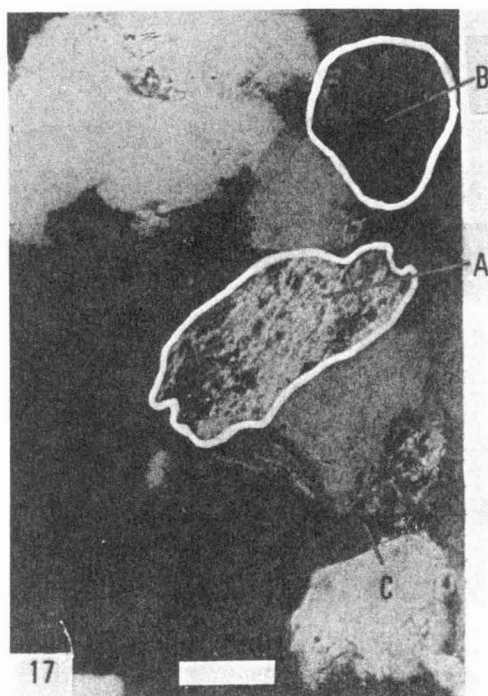
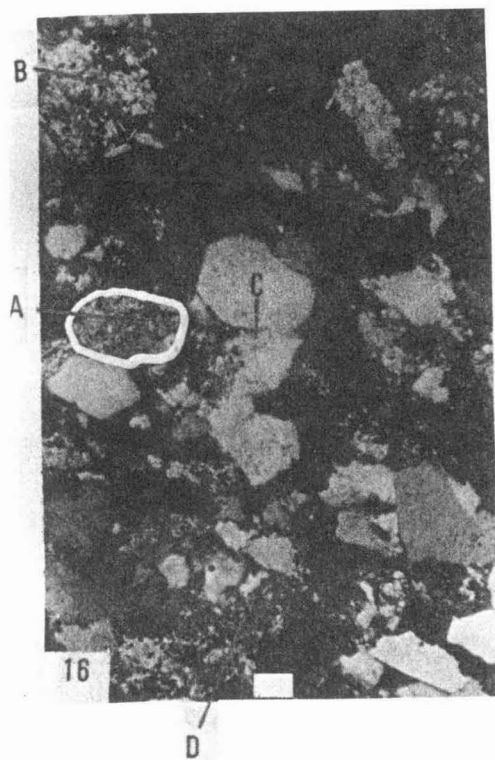
Non-opaque accessory minerals consist of apatite, tourmaline, and zircon. Apatite occurs commonly as greenish inclusions in quartz and rarely as detrital grains, while tourmaline appears as a pleochroic brown or green, moderate relief, highly birefringent grain with euhedral form (Fig. 18). Zircon appears as a colorless, high relief, heavily fractured, subangular grain with high birefringence.

Figure 16.- Untwinned feldspar showing alteration to sericite (light gray elongate specks) and kaolinite (darker specks) (A). The grain is rounded. Schistose meta-quartz is present in upper left of slide (B). Siderite cement is present (C). Psuedomatrix is probably derived from phyllitic rock fragments (D). In the upper right part of the slide are numerous opaques. (x-nicols; 50x); scale= .05 mm. Taken from Jackson Bros. Barrier #36 at 2506 feet (762 m.). (Bartlesville Sandstone)

Figure 17.- Phyllitic rock fragment with subparallel quartz and mica grains (A). Also book-like form of kaolinite (B). Also note compacted psuedomatrix composed of micas between two quartz grains (C). Kaolinite is a diagenetic pore filling cement in this case. (x-nicols; 125x); scale= .05 mm. Taken from an unknown slide.

Figure 18.- Euhedral tourmaline grain (A). Black platy metamorphic rock fragment (B). There is very little porosity in this slide. The metamorphic rock fragment is bent showing the effects of compaction. Also many of the quartz grains show interlocking euhedral quartz overgrowths (C). Dolomite fills up the rest of the interstices (D). (unx-nicols; 50x); scale= .05 mm. Taken from Jackson Bros. Barrier #34 at 2440 feet (742 m.). (Skinner Sandstone)

Figure 19- Excellent slide showing compaction effects on muscovite (A), biotite (B), and chlorite (C). The grains are badly bent. Also note the orientation of the micas and numerous quartz grains toward the lower left of the slide (D). Dolomite is also present making porosity almost non existant (E). (unx-nicols; 50x); scale= .05 mm. Taken from Jackson Bros. Barrier #34 at 2445 feet (743 m.) (Skinner Sandstone)



A heavy mineral separation after crushing would probably yield a more accurate determination of the species present.

Micas - Micas comprise up to 3% of the detrital fraction, with muscovite dominating. Biotite is present in all three sandstones but occurs significantly only in the Skinner zone. Muscovite is lath-shaped (Figs. 12,19), shows little alteration, and contains rare, needle-like inclusions. Biotite is lath-shaped and commonly is partly altered to chlorite (Fig. 19). They commonly are bent due to compaction (Figs. 12, 19).

Clays - Clays constitute 8-29% of the sample and occur as authigenic and detrital minerals. Chlorite (Fig. 19) may occur as detrital grains, or as a prominent mineral in schist fragments, or as an alteration product of biotite. Kaolinite (Figs. 14 & 17) forms from the alteration of feldspars or as a pore filling authigenic mineral. It may appear as dark grey specks on feldspar grains or as vermicular "books" having a spherulitic form in plain light. Illite occurs in association with muscovite, as a detrital mineral, or as sericite. A study of sandstone samples in the Sallyards Field area by James (1976, personal communication) shows that the above three types are the dominant clays present (Table 2). Glauconite occurs rarely as a rounded or crushed grass-green grain with aggregate extinction (Fig. 13).

Matrix - The origin of matrix in sandstones has long been a subject of considerable controversy. McBride (personal communication, 1975) suggests the following categories: true matrix - that matrix which is deposited

### Clay Mineralogy of the Sallyards Sandstones

|                            | <u>1</u> | <u>2</u> | <u>3</u> | <u>4</u> | <u>5</u> |
|----------------------------|----------|----------|----------|----------|----------|
| % Illite-Mica              | 35       | 25       | 35       | 25       | 40       |
| % Kaolinite                | 25       | 50       | 30       | 25       | 20       |
| % Chlorite                 | 40       | 25       | 35       | 50       | 40       |
| % Expandable               | 0        | 0        | 0        | 0        | 0        |
| % " Total Clay in Sample"* | 10       | 8        | 8        | 5        | 29       |

\* includes coarse mica, therefore total clay content as determined from diffraction pattern is higher than would be determined by dispersion and size fractionation.

X-ray diffraction errors may be +/- 5%, i.e. a value of 35% may range from 30 to 40%.

Clay identification by X-ray diffraction gives no information about the tendency of the rock for particle plugging or about the distribution of the clay particles in the rock.

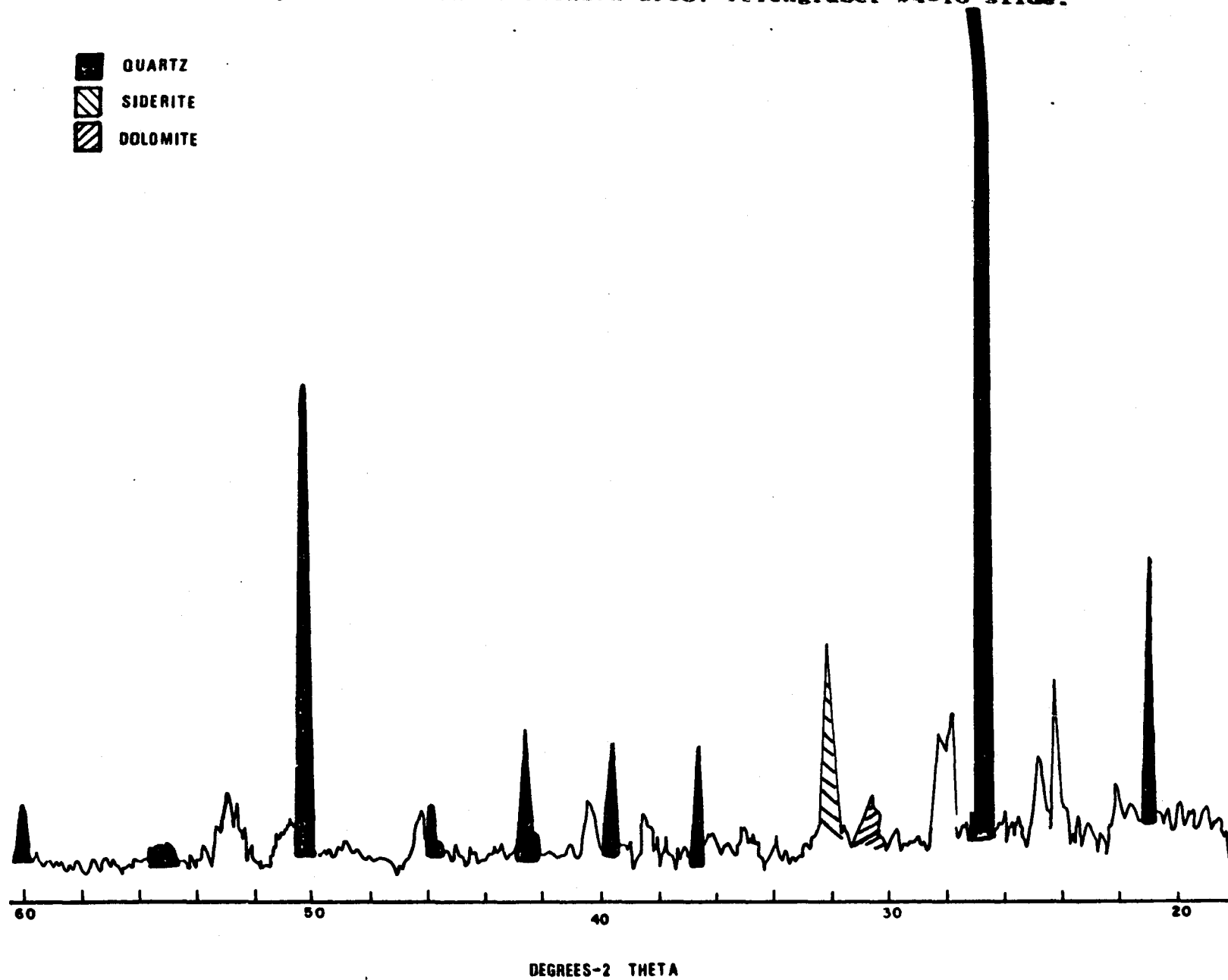
| <u>SAMPLES</u>       | <u>LOCATION</u> | <u>DEPTH OF SAMPLES (FEET)</u> |
|----------------------|-----------------|--------------------------------|
| 1. JB Hendrickson #4 | 16-25S-9E       | 2361                           |
| 2. JB Teichgraber #4 | 14-25S-8E       | 2433                           |
| 3. JB Crew #21       | 3-26S-8E        | 2488                           |
| 4. JB Crew #21       | 3-26S-8E        | 2519                           |
| 5. JB Crew #22       | 34-25S-8E       | 2402                           |

Table 2.- Types of clays in selected samples from the Sallyards Field sandstones and their relative abundance. Work was performed by James (1976).

as clays along with the larger detrital fraction; epimatrix - diagenetically grown clay from clay precursor or other silicates; pseudomatrix - compacted and smashed ductile grains; and clay cement - grown in voids as a pore filling cement. From these descriptions, it is apparent that very little true matrix was deposited with the detrital fraction of the Cherokee Sandstones in the Sallyards Area, with the exception of a few detrital chlorite or sericite grains derived from laterally equivalent shales. The metamorphic rock fragments are compacted and crushed and are classified as pseudomatrix (Figs. 16, 17). Pore-filling kaolinite is present in the form of clay cement (Figs. 14, 17).

Cement - There are seven (7) types of cement present in the reservoir rocks: quartz overgrowth, feldspar overgrowth, kaolinite, calcite, siderite, dolomite, and pyrite. These were determined by observation from hand specimens, thin sections, X-ray diffraction (Fig. 20) and staining (Appendix 2). The first three (3) types of cement have been described above and calcite occurs occasionally in ripple zones. Siderite (Figs. 21, 22) occurs in three forms, bladed, radial and in rhombohedral patches. Usually an iron-oxide stained rim is present (Fig. 22) at the edges of the siderite cement or in its cleavage planes. In the uppermost sandstone zone, siderite is present as a rhombohedral, patchy cement only. Dolomite (Fig. 23) occurs in patches as poikilotopic crystals with rhombohedral form. Some of the lamellae may be curved and the extinction commonly sweeps along the surface of

Fig. 20-X-ray diffraction of Jackson Bros. Teichgraber #4-10 slide.



the cement. The determination of the sequence of cements is complex because of the notable lack of competition between the three cements. Usually only one carbonate cement will dominate in a rock or the two carbonate cements will be present, separately. Siderite forms rims around numerous mud clasts and pyrite. Occasionally the bladed siderite cement is seen to corrode quartz grains on one side of the crystal, while the other side supports an overgrowth. In fact, the silica overgrowths found in siderite-dominated rocks are commonly in areas of no cement. One example of siderite wrapping around an euhedral silica overgrowth was noted suggesting more than one episode of cementation. Dolomite, in contrast, commonly corrodes quartz crystals but wraps around euhedral overgrowths (Fig. 23). It also incompletely replaces siderite cement, leaving small "unreplaced areas" of siderite in the patchy dolomite cement.

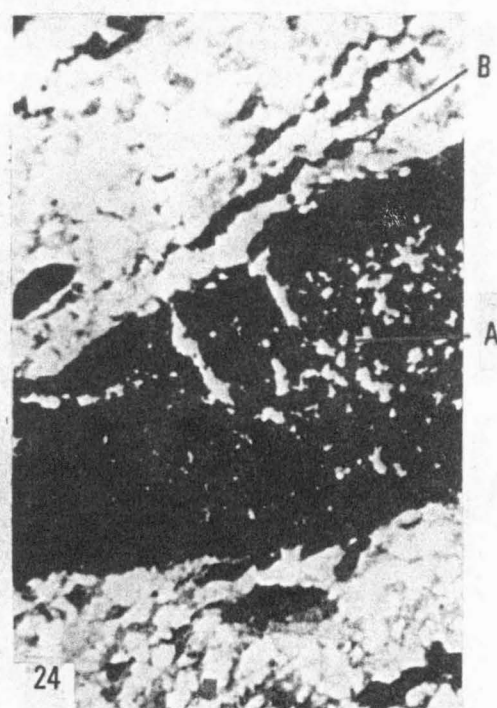
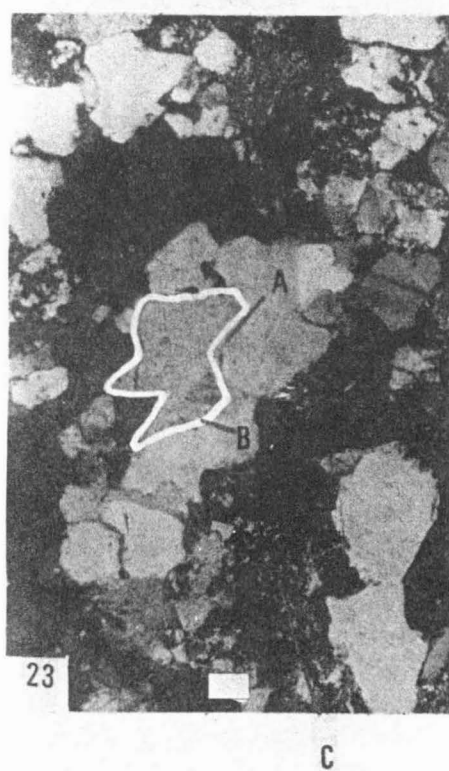
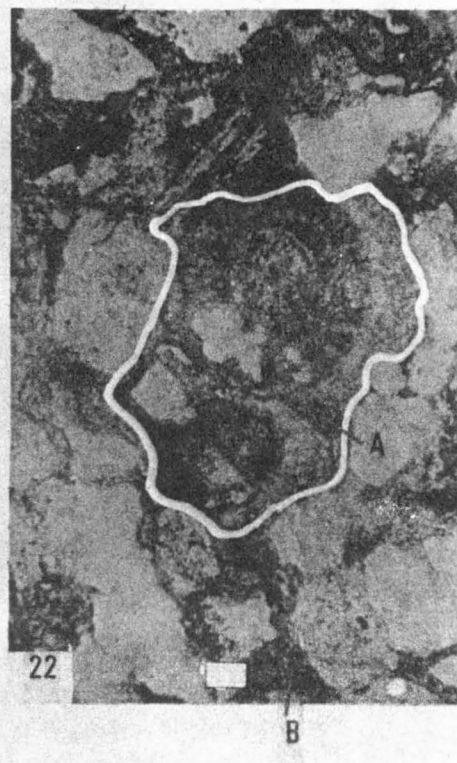
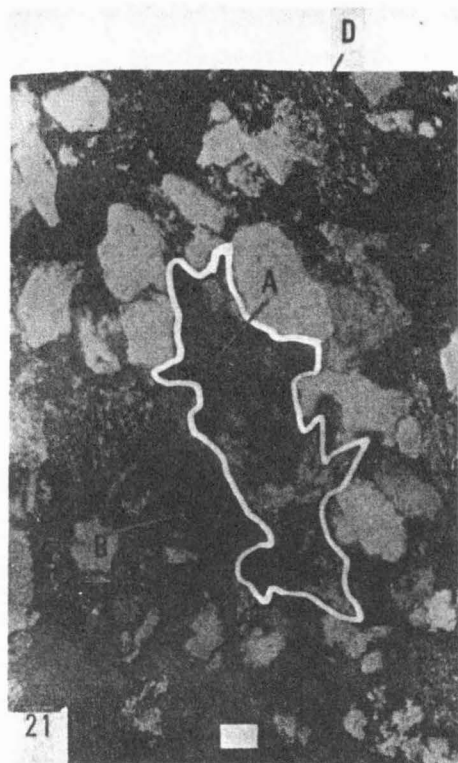
Pyrite was the first cement formed replacing the carbonaceous matter. This suggests that the sulfur came from the organic material (Fig. 24). Siderite probably came next. Its source was possibly fluids from the iron rich gray shales. Silica cement was the third pahse. The source for the silica may be diverse. Pettijohn (1975) suggests that shales upon burial may become supersaturated with silica. As compaction continued, the silica would be driven out of the shales into the sandstone. Another possible source of silica is pressure solution at the points of contact of grains, or the preferred growth of

Figure 21- Bladed siderite cement filling interstices in slide (A). Seems to be corroding the quartz grains. Microquartz (B) and untwinned feldspar (C) are also present. Phyllitic rock fragment is in the upper right (D). Quartz and feldspar grains seem to be oriented from the lower right to the upper left of the slide. (x-nicols; 50x); scale= .05 mm. Taken from Jackson Bros. Teichgraber #4-7 slide. (Burbank Sandstone)

Figure 22- Siderite cement in spherulitic form corroding quartz grains (A). Interstices are completely filled with the cement. Darker areas in siderite cement are iron oxide rims (B). (x-nicols; 50x); scale= .05 mm. Taken from Jackson Bros. Jackson Heirs #19 at 2374 feet (722 m.). (Burbank Sandstone)

Figure 23- Dolomite cement wrapping around a euhedral quartz overgrowth (A) while corroding or replacing a second quartz grain (B). Unidentifiable psuedo-matrix and micas are present in the interstices in the lower right (C). (x-nicols; 50x); scale= .05 mm. Taken from Jackson Bros. Perrier #2 at 2380 feet (723 m.). (Bartlesville Sandstone)

Figure 24- Cross section of plant fragment that is being replaced by pyrite (A). Note the orientation of the iron claystone and organic matter toward the lower left of the slide (B). (unx-nicols; 15x); scale= .05 mm. Taken from Jackson Bros. Barrier #36 at 2506 feet (762 m.). (Bartlesville Sandstone)



larger grains at the expense of smaller grains (Fig. 18). Some anhedral overgrowths in crowded areas suggest that this mechanism accounts for part of the silica; however, many grains show point contacts, not long or sutured contacts. Dolomite cement was the final stage. A number of corroded grains in areas of no cement suggest that at one time carbonate cement may have been present in larger quantities. Decementation may have developed more porosity. The problem with this hypothesis lies in the removal of the fluids from sandstones encased in shale at depth (Pettijohn, 1975).

Organic material - Carbonized plant debris occurs throughout the sandstone body as slightly translucent, reddish-brown stringers and partings. Clasts of 24) are also present. It comprises up to 1% of the sandstone body. Crinkly patterns thought to be formed from fossil leaves are most common, but occasional pieces of plant stems also occur. Oil stain is also common in thin sections, occurring as a light, isotropic, translucent, brown pore filling.

Clay ironstone and Iron nodules - Clay ironstone fragments are light brown with an aggregate type of extinction. They are common throughout the sandstone and may make up to 3% of the total detrital fraction. Iron nodules are commonly found in clast zones and in the laterally equivalent shales. The nodules may contain radiating or spherulitic concentric structures.

## Classification

A descriptive classification using the three most common types of grain, quartz, feldspar, and rock fragments, is used here (Folk, 1968). This is supplemented with modifiers to denote provenance. A technique suggested by McBride (1975, personal communication) is used to denote relative fractions of framework grains, matrix, porosity, and cement, and to calculate proportions of quartz, feldspar, and rock fragments by the following formulas:

$$F + M + P + C = 100\%$$

$$Q + F + R = 100\%$$

The composition of the sandstone samples in the Sallyards Field Area is given in Figure 25.

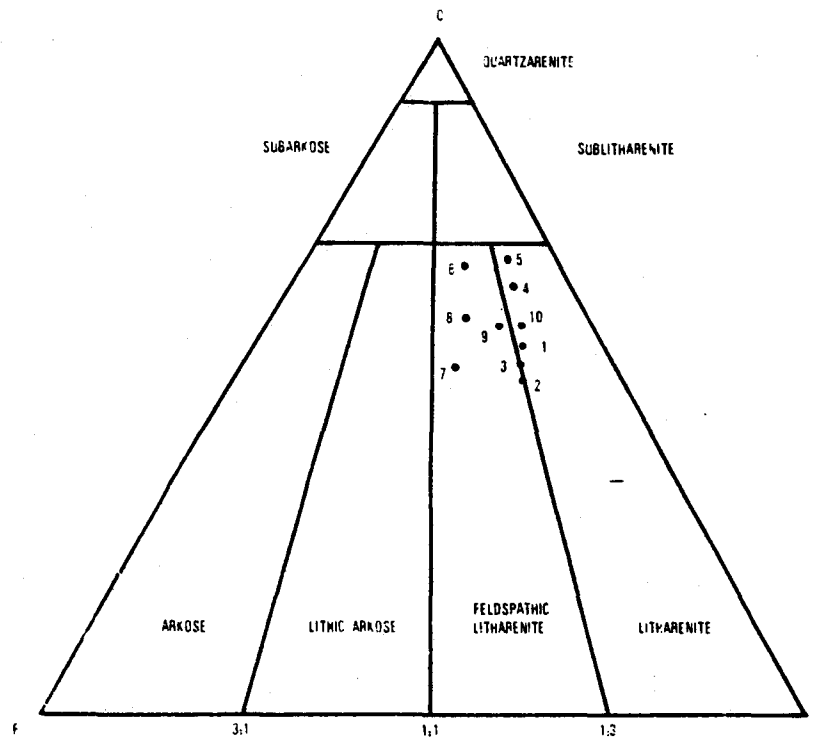
## Sedimentary Structures

Approximately 40 cores representing the Bartlesville, Burbank, and Skinner zones were sawed in half, and described in detail for the types of internal features present in each sandstone zone. Core descriptions were then analyzed both in qualitative and quantitative manners to determine the vertical sequence of sedimentary structures. Logs of all cores described are shown in Appendix B. The location of cores is given in Plate 6.

Underlying Contact - The units underlying the Bartlesville and Burbank Sandstones consist of light to dark gray siltstones or black shale. The underlying shale normally contains carbonaceous fragments and pyrite. A coal is associated with black shale in Jackson Bros. Rice #2 (Appendix B).

Fig. 25- SANDSTONE CLASSIFICATION

|                          | Q  | F  | R (%) | F    | M   | P    | C (%) |
|--------------------------|----|----|-------|------|-----|------|-------|
| <b>BURBANK ZONE</b>      |    |    |       |      |     |      |       |
| 1. Crew #21 2519'        | 63 | 8  | 29    | 74.0 | 1.5 | 15.0 | 12.5  |
| 2. Teichgraber #4 2360   | 46 | 13 | 39    | 74.0 | 1.0 | 14.5 | 11.5  |
| <b>SKINNER ZONE</b>      |    |    |       |      |     |      |       |
| 3. Crew #22 2422'        | 56 | 11 | 33    | 76.0 | 3.0 | 16.0 | 5.0   |
| 4. Rice #1 2447'         | 70 | 9  | 21    | 81.5 | 1.5 | 12.0 | 5.0   |
| 5. Barrier #34 2445'     | 74 | 6  | 20    | 72.0 | 3.0 | 19.5 | 5.5   |
| 6. Barrier #34 2459'     | 72 | 9  | 19    | 72.0 | 2.0 | 19.5 | 6.5   |
| <b>BARTLESVILLE ZONE</b> |    |    |       |      |     |      |       |
| 7. Perrier #2 2373'      | 51 | 19 | 30    | 80.0 | 1.0 | 11.0 | 5.0   |
| 8. Perrier #2 2380       | 65 | 12 | 23    | 73.0 | 0   | 11.0 | 15.0  |
| 9. Perrier #2 2383       | 61 | 10 | 29    | 82.0 | 0   | 10.0 | 8.0   |
| 10. Hendrickson #1 2397  | 61 | 8  | 31    | 71.0 | 2.0 | 10.0 | 13.0  |



The contact beneath both sandstone zones is sharp and is considered to be erosional (Fig. 26) for the following reasons: 1. The bedding of the underlying shale is undisturbed below the contact. 2. Fragments of the underlying shale are found at the base of the sandstone. 3. The sedimentary structures present in the sandstone show little distortion. The contact between the Skinner zone and the underlying greenish gray siltstone, likewise, is sharp. A coal also underlies the sandstone in Jackson Bros. Crew #22 (Appendix B).

Idealized Vertical Sequence - Walker (1975) suggests a statistical method to determine a vertical sequence of internal structures and associated facies within an interval. The vertical sequence of rocks described in each core is divided into distinct facies types or "homogeneous bodies of rock that differ from vertically adjacent rocks by chemical, physical or biological characteristics" (Walker, 1975). In this case facies refers to contacts and bedforms. This is based on observation, and no pre-conceived ideas are forced upon the resultant model. The next step is to analyze which features are related to each other. From the base of the sandstone the adjacent facies are counted and arranged in a tally (Fig. 27) matrix which indicates the number of times that one facies actually changes upward into another facies for that interval. The tally matrix is then compared with a random events matrix. This matrix gives the number of times two adjacent

Fig. 27 - Tally matrix and random events matrix for the Bartlesville Sandstone. The tally matrix is an actual count of how many times two distinct facies types occur vertically adjacent to each other in the sequence. To determine which transitions are significant, a random events matrix is constructed. This is best explained by Walker (1975). If all the observed facies were dropped in a box, shaken, and drawn out in random sequence a new tally matrix would be formed showing a predicted set of facies transitions were their sequence totally random. The two matrices are then compared. Where the number in the tally matrix box is markedly greater than the number in the corresponding box of the random events matrix that facies transition is deemed important (i.e. look at row 1 column 3 in both matrices; the significant facies are underlined). Doveton (1977) suggested that those facies that occurred appreciably greater than once and that had a number less than 1 in the corresponding box of the random events matrix be connected with dashed lines indicating that the occurrence may be significant (see row 8 column 5). The resulting facies relationship diagram and the idealized vertical sequence for the Bartlesville Sandstone are given in Figure 28. The facies observed in the Bartlesville Sandstone and their corresponding numbers in Figure 27 are as follows: 1. ripples, 2. large scale cross-beds, 3. scour surfaces, 4. massive bedding, 5. sharp contacts, 6. clast zones, 7. horizontal bedding, 8. dark gray siltstone, 9. contorted bedding, 10. black shale.

1      2      3      4      5      6      7      8      9      10

### TALLY MATRIX

|          |           |           |           |          |          |          |          |          |   |
|----------|-----------|-----------|-----------|----------|----------|----------|----------|----------|---|
| 0        | 9         | <u>19</u> | 4         | 6        | 3        | <u>4</u> | 0        | <u>2</u> | 0 |
| 15       | 0         | <u>15</u> | <u>11</u> | 1        | 3        | 1        | 0        | 0        | 0 |
| 11       | <u>17</u> | 0         | <u>7</u>  | 0        | 2        | 0        | 0        | 1        | 0 |
| 8        | <u>13</u> | 2         | 0         | <u>5</u> | <u>4</u> | 1        | 0        | 0        | 0 |
| 4        | 0         | 0         | 3         | 0        | <u>5</u> | 1        | <u>7</u> | 0        | 1 |
| 3        | 2         | 0         | <u>5</u>  | 2        | 0        | 1        | 0        | <u>2</u> | 0 |
| <u>4</u> | 0         | 1         | 1         | 1        | 0        | 0        | 0        | 0        | 0 |
| 0        | 0         | 0         | 0         | <u>5</u> | 0        | 0        | 0        | 0        | 0 |
| 0        | 1         | 1         | 1         | 1        | 0        | 0        | 0        | 0        | 0 |
| 0        | 0         | 0         | 0         | <u>4</u> | 0        | 0        | 0        | 0        | 0 |

### RANDOM EVENTS MATRIX

|      |      |      |     |     |     |     |     |     |     |
|------|------|------|-----|-----|-----|-----|-----|-----|-----|
| 0    | 13.7 | 10.6 | 8.9 | 5.3 | 3.7 | 1.7 | 1.2 | 0.9 | 0.9 |
| 13.7 | 0    | 10.3 | 8.7 | 5.2 | 3.6 | 1.6 | 1.1 | 0.9 | 0.9 |
| 10.6 | 10.3 | 0    | 6.7 | 4.0 | 2.8 | 1.3 | 0.9 | 0.7 | 0.7 |
| 8.9  | 8.7  | 6.7  | 0   | 3.4 | 2.3 | 1.1 | 0.7 | 0.7 | 0.5 |
| 5.3  | 5.2  | 4.0  | 3.4 | 0   | 1.4 | 0.6 | 0.4 | 0.4 | 0.4 |
| 3.7  | 3.6  | 2.8  | 2.3 | 1.4 | 0   | 0.4 | 0.3 | 0.2 | 0.2 |
| 1.7  | 1.6  | 1.3  | 1.1 | 0.6 | 0.4 | 0   | 0.1 | 0.1 | 0.1 |
| 1.2  | 1.1  | 0.9  | 0.7 | 0.4 | 0.3 | 0.1 | 0   | 0.1 | 0.1 |
| 0.9  | 0.9  | 0.7  | 0.7 | 0.4 | 0.3 | 0.1 | 0.1 | 0   | 0.1 |
| 0.9  | 0.9  | 0.7  | 0.6 | 0.4 | 0.2 | 0.1 | 0.1 | 0.1 | 0   |

facies are expected to occur if the development of the facies in the sandstone was completely random. The two matrices are compared. Where the number in the tally matrix markedly exceeds the corresponding number in the random events matrix, that occurrence of adjacent facies is likely to be significant. An ideal sequence is then constructed to compare with accepted models, which are distillations of all general features associated with specific modern depositional environments.

A method used by Doveton (1977, personal communication) which computes the random events matrix is used here. A facies relationship diagram for the Bartlesville Sandstone and the resulting idealized vertical sequence are given in Figure 28. Within the sandstone, there is good agreement between qualitative and quantitative observations; however, not all cores included underlying or overlying contacts with the sandstone. Siltstone zones present were placed in their proper position in the ripple zones. The most commonly used statistical test of significance of transition is that of chi-square contingency. The test requires a minimum of five observations per cell in the expected matrix as a conservative safeguard of the validity of the test. This safeguard could not generally be met because of limited observations. A simple criterion for judging the possible significance of facies occurrences was suggested by Doveton (1977, personal communication). Where the random events matrix had numbers greater than one and comparison with the tally matrix deemed that association of facies

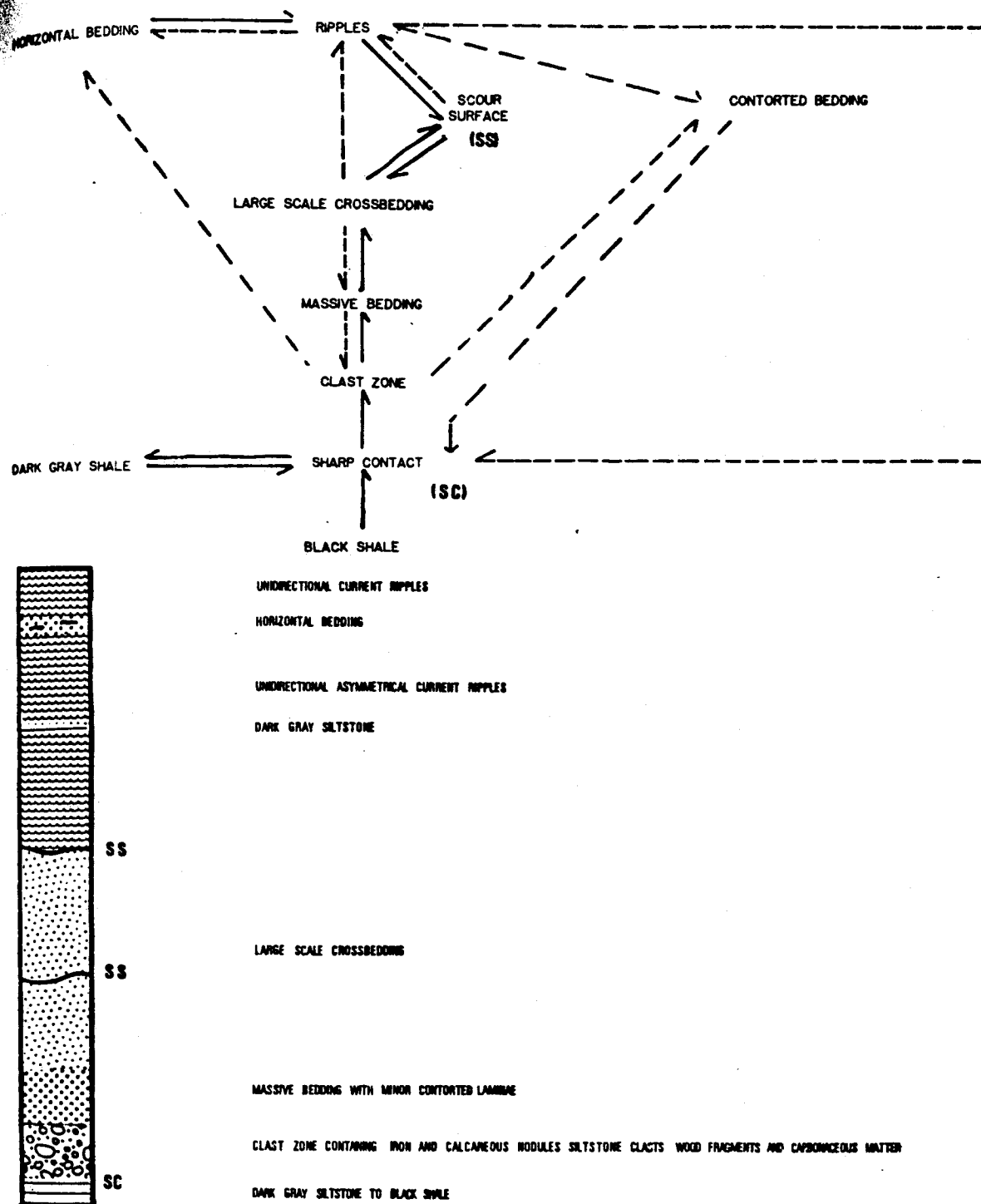


Fig. 28 - At top is the facies relationship diagram derived from comparison of the tally matrix and the random events matrix; below is the idealized vertical sequence. Those relationships that were observed to occur much greater than expected were connected with solid lines while those that occurred only slightly more than expected were connected with dashed lines. To complete the facies diagram dashed lines were added to transitions from large scale cross beds and scour surfaces as these were the only facies from the lower part of the sequence that occurred in conjunction with the ripple facies. The ripples then were overlain by dark gray shales separated by a sharp contact. Dark gray siltstones were placed in the ripple zone as a result of qualitative observations.

type significant, a solid line was used in the model.

Where an association of facies types is deemed significant and the random events matrix is less than 1, a dashed line is used (Fig. 28).

The sequence of sedimentary structures present in the three sandstones is similar. Numerous observations indicate that the lower part of the ideal sequence is dominated by large scale crossbedding (Figs. 29, 30). Although many of the laminae are parallel, occasional divergence and curved laminae are seen (Fig. 30). The laminae steepen in dip upward within a set of crossbeds. This geometry suggests medium or large-scale trough cross-bedding (Hewitt and Morgan, 1965). The three-inch diameter of the cores does not make the true nature of the structures clear. Conglomerate zones consisting of plant fragments, clay chips, and carbonaceous matter appear at various points in the sequence, but they normally occur in the basal portion (Figs. 26, 31). The upper portion of the sequence consists of unidirectional asymmetrical current ripples (Fig. 32). "Massive" sandstone intervals when x-rayed show large-scale crossbedding or small-scale ripples depending on the position at which they occur in the sequence (Fig. 33). Other features included within the sequence are contorted bedding (Fig. 34), horizontal bedding (Fig. 35), thin shale beds, and siltstone conglomerate zones (Fig. 36).

The decrease in the scale of sedimentary structures from larger scale crossbedding to unidirectional asymmetric current ripples, and the decrease in grain size upward

- Figure 26 - Erosional basal contact with cobbles and chips of the underlying shale and limestone included in the sandstone. Repeated flooding in the channel results in scour along the lower and lateral contacts. The included shale and limestone clasts are evidence that the underlying units were at least semi-consolidated and that erosion not compaction was responsible for the nature of the contact. From Perrier #2 core at 2404 feet (733 m.). (Bartlesville Sandstone)
- Figure 29 - Large scale trough cross-bedding outlined by silt and cement. The top part of the core piece shows only inclined planar bedding which is commonly all that is seen. In the lower part of the core piece, however a slight divergence is seen indicating a possible trough. Trough cross-bedding is developed in the lower reaches of the channel as dunes deposited under fairly high flow velocities. Taken from Hendrickson #1 core at 2375 feet (724 m.). (Bartlesville Sandstone)
- Figure 30 - Another example of trough cross-bedding showing divergence of laminae in the trough. From Barrier #26 core at 2498 feet (762 m.). (Bartlesville Sandstone)
- Figure 31 - Conglomerate zone with iron and calcareous nodules, carbonaceous material, and clay chips. These zones form during the initial stages of flooding as scour occurs along the base of the channel. Some of the finer grained sand is winnowed away and the larger lag material is concentrated. From Rice #2 core at 2516 feet (767 m.). (Bartlesville Sandstone)

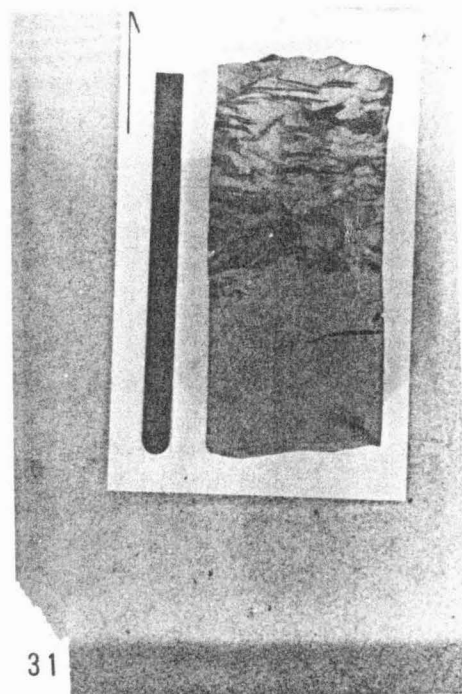
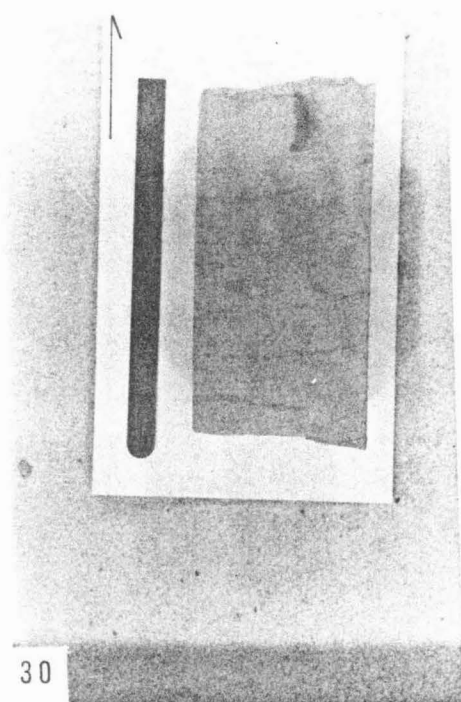
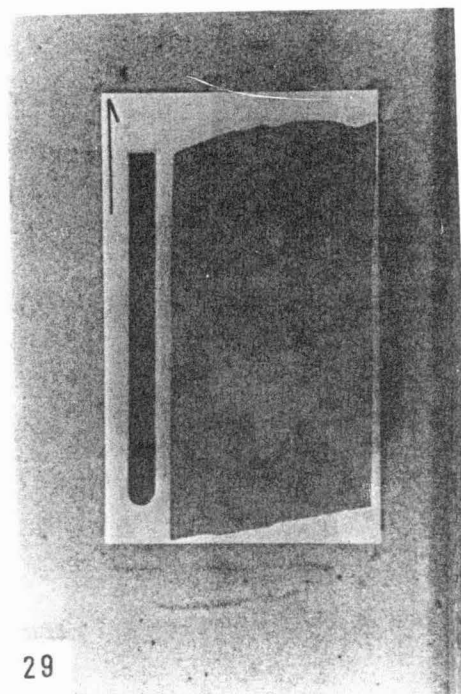
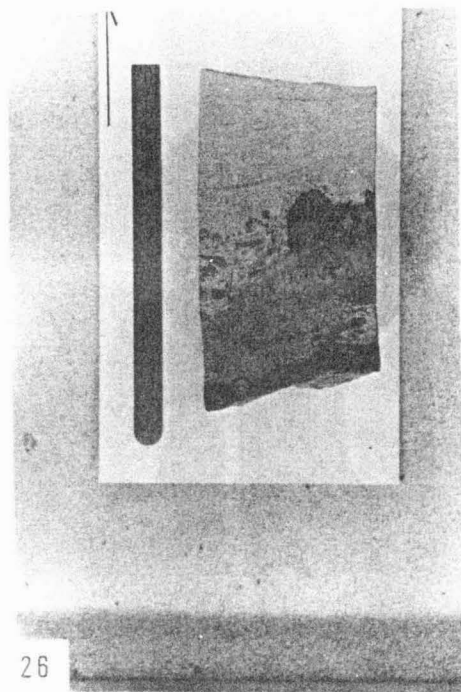


Figure 32. - Small scale unidirectional asymmetrical current ripples. Ripples form on the upper part of the point bar where water velocities are less. From Hendrickson # 3 core at 2331 feet (711 m.). (Bartlesville Sandstone)

Figure 33a.- "Massive" interval with only a hint of inclined laminae because of even texture. From Hendrickson #3 core at 2364 feet (721 m.). See Figure 33b below. (Bartlesville Sandstone)

Figure 33b.- X-ray radiograph of the above sample showing large scale inclined planar bedding.

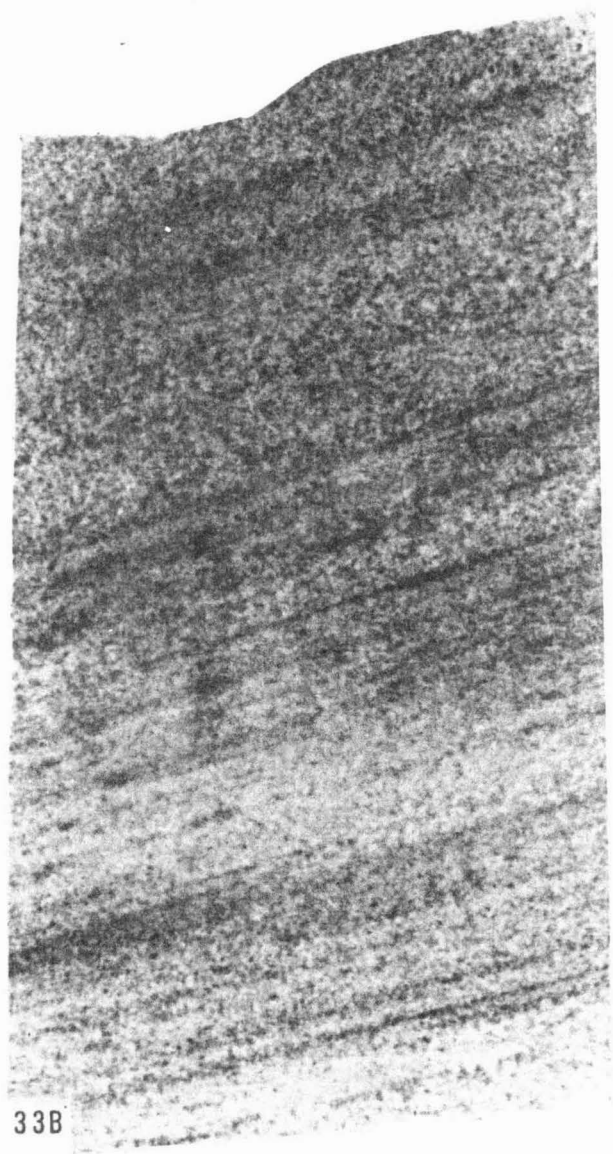
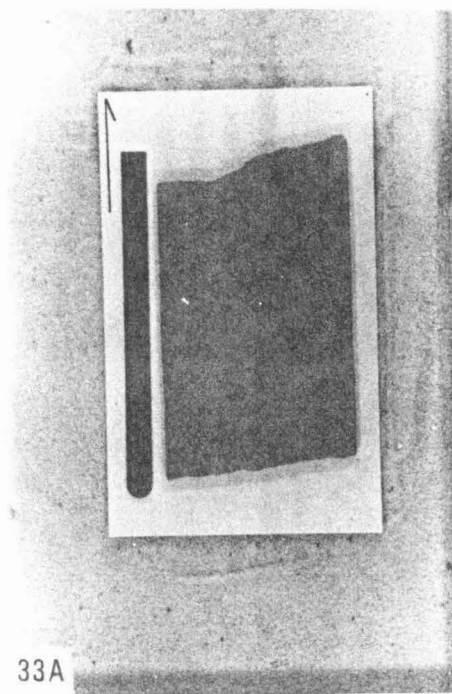
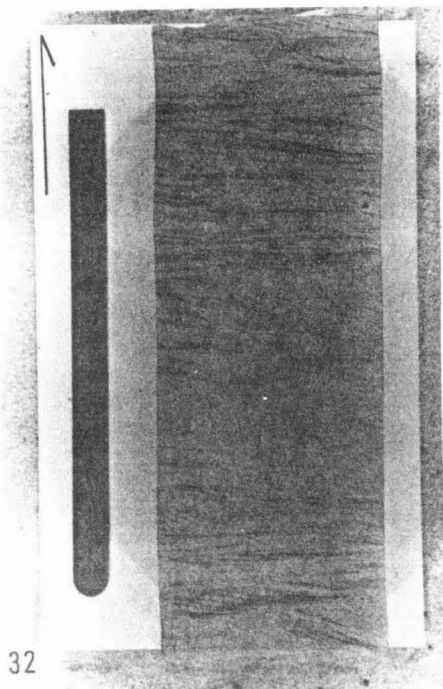
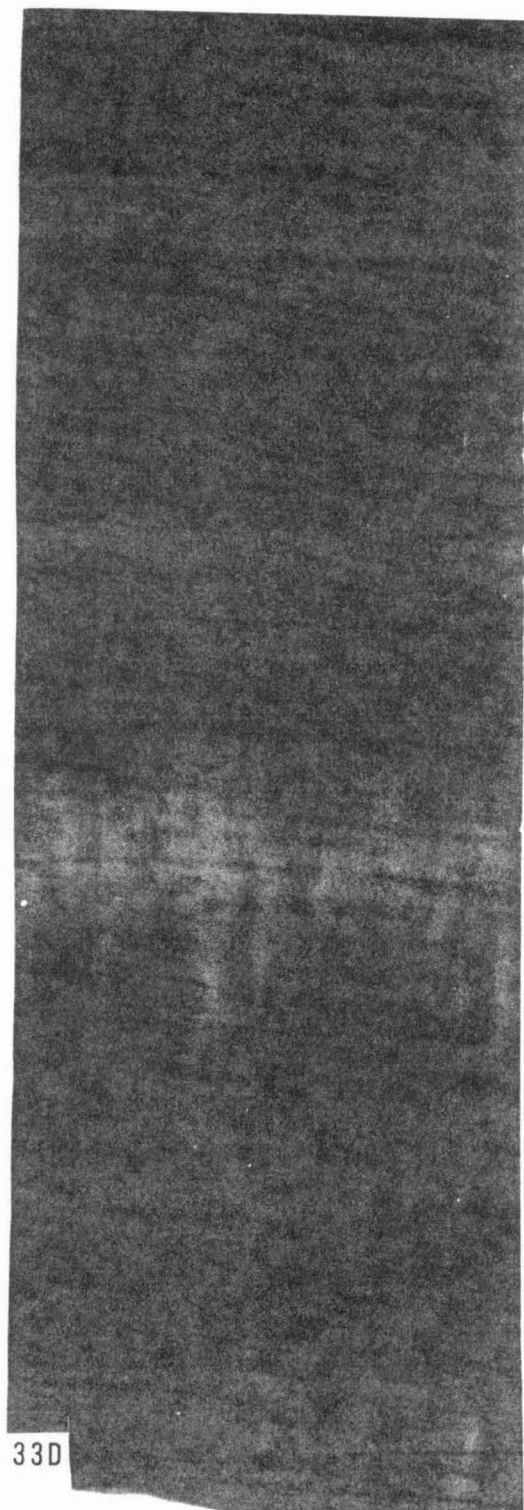
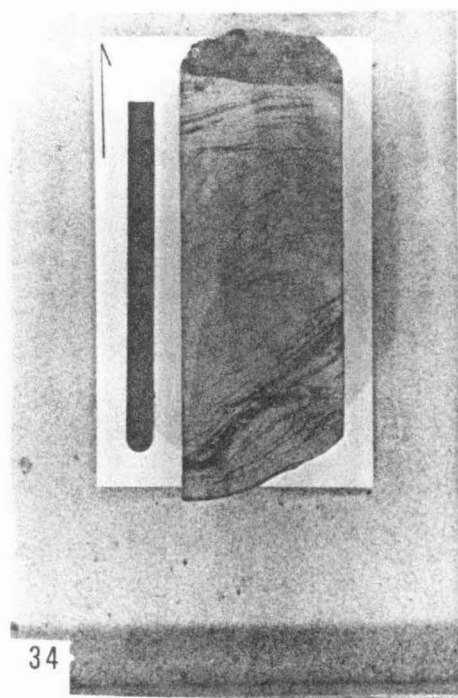
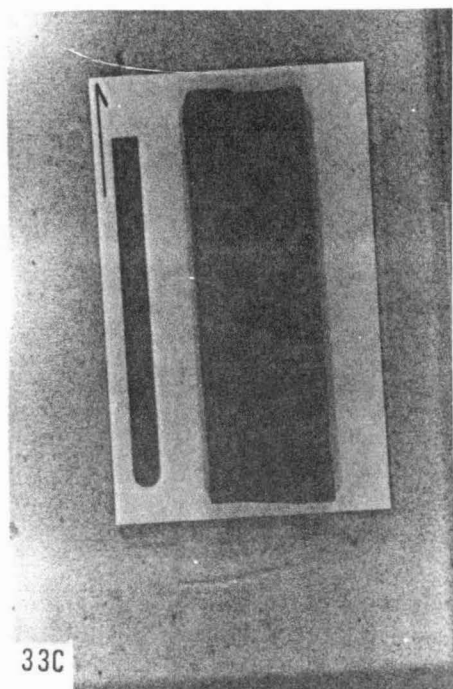


Figure 33c.- "Massive interval". From Bryden #23 core at 2395 feet (730 m.). See Figure 33d below. (Bartlesville Sandstone)

Figure 33d.- X-ray radiograph of the above interval showing small scale asymmetrical unidirectional current ripples in very even parallel sets.

Figure 34. - Contorted bedding. These contortions may have developed from movement of fluid saturated sand along a slope or produced by the drag of sediment-laden currents along the sediment-water interface. From Rice #2 core at 2515 feet (767 m.). (Bartlesville Sandstone)



in the sandstone shown by electric log character, thin section measurements, and permeability variations (Figs. 53, 54) suggest deposition of these sands by a unidirectional current of decreasing velocity. The ideal sequence described above may repeat many times within a core of the sandstone, and it is normally incomplete.

Overlying Units - The upper contacts of all three sandstone zones with overlying beds may be sharp or gradational (Fig. 37). Units overlying the Bartlesville zone consist of graded bedding (Fig. 38), alternating dark and light gray siltstones (Fig. 39), dark or greenish gray siltstones with multidirectional asymmetrical ripples (Fig. 40), and black laminated mudstones.

The Burbank zone commonly grades from the underlying sandstone upward into a greenish gray, indistinctly mottled siltstone with root casts, iron and calcareous nodules, soft-sediment deformation cracks and pyrite (Fig. 41). In three cores this sandstone sequence is truncated at the top by irregular bedding of sand and shale laminae (Fig. 42).

The sediment overlying the Skinner zone consists of dark gray siltstone.

Laterally Associated Facies - The facies associated laterally with the sandstones are incomplete cyclic sequences consisting of: 1. Light to dark gray, fossiliferous, re-worked lime packstones or wackestones containing fragments of brachiopods, echinoderms, and bryozoans (Fig. 43). 2. Black shale with pyrite and carbonaceous material. 3. A variety of greenish gray shale or siltstones with mottling, soft

Figure 35. - Horizontal bedding. This type of bedding is intimately associated with ripple bedding. The laminations may form from a combination of settling of the finer grained material during periods of little water movement and as upper flat beds (in areas of little silt). Taken from Hendrickson #4 core at 2361 feet (720 m.). (Bartlesville Sandstone)

Figure 36. - Siltstone conglomerate zone. This results from slumping of overbank material into the channel. During flood stage winnowing occurs and concentrates the angular siltstone clasts. Some clasts may have soft sediment deformation internally as a result of slumping. Taken from Hendrickson #4 core at 2361 feet (718 m.). (Bartlesville Sandstone)

Figure 37. - Gradational contact from channel sandstone into overbank facies. The overbank facies develops mainly from vertical accretion. From Jackson Heirs #9 core at 2406 feet (734 m.). (Burbank Sandstone)

Figure 38. - Graded bedded units. These were formed probably by two reoccurring sequences of deposition. The ripples were deposited first, then scour occurred. The massive interval may have been deposited under higher flow regime conditions initially, but as the water velocity decreased the fines started settling out and the graded bedding formed. These two processes were repeated a number of times. They probably represent crevasse splay deposits since the bedforms present represent initial traction flow of sediment and vertical accretion occurs at the end. Taken from Barrier #36 core at 2354 feet (718 m.). (Bartlesville Sandstone)

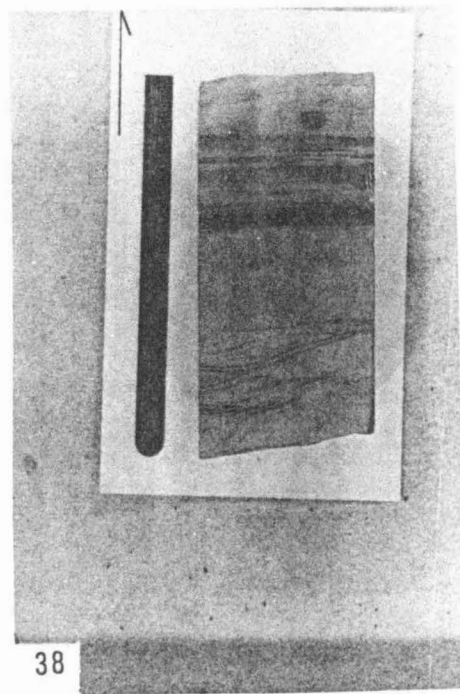
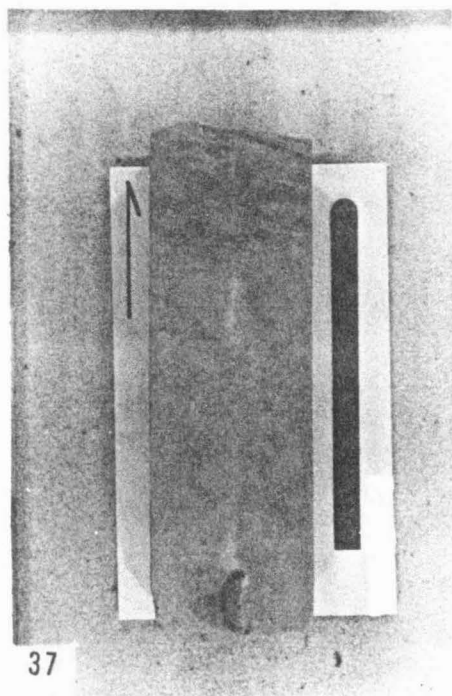
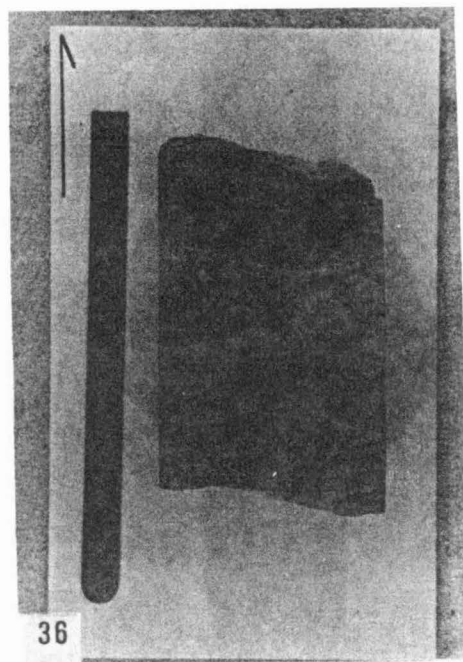
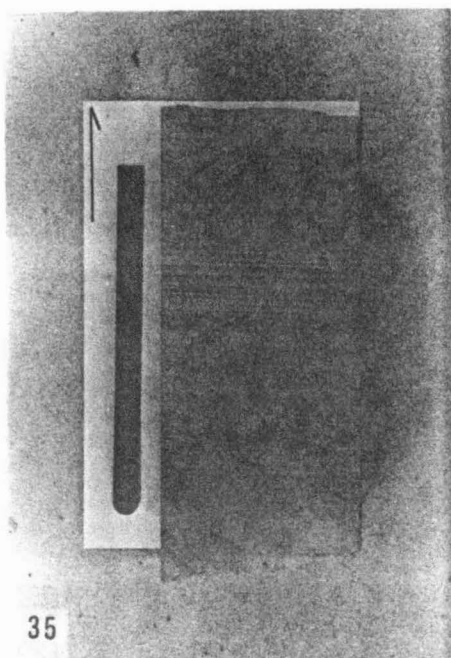


Figure 39. - Alternating dark and light gray siltstones. The light gray silt zones are deposited as wavy laminations or as ripples. This piece is representative of channel fill deposits. The darker laminae which are organic rich and represent vertical accretion deposits. The lighter laminae represent introduction of coarser grained sediment into the abandoned channel under traction transport as sediment from the active channel is carried into the area of deposition during flood stage. The varve-like appearance may also suggest fresh water lake deposition. From Barrier #36 core at 2474 feet (754 m.). (Bartlesville Sandstone)

Figure 40. - Multidirectional asymmetrical current ripples. This type of deposition probably occurred in the natural levee close to the channel or in a crevasse splay deposit. The multidirectional nature of the ripples resulted from the sediment laden currents spreading out in all directions after escaping the confined flow of the channel. From Perrier #7 core at 2377 feet (725 m.). (Bartlesville Sandstone)

Figure 41a.- Mottled green gray siltstone with iron nodules and ferruginous cement zones. The mottling is probably a function of both root and invertebrate burrowing destroying the primary bedding. Roots have disturbed some laminae to give the core a flecked appearance. The iron cement zones probably formed from subarial exposure resulting in a number of iron oxide or carbonate diagenetic products. This facies commonly gradationally overlies the sandstone and probably represents a subarial levee deposit. Taken from Jackson Heirs #22 core at 2464 feet (751 m.). (Burbank Sandstone)

Figure 41b.- Another example of a levee deposit. The inclined wavy laminations suggest some traction transport. The sample, therefore, may have been deposited close to the channel. The oblique fractures present represent non-tectonic cracks resulting from slumping of the overbank material. Taken from Hawthorne #9 core at 2510 feet (765 m.). (Burbank Sandstone)

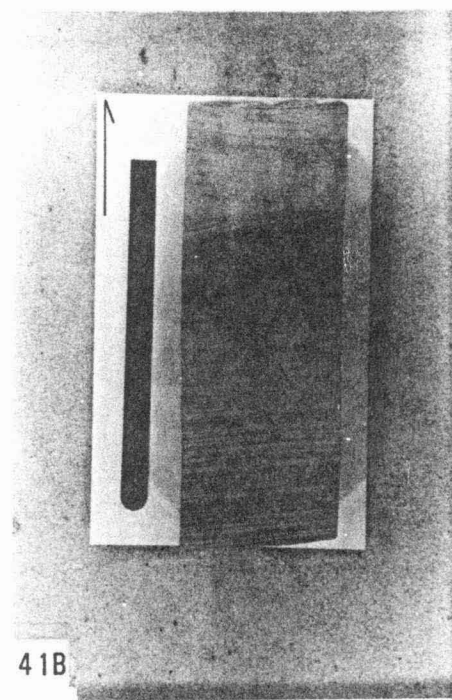
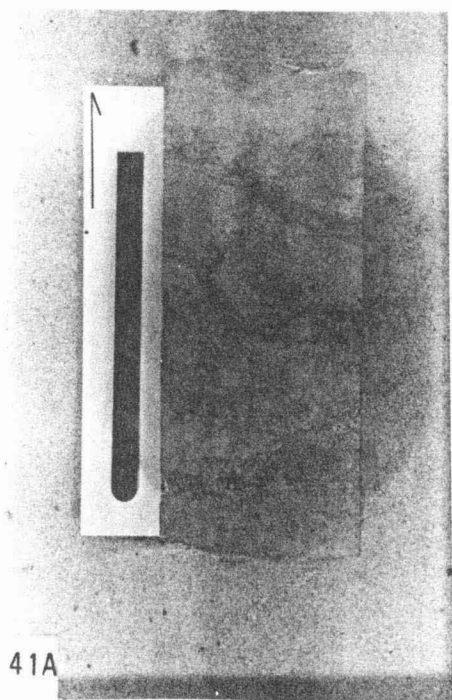
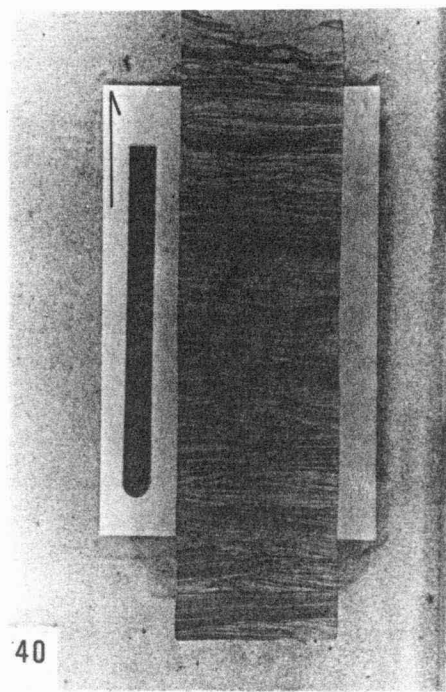
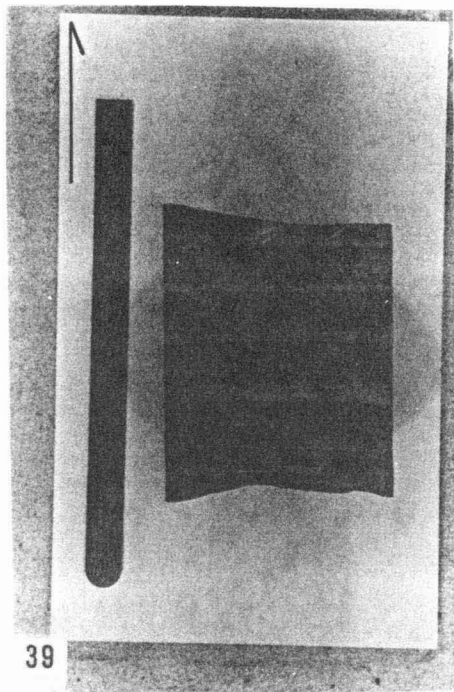
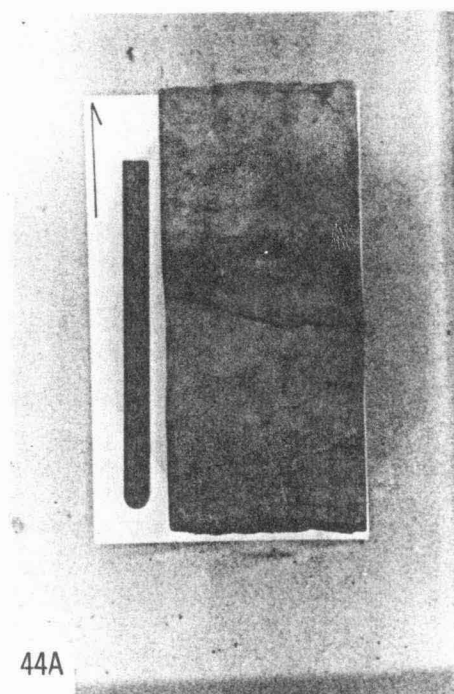
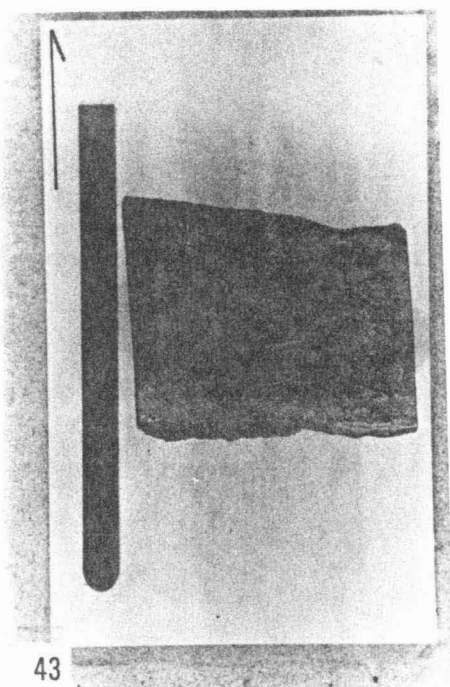
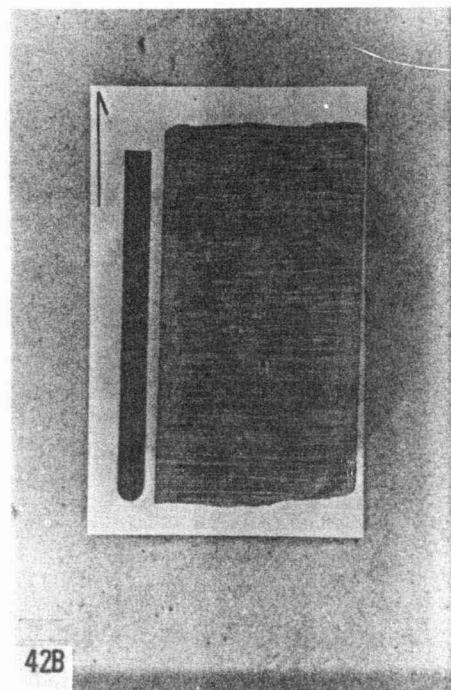
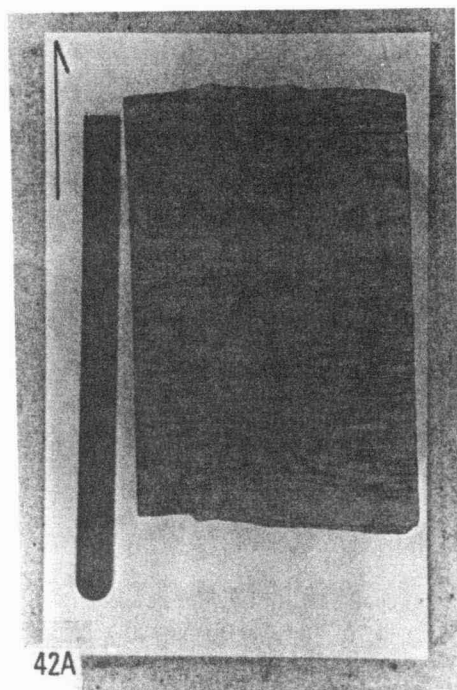


Figure 42a - Irregular sand and silt bedding. This type of bedform is called wavy bedding as the silt laminae are continuous across the core piece and the ripples are vertically isolated from each other. Some horizontal burrows are present and the direction of ripple migration is unidirectional from right to left. These units were formed by a combination of traction transport of sand into ripple bedforms followed by periods of slack water where deposition occurred by settling of fines. The traction transport was not strong enough to erode the siltstone laminae. With the presence of burrows a tidal origin is suggested, however the same facies type was observed in crevasse splay deposits by Dickinson (1975). Taken from Jackson Heirs #16 core at 2414 feet (736 m.). (Burbank Sandstone)

Figure 42b - Another example of wavy bedding. Note the increase in silt as opposed to Figure 42a. This suggests that deposition occurred farther away from the active channel and that vertical accretion was a dominant process. Taken from Jackson Heirs #16 core at 2415 feet (736 m.). (Burbank Sandstone)

Figure 43 - Dark gray fossiliferous lime packstone containing brachiopods, echinoderms and bryozoans in a burrowed lime mud matrix. From H.E. Adair Ladd #1 at 2403 feet (733 m.). (Underlies Bartlesville Sandstone)

Figure 44a - Light gray mottled siltstone with carbonaceous material. The mottling is due to root action. Also present are iron nodules. The presence of abundant carbonaceous material and diagenetic iron nodules suggest levee deposits. From H.E. Adair Ladd #1 core at 2382 feet (726 m.). (Bartlesville Zone)



sediment deformation, carbonaceous material, pyrite, iron and calcareous nodules. 4. A crumbly, olive gray claystone or mudstone with slickensides, fractures, iron and calcareous nodules and carbonate veins. 5. Light to dark gray siltstones with distinct burrows, mottling, root casts, and iron nodules or laminated with nodular pyrite (Fig. 44). 6. Coal beds.

Jackson Bros. Rice #1 at the edge of the Burbank sandstone shows, in part, a coarsening-upward sequence and contains a reddish gray, mottled claystone with slickensides (Appendix B).

Biogenic Structures - Fossils found in the sandstones include a u-shaped burrow (Fig. 45 ) and plant fragments. The overlying and lateral facies are in part mottled by traces of roots and by organic burrowing. Examination of included shales interbedded with the sandstone after their disaggregation (Appendix C) revealed no fossils, however an inarticulate brachiopod was found in one black shale sample. Remains of brachiopods, echinoderms, mollusks, and bryozoans were found in the underlying limestones.

#### Facies Models of the Reservoir Sandstones

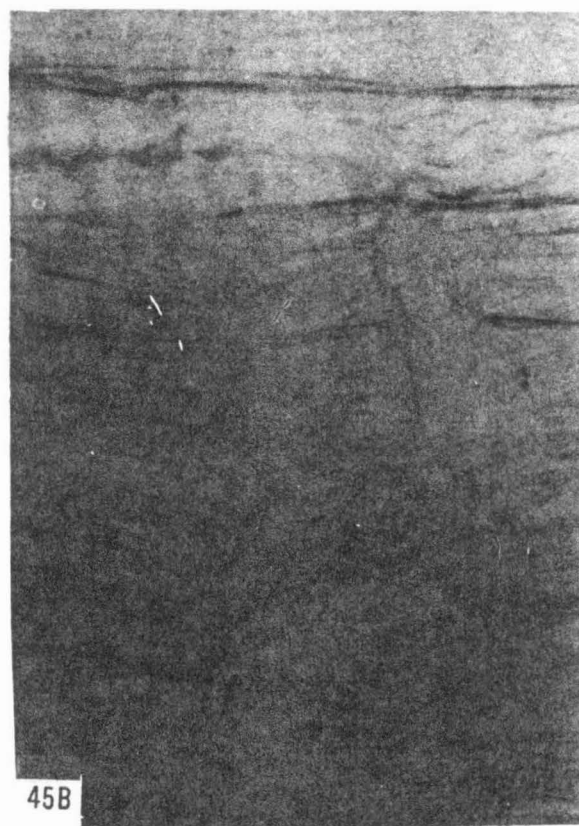
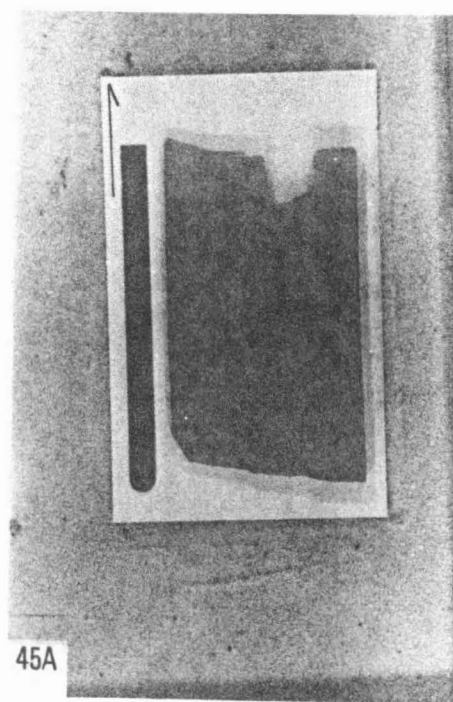
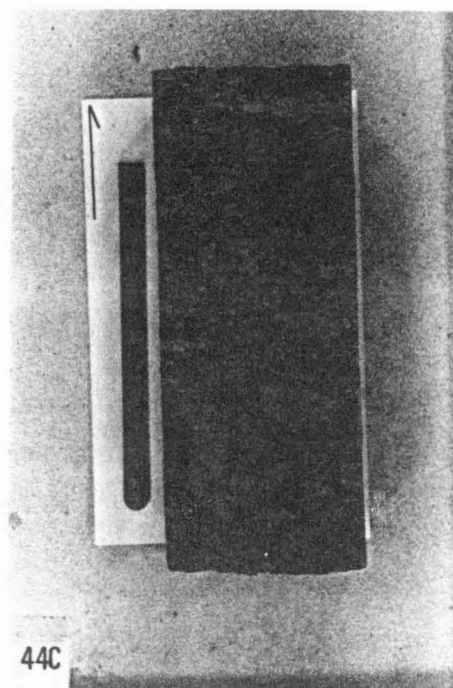
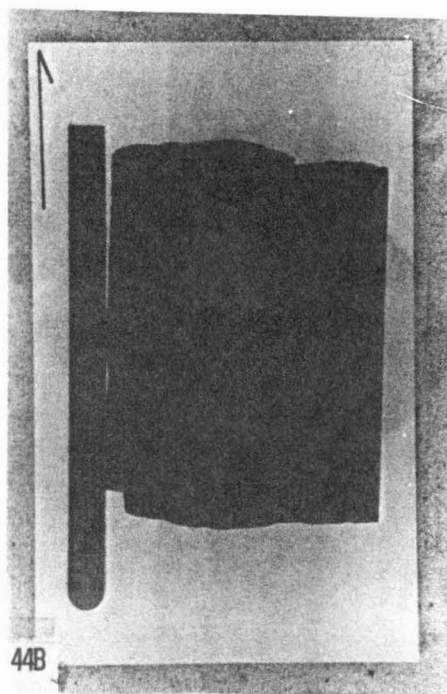
Composition and texture - Clues of the mode of origin may be ascertained from the petrography of the reservoir rocks. The sandstones are mineralogically and texturally immature with abundant metamorphic rock fragments, micas, clays, angular tourmaline, feldspar grains and subangular quartz grains. These types of components indicate that

Figure 44b. - Dark gray laminated siltstone with nodular pyrite along the bedding planes. The dark gray laminated siltstone occurs below the mottled light gray siltstone and is gradational with it. The darker gray facies may be formed in a subaqueous environment while the lighter gray siltstone formed in a subarial, more oxidized environment. From Ladd #1 core at 2380 feet (726 m.). (Bartlesville Zone)

Figure 44c. - Dark gray burrowed siltstone. The burrows seem to follow the bedding planes and are horizontal. The organisms were probably deposit feeders suggesting that deposition was slow and the bottom currents were not very strong. From H.E. Adair Ladd #1 core at 2393 feet (726 m.). (Bartlesville Zone)

Figure 45a. - "Massive" interval of sandstone. The irregular nick in the top of the core piece is a core plug taken out for porosity measurements. See Figure 45b. below. From Crew #17 core at 2538 feet (774 m.). (Burbank Sandstone)

Figure 45b. - X-ray radiograph of a burrow in the Burbank Sandstone. The burrow is narrow going up through the sandstone. If the disturbance were due to a water escape structure the laminae should all be inclined upward at the point of disturbance which does not enter.



slight abrasion and little reworking of the sand occurred during deposition (Blatt et al., 1972) and that the source was nearby. The amount of clays and micas increases and the size of the monocrystalline quartz grains decreases from the base to the top of the sandstones (Figs. 53, 54 ). This indicates that the sandstones were deposited by currents with lessening velocities. Glauconite rarely occurs within the sandstones. Biogenic material includes one chambered shell fragment and a burrow, wood fragments and organic matter.

Geometry of the sandstones - The Bartlesville and Skinner Sandstones are narrow and elongate in plan view and lenticular in cross section. They display a convex-down base which thickens at the expense of the underlying shales and a relatively flat upper contact with the overlying sediments. The sandstones consist of numerous individual sandstone bodies stacked on top of one another separated by continuous and discontinuous shales. The Burbank Sandstone may be distinctly lenticular or uniformly thick within each of its laterally equivalent, elongate but discontinuous sandstone bodies. The base of the sandstone is irregularly flat or cuts down into underlying shales. In plan view the sandstone displays a branching pattern.

Sedimentary structures of the reservoir rocks - The sandstones all show a decrease in the scale of sedimentary structures from the base to the top of the sandstone. The Bartlesville Sandstone normally has a conglomeratic zone just above the basal contact which includes siltstone clasts, iron nodules, calcareous nodules, carbonaceous

matter and wood fragments in a fine grained sandstone matrix. The lower part of the sequence is dominated by large-scale trough or planar crossbedding which grades upward into small-scale, unidirectional, asymmetrical, current ripples. Massive beds and scour surfaces are associated with the lower part of the sequence while horizontal bedding and siltstone beds are associated with ripple bedding higher in the sequence. The vertical sequence in the Burbank zone is similar to that of the Bartlesville with the exception of the conglomeratic zones and horizontal bedding which are not present. The Skinner Sandstone is dominated by large scale trough or planar crossbedding, but ripple crossbeds occur at the top of the sequence.

Associated facies and contacts with adjacent units - The contacts with the underlying and laterally equivalent facies are sharp and considered erosional. The overlying contacts in all three sandstones may be either sharp or gradational. The facies overlying the Bartlesville Sandstone consists of graded bedded units and a series of dark gray siltstones with ripples or horizontal laminations. The Burbank Sandstone normally grades into a greenish mottled siltstone with siderite, pyrite and soft sediment deformation structures or it may be a sharp contact with overlying beds of sand and shale which resembles wavy bedding. The Skinner Sandstone may grade upward into or form sharp contact with light to dark gray siltstones. The sandstones cut down into numerous facies. The most abundant facies are a variety of light to dark gray siltstones with ripple bedding, pyrite,

soft sediment deformation, varve-like alternations of light and dark gray siltstone laminae, root mottling and burrowing. A variety of greenish gray shale or siltstone with mottling, soft sediment deformation, carbonaceous material, pyrite, iron and calcareous nodules are common. Black shale frequently underlies the sandstones and contains pyrite and carbonaceous material. Olive gray claystone, light to dark gray reworked fossiliferous packstones or wackestones and coal beds are also found underlying the sandstones or in the laterally associated facies but are minor in volume relative to the shales.

## Modern Environments of Deposition

Development of three-dimensional models of modern sedimentary environments has led to major advances in recognition of their ancient analogs. These models are a distillation of related features common in numerous examples. They are based on active sedimentation processes and the resultant facies developed within an environment. Comparison of these models to vertical and lateral sequences of facies present in ancient sandstones provides a basis for interpretation. This approach emphasizes descriptive, objective criteria from the rocks with no preconceived stratigraphic ideas being forced upon the models (Fisher and Brown, 1972). Ebanks and James (1974), in a summary of numerous papers on Cherokee sandstones in Kansas, state (p 22-23):

"Cherokee sediments are mainly terrigenous clastic sandstones and shales, interbedded with thin coal deposits, underclays and a few thin limestone beds. Later cyclic sequences... include far more limestone and almost no coal, supporting the concept of increasingly wide-spread marine invasion of this area throughout middle and later Pennsylvanian time, with variations of environmental conditions as the interplay of sediment supply and basin subsidence changed. In this setting, the Cherokee Basin has been depicted as the site of shifting and prograding alluvial and deltaic plains, estuaries, tidal delta complexes, beaches, and shallow marine shelf environments."

For this reason, those environments associated with near-shore sedimentation that develop narrow, elongate, lenticular sand bodies will be compared to the facies model of each sandstone described here. Depositional setting, geometry of the complex and individual units, boundaries, the

vertical sequence of sedimentary structures, associated facies types, depositional processes, grain size distribution, sand texture, composition and biotic constituents for the relevant models are given in Table 3. Accompanying figures are shown in Appendix D. The references for each model are also given in Table 3 (in pocket).

Origin of the Cherokee Sandstones  
in the  
Sallyards Field Area

Provenance

The source area for the Cherokee Group has long been a subject of controversy. A southern source has been suggested by Moore (Mudge, 1956) and Weller (Wheeler and Murray, 1957). Dogan (1969) in a study of the Red Fork sandstone argues for a southern source based on the position of the deltaic facies relative to the Ouachita Mountains. Although a southern source may be locally important, there is appreciable evidence for a northern source. According to Mudge (1956) the increase in the number of Pennsylvanian-Lower Permian channel sandstones to the north in the midcontinent area indicates southward transport. Wheeler and Murray (1957) argue that the total volume of the Pennsylvanian-Lower Permian sandstones west of the Mississippi is too great to be derived from local sources. They suggest that the Canadian Shield area was a major contributor of sediment. Numerous studies of Cherokee sands in northeastern Oklahoma indicate that delta progradation was to the south (Visher et al. 1971; Hudson, 1969; Visher, 1968; Phares, 1969; Cole, 1969). Paleocurrent directions in the Bluejacket and Warner Sandstones trend southeastward (Visher, 1968, Hayes, 1963).

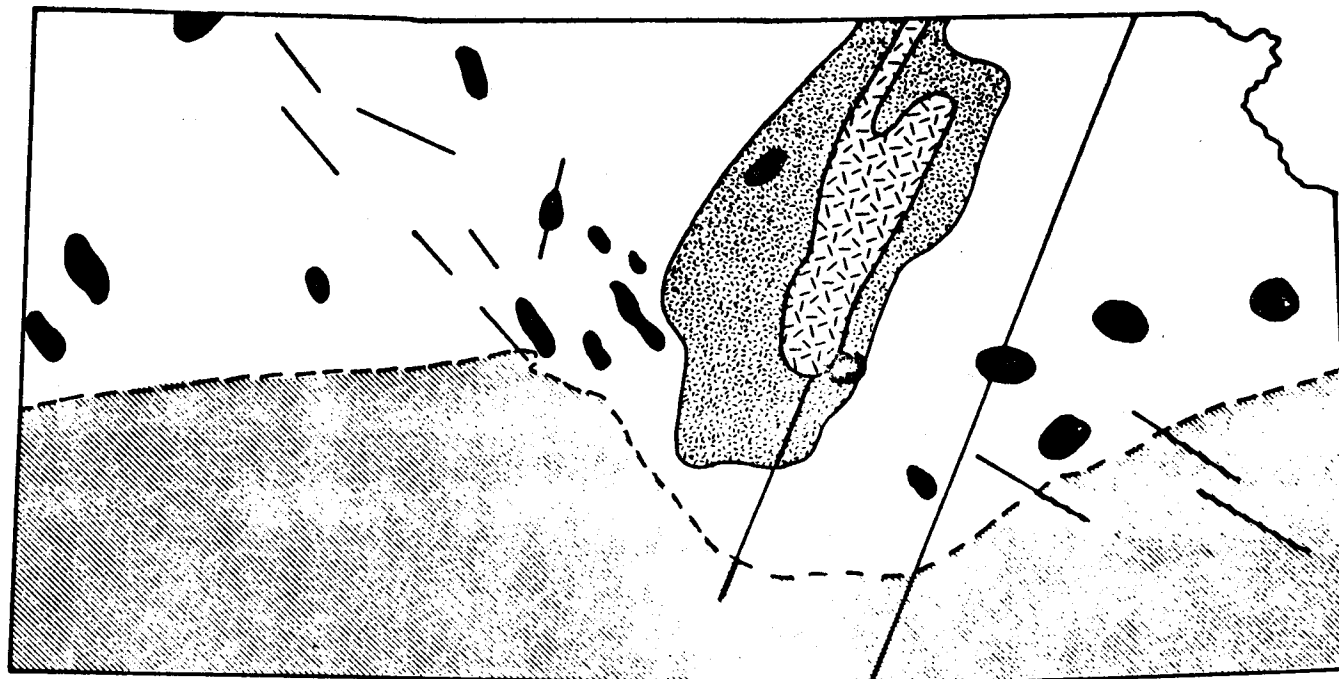
The composition of the sandstones also suggests a local origin. The abundance of strained monocrystalline and polycrystalline quartz, and of such unstable components as feldspar and metamorphic rock fragments suggest an igneous--metamorphic source, while chert, rounded quartz grains, and reworked glauconite indicate a sedimentary rock source (Folk, 1968). In addition to these features the angularity of many of the monocrystalline quartz grains, the abundance of schistose---phyllite rock fragments and the presence of euhedral tourmaline suggests that the sediments underwent only limited transport (Blatt et al, 1972). According to Folk (1968), the presence of both fresh and altered feldspars found in the sandstone indicates a nearby source of high relief.

The paleotectonics map of Desmoinesian time (Fig. 10) shows the positive elements present during the deposition of the Cherokee Group. The Ozark Uplift was capped with a thick carbonate cover and did not contribute an appreciable amount of sediment (McElroy, 1961). Streams from the Ouachita Mountains introduced sediment to both the Anadarko and Arkoma Basins locally (Dogan, 1969; Huffman, 1958) but probably did not contribute to the area of shelf sediments farther north in Kansas. The Canadian Shield Area to the north possibly contributed some of the rounded quartz and chert. The presence of the Bourbon Arch, however, may have inhibited flow from the north into the Cherokee Basin until middle or late Cherokee time (Jewett, 1951). Others suggest that the Bourbon Arch was inundated by

middle Cherokee time (Weirich, 1953; Visher, 1968).

This suggests that the Canadian Shield contributed sediment here only after deposition of the Bartlesville Sandstone. The distribution of local basement rock (Fig. 46) lithologies (Bickford, et al, 1975) indicates the Nemaha Uplift consists of granitic plutons and regionally metamorphosed rocks consisting of gneiss, metaquartzite with subparallel muscovite, muscovite-bearing schists, and to a lesser degree, chlorite-or-biotite-bearing schists. Most of these rocks contain evidence of shearing in the form of strained crystals with undulose extinction and cataclastic textures. Farquhar (1957) found that tourmaline and zircon, the two most abundant accessory minerals in the sandstones, are present in both granites and quartzites, which dominate the eastern part of the Kansas basement terrain. A plan view of the Nemaha Uplift (Weirich, 1953) indicates that older Paleozoic sedimentary rocks were exposed to erosion in the area north and west of Sallyards Field during Cherokee time (Jewett, 1951). Among these older units was the Simpson Group which contains abundant glauconite and subrounded quartz grains (Leatherock, 1945). According to Farquhar (1957), the Nemaha Uplift stood from 1,000 to 3,000 feet in relief above the basinal areas. Metasediments to the east of the Nemaha anticline, in northern Greenwood County, may have supplied a large portion of the rock fragments (Bickford, 1976,

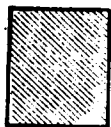
Fig. 46 - Kansas Precambrian Basement Distribution Map. After Bickford et. al. (1975).



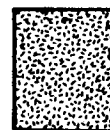
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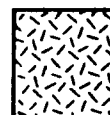
deep seated terrane of regionally metamorphosed rocks and mesozonal plutons; includes gneiss, schist, quartzite and rocks of granitic origin. strongly sheared.



terrane of silicic volcanics, largely rhyolite and rhyolitic ash-flow tuffs; associated silicic epizonal intrusives; many of the rocks are granophyres. metasediments- schists, quartzite, and gneiss.



Rice sedimentary formation, Scott(1976), consisting of arkose, arkosic sandstone and shale.



basalt and gabbro; probable extension of Keeweenaw basaltic terrane of Lake Superior along axis of mid-continent geophysical anomaly.

personal communication). As the Nemaha Uplift and the Metasedimentary area in northern Greenwood County represent areas of locally high relief containing all of the common minerals present in the Sallyards Area sandstones, they are believed to be the major source for these sediments.

#### Environments of Deposition of Cherokee Sandstones

Significant features of facies models developed from the sandstones in the Sallyards Field Area have been compared with the process-response models shown in Table 3 and Appendix D. Braided (Appendix D-1) and coarse-grained meandering fluvial systems (Appendix D-2) may be eliminated as models for the Sallyards sandstones because they lack a fining-upward sequence in grain size and an upward decrease in the scale of sedimentary structures. Barrier bar systems (Appendix D-6) usually have an overall increase in grain size from the base to the top of the sand, while offshore bars (Appendix D-7) may either show an increase or a decrease in grain size upward in the sequence. Both types of marine bar sands contain abundant biotic constituents, and glauconite, and consist of well sorted sand. Sedimentary structures present in these sands show diverse orientations, indicating multidirectional current flow. For these reasons models of barrier bars and shallow marine bars do not explain well the facies observed in the Sallyards Sandstones.

Straight distributary channels (Appendix D-4) are characterized by unidirectional current flow, however, the resulting sand deposit commonly shows no decrease in either grain size distribution or in the scale of sedimentary structures from the base to the top of the sandstone. The trough cross bedding present in distributary channels is commonly contorted due to subsidence of the sandstone into the prodelta muds. Distributary channels, therefore, may probably be eliminated from consideration as an environment in which the Sallyards Sandstones were deposited.

All three Cherokee sandstones have characteristics which suggest deposition by meandering alluvial systems (Appendix D-3): 1. Decrease in grain size from the base to the top of each sandstone. 2. Decrease in the scale of sedimentary structures upward in the sequence. 3. Unidirectional current features. 4. Scarcity of shell debris or bioturbation. 5. Texturally immature and mineralogically immature sandstones.

The Bartlesville and Skinner zones are lenticular with a convex-down base, thicken at the expense of underlying shales, and are multistoried sandstone bodies. They contain an abundance of clay chips, iron and calcareous nodules, and carbonaceous matter in the conglomerate zones. For these reasons, the Bartlesville and Skinner Sandstones are believed to represent deposition in fine grained meandering alluvial systems. The Burbank Sandstone also has many features typical of meandering systems; yet it lacks

the conglomerate zones of the other sandstones. The sandstone also has a branching pattern in plan view consisting of multilateral sandstone bodies. These discontinuous laterally equivalent sandstone bodies may be distinctly lenticular or more uniformly thick in cross section. Features as the top of two cores suggest deposition by tidal currents. A complete model, therefore, of process-response in a meandering alluvial system will be described for the Bartlesville and Skinner zones. The origin of the Burbank Zone however will be discussed in the following section after comparing similarities and differences between tidal channel and meandering stream deposits.

Meandering Alluvial Systems - Alluvial sandstone bodies and their associated facies (Fig. 47) develop in two general ways: by lateral and vertical accretion. Lateral accretion occurs mainly within the confines of the channel and involves traction transport, while vertical accretion results from unconfined flow, and deposition occurs mainly by settling of fine sediment from suspension. Destructional processes such as soft-sediment deformation, burrowing, root mottling, etc. may alter the internal structure of the sandstone during or after deposition. Stream-course changes create the multistoried nature and the lateral discontinuities within the sandstones of an alluvial system, as the channel migrates over the floodplain.

To understand lateral accretion one must look at numerous processes active in the channel. The most characteristic process is unidirectional flow produced by flooding from upstream areas. Repeated flooding in the channel results in scour along the bottom of the stream. This produces erosional lower and lateral contacts (Fig. 26) between the sand and adjacent units (Visher, 1972). During the initial stages of flooding, (Fig. 48) scour occurs along the concave cutbank where water velocities are at a maximum. The finer material is washed away from sediment at the base of the channel, leaving a residual concentration of coarse material (Reineck and Singh, 1975). In the Sallyards Field area, the residual concentration consists of clay chips, iron nodules, and wood fragments (Figs. 26 and 31).

The erosion along the concave bank plays an important role in lateral accretion of point bars (Fig. 49). According to Visher (1972) a meander point bar develops a sloping surface where deposition takes place. A variation in depth is produced which affects the velocity of the transporting medium; consequently, a vertical change in grain size and the scale of sedimentary structures may develop. Although the flow mechanisms are poorly understood, sedimentation in fluvial channels occurs as a result of helical flow of the transporting fluid (Reineck and Singh, 1975). This results from a slight elevation of the water surface along the cutbank (Fig. 48). This cross-current carries sediment transverse to the channel

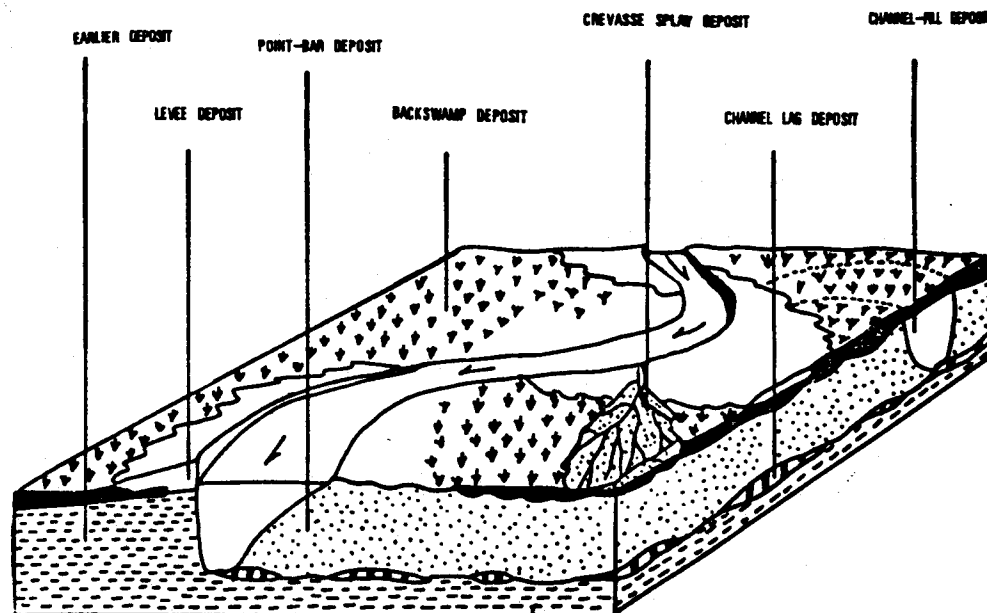


Fig. 47. - A plan and cross-sectional view of a fine grained alluvial meandering system showing the relationship between the channel and the associated facies. After Blatt *et. al.* (1972).

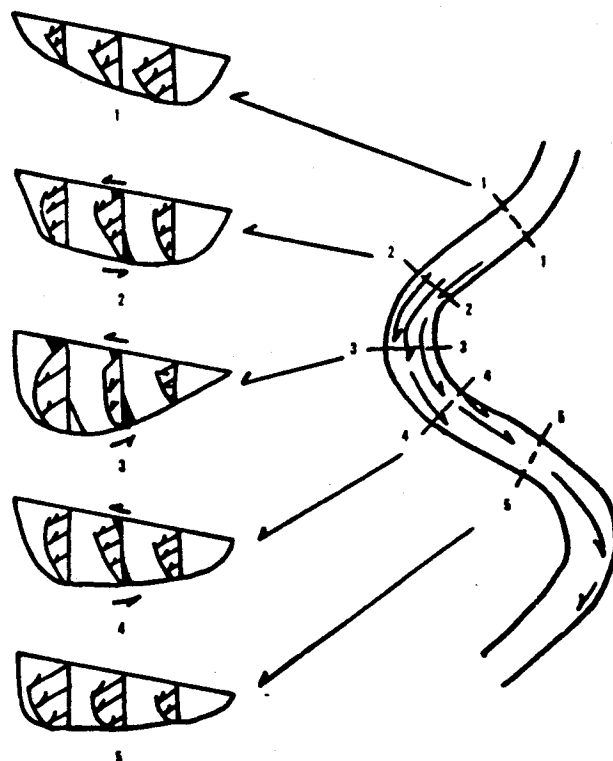


Fig. 48 - Cross sections through a meandering channel showing water flow through the system. Between meanders, flow is fairly uniform. In the meander loop the flow is stronger to the concave bank and reverse flow forms. Lateral erosion of the outside bank and lateral migration of the point bar result. After Reineck and Singh (1975).

axis while the main current moves the sediment downstream to the next point bar (Reinick and Singh, 1975). As the point bar is enveloped during the rising stages of a flood, the coarsest material in transport present is progressively dropped out (Fisher and Brown, 1972). The decrease in flow velocity higher on the point bar is indicated by the vertical sequences of sedimentary structures produced (Fig. 28). The basal portion of the point bar is dominated by medium to large scale, trough cross beds (Figs. 29 and 30); while the upper part of the sequence is dominated by horizontal bedding (Fig. 35) or by asymmetrical current ripples (Fig. 32). Southard (1975) plotted flow velocities versus grain size with data from numerous flume experiments. He found that in general the sequence of bed forms in sediment with grain size greater than .1mm and less than .6mm during increasing flow velocity is: no movements → ripples → sand waves and dunes. For very fine grained sediments the sequence is more simple, consisting of: no movement → ripples → upper flat bed with increasing velocity. This is, in general, consistent with measurements on thin sections from selected cores (Figs. 53 and 54). The finer grained sand is generally deposited as ripples while the coarser grains are deposited as dunes. It also indicates that large scale crossbeds, deposited as dunes, are developed in the lower reaches of the point bar under a higher velocity flow condition than that necessary to form ripples deposited higher on the point bar. The horizontal bedding associated with ripples is probably

formed as a combination of higher flow conditions as upper flat beds (in areas of little silt) and settling of fines during periods of slack water or at the last stages of the flooding episode.

The contact between the overbank sediments and the channel sandstone is gradational in meandering systems, and it generally marks the transition between lateral and vertical accretion deposits.

Most of the sediments overlying the channel sandstone are deposited by settling of fines from suspension (Figs. 37, 41). This occurs when flow escapes the channel, becomes unconfined, and decreases in velocity (Fisher and Brown, 1972). Levees form above the channel banks. The coarsest sediment is deposited adjacent to the channel, while the finer material is carried farther toward the flood basin. Examples of possible levee deposits from the sandstones in Sallyards Field are shown in Figs. 37, 41. Root mottling, burrowing, iron nodules, pyrite, and soft-sediment deformation are common. Channel-fill deposits (Fig. 39) formed by abandonment of part or of the entire stream course consist of laminated fine sediment. Some burrowing and organic matter may be present. The flood basin usually contains the finest sediment in the system because it develops in low areas marginal to the levees. Root mottling and homogenized soil zones are common.

Vertical accretion may also occur within the channel as clay drapes may form on the point bar during low stages of flow (Walton, 1976; personal communication).

A process which develops from both lateral and vertical accretion is crevassing. Crevassing occurs when flood waters escape the channel through a low area in the overbank sediments. The resultant deposit is sinuous or lobate in plan view and develops on the lower part of the levee (Fisher and Brown, 1972). Small-scale crossbedding, climbing-ripple lamination and horizontal bedding are sedimentary structures common to crevasse splay deposits. The sandy portion of the deposit is capped by muddy sediments (Reineck and Singh, 1975). The sediment in Fig. 38 may be interpreted as a crevasse splay deposit. The ripples in this deposit probably represent the initial sediment through the levee break. As the flood rises, coarse sediment is transported through the break under higher flow conditions producing the scour surface. The massive sandstone, therefore, represents deposition as an upper flat bed. As the flood recedes, deposition from traction-transport is replaced by settling from suspension and the graded siltstone is deposited. Another type of splay deposit features multidirectional current-ripple beds with abundant silt. The break in the natural levee, analogous to a point source of sediment, acts as a passage into unconfined flow conditions, and the water spreads over the entire area producing multidirectional ripples (Fig. 40).

Destructive processes alter the internal features of the sandstone and the associated facies. Root mottling and burrowing occurs in the sandstone (Fig. 45) and over-

bank sediments (Fig. 41 A). Soft sediment deformation from slumping of the unconsolidated material in levees results in soft-sediment cracks (Fig. 41 B). If the overbank material slumps into the channel the result is a zone of distorted siltstone clasts with angular, compacted boundaries. Deformation in the clasts resulted from plastic deformation of the unconsolidated material during the slumping process (Fig. 36). Laminations overlying clast zones are commonly distorted. This occurs because of interference patterns developed in the sediment-laden currents as they pass over the clast zones during deposition. Other causes of overturned laminations are: the drag of strong sediment laden currents across the bottom (Fig. 34), from gravitational movement of fluid saturated sand along a slope or from subsidence of sand into underlying incompetent shales. Distorted laminae result as water under high pressures moves through the sand (Coleman et al, 1965).

Changes in the course of a stream occur on a large scale (Fig. 50). Avulsion occurs as a stream "jumps" its present course and occupies a new area lower on the flood plain (Fisher and Brown, 1972). This normally happens when a stream attains a near-zero gradient and becomes sluggish. The river will again build in a similar fashion. Later avulsion may cause the river to re-occupy or to cut through part of the abandoned course. This process leads to a multistoried sand deposit with numerous lateral discontinuities. All of the processes mentioned above are represented by features which developed

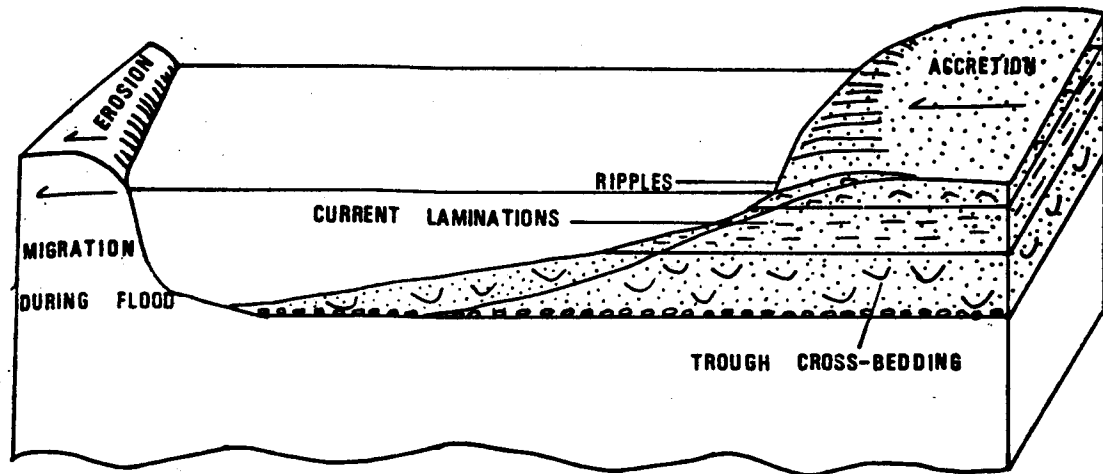


Fig. 49 - Cross section of a point bar following a flood event. River has laterally accreted and eroded to the left. Epsilon cross-bedding has formed on the sloping surface of the point bar. Note that the fining upward sequence in grain size results from lateral accretion of the upper part of the point bar over previously deposited lower reaches of the point bar. Finer sized grains and smaller sedimentary structures are deposited at the top of the point bar because the stream has decreased in flow velocity. After Visser (1965).

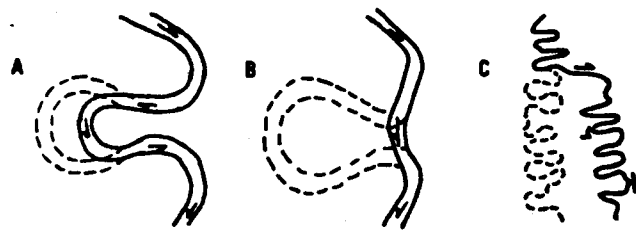


Fig. 50 - Three ways for a stream to change course. A. A chute cutoff, B. A loop cutoff, C. Avulsion- the entire stream changes course. After Reineck and Singh (1975).

in the Bartlesville and Skinner zones. The Burbank Sandstone contains most of the features described above, yet:

1. It lacks the lag deposits found in the Bartlesville and Skinner zones.
2. It has developed into a multi-lateral, branching sandstone body.
3. It has sedimentary structures at the top of two cores which are typical of tidal flat sedimentation. Its origin is discussed in the next section.

Tidal Channels - As seen in Table 3, tidal channels (Appendix D-5) show a decrease in grain size and scale of sedimentary structures from the base of the sandstone to the top; they contain shell debris in basal lag deposits; and they show bi-directional current bedding features resulting from the flood and ebb flow of tidal currents. The bi-directional bedforms, known as flaser, lenticular or wavy bedding, may be burrowed. The facies models of the Sallyards sandstones differ from deposits of tidal channels in having uni-directional sedimentary structures and conglomeratic zones which contain no shell debris. A lack of bi-directional bedforms or shell debris, however, does not necessarily rule out a tidal channel setting for these deposits. Hayes (1963) presented evidence from studies in the Wadden Sea that unidirectional bedforms result when one stage of the tidal cycle, either ebb or flood flow, dominates over the other. According to Klein (1967), the ideal vertical sequence of sedimentary structures of fluvial and tidal channels are so similar that the composition of the channel lag was the only way to dis-

guish between them. Estuaries contain a mixture of shell debris, clay clasts, and plant fragments and are highly bioturbated (Klein, 1967), while fluvial sands contain little, if any, marine fauna or burrowing. In ancient deposits, if the shell material has been dissolved, recognition of the depositional environment could be difficult. Two previous studies on the Warner (Hayes, 1963) and Bluejacket Sandstones (Visher, 1975), however, indicate that while no fossils were found, oscillation ripples, and tracks and trails of organisms were present in these interpreted tidal flat deposits. Since the Bartlesville and Skinner Sandstones contain no burrowing, have no fossil debris in the clast zones, and show no oscillation bedding or tracks or trails of organisms, these sandstones are interpreted as alluvial stream deposits.

The Burbank Sandstone, however, has interbedded sand and shale at top of two cores that is characteristic of continuous wavy bedding (Fig. 42). The sand in such units is deposited during periods of current activity, while mud is deposited during slack water periods (Reinech and Singh, 1975). These structures are commonly widespread in tidal flats. Phares (1969) suggests that these bedforms mark a more seaward facies in the Bartlesville deltaic complex. In the Sallyards Area, though, these bedforms are areally restricted, the sequences in which they occur are separated from the sandstone by a sharp erosional contact, the ripples within are unidirectional, and each sequence fines upward in grain size.

Dickinson (1975) reports the presence of flaser-like structures in levee deposits of alluvial streams. The Burbank Sandstone contains no burrows or shell debris. The cross laminations present are strongly unidirectional. The multilateral nature of the channel sandstones may be due to a lack of confinement from the underlying paleo-topography, unlike the lower Bartlesville zone. These reasons, plus the fining-upward sequence in grain size and upward decrease in the scale of sedimentary structures also suggest that the Burbank Sandstone was also deposited by a low gradient meandering stream system. The wavy bedding probably represents structures found in distal parts of crevasse splays (Dickinson, 1975), however, the suggestion by Phares (1969) cannot be discounted.

#### Environments of Deposition of the Laterally Associated Facies

The formation of cyclic deposits in the Cherokee Group by alternation of delta progradation and marine transgression has been amply substantiated by Dickey and Rohn (1955), Berg (1963), Saitta (1968), Visser (1968), Cole (1969), Phares (1969) and Visser et al. (1971). The depositional setting of the Cherokee Shelf was one of continuous subsidence to the south (Visser et al., 1971). and intermittent uplift in the north and west (Jewett, 1951; Weirich, 1953; Ebanks, and James, 1974). This resulted in an overall transgression of the sea to the north which was interrupted by the progradation of several deltas southward (Visser et al., 1971) following periods

of uplift. During progradation, constructive facies, such as, prodelta mudstones, delta-front sandstones, channel-mouth bar sandstones, and distributary channel fill and delta-plain sediments advanced basinward. As an equilibrium between sediment supply, compaction and the volume of the area of deposition was reached, delta-destructive facies such as lagoons, estuaries, peat deposits, and limestones were formed over the delta sequence (Visher et al., 1971). As a result of repeated progradational and transgressive episodes, seven laterally associated facies dominate within the Cherokee group. These are all present in the Sallyards Field Area.

1. Gray shale - In the Sallyards Field Area the underlying facies is dominated by silty, non-fossiliferous, pyrite-rich gray shales which contain abundant organic matter. The lack of fossils in the lower gray shales and their association with coal and underclay suggest non-marine deposition (Baker, 1962). In H. E. Adair Ladd #1 dark gray laminated siltstone with nodular pyrite (Fig. 44 b) grades up into light gray, root mottled siltstone with abundant organic material and iron nodules (Fig. 44 a). The presence of pyrite and lack of burrowing suggests that the black shale was deposited in a reducing environment which was hostile for living organisms. In the Colorado River Delta, Texas, low marsh deposits are forming under reducing conditions, and laminations are common. Burrows, shell material, and roots, on the other hand, are less common (Kanes, 1970). The low marsh deposits

then grade into natural levee deposits which are root mottled and contain iron nodules. This type of environment may explain the sequences seen in H. E. Adair Ladd #1. Some gray shales overlying the sandstones are burrowed (Fig. 44 b) and do not contain pyrite which may suggest a shallow marine environment with better water circulation such as an interdistributary bay (Reineck and Singh, 1975).

2. Underclays - The olive gray, fractured, mottled slickensided claystones in the lower part of the Cherokee Group represent either "fossil" soils (Baker, 1962) or gley, a substance which forms under peat beds following reactions between the underlying clay and organic compounds produced in the peat (McMillan, 1956). Both origins represent non-marine deposition. Soil formation would follow exposure of the clays to land processes of weathering and erosion generally under oxidizing conditions. Gley, on the other hand, is formed in marshy areas where the water table is high, under large beds of peat where reducing conditions prevail and leaching effects are minimized (McMillan, 1956). The association of the underclays in the lower part of the Cherokee Group with coals and occurrence of ferrous compounds in the underclays may suggest that the claystones were found as gleys in a black swamp area of a river or on the marsh lands of an upper delta plain. Those underclays not associated with coals that have a reddish and gray mottled color may represent soils formed under oxidizing conditions

(Rice #1; Appendix 3).

3. Coals - The coals represent areas of little clastic deposition along swampy coastal plains or flood plains where abundant vegetation grew. The coal (peat) swamps flourished in the humid sub-tropical climate in Middle Pennsylvanian time (Moore, 1964; Gould, 1975; Van Dyke, 1975). Migration of the swamps during transgressive episodes resulted in wide-spread distribution of coals.

4. Iron claystone - Occasionally, thin beds of iron claystone occur within or immediately underlie the Bartlesville Sandstone. These have been interpreted by Baganz et al. (1975) to be subaqueous contemporaneous equivalents of coal beds. This is possible for the iron claystones underlying the Bartlesville Sandstone in Perrier No. 6 core; however, the claystones within the sandstone occur in the ripple cross bedded units and are not continuous. For these reasons, the iron claystones in the sandstone probably represent clay drapes that underwent diagenetic alteration.

5. Greenish-gray shale - Greenish-gray shale present in the area of study is fissile and calcareous, contains siderite nodules, and includes some plant material.

The sparse fauna found by Baker (1962) consists of Foraminifera, inarticulate and productid brachiopods, conodonts, gastropods, pelecypods, ostracods, and echinoids. The presence of siderite instead of pyrite

may suggest that more oxygenated conditions prevailed during deposition of this shale than the gray shales. This variety of shale may form in brackish water lakes or in inter-distributary embayments (Fisher et al. 1973).

6. Black carbonaceous shales - The Bartlesville, Burbank, and Skinner zones overlie black, pyritic, organic-rich shales in some wells. Fossils in the black shale consist of inarticulate brachiopods, conodonts, cephalopods, fish bones, and plant material (Baker, 1962). Historically, black shales have been interpreted by Moore (1949), Weller (1957), and Baker (1962) as being deposited in an extremely shallow marine swamp which was rich in organic matter. This type of deposition today occurs in shoreline embayments or lagoons and is normally associated with peat deposits or marshes. The association of the black shales with coal and underclay indicates deposition in areas analogous to modern shoreline environments. Some black shales, however, are associated with normal marine limestones and contain abundant phosphate. These black shales were probably deposited during times of maximum transgression when the water was deep enough to develop a thermocline which prevented bottom oxygenation by wind driven currents (Heckel, 1977). As winds moved the surface water seaward, it was replaced by cold, oxygen depleted, and phosphate rich water. The increase in phosphate led to plankton blooms. As the phosphate-rich water settled to the bottom the concentration of the phosphate reached a critical point and was pre-

cipitated. The plankton also settled to the bottom enriching the shales in organic matter (Heckel, 1977).

In this way the shales formed as widespread transgressive deposits. This interpretation may be valid for the black shale underlying the Verdigris Limestone.

7. Limestone - Limestones found in the Cherokee Group are light to medium gray in color and contain brachiopods, echinoderms, and bryozoans in a microcrystalline reworked calcite matrix or a dolomitized matrix. The lighter gray varieties (Fig. 43) were formed on the shallow open marine shelf while the darker varieties with a higher degree of silt may represent deposition closer to the delta in interdistributary bays during a transgression or abandonment of a delta lobe (Fisher et al., 1973).

#### History of Deposition of the Sallyards Area Sandstones

The Cherokee Basin developed by gentle downwarp to the south after the rise of the Nemaha Uplift during post-Mississippian time (Jewett, 1951). Folding, faulting and erosion on the pre-Pennsylvanian surface created an irregular topography with considerable relief. The most important influence on sedimentation patterns on the Cherokee shelf in southeastern Kansas and northeastern Oklahoma was the Arkoma Basin farther south, which was an actively subsiding marginal basin between the craton and Ouachita Mountains during middle Pennsylvanian time (Baker, 1969). Visher et al., (1971) suggested that the Arkoma Basin underwent continuous subsidence during

Desmoinesian time. This is substantiated by transgressive onlap of units progressively northward on the shelf area and by a higher proportion of carbonates to clastics present in the Marmaton Group (Weirich, 1951; Visher et al., 1971; Ebanks and James, 1974). Branson (1968) estimated that marine waters over the shelf area were never deeper than 60 meters and that emergence occurred at least 20 times. This pattern of alternating regressive-transgressive sedimentation is explained by some geologists as having been caused by repeated episodes of southward rapid progradation of delta sequences, alternating with transgressive episodes instead of changes in sea level (Visher et al., 1971).

The initial sediments underlying the Bartlesville Sandstone contain numerous sequences of dark gray unfossiliferous shale-underclay and coal (Fig. 51) and these sediments are interpreted by Baker (1962) as predominantly non-marine. During deposition of a regressive sequence, the olive gray underclays developed as gley beneath peat deposits or as soils on the underlying non-fossiliferous gray shales which were deposited in marshes and flood basins on the lower alluvial plain (McMillan, 1956; Baker 1968). The absence of limestones in the early sediments indicates that the transgressive episodes did not advance far enough north for non-clastic deposition. The appearance of limestone and black fissile shales immediately below the Bartlesville Sandstone indicates that the overall transgression had migrated farther north

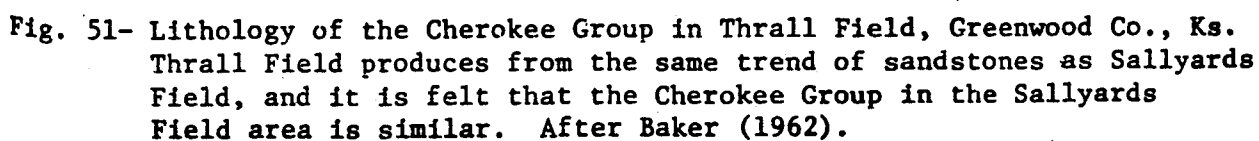


Fig. 51- Lithology of the Cherokee Group in Thrall Field, Greenwood Co., Ks. Thrall Field produces from the same trend of sandstones as Sallyards Field, and it is felt that the Cherokee Group in the Sallyards Field area is similar. After Baker (1962).

by this time. During these transgressions clastic deposition ceased and widespread embayments and lagoons slowly encroached over the delta plain depositing widespread peat deposits and black shale. Carbonate deposition could also take place either as limestone or clay ironstone.

The Bartlesville Sandstone was then deposited during a regressive episode by a southwestward flowing, perennial, low-gradient meandering stream. The source for the sediments carried by this stream system was the Nemaha Uplift to the west, metasediments in northern Greenwood County, and, possibly, the Canadian Shield area to the north. The straightness of the shoestring sands, the narrow confined nature of the sandstone, and the indication of deposition in a low in the pre-Pennsylvanian surface suggest that deposition of the Bartlesville Sandstone was structurally controlled. The Bartlesville Sandstone developed as a multistoried sandstone body within the narrow confines of its "paleovalley" and built up to thicknesses approaching 30 meters (100 feet).

The relationships of the sandstones in the Sallyards Field area to the deltaic complexes in Oklahoma are obscure. Correlations between Kansas and Oklahoma are hampered by a lack of information and by disagreement on the correlation of some formations. The relationship between the Bartlesville Sandstone in the Sallyards Field area to the Bartlesville-Bluejacket deltaic complex to the south is based on correlation to the surface Blue-

jacket Sandstone in southeastern Kansas (Ebanks 1977, personal communication). Assuming the surface correlations to be correct between Kansas and Oklahoma, the Bartlesville Sandstone in the study area may represent deposition in the lower alluvial plain or upper deltaic plain of the deltaic complex to the south.

The Burbank Sandstone is separated from the Bartlesville Sandstone by a thin but continuous shale unit (all cross sections; Plates 2-5). This shale unit was probably deposited during a transgressive episode after deposition of the Bartlesville Sandstone and prior to the development of the Burbank Sandstone. The Burbank zone was also deposited by a perennial, low gradient, meandering river. It was free of structural confinement, as evidenced by its occurrence on both sides and overlying the Bartlesville Sandstone. The crossing pattern of arrows on the net sandstone map (Plate 9) in secs. 18 and 19-25S-9E suggests that the two episodes of deposition may have occurred in the Lower Burbank interval. The isopach map from the Base of Verdigris Limestone to the base of the sandstone (Plate 8) shows that the Burbank Sandstone bodies closer to the Bartlesville Sandstone are incised deeper into the Cherokee shales than the Burbank Sandstones in Teichgraber Field. While this may be a function of draping of the limestone over the sandstones, it may also indicate that the sandstones closer to the Bartlesville zone were deposited first. Avulsion then occurred shifting deposition of the sand to the west. In

this fashion both a multistoried and multilateral sandstone developed. The wavy bedding at the top of the sequence in three cores may represent the initial transgression of the sea following deposition of the sandstone (Phares, 1969), or a crevasse splay deposit in the flood plain (Dickinson, 1975). The other alternative, of origin in a tidal channel, is unlikely because of a lack of shell debris or molds of shells which would indicate marine conditions (Klein, 1967). The appearance of a black shale above the lower Burbank Sandstone may indicate the drowning of the river system by a shallow restricted bay or lagoon. The upper Burbank Sandstone which occurs in the northern part of the study area has an electric log pattern similar to that of the lower Burbank, and may represent another regressive episode of deposition.

The relationship of the Burbank Sandstones to the deltaic complex in Oklahoma is also obscure. The distribution of the Burbank delta to the north and west of the Bartlesville delta (Visher et al., 1971) indicates that the overall transgression of the Cherokee Sea had progressed northwestward. The sandstones may also represent a lower alluvial plain facies, upland from the delta, or an upper deltaic facies.

Following another transgression and deposition of muds in a shallow, restricted, marine bay, the Skinner Sandstone was deposited as a southward flowing perennial, low gradient meandering stream. The distribution of the Skinner Sandstone in Kansas is not well known, but the

Skinner in the study area may represent a fluvial facies which was more landward than one of the three Skinner horizons in Northern Oklahoma by Cole (1969).

## Petroleum Geology Of The Sallyards Field Area

### Source Rock, Migration and Trapping Mechanism

The oil found in the Cherokee Sandstones is limited largely to sandstones which were deposited in shelf environments (Weirich, 1953). No continuous avenues for oil migration extend northward out of the Arkoma Basin, with the exception of the Bartlesville Sandstone, indicating that the oil originated in the shelf sediments (Weirich, 1953). Baker (1962) suggests that the oil was generated in the gray or black shales which are rich in organic matter. The oil then migrated only short distances into laterally adjacent sandstones. The source rock, when compacted, also provided the seal for the reservoir rocks.

Production from the Cherokee Sandstones in Sallyards, Teichgraber and Jackson Fields is limited by impermeable shales surrounding or adjacent to the reservoir rock. Sallyards Field, as determined by electric log examination, is bounded by impermeable shales laterally and is separated from Blankenship and Polhamus Fields, to the south and north, respectively, by areas of shaley sand. The bouyant force generated by the height of the oil column was too weak to overcome the high capillary pore pressures present in the shaley sands at each end of the Bartlesville Sandstone (Berg, 1975). These shaley sands formed the lateral traps. The drape of the sandstones over high areas on the pre-Pennsylvanian surface (formations) and the westward dip of the sandstone imparted by later

structural movement of the Ozark Uplift may have localized the oil accumulations into updip areas. Core analyses show that wells in Section 30, T-25-S, R-9-E have thicker oil columns than wells in Section 2, T-26-S, R-8-E because the sandstone in Section 30, T-25-S, R-9-E is structurally higher than the sandstone in Section 2, T-26-S, R-8-E. Mechanisms for entrapment and localized updip accumulations of oil are thought to be similar also for the Burbank and Skinner Sandstones. This type of reservoir is a combination structural-stratigraphic trap (Busch, 1959) and is characteristic of most oil fields occurring in Cherokee Sandstones on the Cherokee Shelf.

#### Primary Production and Waterflooding

Information citing the primary production mechanism and important parameters of selected waterfloods in the study area are given in Table 4 . Primary production (solution gas drive), limited because of the quick loss in reservoir energy (Levorsen, 1973), peaked in 1922 with 660,000 barrels of oil (BO) and declined to 95,000 BO in 1945.

Waterflooding began in 1946. In the past thirty years, a number of projects have been attempted in all three fields in the study area. From 1963 to 1973 production has dropped from 300,000 BO/year to 95,000 BO/year, a portion of which comes from a Douglas Sandstone reservoir. This decline in production is occurring in a great number of fields producing oil from Cherokee Sandstones in

southeastern Kansas. API estimates indicate that only 50 to 60% of the oil originally-in-place will be recovered from the four producing zones in Sallyards Field and even less from Teichgraber Field. Studies are underway, therefore, to find better methods of recovery. These processes, known as enhanced oil recovery (EOR) methods, may be defined as processes which promote "the additional recovery of oil from a petroleum reservoir over that which can be economically recovered by conventional primary and secondary methods" (Haynes et al., 1976).

#### Enhanced Oil Recovery Methods

Three types of EOR methods are probably applicable to the Sallyards Field sandstones. Of these, chemical methods seem to hold the most promise and these will be emphasized in the following discussion.

Thermal Processes - Thermal processes introduce heat to the reservoir to reduce oil viscosity or to vaporize the oil. This causes the oil to be more mobile, so that it can be driven more effectively to the producing wells (Haynes et al., 1976). These processes are usually applied to low gravity, high viscosity oils which are resistant to flow at normal reservoir temperatures. Thermal processes, though, have been successfully applied to fields with high gravity, low viscosity crude oil. One important limiting factor in the feasibility of using thermal methods is transmissibility which is defined as the average permeability of the reservoir rock x the thickness

of the reservoir divided by the average viscosity of the oil. For steam injection processes, the minimum transmissibility is 100 md-ft./cp; for in situ combustion, the minimum transmissibility is 20 md-ft./cp. Using average values of permeability, the average number of permeable feet in the reservoir, and viscosity at 100°F taken from Tables 6 and 8, transmissibilities of slightly over 150 were calculated for the Bartlesville and Skinner zones and values slightly over 30 for the Burbank zone in the Sallyards Field area. The values calculated are speculative, but they indicate that the utility of steam processes is marginal in the Sallyards Field area. In situ combustion processes, seems to have more possibilities; however, study should be undertaken to determine if this process is economically feasible. For a detailed description of the thermal process the reader is referred to Haynes et al. (1976), Crawford (1974) or Farouq Ali (1974).

Carbon Dioxide - Miscible Flooding - Carbon dioxide miscible flooding occurs when CO<sub>2</sub> is injected into a reservoir under sufficiently high pressures for the CO<sub>2</sub> to be soluble in the oil. The CO<sub>2</sub> is not miscible with the oil initially; however, as CO<sub>2</sub> contacts the oil some of the hydrocarbons are vaporized (Haynes et al., 1976). At the displacement front the mixture of vaporized hydrocarbons and CO<sub>2</sub> become miscible with the in-situ oil. The addition of the CO<sub>2</sub> into the oil decreases the viscosity of the oil and makes it move more easily resulting in improved recovery (Haynes et al., 1976). Pressures in the

Table 5.- Properties of contained fluids in the producing Sandstones in the Sallyards Field Area

| Name of Sandstone | (Initial)    |      | (Initial) | Laboratory Tests           |                     |                          | Cl <sup>-</sup> Content<br>ppm |
|-------------------|--------------|------|-----------|----------------------------|---------------------|--------------------------|--------------------------------|
|                   | % Fluid Sat. | oil  |           | Oil Content<br>bbl./ac-ft. | Orig. Oil Sat.<br>% | Residual Sat. (%)<br>oil |                                |
| Skinner*          | 23.8         | 44.7 | 371.1     | 28.7                       | 22.2                | 71.9                     | 77,465                         |
| Burbank*          | 24.3         | 56.9 | 330.3     | 25.4                       | 19.0                | 72.8                     | 84,172                         |
| Bartlesville*     | 23.8         | 51.0 | 364.2     | 27.2                       | 18.0                | 69.4                     | 62,234                         |

\*These are average values.

Table 6.- Physical Properties of the crude oils in the producing Sandstones of the Sallyards Field Area

| Formation       | Gravity (API) |           | Viscosity |                 |        |                 |        |                 | Interfacial Tension (oil to water) |                 |
|-----------------|---------------|-----------|-----------|-----------------|--------|-----------------|--------|-----------------|------------------------------------|-----------------|
|                 |               |           | @70°F     |                 | @100°F |                 | @120°F |                 | dynes/cm. @60°F                    |                 |
|                 | ave.          | range     | ave.      | range           | ave.   | range           | ave.   | range           | ave.                               | range           |
| "Bartlesville"* | 38.8          | 37.2-40.3 | 5.234     | 4.284-<br>6.323 | 3.482  | 2.993-<br>4.139 | 2.784  | 2.409-<br>3.272 | 33.23                              | 30.03-<br>36.17 |

\*Samples averaged come from the Blankenship, Teichgraber, and Sallyards Fields. The oil samples probably are from the Burbank and Bartlesville Sandstones. The depths ranged from 2352 to 2525 feet.

Table 7.- Chemical composition of a crude oil sample from Quincey Field in the "Golden Lanes" Area. After Gould (1975)

|                                       | % Saturate HCS.                                      | % Aromatic HCS. | % NSOS. | % Asphaltenes | Saturated HCS./ Aromatics |
|---------------------------------------|------------------------------------------------------|-----------------|---------|---------------|---------------------------|
| C 15 <sup>+</sup> Oil Fraction        | 62.1                                                 | 30.9            | 4.6     | 2.4           | 2.0                       |
| Normalized C 15 <sup>+</sup> Fraction |                                                      | 81.4            | 12.2    | 6.4           |                           |
| By Groups of Compounds                | %HCS= 95.5 %non-HCS= 4.5 HCS.= Hydrocarbon Compounds |                 |         |               |                           |

Table 8.- Values of the Petrophysical Properties of the producing Sandstones in the Sallyards Field Area

| Name of the Sandstone | No. ft. of permeable sand | Porosity (%) | Permeability (md)<br>(to dry air) | Effective Permeability (to water)<br>(at residual oil saturation-md.) |
|-----------------------|---------------------------|--------------|-----------------------------------|-----------------------------------------------------------------------|
| Skinner*              | 14.8                      | 18.4         | 32.7                              | 2.74                                                                  |
| Burbank*              | 10.7                      | 16.2         | 11.8                              | 1.58                                                                  |
| Bartlesville*         | 25.3                      | 14.9         | 23.9                              | 1.82                                                                  |

\*These are average values.

reservoir must be kept high enough to keep the CO<sub>2</sub> soluble with the crude oil (Haynes et al., 1976). Carbon dioxide flooding is applicable to both sandstone and carbonate reservoirs and appears to be potentially significant as an enhanced recovery method (Haynes et al., 1976). Although the pressure needed for the CO<sub>2</sub> to become soluble decreases with higher gravity oils, the minimum depth to attain the necessary miscibility is approximately 2,500 ft. if the gravity is greater than 30° and the reservoir temperature is less than 120°F (Green, 1977; personal communication). The availability of CO<sub>2</sub> is limited and transportation costs for the needed supply may be prohibitive (Haynes et al., 1976). As no nearby sources of CO<sub>2</sub> exist, CO<sub>2</sub>-miscible flooding is not considered feasible at this time. Solubility tests should be run, however, to determine the miscibility of CO<sub>2</sub> with oil in the Sallyards Field area which varies in depth from 2300 to 2500' (700-760m).

Surfactant Flooding - Chemical methods seem to have the widest range of applicability for the sandstones in the Sallyards Field area. Where waterflooding has been successful in sandstones, chemical methods generally will apply (Poettmann, 1974). Chemical floods are the most complex and least tested methods of enhanced recovery; however, if chemical methods are applied properly, they may recover the maximum amount of oil (Haynes et al., 1976).

In surfactant flooding a mixture of water, alcohol, hydrocarbons, polymers, sulfonates, and inorganic salts are introduced into the reservoir to displace the oil by decreasing the forces which hold the oil in the pore space. It is a miscible process designed to displace 100% of the oil that is contacted in the reservoir (Poettmann, 1974). The surfactant is very expensive, typically about \$8.00 per barrel depending on the oil price (Green, 1977; personal communication), so only a small slug of this material is injected into the reservoir rock (Fig. 52). Water with a thickened concentration of polymer is injected behind the surfactant to displace the fluid to the producing wells. The polymer is added to increase the viscosity of the water and reduce the possibility of interfingering with or bypassing the oil-surfactant front by the displacing fluid. The polymer concentration added is gradually decreased as the flood advances. The best reservoir rocks (Table 9) for chemical flooding are laterally continuous, homogeneous sandstones with highly uniform values of porosity and permeability and only a small amount of clay (Haynes et al., 1976). Reservoirs such as these require smaller amounts of surfactant and allow the flood to contact and displace a maximum amount of oil.

Many natural reservoirs, though, have a number of characteristics which limit the effectiveness of surfactant floods. They include: 1. Low oil saturations. 2. Grain texture and fabric, and types of sedimentary structures which detrimentally influence the movement of fluids within

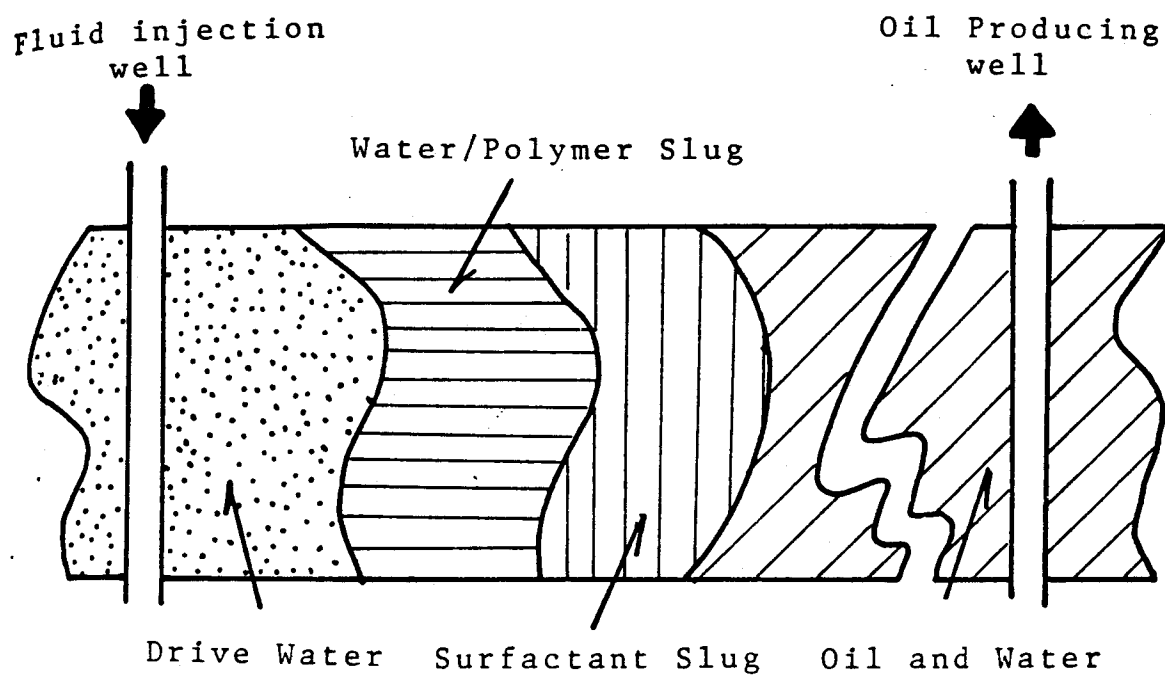


Fig. 52 - General Diagram of a Micellar-Polymer flood in a sandstone reservoir. (After Haynes et. al., 1976)

| <u>Process Parameters</u>           | <u>Limit by year</u>                                                                                         |                  |                                                                         |                  |             |
|-------------------------------------|--------------------------------------------------------------------------------------------------------------|------------------|-------------------------------------------------------------------------|------------------|-------------|
|                                     | <u>1976</u>                                                                                                  | <u>1980</u>      | <u>1985</u>                                                             | <u>1990</u>      | <u>1995</u> |
| Temperature (°F)                    | 120                                                                                                          | 170              | 200                                                                     | 225              | 250         |
| Salinity (wt. % TDS)                | 2                                                                                                            | 15               | 15                                                                      | 15               | 20          |
| Viscosity (cp)                      | 10                                                                                                           | 20               | 20                                                                      | 20               | 30          |
| Permeability (md)                   | 50                                                                                                           | 20               | 20                                                                      | 20               | 20          |
| <u>General Reservoir Parameters</u> |                                                                                                              | <u>1976-1985</u> |                                                                         | <u>1985-2000</u> |             |
| Geologic Criteria                   | Only sandstone reservoirs                                                                                    |                  | Only sandstone reservoirs                                               |                  |             |
|                                     | Uniform and continuous sands                                                                                 |                  | Minor variations in uniformity, if good well-to-well correlations exist |                  |             |
|                                     | Exclude reservoirs with extensive faulting, conglomerate rock, or lense type deposits interbedded with shale |                  |                                                                         |                  |             |
|                                     | Carbonate reservoirs excluded                                                                                |                  |                                                                         |                  |             |
| Natural Reservoir Energy            | No bottom water-drive reservoirs                                                                             |                  |                                                                         |                  |             |
| Deposit Characteristics             | No reservoirs with gas caps, unless water-flooding has been successful                                       |                  | No thin oil column overlain with gas                                    |                  |             |
| Hydraulic Characteristics           | No reservoirs where fluid movement is primarily through fractures                                            |                  |                                                                         |                  |             |
| Secondary Recovery Efficiency       |                                                                                                              |                  | 30-70 percent                                                           |                  |             |

Table 9.- Above are the criteria for screening reservoirs which might be favorable for the surfactant process. (After Haynes et. al., 1976)

the reservoir. 3. Shale, either as a continuous bed or as partings in sedimentary structures which acts to produce impermeable barriers and to compartmentalize fluid flow limiting the extent of the reservoir rock available for flooding. 4. Adsorption of chemicals and swelling by certain types of clays which create a need for greater amounts of surfactant (Bernard, 1975). 5. Cementation and compaction of the reservoir rock which decreases the amount and size of available pores and makes the oil more difficult to displace (Pettijohn et al., 1972). 6. Formation water high in NaCl or rich in Mg or Ca ions which may cause precipitation of the surfactants (Strange and Cloud, 1976).

Polymer Flooding - Polymer flooding is, in actuality, an enhanced waterflood. The polymer is added to the water to increase its viscosity. This results in increased "sweep efficiency" of fluids displacing the oil by improving their ability to contact oil in otherwise bypassed pore spaces. Two types of polymer are available: polyacrylamide and polysaccharide. Polyacrylamides not only increase the viscosity of the water, but also decrease the permeability of the formation to water (Haynes et al., 1976). When this happens the amount of polymer needed for the flood is less. Problems with polymers do arise, though. Polyacrylamides must be injected at moderate rates or the large molecules will shear as they flow through the perforations (Haynes et al., 1976). Polyacrylamides are also sensitive to high salinities and to high divalent ion

concentrations of formation waters. Polysaccharides, on the other hand, are not as sensitive as polyacrylamides to these factors of water chemistry and are less likely to shear during injection (Haynes et al., 1976). They are, however, susceptible to bacterial attack and need to be filtered to prevent well-plugging (Haynes et al., 1976). Polysaccharides are also more expensive than polyacrylamides. Large amounts of clay in the reservoir rock are undesirable because the polymers may be adsorbed.

Polymer flooding is not as efficient in recovering oil as surfactant flooding is, but it is cheaper (Willhite, 1977; personal communication). If a chemical flood is considered, an operator must decide if a more efficient surfactant flood will increase oil production enough to justify the increased costs, whether a polymer flood is more applicable, or if either approach will work. This depends on the conditions in the reservoir as outlined above, namely: 1. The remaining fluid saturations, the salinity and composition of the connate brine, and the composition of the crude oil, and 2. Geologic parameters such as grain size and orientation, sedimentary structures, mineral composition, diagenetic effects which may affect porosity and permeability and influence fluid movement through the reservoir rock. These features have been studied for the reservoir sandstones in the Sallyards Field area and the results are given on the following pages.

## Reservoir Fluids in the Sallyards Field Area

Average initial oil and water saturations and results of laboratory flooding tests in each sandstone are given in Table 5 . These values were calculated from core analyses provided by Jackson Bros., Beard, English and Martin and R. R. Abderhalden. An Ohio Oil Co. water-flooding report also contained some values of fluid saturation. The average initial oil saturation accounts for slightly less than 25% of the pore space in all three zones. The Ohio Oil Co. report indicated that these values are incorrect because of flushing of the core with water-based mud during drilling. Some of the oil is believed to have been replaced by the water from the drilling mud. The initial oil saturation for the Bartlesville Sandstone was calculated volumetrically to be 50.635% of the pore volume at the start of the Bryden-Ladd waterflood project of the Ohio Oil Co. The actual oil saturation today is unknown, however, production estimates indicate that a little less than 50% of the oil originally-in-place will remain behind (production from four zones) with the cessation of waterflooding. The  $\text{Cl}^-$  concentration, also given in Table 5 , varies widely in all three zones, from 20,000 ppm. to 200,000 ppm., with an average value of more than 60,000 ppm.

Everett and Weinaug (1955) performed tests for API gravity, viscosities at three temperatures and interfacial tension measurements (oil to water) on six oil samples from Blankenship, Teichgraber, and Sallyards Field (Table 6).

They found that the crude samples from the Sallyards Field area have gravities of 37 to 40°API and their viscosity decreases with increasing gravity. Interfacial tension ranges from 30 to 36 dynes/cm. According to Ebanks and James, (1974), these samples are characteristic of the oils from areas in the western part of the Cherokee Basin, which have gravities greater than 35°API and sulfur contents lower than 0.2%.

Neumann (1947) conducted chemical tests on 80 crude oil samples from 53 fields in the "Golden Lanes" trends in southeastern Kansas and northeastern Oklahoma. He found that all of the samples belonged to the same compositional class. Baker (1962) later expanded this study by analyzing the Cherokee shales present in Burbank Field, Osage Co., Oklahoma and Thrall Field, Greenwood Co., Kansas. He found that the oil in both fields was originally formed in similar types of shales and migrated only short distances to adjacent sandstones. He then concluded that the oil present in Cherokee sandstones of the "Golden Lanes" were formed from similar types of shale and that the crude oils in the reservoir rocks were similar in chemical composition. For these reasons it is felt that chemical analyses by Baker (1962) and Gould (1975; Table 7 ) for the Thrall and Quincy Fields in the Golden Lanes area are applicable also to Sallyards Field. Other chemical analyses of oils from Sallyards Field by Lane and Garton (1943) and Neumann (1947) are also applicable.

## Reservoir Geology of Sandstones in the Sallyards Field Area

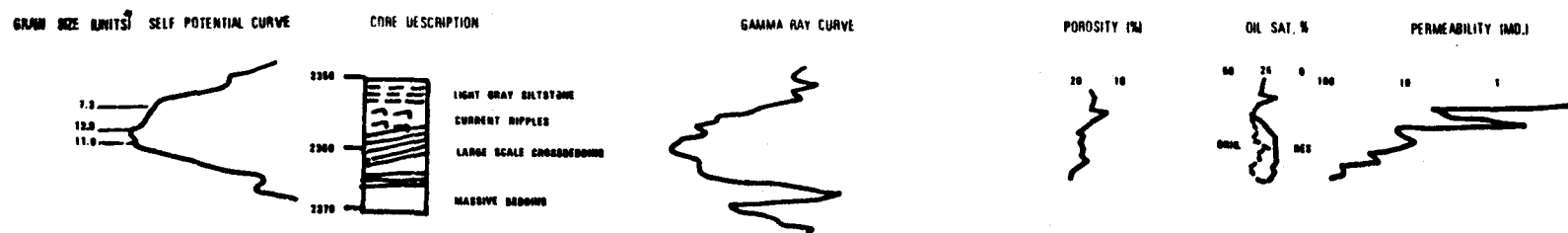
The average values for the number of feet of permeable sand, porosity, permeability to air, and effective permeability to water are given in Table 8. The porosity ranges from 7 to 23%, while permeability varies from almost zero to 400 md. for each of the sandstones. The effects of grain size, sedimentary structures, clay content, and cementation on permeability and porosity were studied to determine which parameters were important in influencing fluid flow; also, the effects of clays and cements present in the Sallyards Field area reservoirs on surfactants and polymers are discussed. The lateral continuity of the reservoir rocks was studied to determine the influence of discontinuities on fluid movement. The present day structural attitudes of the reservoir sandstones were also looked at to determine the possible gravitational effects on the displacing fluids as they move through the reservoir. The following is a summary of the observations made.

Effects of Grain Size and Sedimentary Structures on Permeability Distribution - A number of workers have attempted to demonstrate the effects of grain size on permeability (Krumbein and Monk, 1942; Hutchinson et al., 1961). Some have used a vertical representation of engineering properties, core descriptions, and electric log character to determine the relationships between grain size distribution, bedding types, and values of porosity and permeability (Hrabar and Potter, 1969; Hewitt and Morgan, 1965).

This method of portrayal was used for four selected cores in Sallyards Field area. Oil displacement tests were added to the graphs in an effort to determine the ease of oil displacement and its relationship to geologic factors. To determine whether changes in permeability variations were due solely to an increase in clay content or also to decreasing grain size, electric log response was examined and 11 grain size measurements were made in three of the selected cores at the base, middle and top of each core. The results are shown in Figures 53 and 54.

The self potential curves of Teichgraber 4, Crew 21, (Fig. 53) and Barrier 34 (Fig. 54) wells show stronger deflections from the shale base line than does that of Hendrickson 1 (Fig. 54). Each log has a decreasing deflection from the base to the top of the sandstone, paralleling vertical changes in the permeability. Examination of the core from the Hendrickson 1 well revealed that the bedforms present include more silt laminae than do those present in the other three cores. This feature was also present in other Hendrickson cores. The electric log response of the other Hendrickson cores was similar to that of Hendrickson 1. This indicates that sandstones with more shaley laminae will show reduced SP deflections, which is a well known effect. Griffiths (1952) suggested that as little as a 1% increase in clay content can greatly reduce the observed maximum deflection of the SP curve.

JACKSON BROS TEICHGRABER NO. 4 14-25S-BE



\*ONE UNIT OF MEASURE IS 0.75 MICRONS

JACKSON BROS CREW NO. 21 3-28S-BE

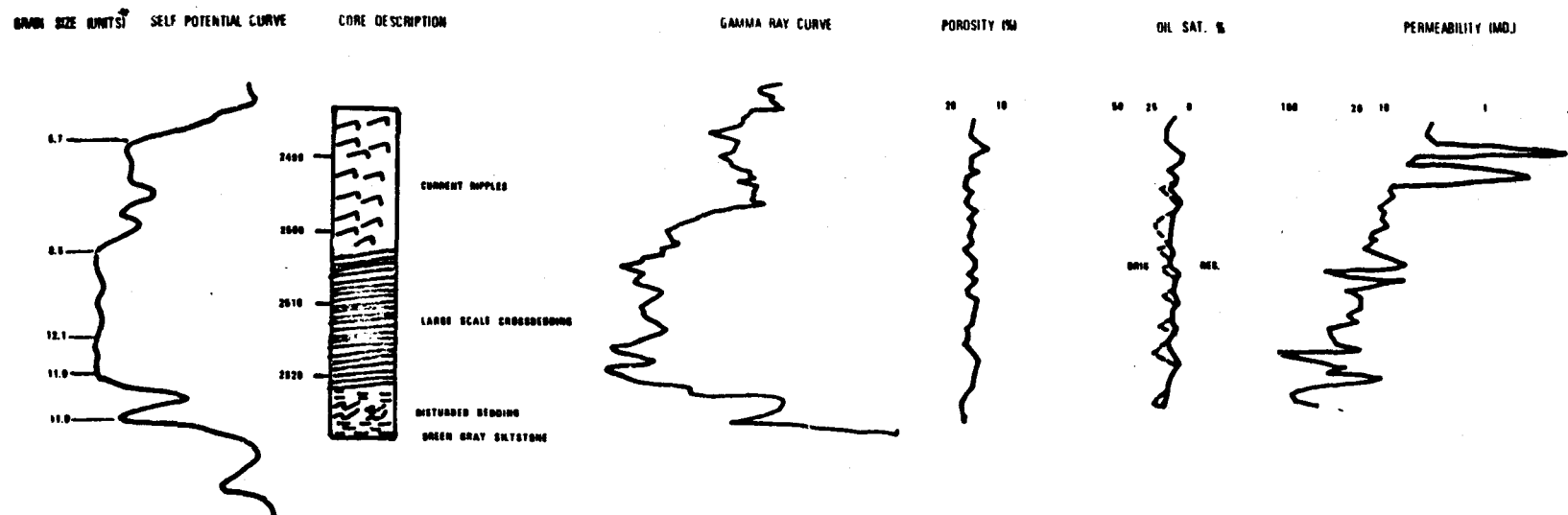


Fig. 53 - Vertical representations of Jackson Bros. Teichgraber 4 and Crew #21 showing relationships between geologic properties and reservoir parameters.

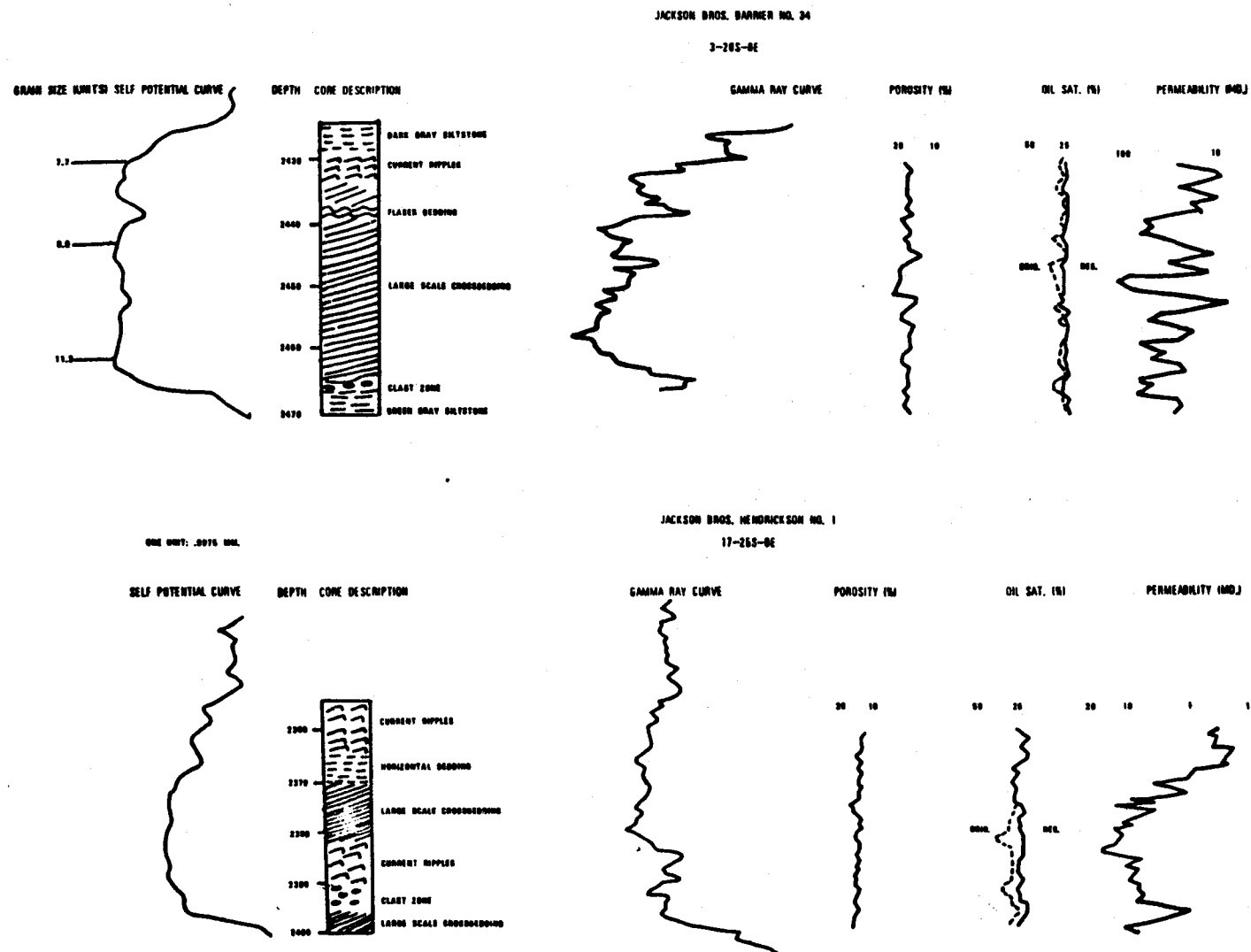


Fig. 54 - Vertical representation of Jackson Bros. Barrier #34 and Hendrickson #1 showing relationships between geological properties and reservoir parameters.

Gamma ray logs, however, are best used as a qualitative measure of shale content. Since  $K^{40}$  and the uranium-thorium radioactive elemental series are commonly associated with feldspars, micas and clays, a sandstone with a high clay content will have a pronounced effect on the gamma ray log curve (Wood et al., 1974). The mica and clay fraction in these sands consists of muscovite, biotite, chlorite, illite, sericite, kaolinite, and glauconite in amounts ranging from 8 to 29% of the total rock (Table 2). The minimum deflection on the gamma ray log normally correlates with the maximum values of permeability in the core; yet exceptions to this are noted. In the core from the Bryden 12 well (Fig. 55), the highest values of permeability occur at the base of the sequence yet the maximum deflection of the gamma ray log corresponds to sandstone higher in the sequence with lower permeability values. This may be a function of mineralogical changes in the sandstone. That is, the lower portion of the sandstone may contain a larger amount of potassium rich minerals, there may be variations within the sandstone of the ratios of various clay minerals with differing uranium-thorium contents, or cutting through radioactive shales by the sandstone may provide enough clay upon re-deposition to cause the deflection. This points out the need for care when using gamma ray logs for environmental interpretation or for calculations of shale content.

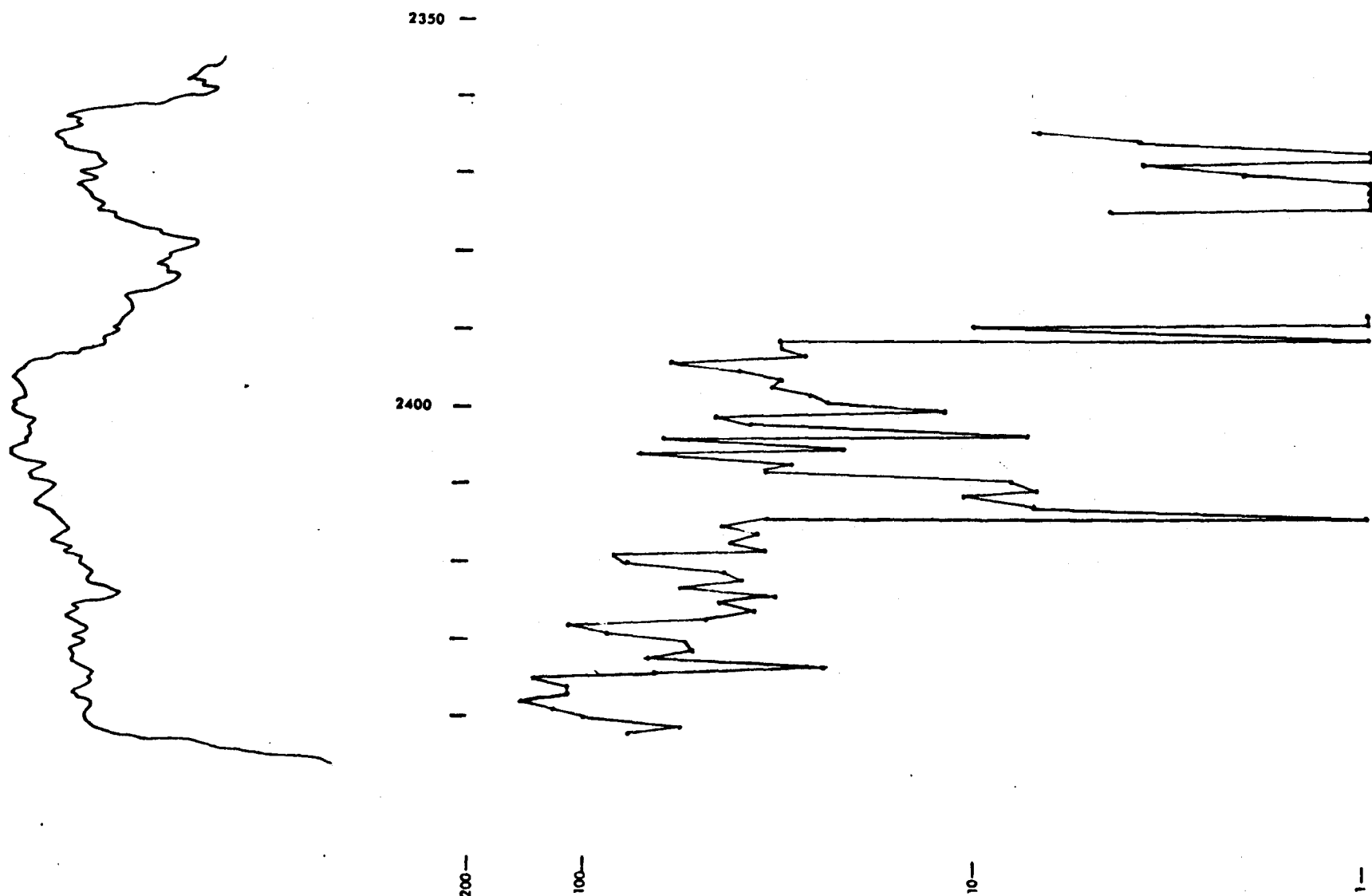


Fig. 55 - Comparison of gamma ray log to vertical permeability representation of Bryden #12.

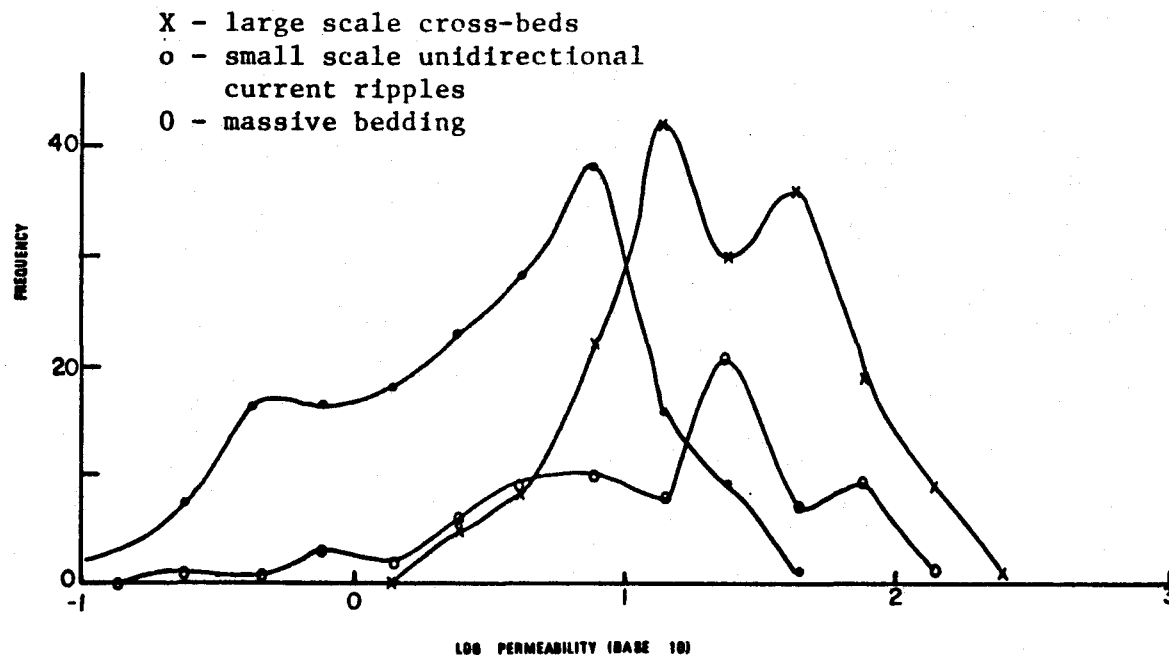
The average size of the sand grains, as determined by measurements of thin sections, decreases from the base of the sandstone to the top in each core. This coincides with the decrease in permeability and the change in electric log character. From these results, it is concluded that permeability changes according to changes in grain size and clay content in the sandstones of the Sallyards Field area (Figs. 53, 54).

Relationships between grain size, clay content, and sedimentary structures in sands have been documented by numerous workers (Simons et al., 1965; Southard, 1975). Large scale crossbeds usually are composed of coarser sand which contains less clay than the sand in small scale asymmetrical ripples, as the larger bedforms were formed under more rapid flow conditions (Southard, 1975). In the vertical representations of cores (Figs. 53, 54), larger scale crossbedding corresponds with more negative SP deflections and coarser grain size, whereas the opposite is true for intervals of small scale ripples. This suggests a relationship between permeability values and sedimentary structures. A method developed by Stiles (1949) was used to substantiate this observation. Permeabilities of the cores in Figures 53 and 54 were plotted as a function of cumulative frequency (Appendix E). Permeability is distributed log normally (Law, 1944); therefore differing populations of permeability values may appear as straight line segments, each indicating a change in geologic conditions. The type of bedding structure present at each interval of permeability

measurement was also noted. The results from the four selected cores (Appendix E) indicate that small scale, or ripple, crossbeds are the dominant bedform which has permeabilities in the range lower than 10 md., while large scale crossbeds normally have permeabilities greater than 10 md.

Each diagram represented in Appendix E also indicates that cores with either ripples or large scale crossbeds have large ranges of permeabilities. A permeability vs. frequency graph for each specific type of bedding was constructed for large scale crossbeds and for ripples (Fig. 56). Values for massive units were also included, but other sedimentary structures, which were represented by fewer than fifteen values, were deleted. Because massive beds were deposited either as ripple crossbeds or as large scale crossbeds (Figs. 32, 33), attention was focused on these latter two structures (Fig. 56). To divide the massive units into their respective categories, a large volume of samples would have to be X-rayed, yet it appears that those massive units with permeability values larger than 10 md. are likely large scale crossbeds while massive units with permeabilities lower than 10 md. are ripple crossbedded (Fig. 56). The permeabilities of ripples and large scale crossbeds overlap and the range of values within each type of sedimentary structure varies by a factor of 100. This range in permeability values may be partly due to differences in grain size within each group of sedimentary structures resulting from differing velocities

Fig. 56 - Permeability vs. frequency graph for small scale ripple cross-beds and large scale cross-beds. Based on work by Law (1944) who stated that permeability plots logarithmically, permeabilities were converted to their logarithms and spaced within four equivalent groups within a magnitude of permeabilities. For example, from 0 to 1 log permeability individual values were placed in groups 0 to .25, .26 to .50, .51 to .75, and .76 to 1.0. The type of bedform (ripple, large scale cross-bed, or massive bed) was counted within each group and its frequency was noted on the vertical scale.



of flow of the transporting medium. Ripples or dunes deposited under slower flow conditions within a single channel would contain more clay or micas and smaller grains (Appendix E-1; Figs. 17, 29) than would the same bedforms deposited at more rapid flow conditions in the same channel (Appendix E-2). Porosity and permeability would be correspondingly reduced in the ripples formed at lower flow velocities. The yields from laboratory waterflooding tests (Figs. 53, 54) indicate that oil displacement may occur in sandstones with ripples or large scale crossbeds; however, production occurs mainly from intervals of the more permeable large scale crossbeds. The core from the Hendrickson #1 well shows another interesting feature; there is no oil displacement from the low permeability zones of silt-laden ripple crossbeds (Appendix E-4; Fig. 32). This is also typical of the other Hendrickson cores. According to Pettijohn, Potter and Siever (1972) zones of ripple bedding with an abundance of included silt have low permeabilities and may act as barriers to flow.

The orientation of the sedimentary structures may result in directional permeability in the rock which is parallel to the dip of the sedimentary structure, due to the alignment of micas, clays and elongate grains parallel to the flow of the currents during deposition of the sand (Figs. 19, 24). This effect has been demonstrated by Hewitt and Morgan (1965) in the middle Pennsylvanian Robinson Sandstone of Illinois in which

the direction of dip of cross bedding of the sandstone parallels the direction of elongation of the sandstone trend. This sandstone probably was formed in an alluvial stream. As seen in Table 3, in alluvial systems the flow indicators parallel the direction of flow of the stream. The Sallyards Sandstones show vertical variations similar to the Robinson Sandstone in permeability, electric log character and the sequence of sedimentary structures, and they are interpreted as fine grained deposits of meandering streams. It is likely, therefore, that the favored direction of the flow of fluids in the sandstone bodies is parallel to their trends in a northeast-southwest direction. Further study is needed, however, to determine whether permeability is affected by directional bedforms.

#### Effects of Diagenetic Alteration on Permeability -

Diagenetic effects also contribute to the variability of permeability within each facies. Hutchinson et al., (1961) noted that the permeability of uncemented marine sand varies by a factor of five within a given group of sedimentary structures, while the permeability of cemented marine sandstones may vary by a factor of 100 within a given group of sedimentary structures. The patchy and streaky distribution of cements within the reservoir rocks in the Sallyards Field Area (Figs. 21, 22, 23) may be a major factor for the wide range of permeability values within the rock intervals containing ripple and large scale crossbedding. Compaction of ductile grains around

framework grains may block off pores, also reducing permeability (Fig. 17).

#### Use of Permeability to Predict Sedimentary Structures

Inspection of the graph of frequency distribution vs. permeability for groups of sedimentary structures (Fig. 56) shows that a fair separation exists between ripples and large scale crossbeds. The graph, in this sense, is simply a representation of the distribution of facies in the reservoirs. Using 10 md. as a boundary, prediction of the structures present may be made from core analyses without examining the rocks themselves by assigning those values above 10 md. to large scale crossbeds and those below this value to ripples. A significance-test suggested by Doveton (1977; personal communication), is as follows: A ratio of ripples to ripples + large scale crossbeds indicates that samples with permeability values less than 10 md. have an 80% probability of having ripple crossbeds, while a ratio of large scale crossbeds to large scale crossbeds + ripples indicate that values greater than 10 md. also have an 80% probability of being from intervals with large scale crossbeds. From these data a geologist could extrapolate from areas with available cores to areas within the same field area where the cores were destroyed, and he could determine the lateral continuity of bedding-types or determine the vertical sequence of sedimentary structures within the sandstone.

Porosity Distribution - Porosity seems to show little,

if any, relationship to grain size, clay content, or the sequence of sedimentary structures on the vertical representations shown in Figures 53 and 54. A plot of porosity versus permeability however, for a number of wells (Fig. 57), indicates a general but scattered trend which shows porosity increasing as permeability increases. A regression analysis was run by Doveton (1977; personal communication) to determine the validity of the relationship between porosity and permeability as suggested above. The general equation  $K$  (permeability) =  $a$  (constant)  $\phi^m$  (porosity) (Muskat, 1950) was selected in which porosity, a known value, is used to predict permeability. Using logarithms the equation changes to  $\log K = \log a + m \log \phi$ .  $\log a$  becomes the vertical intercept on the graph and  $m$  is the slope of the straight line. Using the 103 samples from the six wells selected in a regression of  $\log K$  on  $\log \phi$ , values were calculated for  $\log a$  of -17.53 and  $m = 7.6$  (Fig. 58). The correlation ( $r$ ) coefficient (0 being no correlation, 1 a perfect positive correlation), between  $\log K$  and  $\log \phi$  is 0.58 implying that some kind of positive relationship between porosity and permeability exists. The validity of the positive correlation coefficient can be tested statistically with a  $t$  test. The calculated " $t$ " value corresponding to a samples size of 103 and a correlation coefficient of 0.58 is 7.14. Using the 5% significance level and 101 degrees of freedom the  $t$  value is 1.98. Therefore this correlation is judged to be significant. The coefficient of deter-

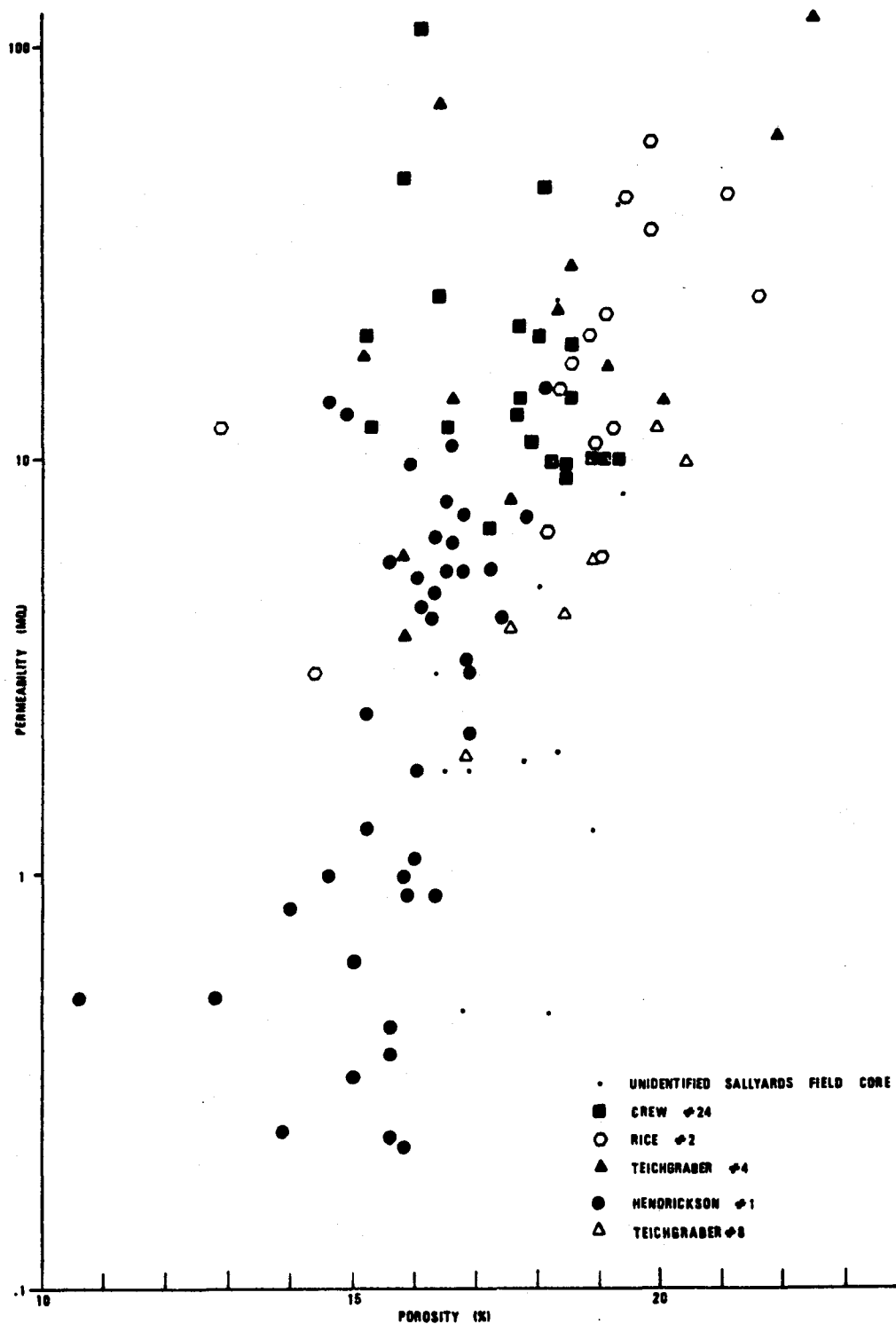


Fig. 57 - Porosity vs. permeability diagram for selected cores in the Sallyards Field Area.

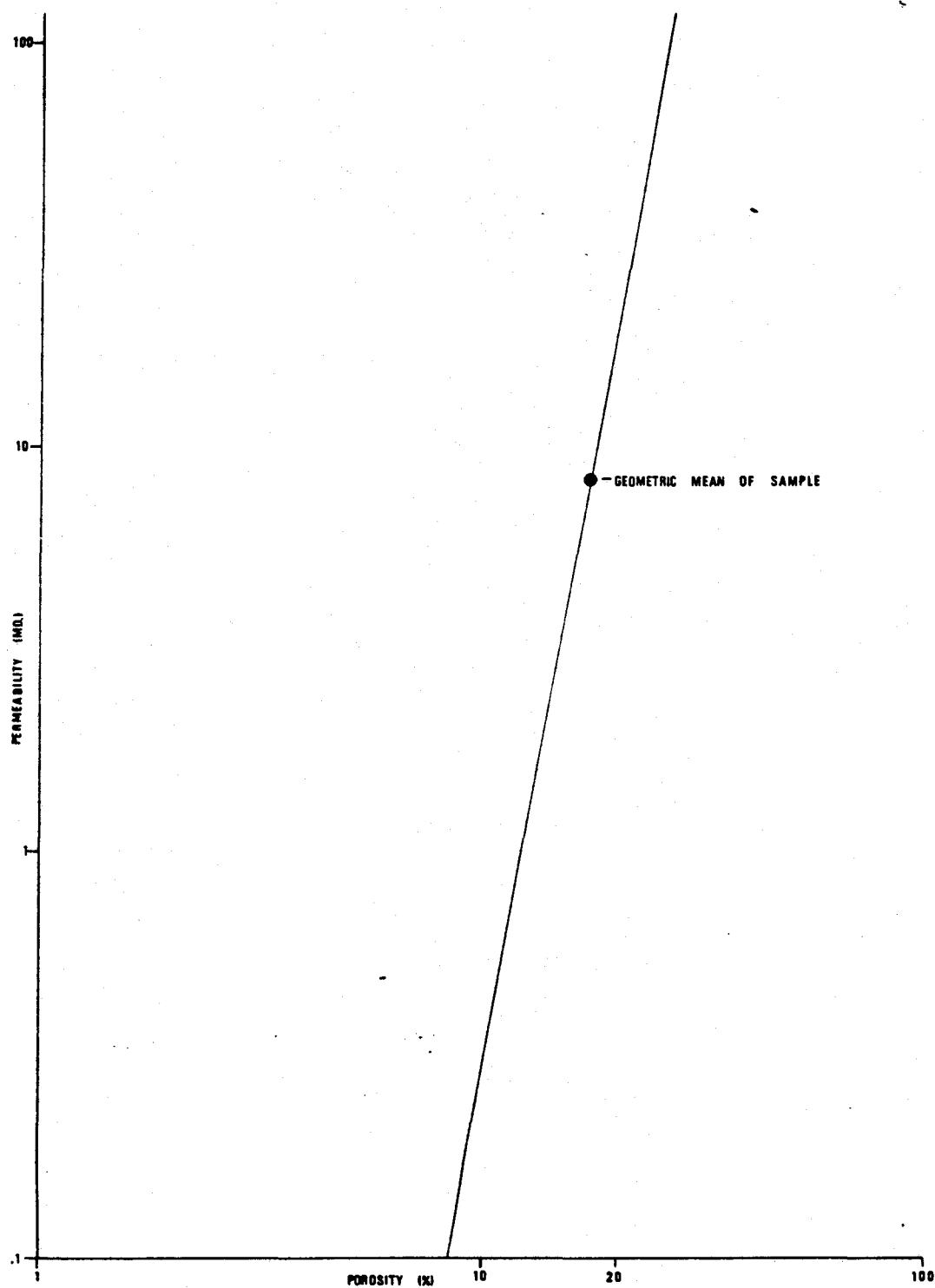


Fig. 58 - Regression line of log permeability on log porosity for the Bartlesville Sandstone in 6 wells.  $n = 103$   
 $\log k = -19.5 + 7.61 \log \phi$ .

mination ( $r^2$ ), however, is .34. This means that only 34% of the total variation in the scatter of points is accounted for by the regression line. In other words, the correlation coefficient tells us that there is probably a significant positive relationship between porosity and permeability in a general way. The variation satisfied by the regression line is fairly poor, however, so that if the equation were used to predict permeability from porosity, there would probably be a fair degree of error in the calculated answer. A number of errors can explain the high calculated variance in the coefficient of determination. First, there may have been an error in measurement. The samples were measured at a core laboratory so the error should be minor. Geologic properties of the rocks such as grain texture and fabric, directional variations due to sedimentary structures and diagenetic effects determine both porosity and permeability. Porosity is theoretically independent of grain size; however, results of studies have indicated that sorting affects porosity. A sand with a high variation in grain size will have lower porosities than a sand with the same grain size (Pettijohn et al., 1972) as the smaller grains will settle in the interstices of the larger grains. Likewise, a high degree of silt or clay interspersed with the sand will have lower porosities as the ductile grains will be crushed around the framework grains during compaction and clog pore spaces. Closer packing of the framework grains due to compaction also reduces porosity

(Pettijohn et al., 1972). In general, grains of higher sphericity tend to pack with minimum pore space while flatter grains tend to have higher porosities (Pettijohn, 1975) because of the increase in surface area of the grains. Finally, cements also reduce available pore space.

As mentioned before, permeability decreases with grain size (the fineness of the pores reduces the ability of fluid to move through the rock), tighter packing, poor sorting, cements present in the sandstone, and directional variations in grain orientation and sedimentary structures (Pettijohn et al., 1972).

Study of the cores from which the samples were taken indicates that many of the properties mentioned above affected porosity and permeability in the sandstones. Hendrickson #1 samples contained a high degree of silt and cement in the dominant ripple and horizontal bedded zones. Variations in the amount of silt and cement in the current ripple beds probably caused the high variations between porosity and permeability. The widespread variation in measurements in Teichgraber #4 is due to differences in the amount of cement in the larger scale crossbedding and differences in the amount of silt in the ripple zones. Teichgraber #8, on the other hand, shows a closer conformance to the regression line. This indicates that sorting by the depositional currents was mainly responsible for the distribution of porosity and permeability. The lesser values of porosity and permeability were produced when low velocity currents deposited

finer grained sands with higher amounts of silt. The greatest values were produced under the highest energy conditions of the depositional currents. Porosity and permeability values in Rice #2 also have good correlations except for some scattered points. These points correspond to samples taken from clast zones and contorted bedding. The grain fabric is disturbed creating the large variation of porosity and permeability values.

Finally, the sand in Crew #24 was deposited under higher energy conditions than most of the other sandstone samples. The ripple zones contain little silt and the entire sandstone is well sorted. The higher porosities and lower permeabilities correspond to ripple zones. The decrease in permeability may be due to the fineness of the pores in the finer grained sand but porosity is high because of the good sorting. The lower porosities in the coarser grained part of the sandstone may be due to cement variations. Like permeability, porosity is greatly affected by the amount of silt present in the sand and the degree of cementation that occurs after deposition.

To eliminate the high degree of variation between values of porosity and permeability, an equation would need to include symbols for the amount of silt, degree of sorting, cement variations and directional variations of the grains and sedimentary structures. A positive correlation between increasing porosity and permeability, however, does seem to exist.

Composition - The sandstones in the Sallyards Field Area may be classified as litharenities or feldspathic litharenites consisting mainly of quartz, with lesser feldspars, metamorphic rock fragments, biotite, muscovite, a varied clay fraction, and two dominant varieties of cement as described below.

Not only do clays and cements act as physical deterrents to fluid flow by decreasing the size of the available pore space through compaction and cementation, but they may adversely adsorb chemical surfactants or polymers and they may swell, further reducing porosity and permeability of the rock.

Three types of clays are present in Sallyards Area Cherokee rocks, according to X-ray diffraction analyses by James (1976), personal communication: interlayered serecite-illite-muscovite, kaolinite, and chlorite. None of these varieties of clays swells when exposed to water (Pettijohn, 1975). Grim (1968) notes that all clays show some affinity for adsorbing organic molecules. Displacement tests using surfactant or polymer solutions should be run in cores of Cherokee rocks to determine the extent of adsorption of these chemicals by the clays present. A technique developed by Thomas et al., (1976) using a scanning electron microscope and an X-ray diffraction devise to photograph and to identify clays subjected to oil-soluble floods may be applicable in such tests.

Dolomite and siderite may be present in amounts up to 10% in certain samples of the rocks studied here. Bernard (1975) presented evidence that solid  $\text{CaCO}_3$  in an unconsolidated sand pack had no influence on oil-soluble fluids. Carbonate cements present in the reservoir rock with high salinity brines may react with the brines to change the salinities and affect the chemicals injected into the reservoir, however, and these cements should be studied in conjunction with clays.

Structure and Continuity - The sandstones studied here have changes in continuity which may influence fluid flow. Stratigraphic cross sections A-A', C-C' and D-D' (Plates 2, 4, 5) indicate that continuous and discontinuous beds of shale are present in the Bartlesville Sandstone. Cross section C-C' illustrates two apparently laterally discontinuous sandstones within the same vertical interval. The cross sections show that the Bartlesville Sandstone is lenticular and that the net-sandstone map (Plate 7) shows a great variability of sand thickness within the trend. This distribution of sand is typical of the deposits of streams cutting back and forth over a flood plain. Stratigraphic cross section B-B' and the net-sandstone map of the Burbank zone indicate that this sandstone is more uniform in thickness and has good continuity within each of the laterally equivalent sandstone bodies.

The thicker, more continuous areas of sandstone in Sallyards Field usually occur in the middle of the sand-

stone trend and these areas are the most likely candidates for chemical flooding. The Burbank Sandstone in Teichgraber Field, in particular, is continuous, and this may also be a favorable area for chemical flooding.

The present shapes of both the Bartlesville and Burbank Sandstones are influenced by the structure of the underlying pre-Pennsylvanian surface and by the westward dip resulting from regional post-depositional tilting. The sandstones seem to drape over highs on the underlying surface (Plate 11). This draping causes the sandstones to dip to the west and to the east (see structural cross sections A-A', B-B' and D-D') (Plates 2, 3, 5). A lack of electric logs in some areas prevents illustrating the relationship of the sandstone and structure, but efforts should be made to determine the updip direction prior to flooding. The fluids should be injected downdip of the producing wells to take advantage of the effect of gravity in "smoothing-out" the advancing front of injected chemicals.

#### Feasibility and Design of Enhanced Recovery Projects -

Chemical methods may be the type of enhanced oil recovery process which is most applicable to the sandstones in the Sallyards Field area. However, in situ thermal processes may also be a viable alternative. A feasibility study of both methods should be made to determine the most favorable process to use. The characteristics which will determine the feasibility of the methods are given below.

1. The remaining oil saturation in each sandstone is unknown; however, production estimates indicate that 40-50% of the original-oil-in-place will remain after cessation of waterflooding (Oros, 1976, personal communication).

2. Chloride concentrations in produced water are, on the average, more than 60,000 ppm for each of the three sandstone zones.

3. Gravities of the oil range from 37-40° API; average viscosities are 2.784 cp. at 120°F to 5.234 cp. at 70°F, and interfacial tension ranges from 30.13 to 36.17 dynes/cm.

4. Porosity and permeability, respectively, average 18.4% and 33 md. in the Skinner zone, 16.2% and 11.8 md. in the Burbank zone, and 14.9 and 23.9 md. in the Bartlesville zone; however, the range of permeability varies from essentially zero to 400 md.

5. Crude oil in the Sallyards Field Area has a composition with a ratio of saturate to aromatic hydrocarbons of 25:1, 0.2% sulfur and 2.4% asphaltenes (Table 7).

6. Permeability is lower in rocks with smaller grain size, higher clay content, smaller-scale sedimentary structures, and in cemented areas.

7. The variation of permeability values within each group of sedimentary structures is due to the amount of silt deposited initially with the sand and later compaction and cementation of the sandstones.

8. Ripple crossbeds with large amounts of included silt may act as barriers to flow. The orientation of sedimentary structures in the Sallyards Field Area may cause the injected fluids to follow a preferred path parallel to the trend of the sandstone.

9. Porosity is largely independent of other geologic characteristics; however, an ill-defined trend shows porosity increasing with increasing permeability, probably due changing velocities of depositional currents which affected sorting (i.e. the amount of silt deposited with the sand) of the sandstones. Cement and disturbed bedding also causes great variations in porosity.

10. Clays are known to react with organic compounds. Tests should be made to determine the adsorption characteristics of the clays in Sallyards Field. Cements may not be reactive, but further tests should be made on the dolomite and siderite cements present.

11. The Bartlesville Sandstone is characterized by a highly variable thickness, and it contains numerous interbeds of shales. Within the Teichgraber Field, in contrast, the Burbank Sandstone has a more uniform thickness and good continuity. Areas for chemical flooding projects should be selected from the thicker, more continuous sandstones in the middle of the Bartlesville trend.

12. The sandstones show a westward or eastward dip as a result of movement of regional structures and drape over underlying high areas. Care must be taken to flood

updip from the injection wells to allow the effects of gravity to maintain a uniform flood front.

13. A graph of the frequency distribution of permeability indicates that permeability values less than 10 md. are usually associated with ripple crossbeds, while values greater than 10 md. are associated with large scale crossbeds. This information may be used to determine the lateral continuity of bedding types or a vertical sequence of sedimentary structures within parts of the field where cores have been destroyed.

## SUMMARY

From data presented in this paper, it is concluded that the Bartlesville, Burbank, and Skinner Sandstones were deposited as north to south flowing, perennial, fine grained, meandering streams. The source for the sandstones was the Nemaha Uplift to the west, metasediments in northern Greenwood County, and possibly the Canadian Shield to the north. The Bartlesville Sandstone was deposited as a narrow, elongate sandstone body following a low in the pre-Pennsylvanian surface. While topographic lows cannot be ruled out, the parallelism of the Sallyards Trend to faults in the Precambrian subcrop suggests that the underlying pre-Pennsylvanian surface underwent deformation prior to deposition of the Bartlesville Sandstone developing a northeast-southwest trend of highs and lows.

Following a transgressive episode where the Bartlesville Sandstone was covered by a thin continuous shale, the Burbank Sandstone was deposited. The sandstone developed as multilateral discontinuous sandstone bodies displaying an overall branching pattern which covers the entire area. Finally, the Skinner Sandstone was deposited in narrow elongate sandstone bodies over the entire area. The widespread nature of the two upper sandstones suggest that they were free of structural control. All the sandstones were probably deposited in upper deltaic plains of constructive delta complexes actively prograding to the south in Oklahoma.

The Bartlesville Sandstone is probably correlative to the surface Bluejacket Sandstone in extreme southeastern Kansas, while the Skinner Sandstone correlates to the surface Chelsea Sandstone. The Burbank Sandstone is probably equivalent to the Weir-Seville cyclothems in outcrop.

The sandstones are strikingly similar in composition and are classified as litharenites or feldspathic litharenites. They are mineralogically and texturally immature with abundant phyllitic rock fragments, micas and clays, feldspars, subangular quartz and angular tourmaline.

The laterally associated facies were deposited during episodes of delta progradation and abandonment. The dark gray siltstones may represent deposition on the deltaic plain as marsh deposits or backwater swamp deposits. The underclays may have developed as soil zones or as "gley" associated with coals. The presence of fossils in the green gray shales and limestones suggest fairly normal shallow marine deposition. The black shale, on the other hand, represents deposition under restricted circulation conditions either in a lagoon or on the open shelf.

A reservoir study of the Sallyards Sandstones show that the sandstones change abruptly into shale, laterally or have areas of silty sands which form the trap. The oil column is thicker in structurally higher areas of the sandstones suggesting that structure, in part, controls accumulation of the oil.

Finally the reservoir parameters of the Sallyards Sandstones were studied to determine the feasibility of designing and developing an enhanced recovery flood. With an estimated 40 to 50% of the oil remaining in the reservoirs, the sandstones are prime candidates for enhanced recovery processes. Chemical methods or in-situ combustion are considered to be most applicable in the area. The following factors must be considered when planning an enhanced recovery project for these sandstones.

1. The oil found in the sandstones has a high gravity, fairly low viscosity, low sulfur content, a ratio of saturate to aromatic hydrocarbons of 25:1, an average of 2.4% asphaltenes and interfacial tensions from 30 to 36 dynes/cm.
2. Connate water salinities are high, averaging over 60,000 ppm in each sandstone.
3. Porosity averages 18.4%, 16.2% and 14.9% for the Bartlesville, Burbank and Skinner zones, respectively. Permeability is, on the average, low in all three zones but in some samples permeability measures up to 400 md.
4. Permeability is lower in rocks with smaller grain size, higher clay content, smaller scale of sedimentary structures and in cemented portions of the sandstone. Those areas in which large scale crossbedding is the dominant bedform should have the best permeability and may be the best areas to flood.
5. Ripple crossbeds with large amounts of included silt may act as barriers to flow. The orientation of sedimentary structures may cause the injected fluids to follow a preferred path parallel to the trend of the sandstone.
6. The clays

present do not swell with the addition of fresh water, however, all clays are known to react with organic compounds. Tests should be made to determine the adsorption characteristics of the clays in sandstones of the Sallyards Field Area. The carbonate cements should also be tested for their effects on surfactants. 7. The Bartlesville Sandstone has a variable thickness and contains numerous shale interbeds. Areas for chemical flooding projects should be selected from the thicker more continuous sandstones in the middle of the Bartlesville trend. The Burbank Sandstone in Teichgraber Field, on the other hand, has a more uniform thickness and better continuity than the Bartlesville Sandstone and is a potential area for flooding. 8. The structural position of the sandstones should be determined so the fluids can be injected updip. The effect of gravity will help to maintain a uniform flood front.

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## APPENDIX A

Lithologic Descriptions of Marker Units and  
Sandstone Zones within the Cherokee Group in the  
Sallyards Field Area, Greenwood County, Kansas

|                                  |     |
|----------------------------------|-----|
| Marmaton Group.....              | A-1 |
| Higginsville Limestone.....      | A-1 |
| Little Osage Shale.....          | A-1 |
| Blackjack Creek Limestone.....   | A-1 |
| Cherokee Group                   |     |
| Breezy Hill Limestone.....       | A-2 |
| Squirrel Sandstone Zone.....     | A-2 |
| Verdigris Limestone.....         | A-2 |
| Cattleman Sandstone Zone.....    | A-3 |
| Skinner Sandstone Zone.....      | A-3 |
| Tebo Shale Marker.....           | A-4 |
| Burbank Sandstone Zone.....      | A-4 |
| Bartlesville Sandstone Zone..... | A-5 |
| Burgess Sandstone Zone.....      | A-6 |
| Cherokee Shales.....             | A-6 |
| Cherokee Coals.....              | A-7 |

## Appendix A

The following, in descending order, are descriptions of subdivisions of the Desmoinesian Stage which are important to this study. A more complete discussion maybe found in Howe (1956).

### Marmaton Group

The Marmaton Group, which is considered as upper Desmoinesian and overlies the lower Desmoinesian Cherokee Group, contains a higher proportion of limestones than the Cherokee. The basal formation of the Marmaton Group, the Fort Scott Limestone, consists of three members. In descending order they are:

1. The Higginsville Limestone - a light gray, thin to massive bedded limestone with abundant crinoid stems and fusulinids.

2. The Little Osage Shale - a black, platy fissile shale with phosphatic concretions, minor limestone, coal, and gray calcareous shale.

3. The Blackjack Creek Limestone - a fossiliferous, light gray, coarsely crystalline, regularly bedded limestone in the upper part, changing to a sparsely fossiliferous brownish gray limestone at the base.

Underlying the Fort Scott Limestone are black, platy, phosphatic shales and dark gray claystones. The black phosphatic shales, both above and below the Blackjack Creek Limestone are naturally radioactive and are easily recognizable on geophysical gamma ray logs over the entire area.

The top of the Cherokee Group is picked on logs at the top of the lower radioactive marker. The Fort Scott is uniform in thickness over the entire area and its top may be used as a datum for cross sections and maps.

Breezy Hill Limestone - The Breezy Hill Limestone was first described by Pierce and Courtier in 1937 from exposures at Breezy Hill in eastern Crawford County, Kansas (Howe, 1956). The lithology is variable but it is commonly nodular to irregularly bedded, sandy and conglomeratic (Zeller, 1968). Thickness ranges from 1 to 4 meters.

Squirrel Sandstone Zone - The Squirrel Sandstone was first named by Shannon and Trent in 1915 for the Linnie Squirrel farm in Bartlesville Field, Washington County, Oklahoma (Jordan, 1957). According to Jewett (1954) it is equivalent to the surface Lagonda and to the sub-surface Prue, Bixler and Perryman Sandstones. The Squirrel is tentatively correlated to the Prue-Calvin zone of Cole (1969). It is a gray to buff, fine grained micaceous argillaceous, cross bedded sandstone (Howe, 1956). In the Sallyards Field Area the Squirrel interval includes two sandstones within a 15 meter interval above the Verdigris Limestone.

Verdigris Limestone - The Verdigris Limestone was named and described by Smith in 1928 for the Verdigris River in Rodgers County, Oklahoma (Jordan, 1957). It occurs approximately 25 meters below the Fort Scott Limestone and has a uniform thickness of 4 meters. Zeller (1968) describes the Verdigris as a dark gray foraminiferal

limestone. Its widespread occurrence, the association with an underlying black shale, and the uniform thickness make the Verdigris Limestone an important marker unit in the Cherokee Group separating the Squirrel and Cattleman Zones.

Cattleman Sandstone Zone - According to Jewett (1954) the Cattleman Sandstone is an oil-producing sandstone lying 30 to 35 meters below the base of the Fort Scott Limestone. It occurs in an 8 meter interval below the Verdigris Limestone and is separated from the Skinner zone by a black shale or coal. Comparison with detailed sections from outcrops in southeastern Kansas by Howe (1956) indicates that the Cattleman Sandstone may be equivalent to sandstone within the Croweburg cyclothem (Fig. 5). He describes the sandstone as brown to tan, massive to flaggy bedded, lenticular, well sorted, fine grained, and micaceous with local calcite cement. The zone may be equivalent to the upper sandstone of the Skinner Zone of Cole (1969).

Skinner Sandstone Zone - The Skinner Sandstone was named by Wood in 1913 for the sand below the Skinner lease of Lauderdale Field, Pawnee County, Oklahoma. It is equivalent to the Chelsea Sandstone of the surface and occurs in a 13 meter interval above, and cuts down into the radioactive black shale overlying the Tebo Coal. The zone may be equivalent to the lower part of the Skinner zone of Cole (1969).

Tebo Shale Marker - Another persistent marker unit similar to that underlying the Verdigris Limestone occurs 50 m. (160-170 feet) below the Fort Scott Limestone in the Sallyards Field area. Correlations (Plate 1) place this black shale marker directly above the Tebo cyclothem of the surface (Howe, 1956). The Chelsea Sandstone member overlies and cuts down into the shale and the underlying Tebo Coal bed. The widespread distribution of the radioactive shale in southeastern Kansas makes it an important marker unit in the subsurface. The black shale is overlain by the thin, discontinuous Tiawah Limestone, which is laterally equivalent to the Pink Limestone in Oklahoma. For this reason, the marker serves as the boundary between the Skinner and Burbank (Red Fork) zones.

The Burbank Sandstone Zone - The Burbank Sandstone was originally named for the oil-producing sandstone in Burbank Field, Osage County, Oklahoma (Jordan, 1957). It is considered equivalent to the subsurface Red Fork and Surface Taft Sandstones. An interval containing a surface sandstone which is equivalent to the Burbank Sandstone is not present in outcrop in southeastern Kansas (Fig. 5). A study by Baker (1962) and a correlation to the outcrop area (Plate I) places the interval of the Burbank zone (Fig. 9) into the Weir and Seville cyclothems. The Burbank zone consists of two sandstones separated by a black shale in an interval of 18 meters below the Tebo Shale. The lower horizon is the main producing sandstone in Jackson Field whereas both zones are developed in Teichgraber Field.

The Burbank Zone is either separated from the Bartlesville Zone by a light gray to black shale or is in part laterally equivalent to the uppermost Bartlesville Sandstone.

Tentative correlations place the boundary between the two zones at the interval of the discontinuous Seville Limestone. The Seville Limestone has been correlated to the Inola #1 Limestone in Oklahoma (Baker, 1962) which is the first limestone above the Inola, the boundary for Cole's Bartlesville zone (Fig. 9).

Bartlesville Sandstone Zone - "Bartlesville" was first used by Hutchinson in 1911 for the producing sandstone in Bartlesville Field, Washington County, Oklahoma. Correlations (Plate 1) confirm earlier studies which designate the Bartlesville zone as laterally equivalent to the surface Bluejacket Sandstone (Howe, 1956). A coal-bearing interval beneath the Bartlesville Sandstone separates it from the underlying Warner zone. The Bartlesville Sandstone occurs in a 15 meter interval immediately below the Burbank zone; however, its thickness may be almost 30 meters because of downcutting into the zone below. It is the most prolific oil-producing sandstone in the Cherokee Group in southeastern Kansas and is the main producing sandstone in the Sallyards Field area. The Bartlesville Sandstone is tentatively correlated, in part, to the Bartlesville zone of Cole (1969).

Burgess Sandstone Zone - The Burgess Sandstone was first described by Ohern and Garret in 1912 for the Burgess lease in Bird Creek Field, Tulsa County, Oklahoma (Jordan, 1957). Howe (1956) states that the Burgess Sandstone is equivalent to the surface Little Cabin, or the Warner Sandstone in Kansas. The distinguishing characteristic of the Burgess Sandstone is its proximity to the pre-Pennsylvanian surface, occurring in a six meter interval some three meters above the unconformable contact. The Warner Sandstone in outcrop is composed of fine to medium grained, angular to subrounded quartz sand with abundant muscovite. A complete succession of the Warner Sandstone consists of a lower massive member with coarse crossbedding. The middle member consists of micaceous siltstone and shale overlain by a massive sandstone. The Burgess Sandstone is not present in the Sallyards Field area. It may be equivalent to the Booch interval of Cole (1969).

Cherokee Shales - Baker (1972) recognized four types of shales in the Cherokee Group. They are: 1. Silty, mostly unfossiliferous greenish gray shales composed chiefly of quartz, chlorite, sericite and minor siderite. 2. Gray, organic rich, pyritic shales composed of quartz, chlorite, sericite containing plant and marine fossils. 3. Black, fissile, phosphatic shales containing quartz, illite, chlorite, and carbonized remains. 4. Olive gray underclays composed of quartz, some expandable clays, limestone, nodular pyrite, ankerite veins and carbonized plant remains.

Cherokee Coals - According to Howe (1956), coals in the Cherokee Group are economically the most important rock. The lateral extent, thickness and quality of these coals are quite variable.

## APPENDIX B

### Laboratory Methods

Thin Section Petrography - The purpose for thin section analysis was two-fold: 1. To determine the mineralogical constituents present in the sandstone and identify the constituents which may affect the movement of chemical fluids. 2. Grain size measurements were made to determine the relationships between permeability, grain size distribution, and sedimentary structures.

To achieve these goals samples for thin sections were chosen from cores whose self potential or gamma ray logs indicated a "clean" and blocky pattern or a decreasing upward vertical deflection. Seven cores representing the three zones were picked on this basis. Samples were then picked at the lower, middle, and upper portions of each sandstone. No special care was taken to pick samples with differing sedimentary structures. The samples were cut parallel to the maximum dip of the bedding structure to observe grain orientation.

From fifty samples, eleven were selected for point counts. These were selected mostly from the coarser fraction of the sandstone and are not believed to be representative of each sandstone overall. Two hundred counts were made in an imaginary rectangular grid pattern for each slide.

The slides selected for point counts were then

stained for carbonate cement identification, using a method suggested by Hutchinson (1974). The slides were etched in dilute HCL for three minutes, then stained with a solution of Alizarin red S for five minutes. Staining was then repeated in a boiling solution with equal volumes of Alizarin red S and 30% NaOH. The siderite turned brown. At this point, the mounting cement on the slides started to dissolve and the experiment was discontinued. X-ray diffraction results revealed that both ferroan dolomite and siderite were present.

Measurements of grain size in thin sections were chosen over disaggregation and dry-sieving, because it was felt that the mechanical breakdown and acid-etching of the rock would distort the grain size distribution. Numerous sources of error are present in the thin section measurements:

1. The diameters of the grains seen are always smaller than the true diameter of the grains.
2. The orientation of the grains seen varies and the cut within the thin section may not reveal the true diameter of the grain.
3. The samples may not be representative of that interval.
4. The operator may err in the measurement.
5. The deviation between sample estimates of the areal populations may be large.
6. Differing mineralogies may be etched, corroded or compacted by diagenetic effects.

Regardless of the difficulties Chayes (1950) presents a complicated mathematical proof that differing grain size distributions can be differentiated through measurements in thin section. Effects one and two are present

throughout the sandstone sequence and are inherent problems, yet relative size distributions can be distinguished. Consistent agreement between maximum SP deflection and grain size measurements in the different cores measured minimized effects three and four. Fifty counts, as suggested by Doveton (1976, personal communication), was sufficient in reducing the standard deviation, or error, to an acceptable level, i.e., to clearly differentiate grain size differences in bed forms of differing scales. Finally, only quartz grains and fresh feldspar grains were counted to minimize diagenetic effects as micas and rock fragments were normally compacted.

X-Ray Radiography - A technique used by Hamblin (1962) was used to determine sedimentary structures present in the apparently massive intervals of the sandstone. Slabs were cut to .5 cm thick and slightly polished to remove the rough cutting edges. These were subjected to X-ray photography on a standard, hospital, body-X-ray unit.

Breadown of Shales - A technique suggested by Kaesler (1976, personal communication) was used to search for fossils in included shales of the sandstones. Each sample was dried in an oven for 24 to 72 hours to remove the water and then submerged into amosol for 24 hours. The samples were then immersed in water, and breakup of the shales normally occurred within 24 hours. More indurated samples required repeated treatments. The pieces were then searched for evidence of fossils.

# APPENDIX C

## Core Descriptions of the Sandstones in Sallyards Field (Check Plate 6 for exact locations)

| Operator      | Well Name       | Location  | Sandstone    | Page |
|---------------|-----------------|-----------|--------------|------|
| Jackson Bros. | Barrier #26     | 4-26S-8E  | Bartlesville | C-1  |
| Jackson Bros. | Barrier #36     | 3-26S-8E  | Bartlesville | C-2  |
| Ohio          | Bryden #23      | 36-25S-8E | Bartlesville | C-3  |
| Ohio          | Bryden #26      | 36-25S-8E | Bartlesville | C-3  |
| Jackson Bros. | Hendrickson #1  | 17-25S-9E | Bartlesville | C-4  |
| Jackson Bros. | Hendrickson #3  | 17-25S-9E | Bartlesville | C-5  |
| Jackson Bros. | Hendrickson #4  | 17-25S-9E | Bartlesville | C-6  |
| Jackson Bros. | Hendrickson #5  | 17-25S-9E | Bartlesville | C-7  |
| Jackson Bros. | Perrier #6      | 17-25S-9E | Bartlesville | C-8  |
| Jackson Bros. | Hendrickson #7  | 17-25S-9E | Bartlesville | C-8  |
| Jackson Bros. | Perrier #2      | 17-25S-9E | Bartlesville | C-9  |
| Jackson Bros. | Perrier #7      | 17-25S-9E | Bartlesville | C-10 |
| Jackson Bros. | Rice #2         | 10-26S-8E | Bartlesville | C-10 |
| H. E. Adair   | Ladd #1         | 32-25S-9E | Bartlesville | C-11 |
| Jackson Bros. | Teichgraber #4  | 14-25S-8E | Burbank      | C-12 |
| Jackson Bros. | Teichgraber #8  | 14-25S-8E | Burbank      | C-12 |
| Jackson Bros. | Jack. Heirs #9  | 23-25S-8E | Burbank      | C-13 |
| Jackson Bros. | Jack. Heirs #19 | 23-25S-8E | Burbank      | C-13 |
| Jackson Bros. | Jack. Heirs #14 | 23-25S-8E | Burbank      | C-14 |
| Jackson Bros. | Jack. Heirs #16 | 23-25S-8E | Burbank      | C-15 |
| Jackson Bros. | Jack. Heirs #23 | 23-25S-8E | Burbank      | C-16 |
| Jackson Bros. | Jack. Heirs #22 | 23-25S-8E | Burbank      | C-16 |
| Jackson Bros. | Jack. Heirs #25 | 23-25S-8E | Burbank      | C-17 |
| Jackson Bros. | Barrier #35     | 23-25S-8E | Burbank      | C-17 |
| Jackson Bros. | Jack. Heirs #11 | 23-25S-8E | Burbank      | C-18 |
| Jackson Bros. | Barrier #33     | 3-26S-8E  | Burbank      | C-18 |
| Jackson Bros. | Barrier #39     | 3-26S-8E  | Burbank      | C-19 |
| Jackson Bros. | Crew #18        | 3-26S-8E  | Burbank      | C-19 |
| Jackson Bros. | Crew #21        | 3-26S-8E  | Burbank      | C-20 |
| Jackson Bros. | Crew #22        | 34-25S-8E | Burbank      | C-21 |
| Jackson Bros. | Crew #24        | 3-26S-8E  | Burbank      | C-22 |
| Jackson Bros. | Crew #14        | 34-25S-8E | Burbank      | C-23 |
| Jackson Bros. | Rice # 1        | 10-26S-8E | Burbank      | C-23 |
| Jackson Bros. | Barrier #34     | 3-26S-8E  | Skinner      | C-24 |
| Jackson Bros. | Crew #22        | 34-25S-8E | Skinner      | C-25 |
| Jackson Bros. | Barrier #37     | 3-26S-8E  | Skinner      | C-26 |
| Jackson Bros. | Rice #1         | 10-26S-8E | Skinner      | C-27 |

# LEGEND



SMALL SCALE UNIDIRECTIONAL ASYMMETRICAL CURRENT RIPPLES



LARGE SCALE INCLINED PLANAR BEDDING



MASSIVE BEDDING



CLAST ZONE



MEDIUM SCALE CROSSBEDDING



DARK GRAY SILTSTONE



LIGHT OR GREEN-GRAY SILTSTONE



BLACK SHALE



COAL



LIMESTONE



HORIZONTAL LAMINATIONS



IRREGULAR WAVY BEDDING



iron claystone



root casts or slump cracks



siltstone clast w/ iron coat



mud clast or iron nodule



contorted bedding



silty zone



inclined planar laminae



scour surface



gc gradational contact



sc sharp contact

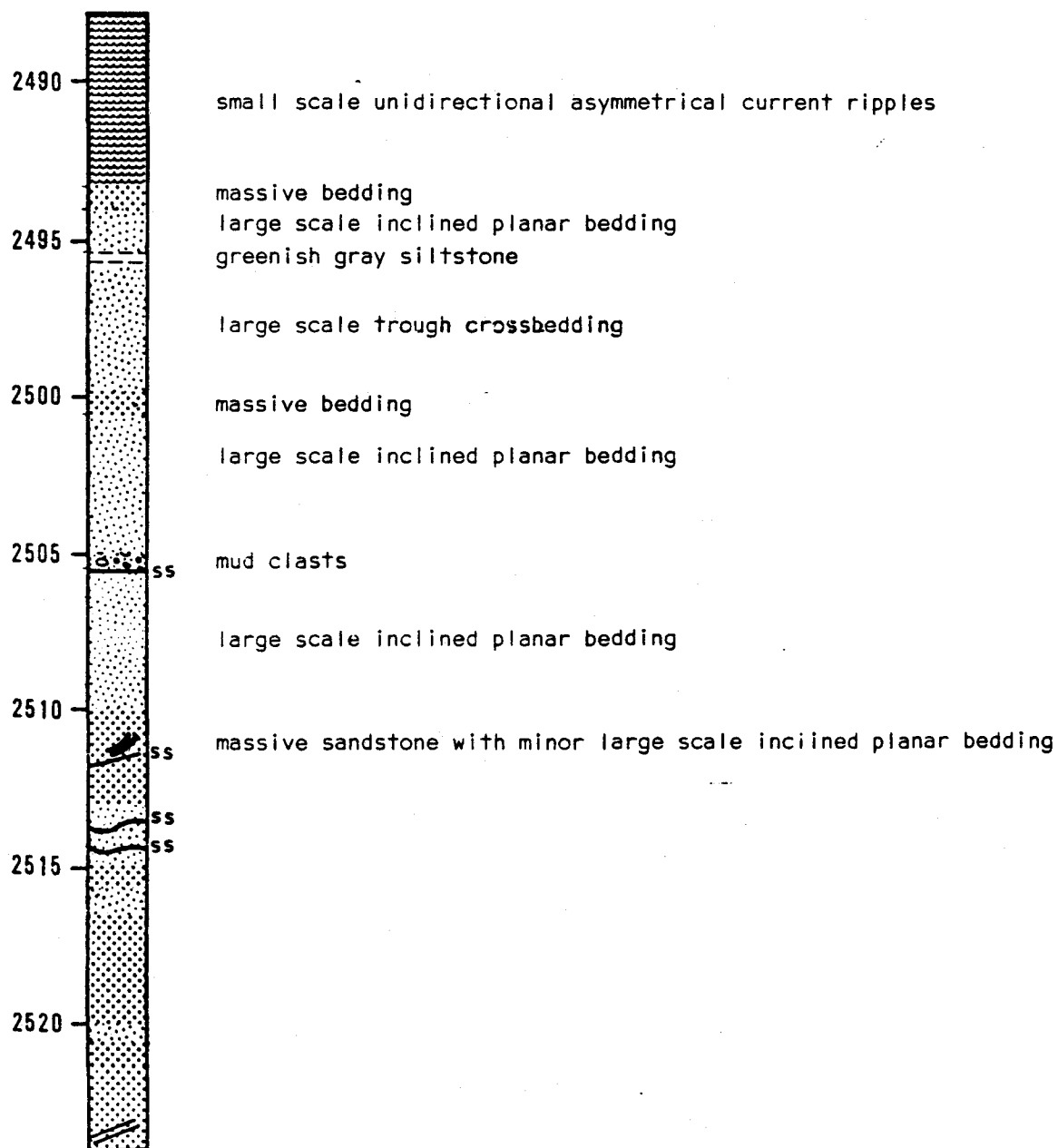


c calcareous cement

SCALE IS 1 INCH - 5 FEET

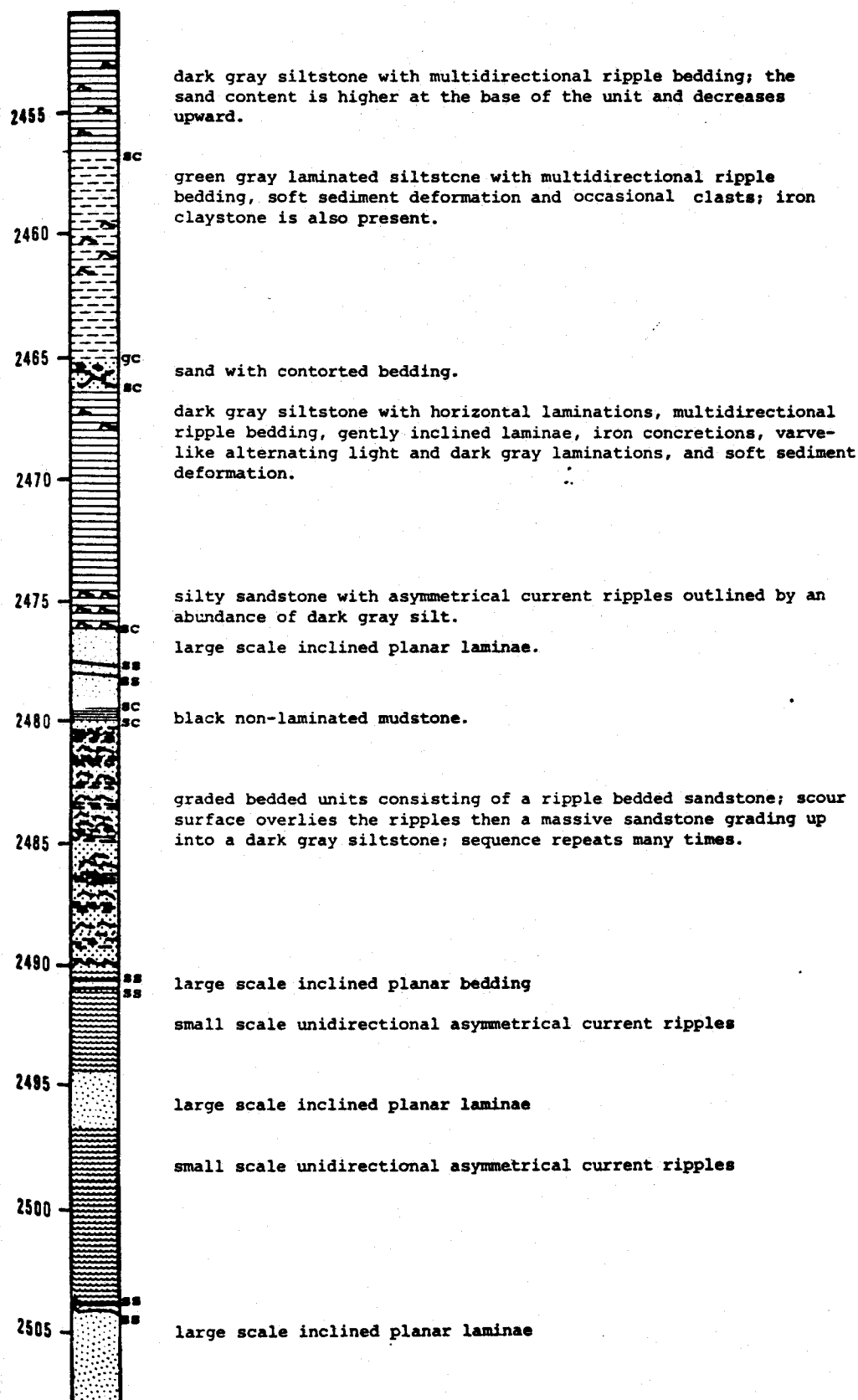
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4-26S-8E



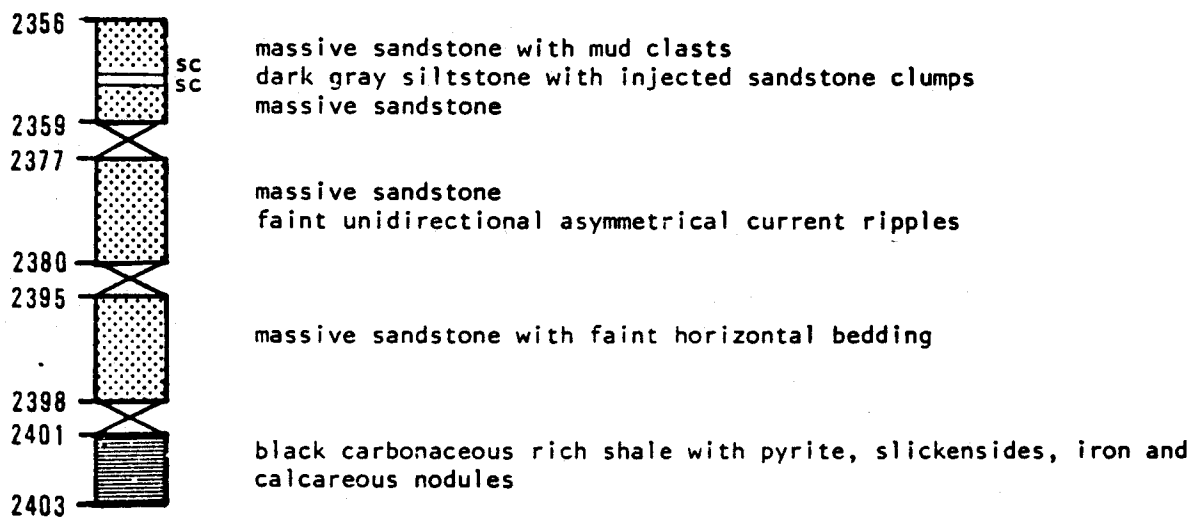
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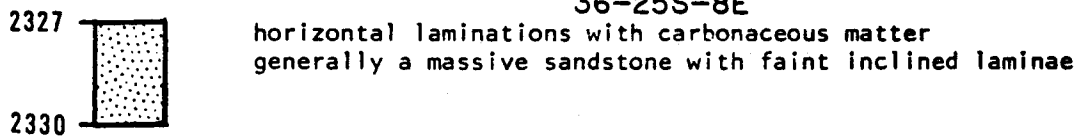
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36-25S-8E



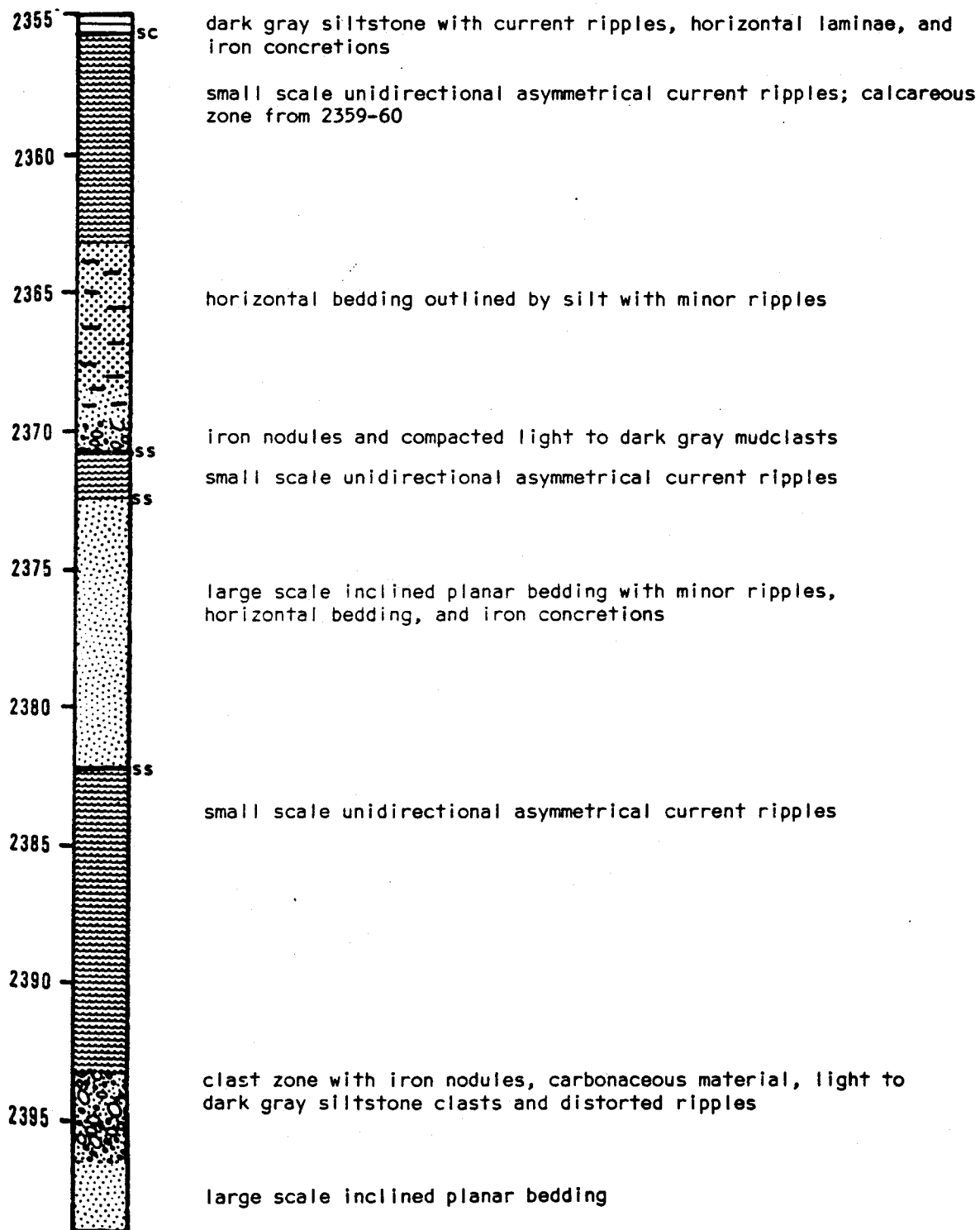
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36-25S-8E



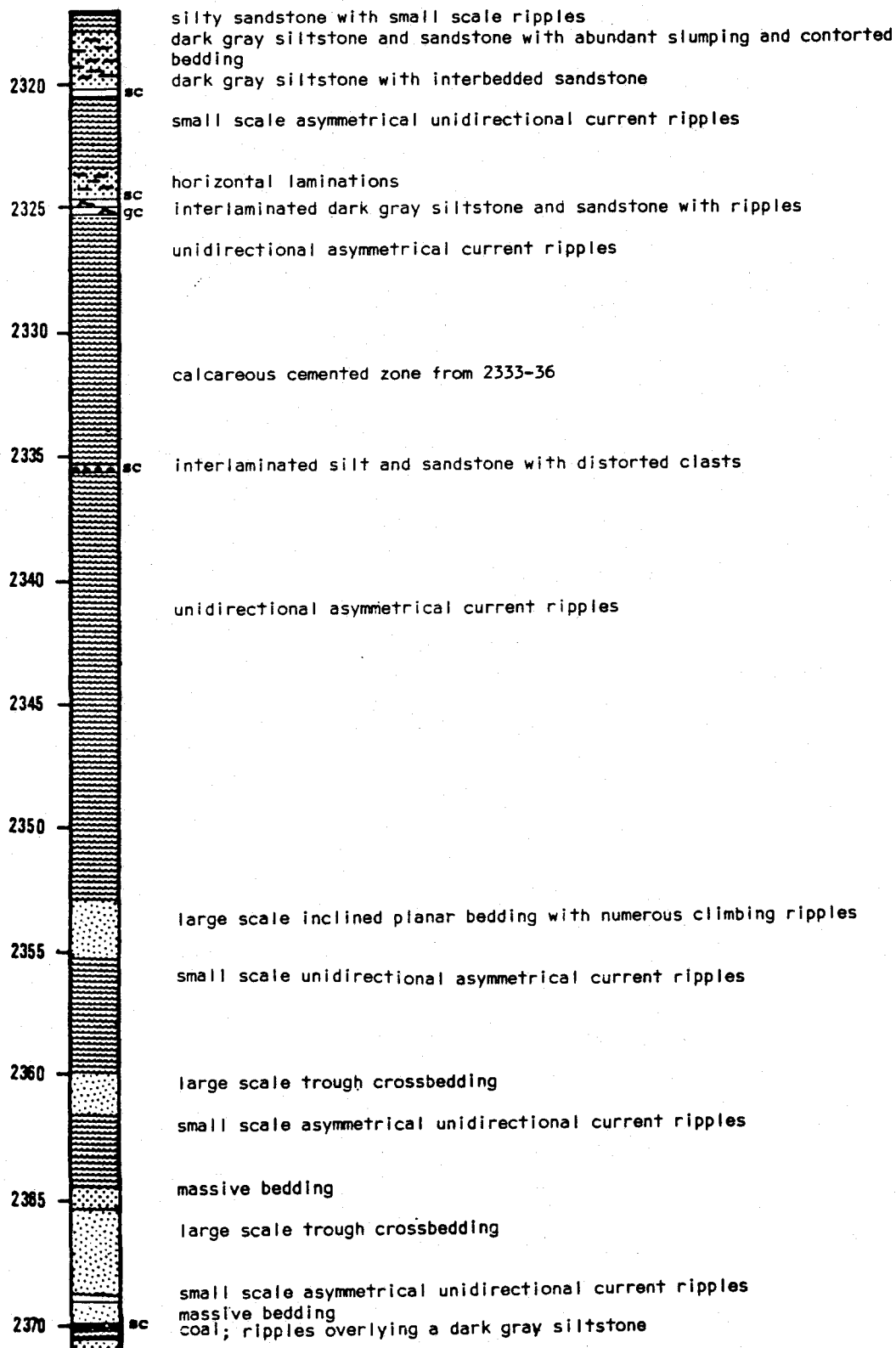
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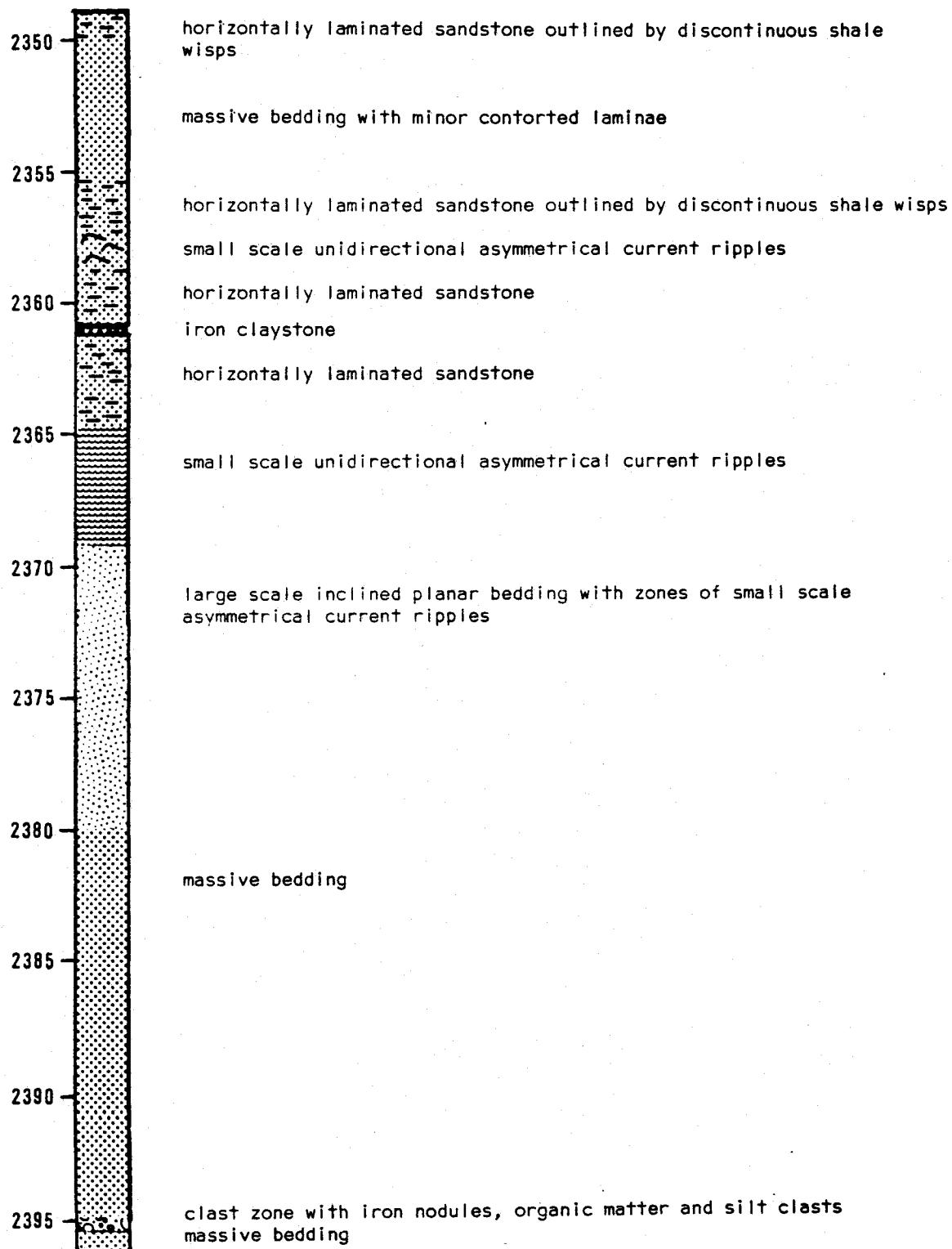
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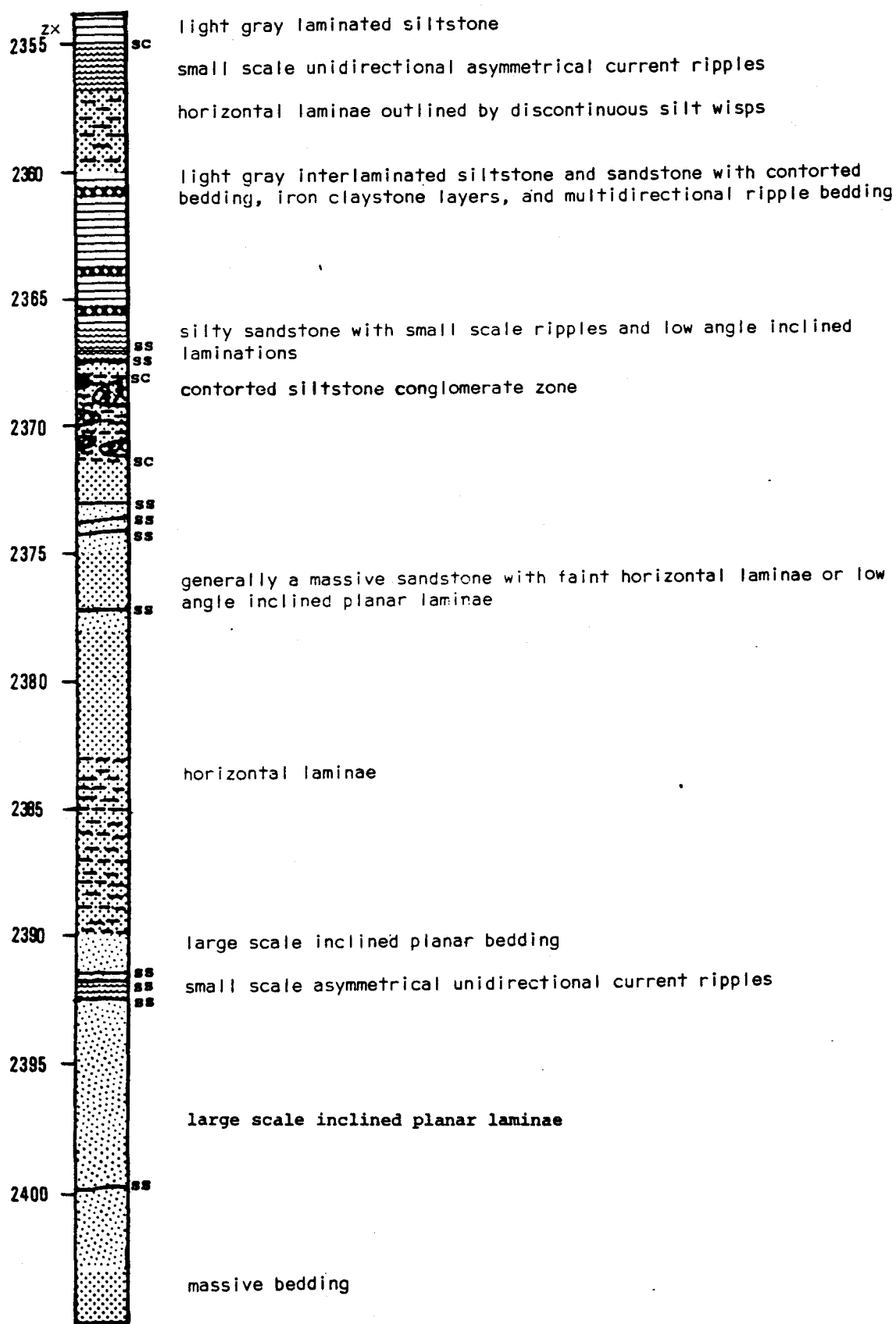


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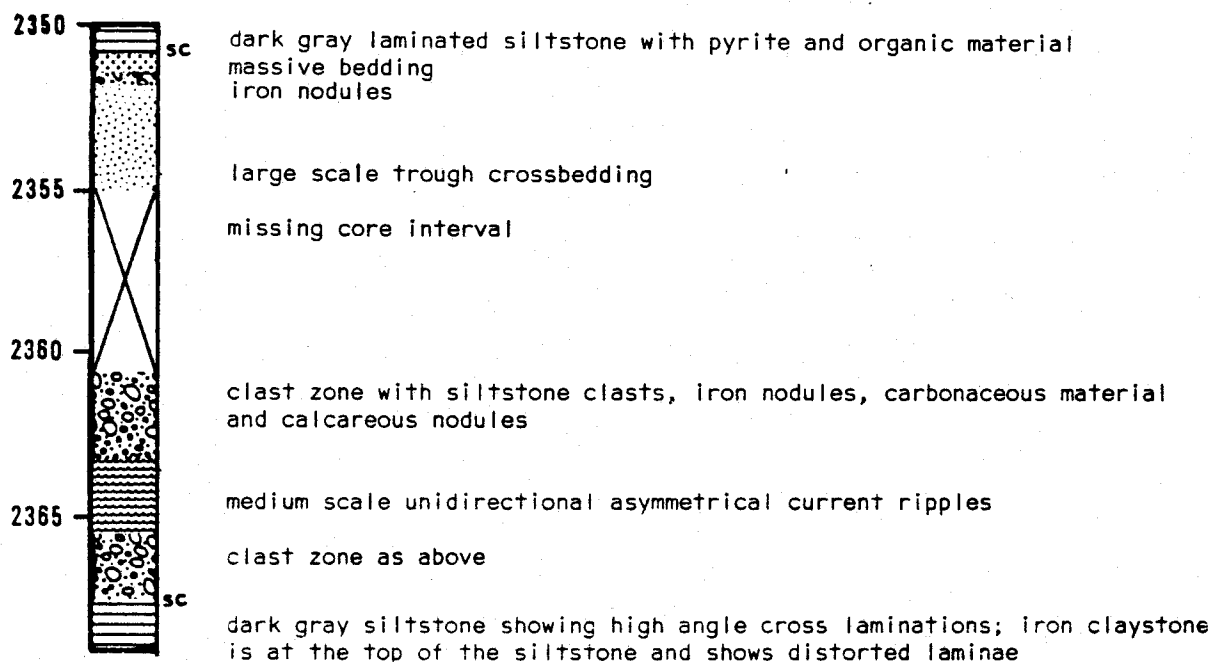


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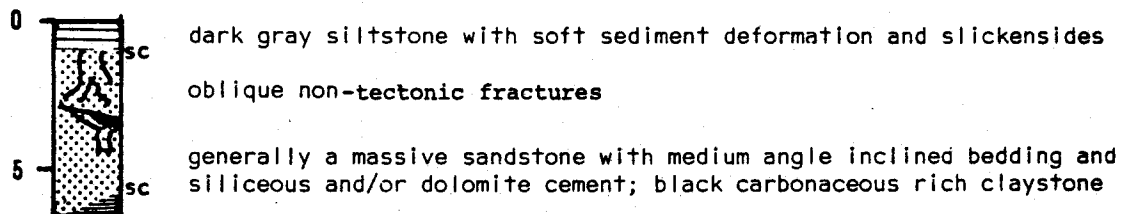
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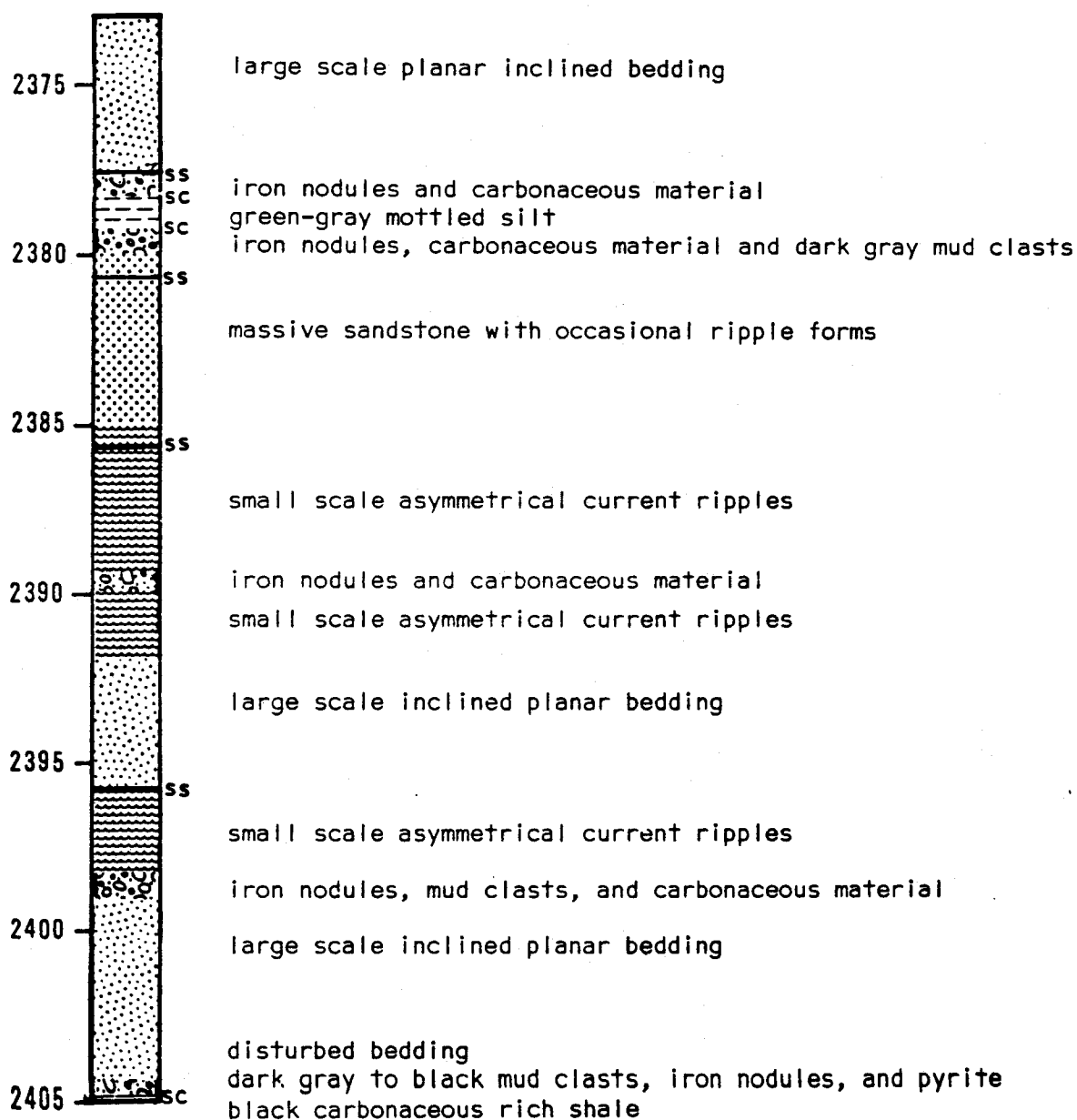
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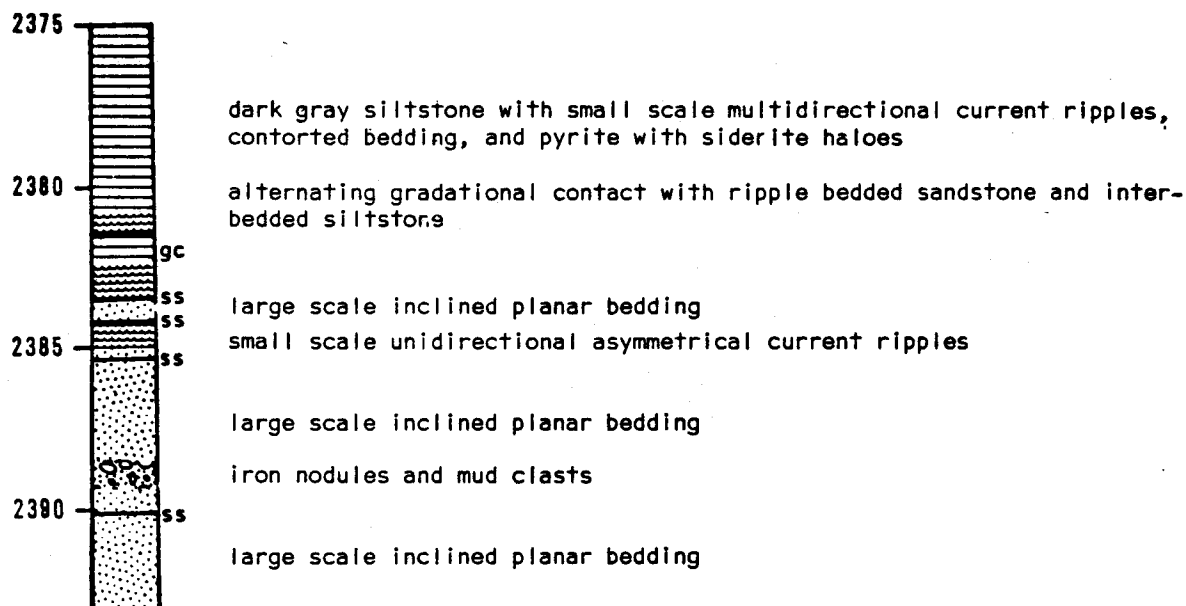
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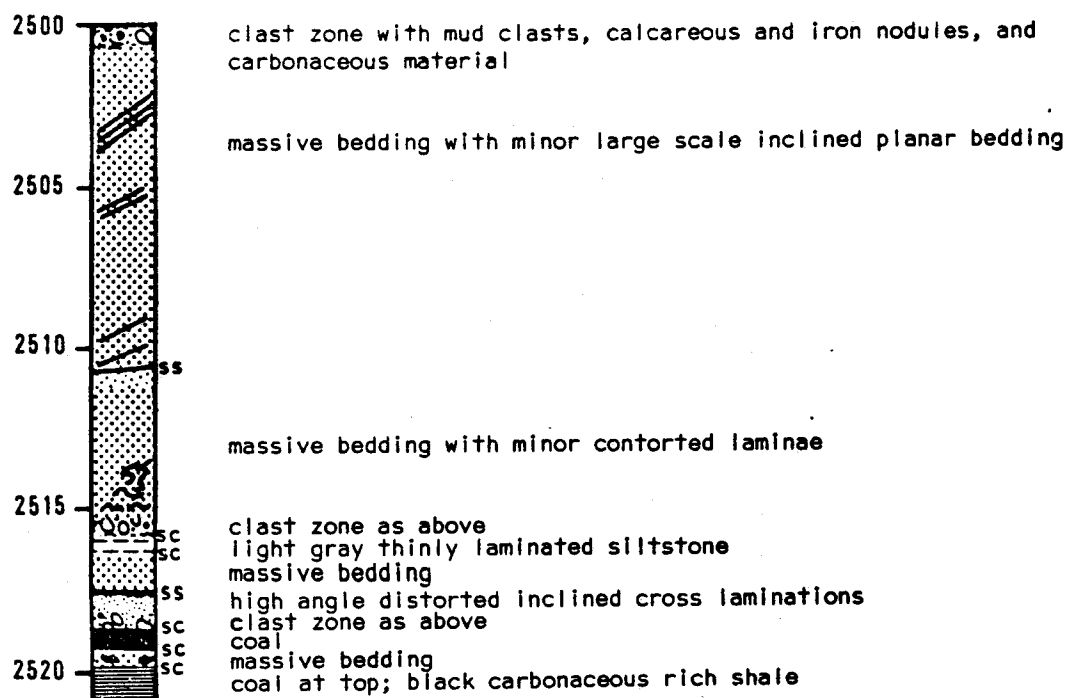
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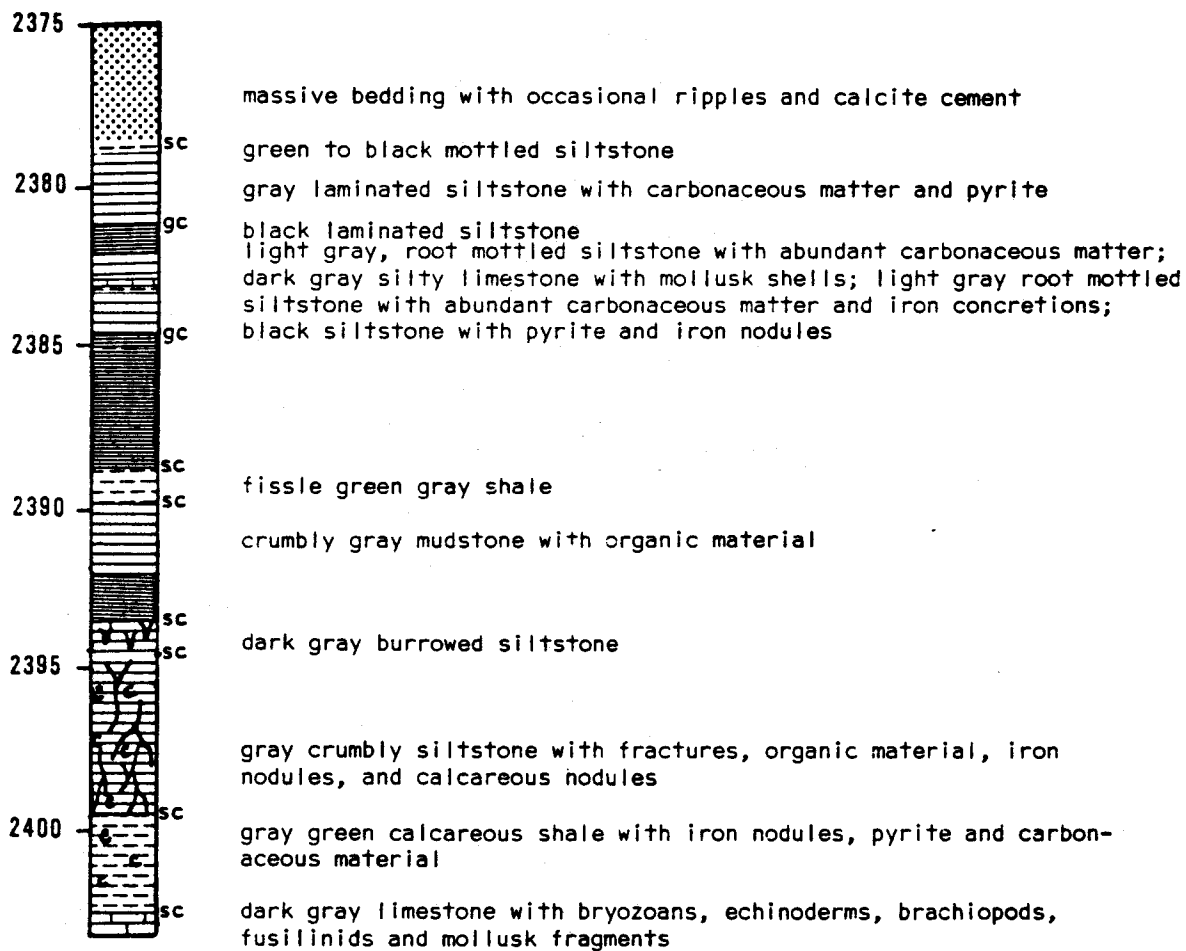
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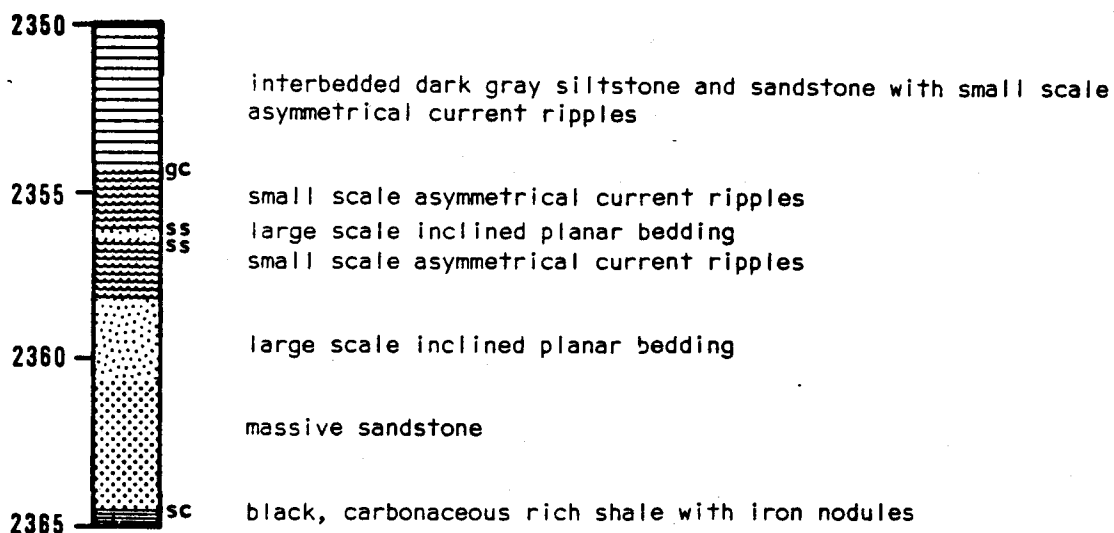


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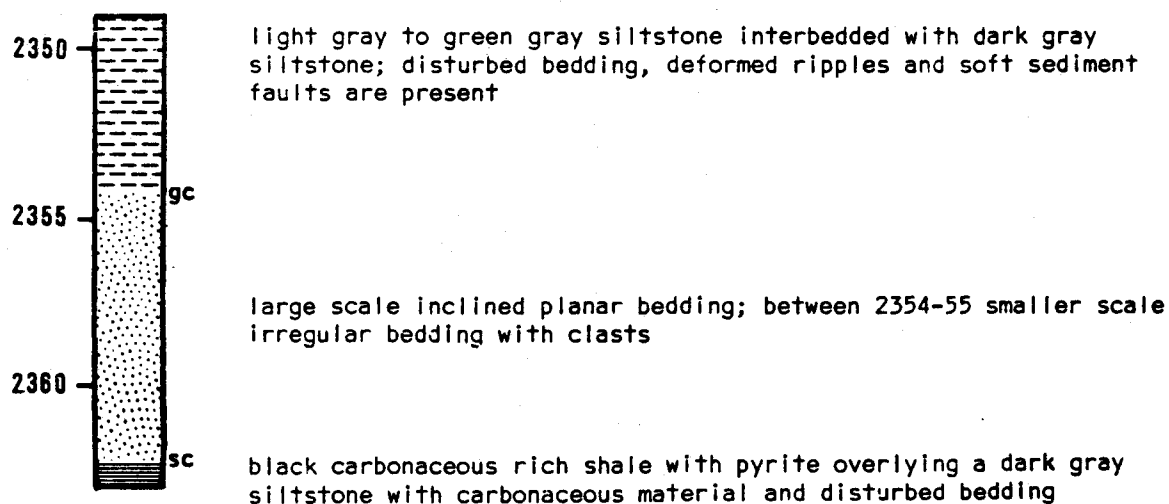
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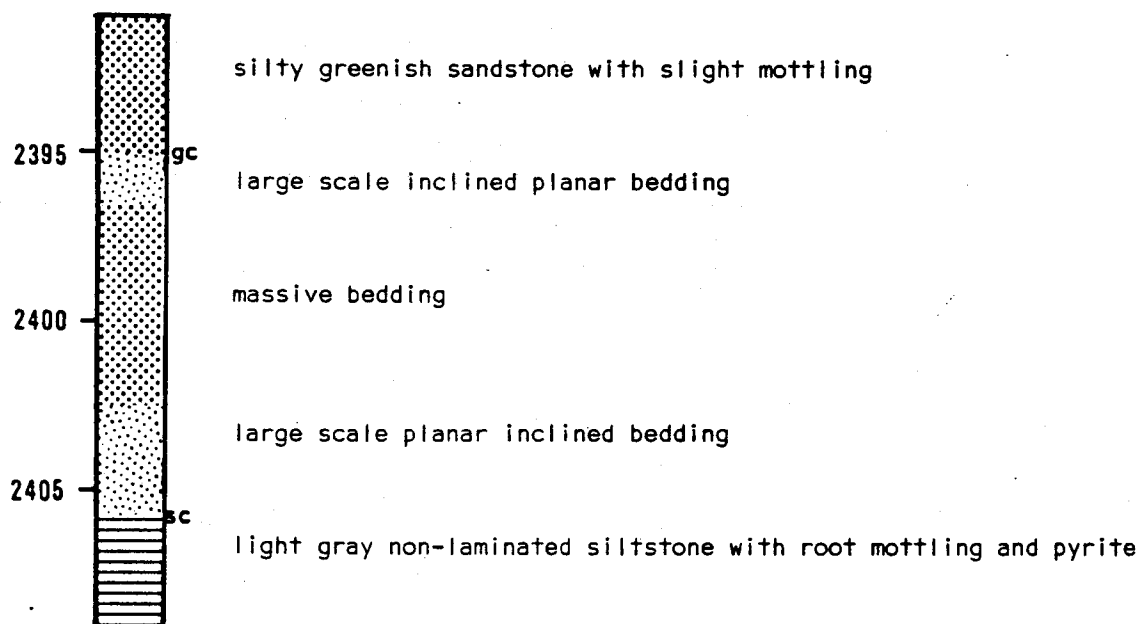


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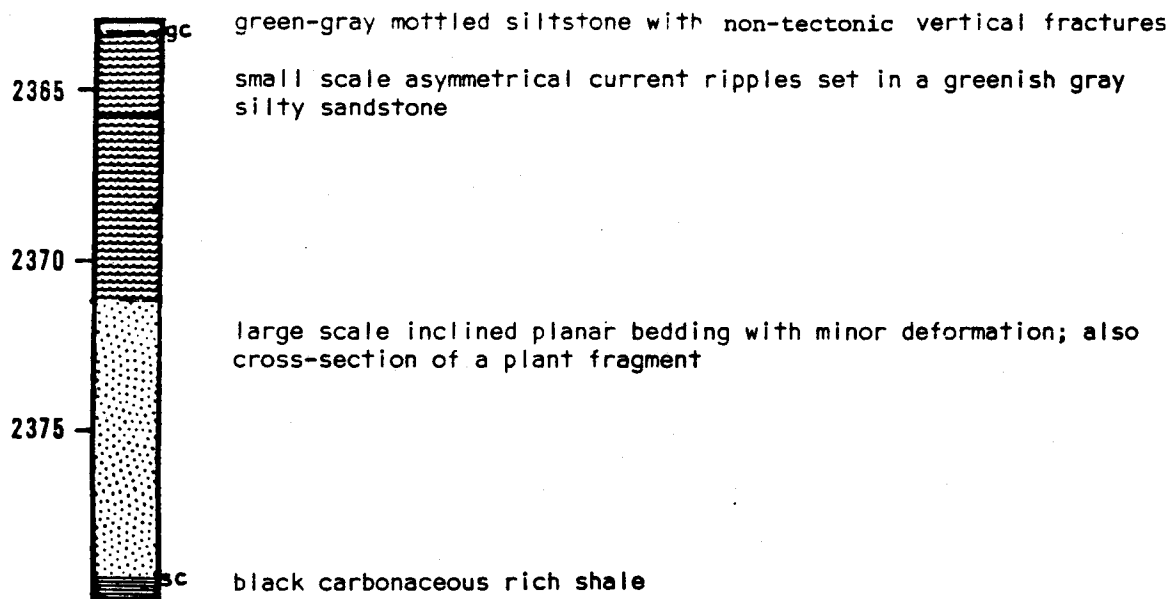
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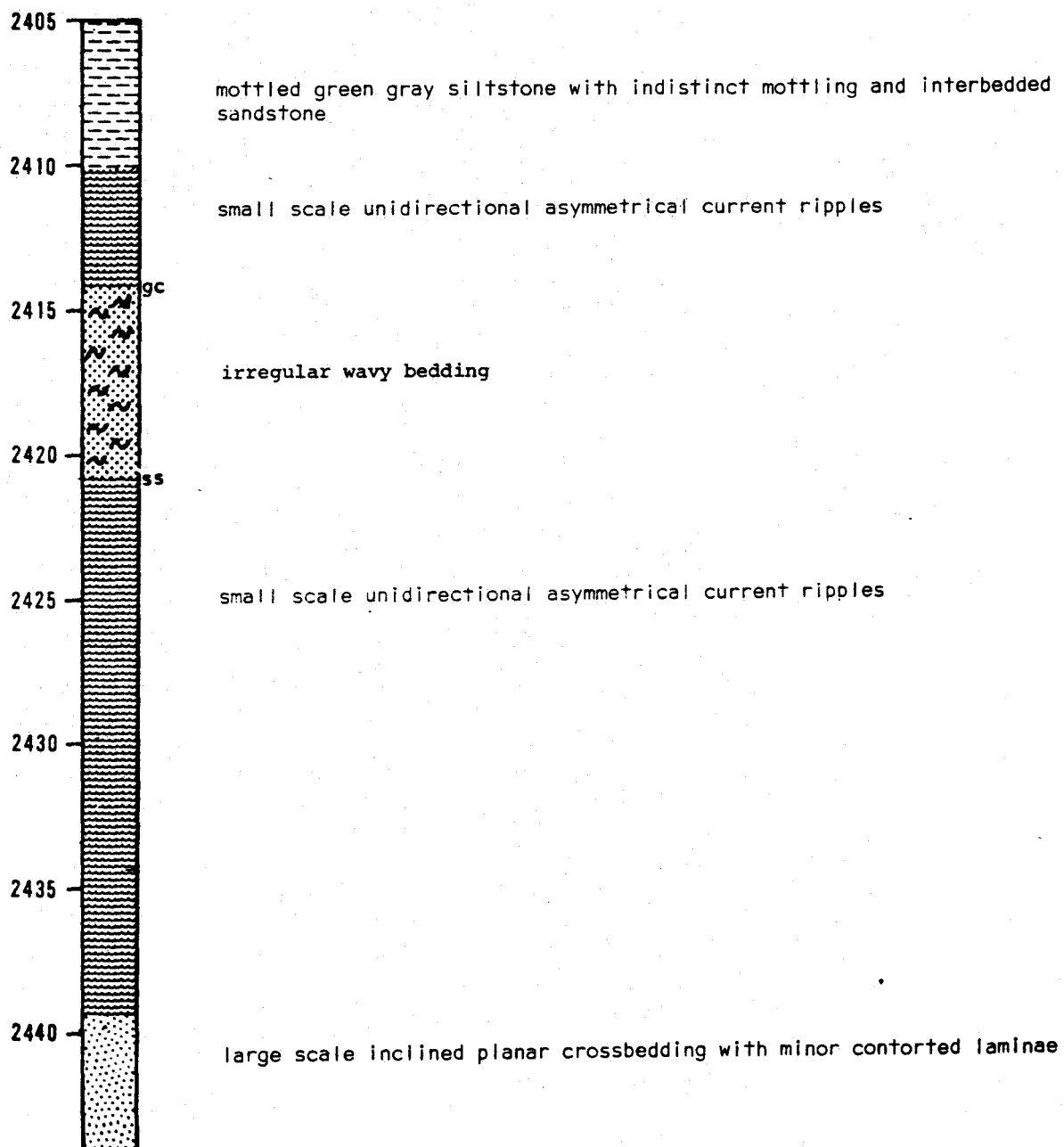


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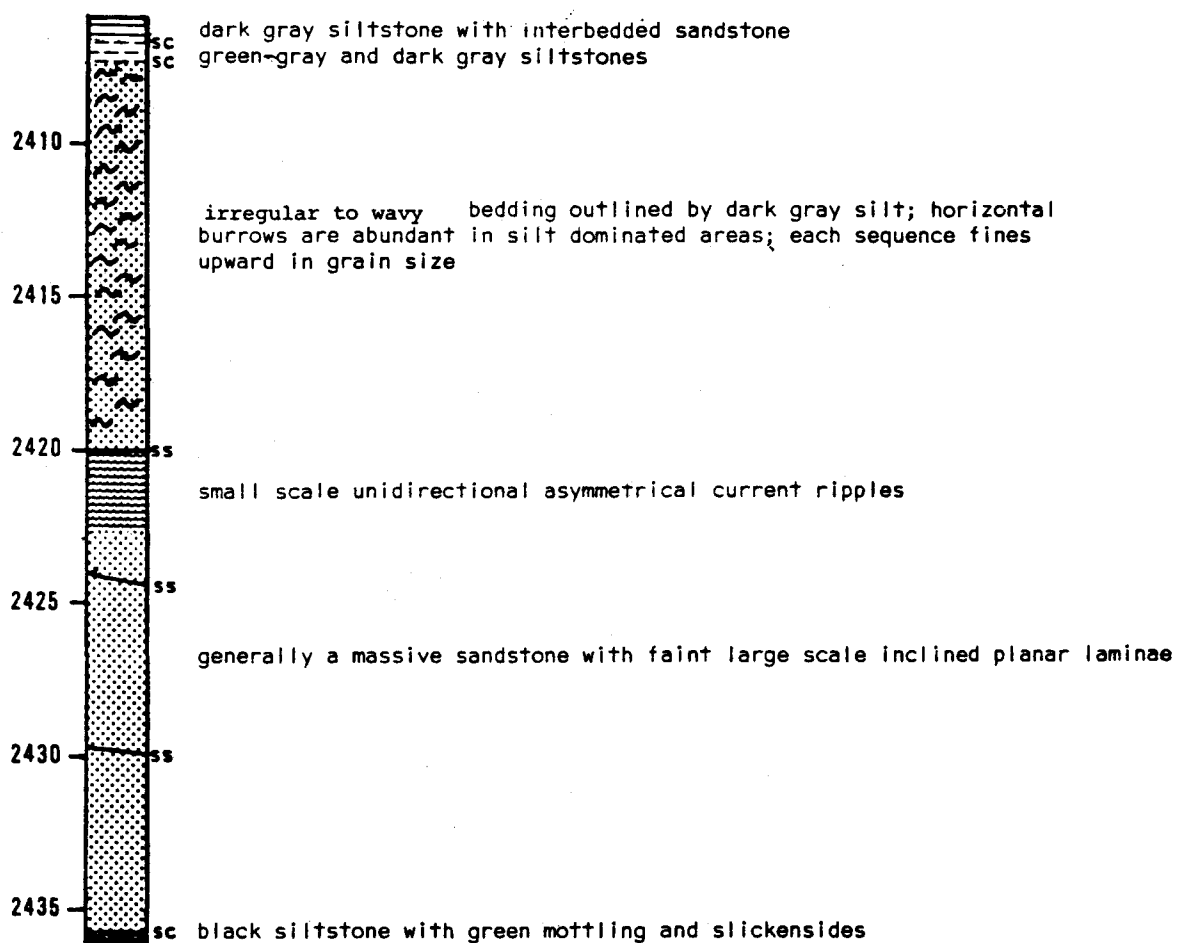
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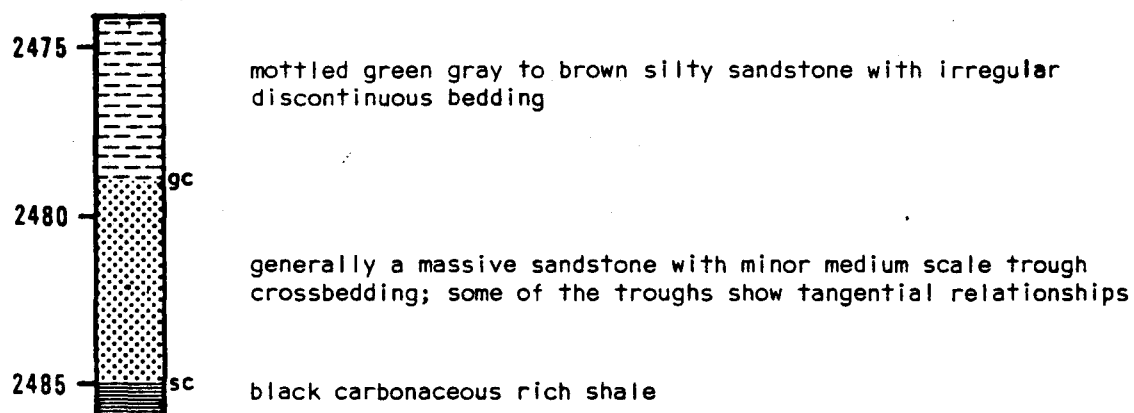
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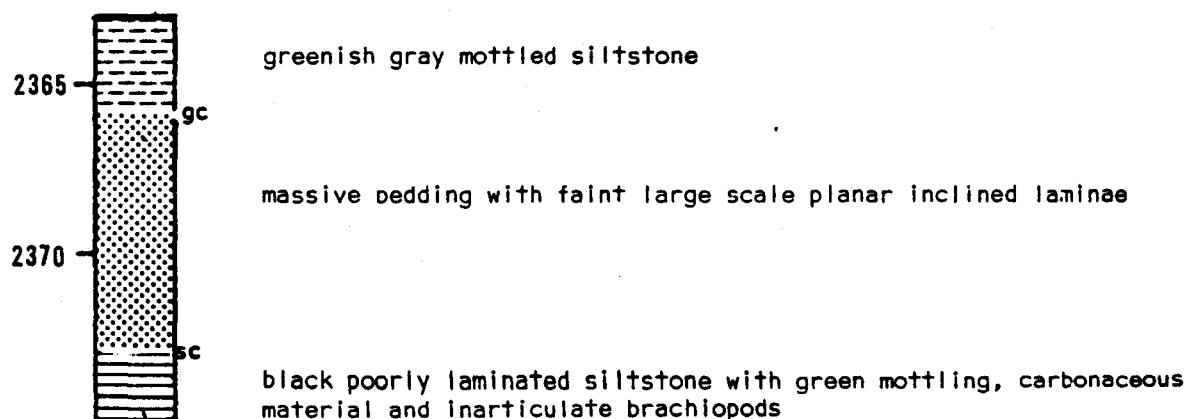
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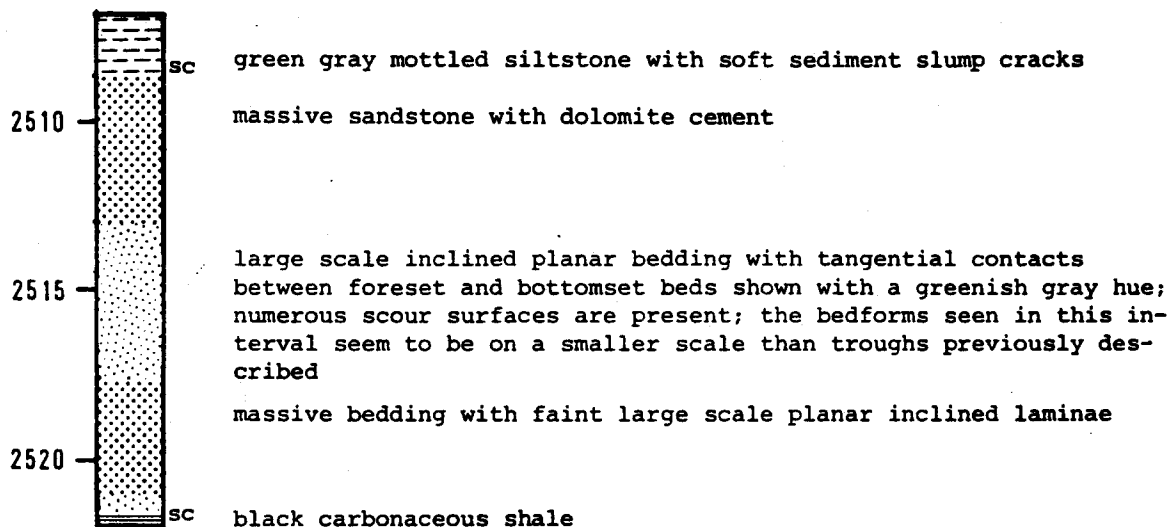


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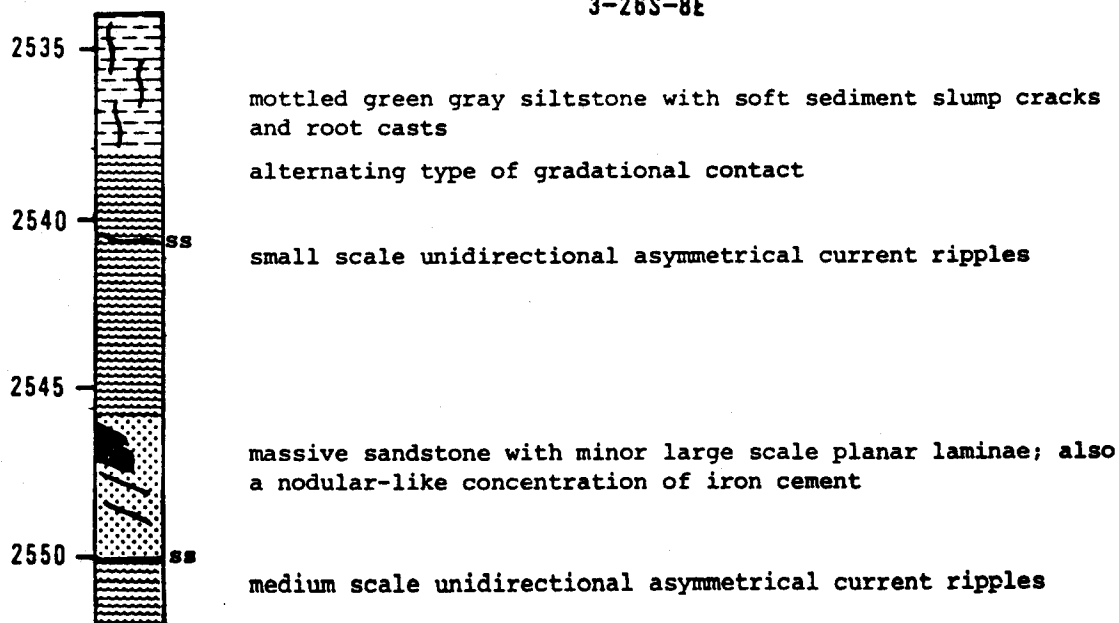
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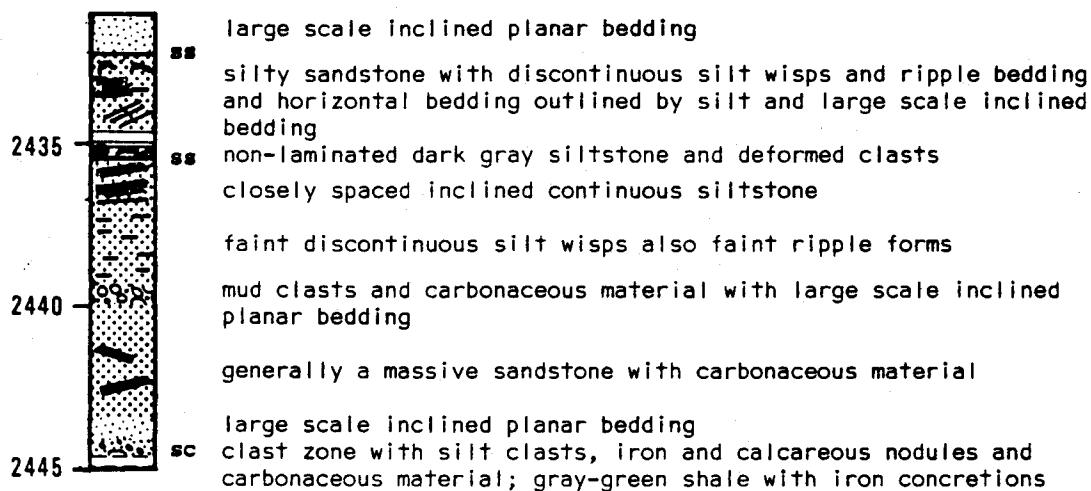
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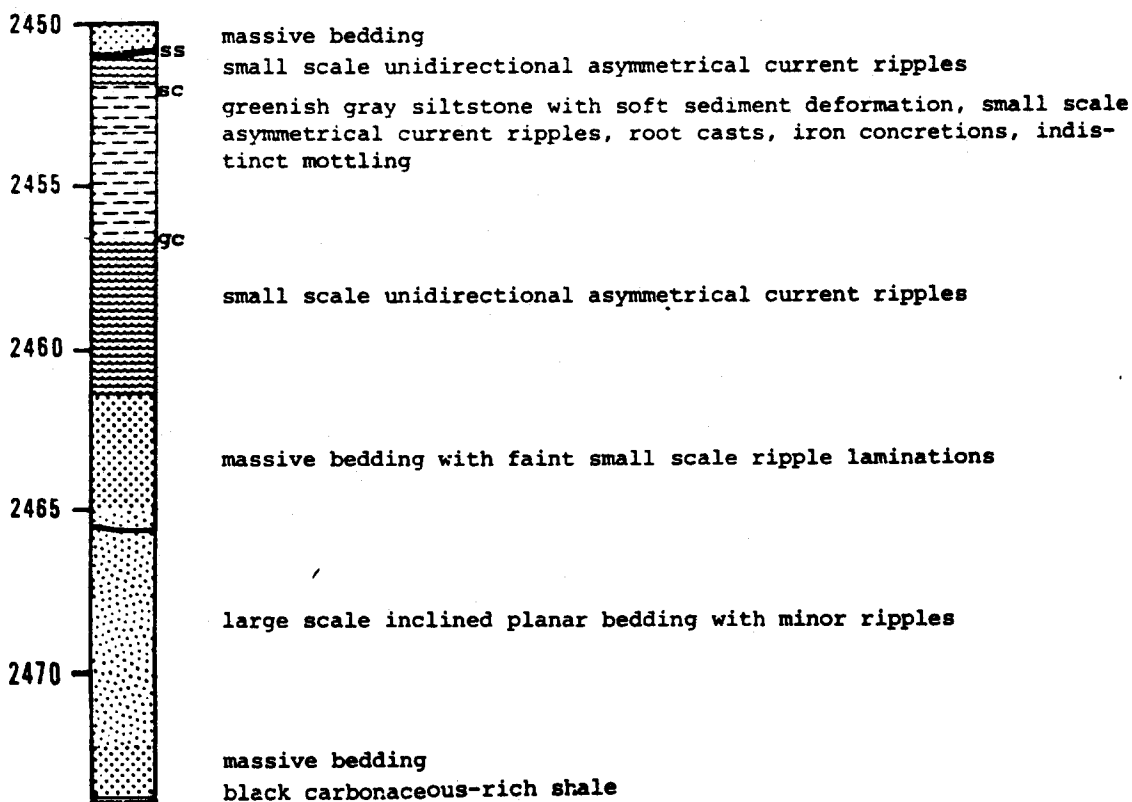
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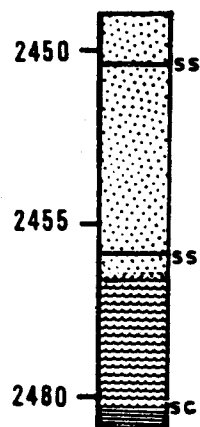
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## JACKSON BROS. BARRIER NO.39

3-26S-8E



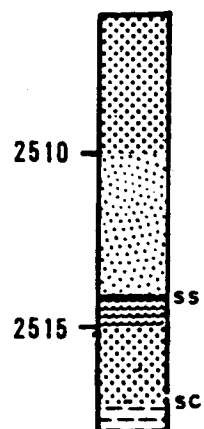
larger scale inclined bedding with tangential relationships and medium scale trough crossbedding whose laminae show divergence; some small scale unidirectional asymmetrical current ripples are present

small scale unidirectional asymmetrical current ripples

low amplitude asymmetrical current ripples outlined by green gray silt  
black carbonaceous rich shale

## JACKSON BROS. CREW NO.18

3-26S-8E



massive sandstone with faint ripple bedding

large scale inclined planar bedding

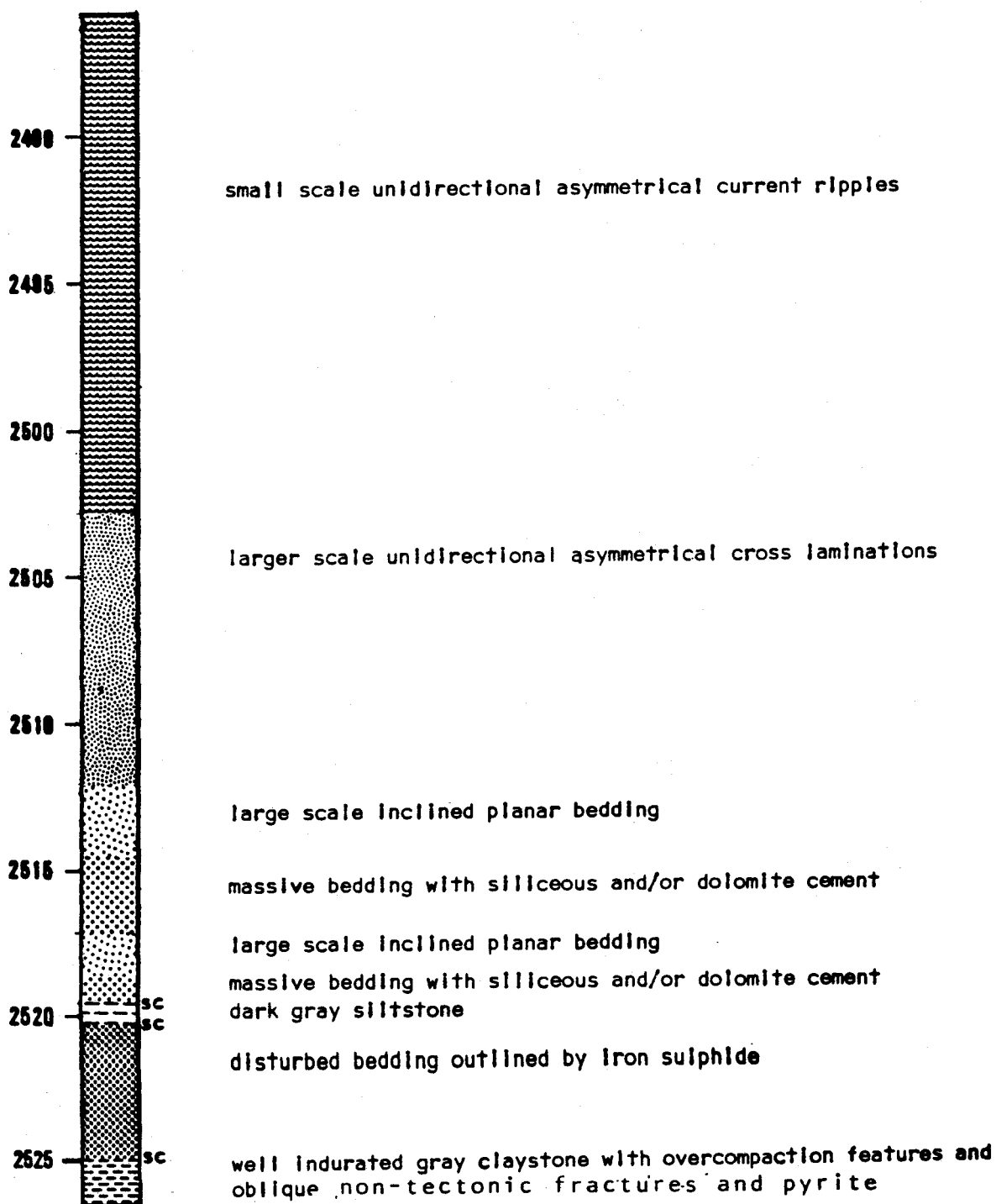
small scale unidirectional asymmetrical current ripples

massive bedding

mottled green-gray siltstone

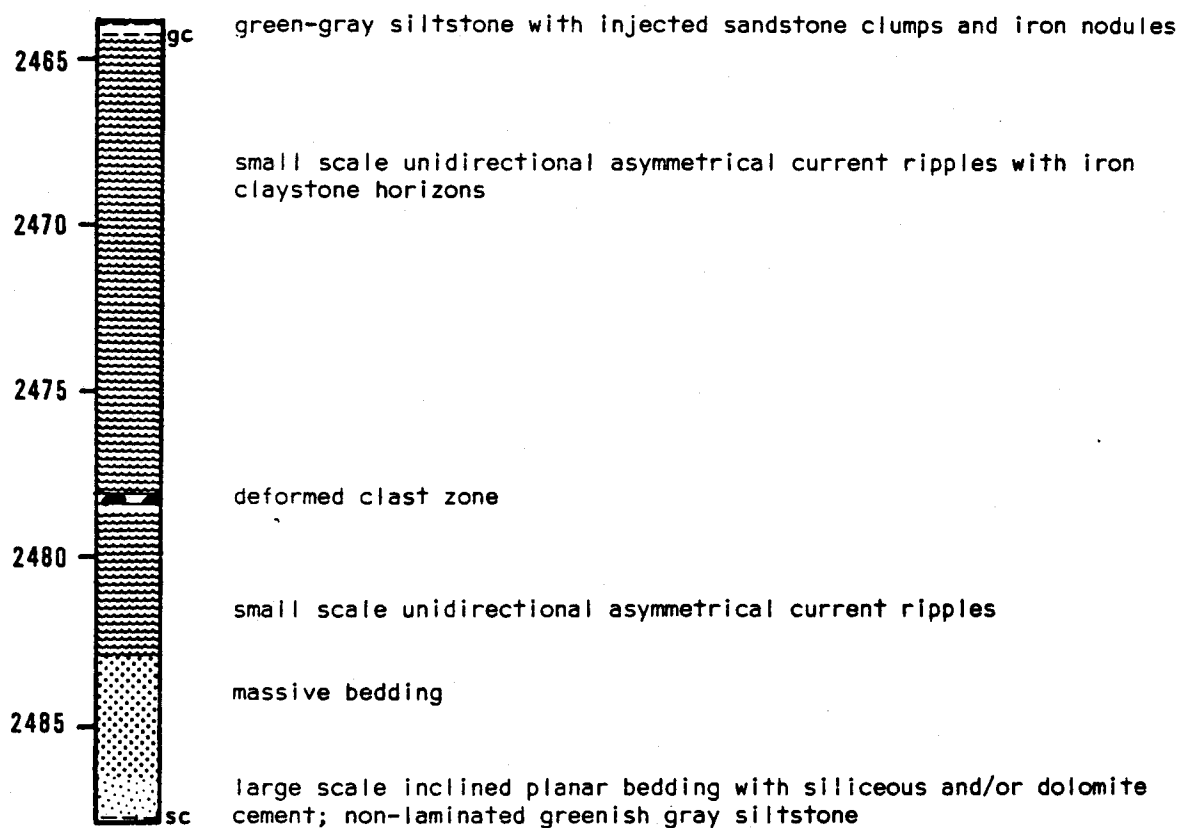
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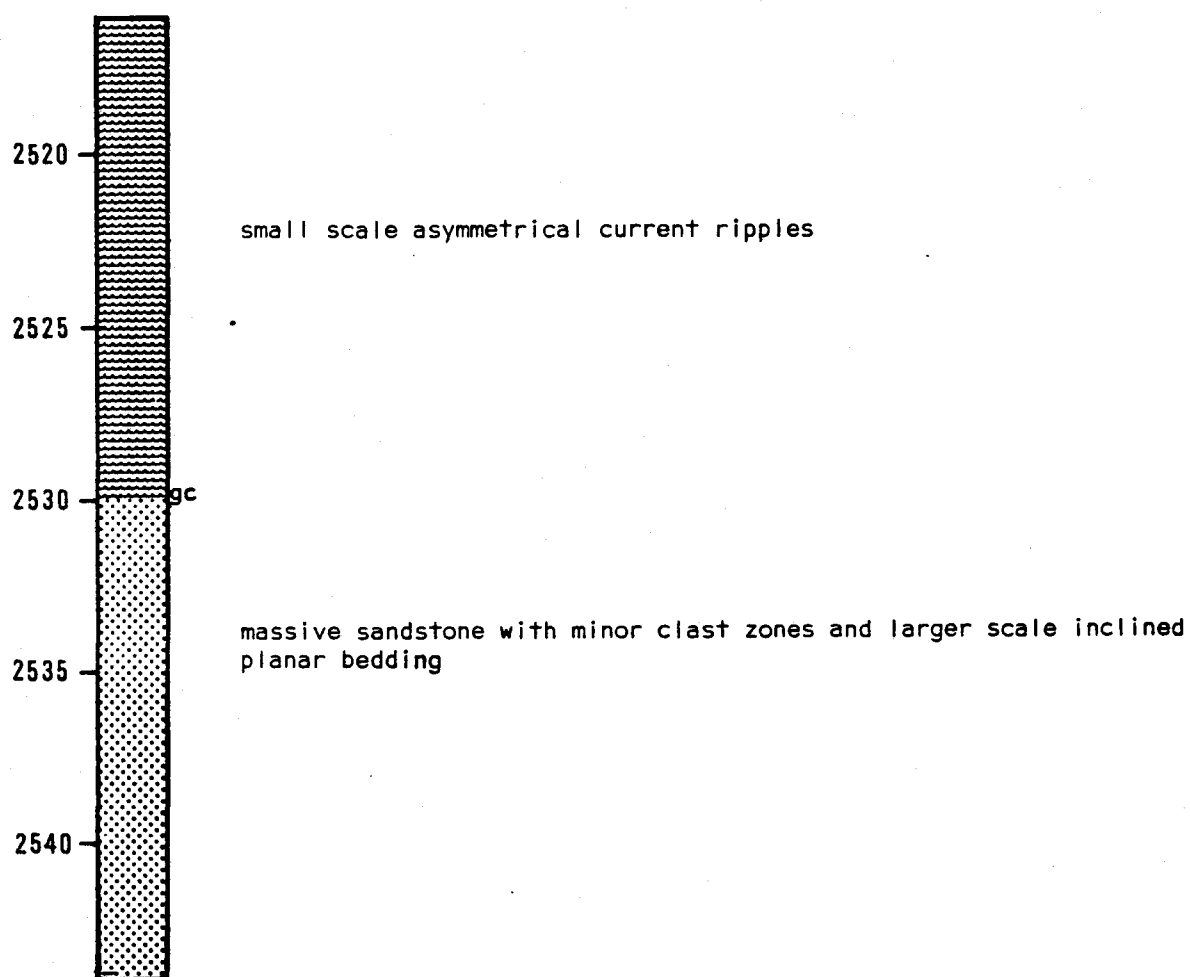


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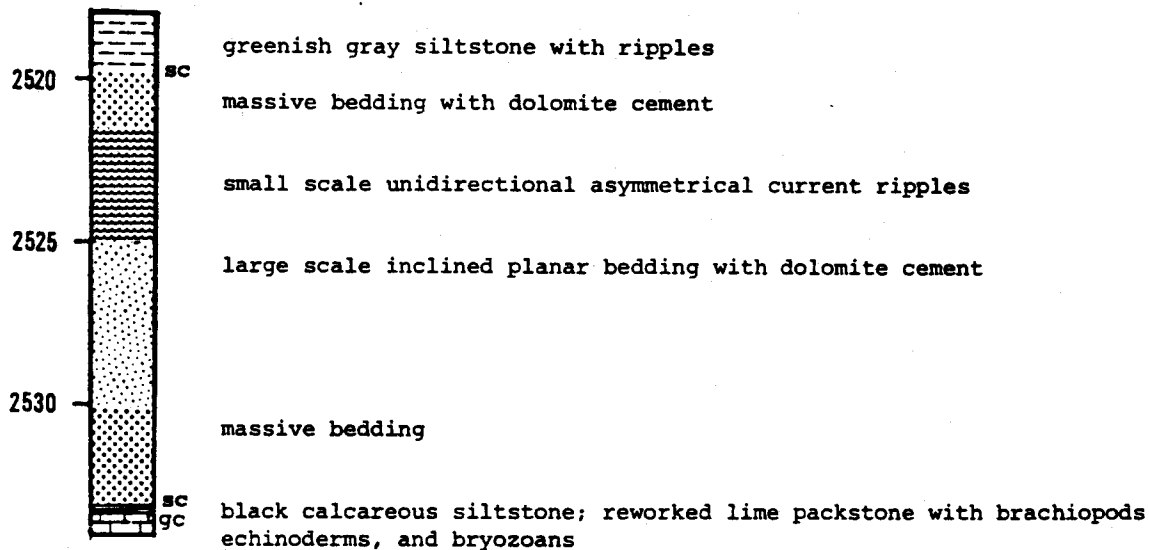
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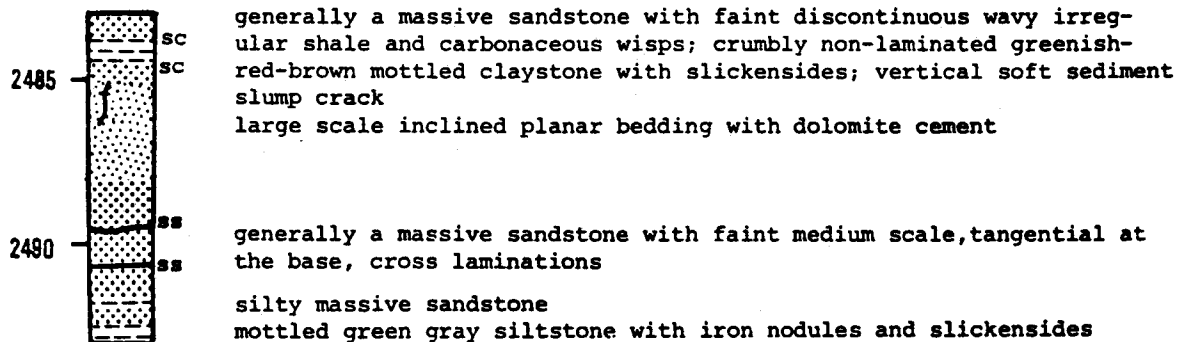
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3-26S-8E



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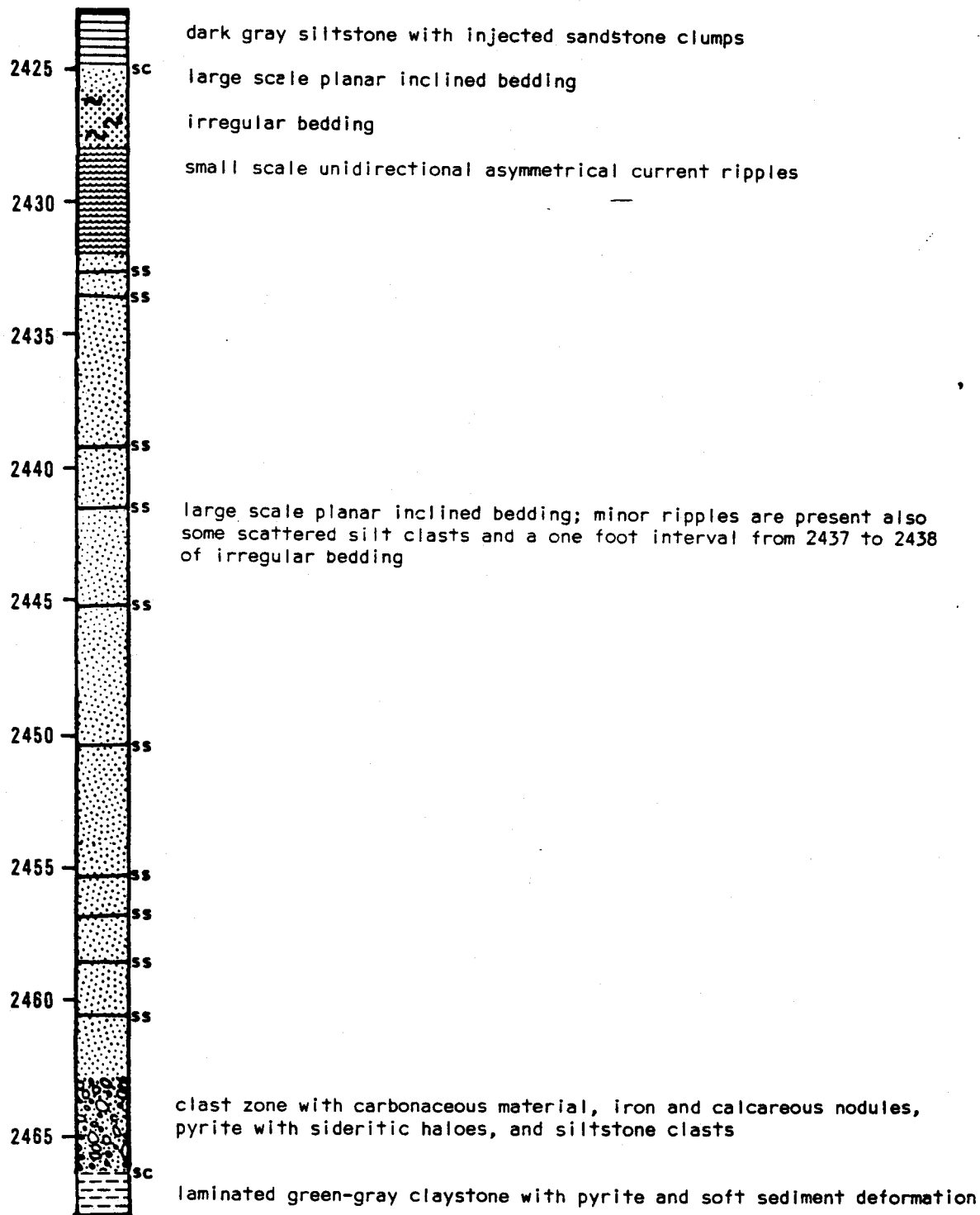


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10-26S-8E



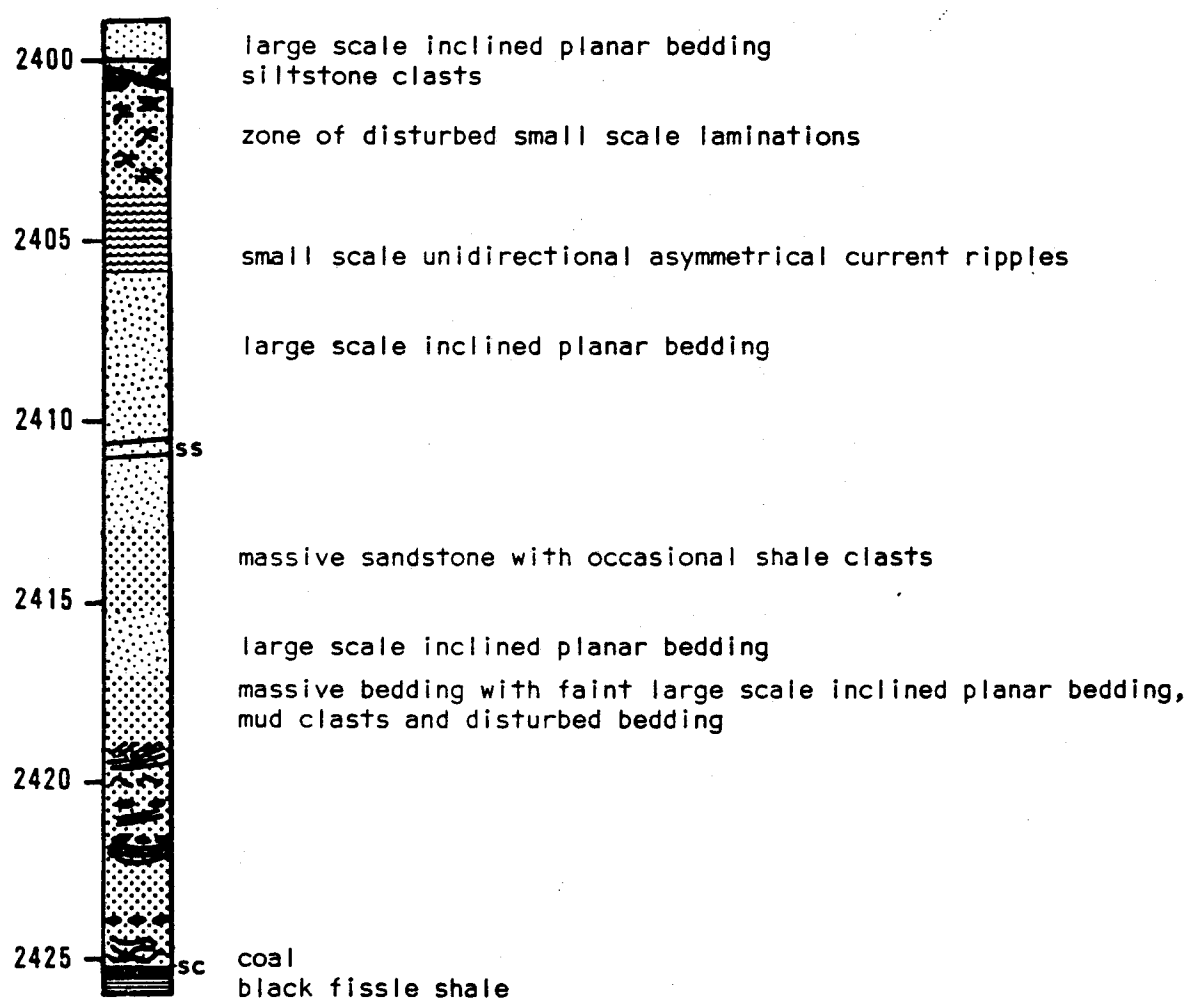
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3-26S-8E



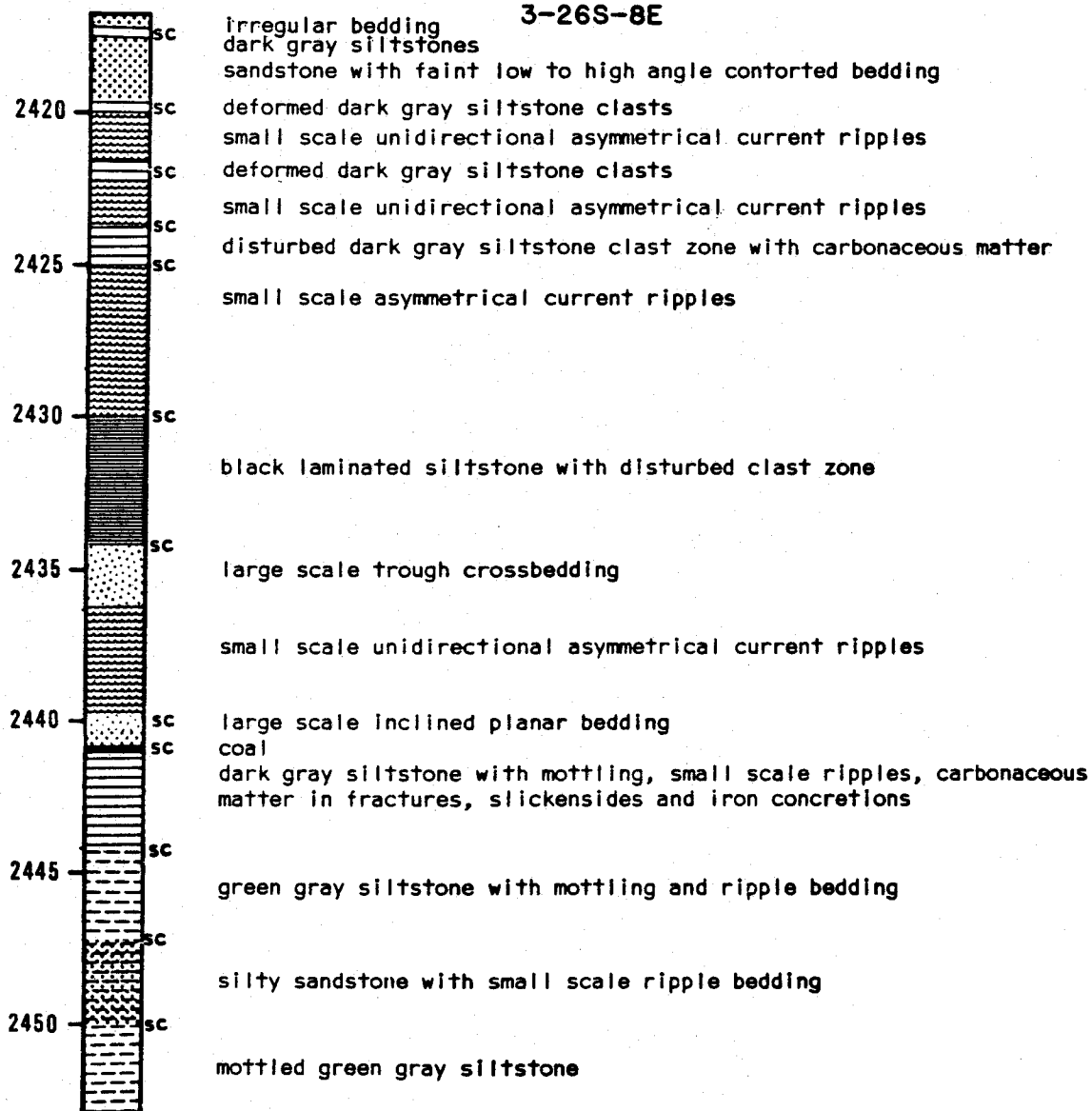
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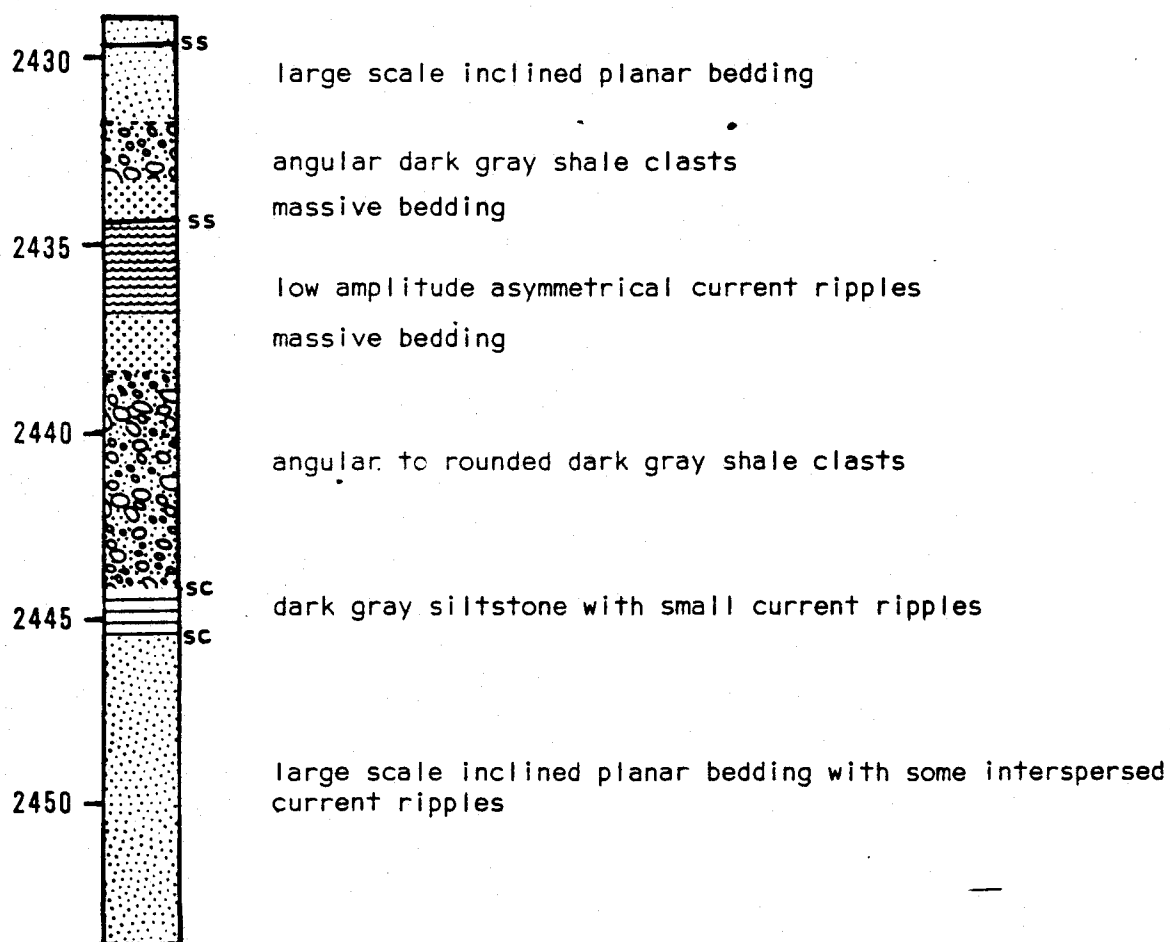


## JACKSON BROS. BARRIER NO. 37

3-26S-8E



JACKSON BROS. RICE NO. 1  
10-26S-8E



## APPENDIX D

### PICTORIAL REPRESENTATIONS OF SELECTED SANDSTONE BODIES DETAILED IN PLATE 13

Figure D-1. - Braided Stream Systems

Figure D-2. - Coarse Grained Meander Belts

Figure D-3. - Fine Grained Meander Belts

Figure D-4. - Constructive Delta Distributary Channels

Figure D-5. - Tidal Flat-Channel Systems

Figure D-6. - Barrier Bar Systems

Figure D-7. - Shallow Marine Sand Bars

Figure D-1. - Braided Stream Systems  
(All figures taken from Brown et. al., 1973)

Figure D-1a. - Types of stratification that normally develop in braided stream systems.

Figure D-1b. - Plan and cross sectional view of individual channel showing distribution of stratification types in a typical channel.

Figure D-1c. - Vertical sequence of sedimentary structures in a braided stream system. Note that there is no decrease in the scale of sedimentary structures or in grain size distribution.

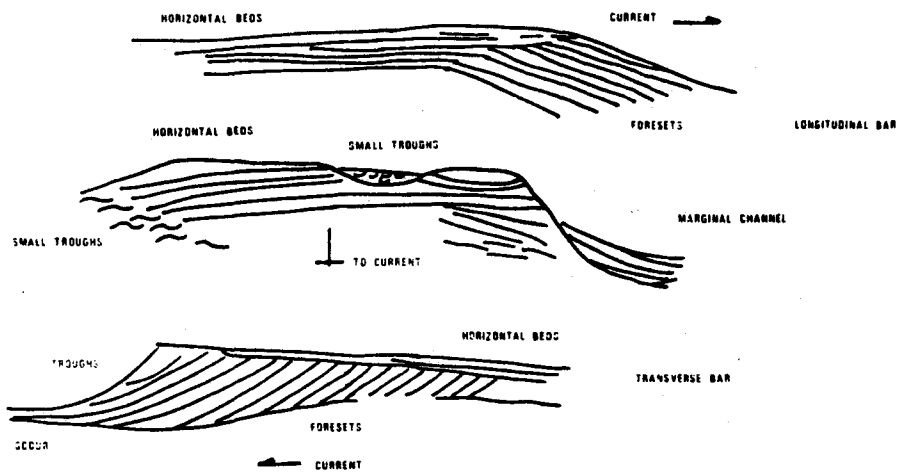


Fig. D-1a.

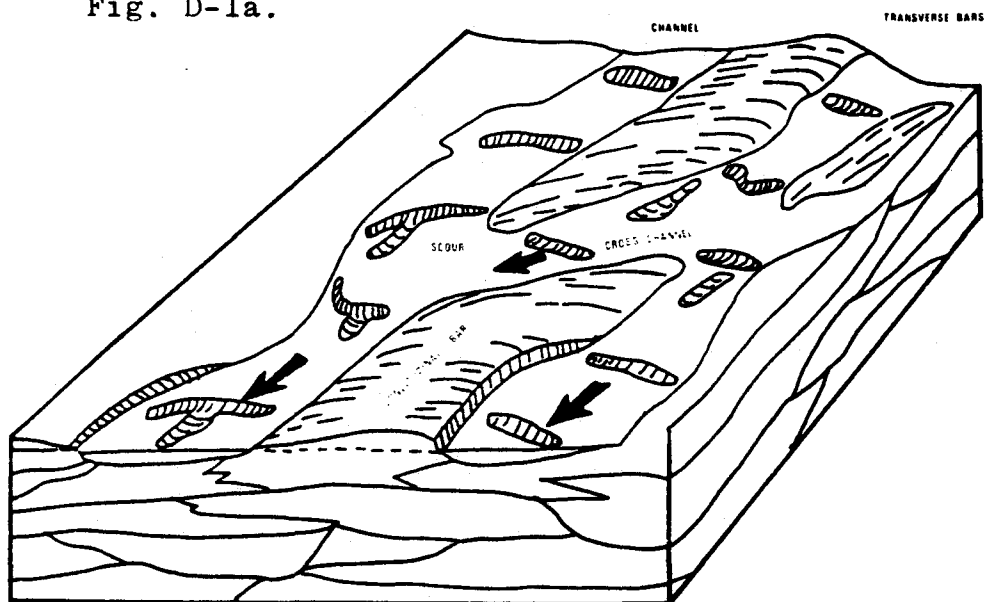
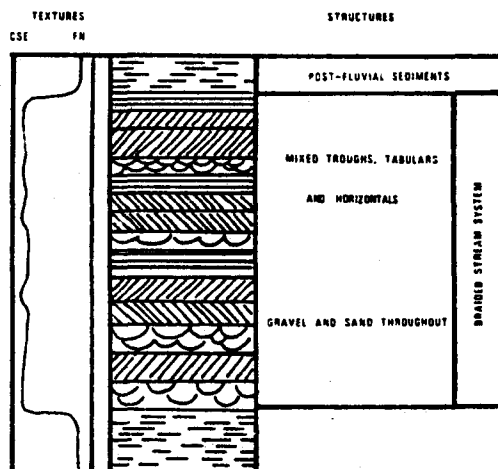


Fig. D-1b.



TABULAR TO SHEET-LIKE SAND BODY; MULTILATERAL SANDS

Fig. D-1c.

Figure D-2. - Coarse Grained Meander Belts  
(All figures taken from Brown et. al., 1973)

Figure D-2a. - Cross section of coarse grained meander belt channel showing positions of channel, point bar and associated facies relative to each other.

Figure D-2b. - Same as above in plan view and cross section.

Figure D-2c. - Vertical sequence of sedimentary structures in an idealized coarse grained meander belt system. Note that grain size distribution may increase or decrease and has no ideal pattern.

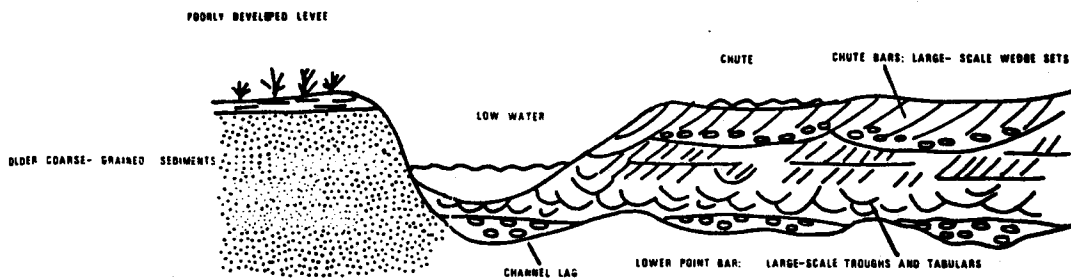


Fig. D-2a.

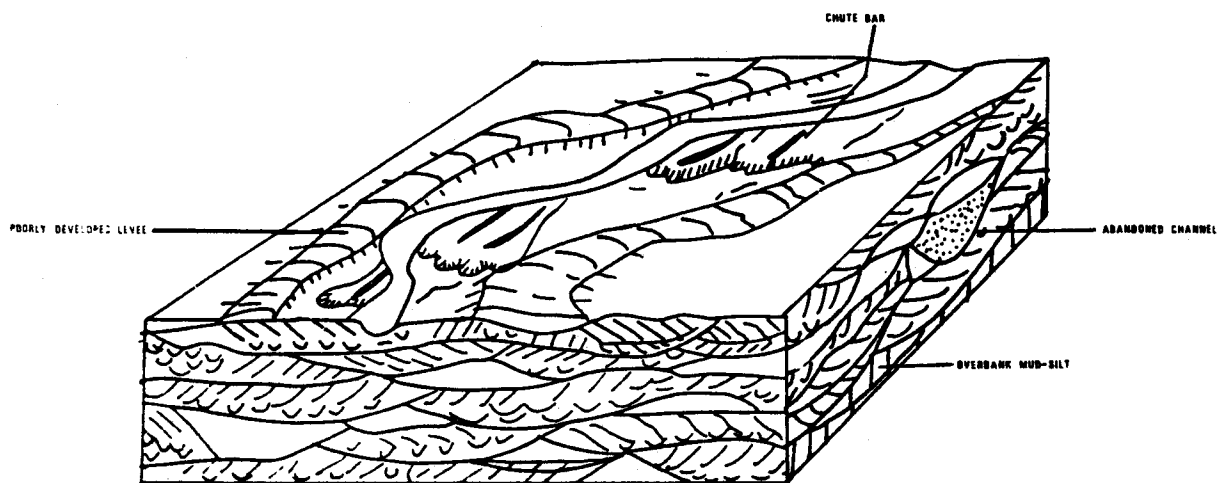
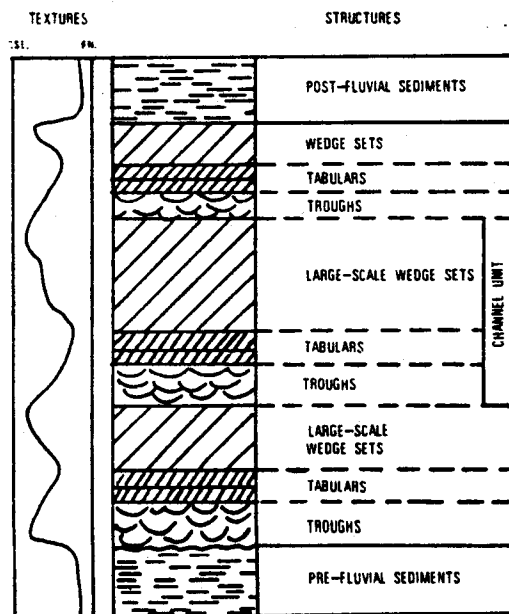


Fig. D-2b.



TABULAR TO SHEET-LIKE SAND BODY: MULTILATERAL SANDS

Fig. D-2c.

Figure D-3. - Fine Grained Meander Belt

Figure D-3a. - Diagrammatic representation of the Brazos River point bar showing the lateral and vertical relationships between zones of stratification and vertical grain size distributions. (After Bernard et. al., 1970).

Figure D-3b.- Vertical sequence of sedimentary structures and grain size distribution of the point bar sequence in the Brazos River alluvial plain. (After Bernard et. al., 1970).

Figure D-3c. - Plan view of a meandering system showing a point bar and the associated facies. (After Reineck and Singh, 1975).

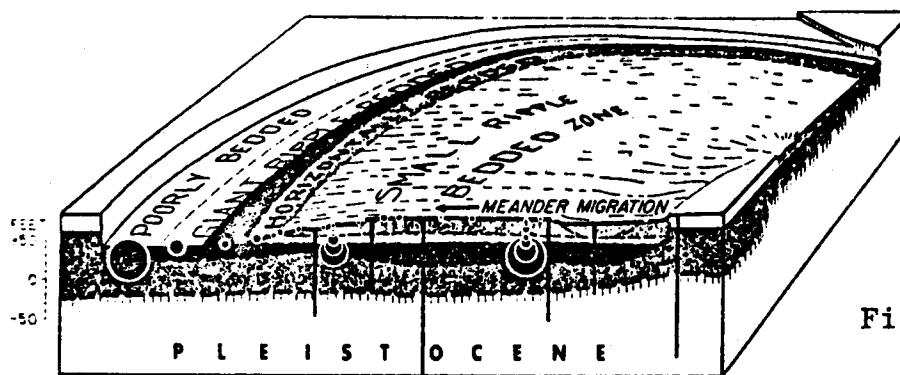
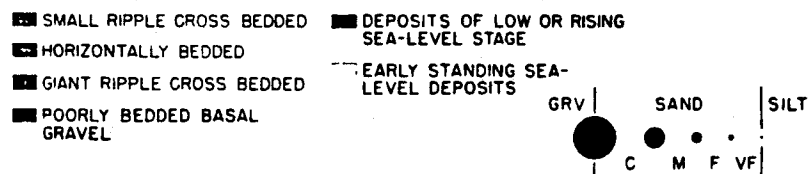


Fig. D-3a.



### POINT BAR SEQUENCE, BRAZOS ALLUVIAL PLAIN

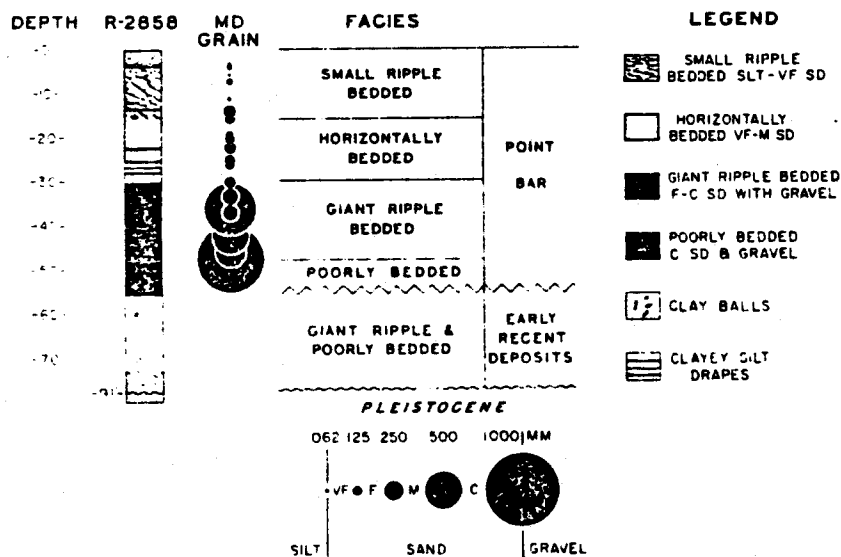


Fig. D-3b.

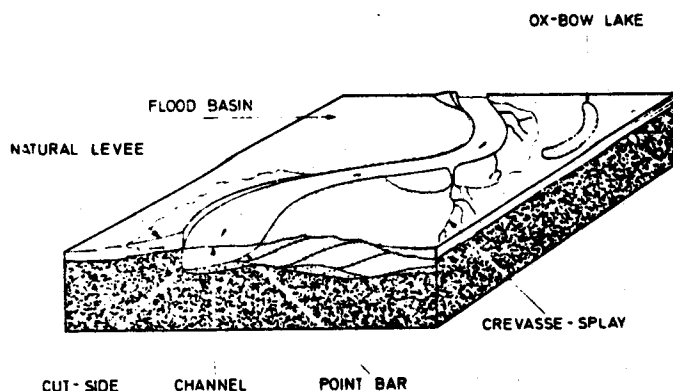


Fig. D-3c.

Figure D-4. - Constructive Delta Distributary Channel

Figure D-4a. - Cross section and plan view of a delta distributary channel and associated facies. (After Brown et. al., 1973).

Figure D-4b. - Vertical sequence of sedimentary structures and grain size distribution in a lobate delta distributary channel. Note that the grain size coarsens upward. (After Brown et. al., 1973).

Figure D-4c. - Vertical sequence of sedimentary structures and grain size distribution in an elongate delta distributary. Note that the scale of sedimentary structures and the grain size are fairly uniform throughout the sequence. (After Brown et. al., 1973).

Figure D-4d. - Block diagram of a deltaic sequence resulting from the progradation of Mississippi River distributaries, related environments and sediments. (After Fisher and Brown, 1969).

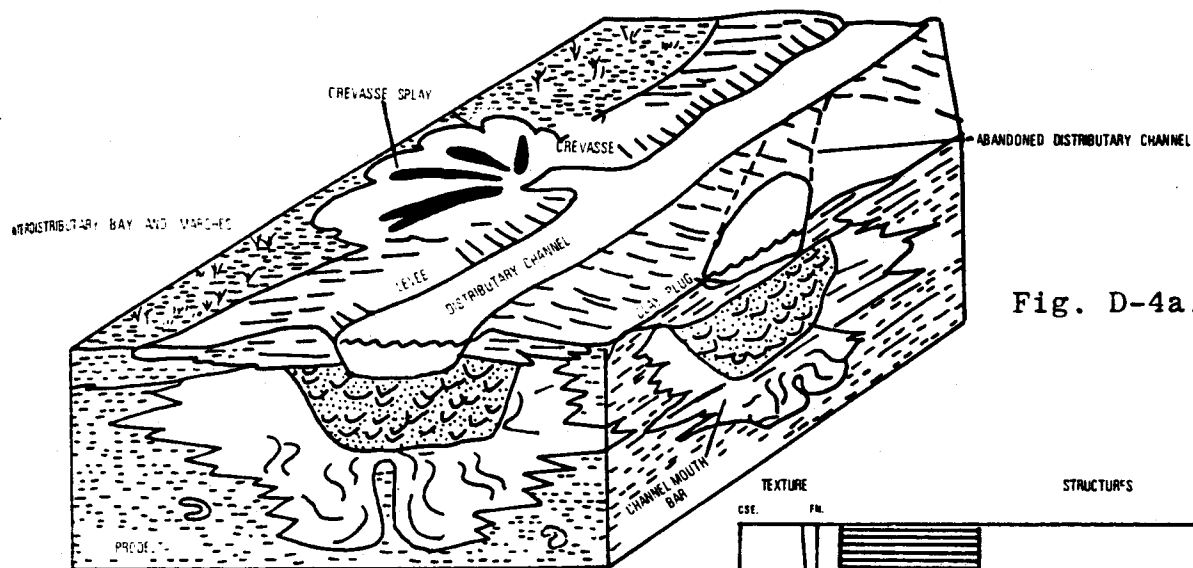


Fig. D-4a.

| TEXTURE |    | STRUCTURES                          | FACIES           |
|---------|----|-------------------------------------|------------------|
| CSL     | FN |                                     |                  |
|         |    | MUD AND SILT                        | PRODELTA         |
|         |    | MUD, SAND, COAL                     | SHELF            |
|         |    | HORIZONTAL-BEDDED SAND              | DELTA PLAIN      |
|         |    | SOME TROUGHS                        | BAR CREST        |
|         |    | HIGHLY CONTORTED SAND               | DISTAL           |
|         |    | LAMINATED TO CONTORTED MUD AND SILT | PRODELTA (THICK) |

NARROW, ELONGATE SAND BODY

| TEXTURE |    | STRUCTURES                            |
|---------|----|---------------------------------------|
| CSL     | FN |                                       |
|         |    | ABANDONED CHANNEL FILL MUD            |
|         |    | TROUGHS AND TABULARS                  |
|         |    | TROUGHS                               |
|         |    | CLAY CLASTS                           |
|         |    | TROUGHS                               |
|         |    | CONTORTED BEDDING                     |
|         |    | INTERDISTRIBUTARY SAND, MUD, ORGANICS |

ELONGATE SAND BODY; MULTISTORY SANDS

Fig. D-4c.

Fig. D-4b.

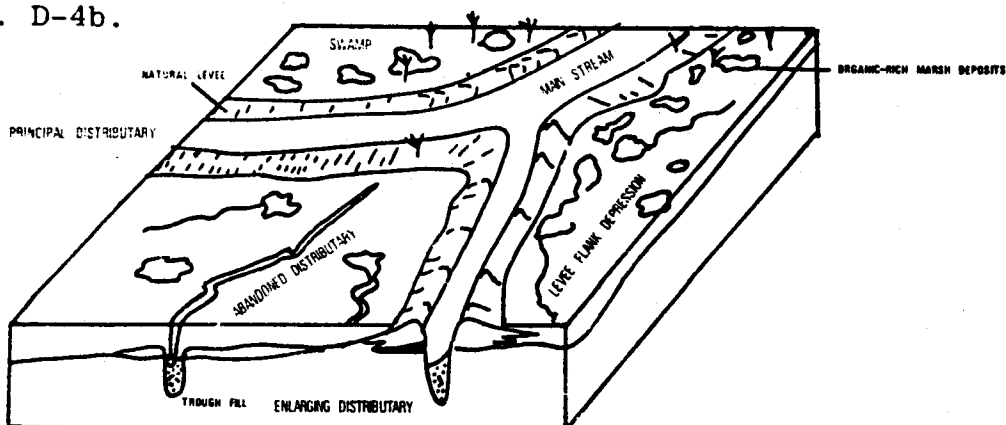


Fig. D-4d.

**Figure D-5 - Tidal Flat-Tidal Channel System**

**Figure D-5a. - Cross section showing a vertical sequence of related environments in a tidal flat system. (After Reineck and Singh, 1975).**

**Figure D-5b. - Vertical sequence of sedimentary structures in a tidal channel and the processes by which they form. Not shown are the lag deposits that normally consist of shell debris. Usually the only way to distinguish between fine grained alluvial meander belts and tidal channels are by the composition of the lag material. (After Klein, 1970).**

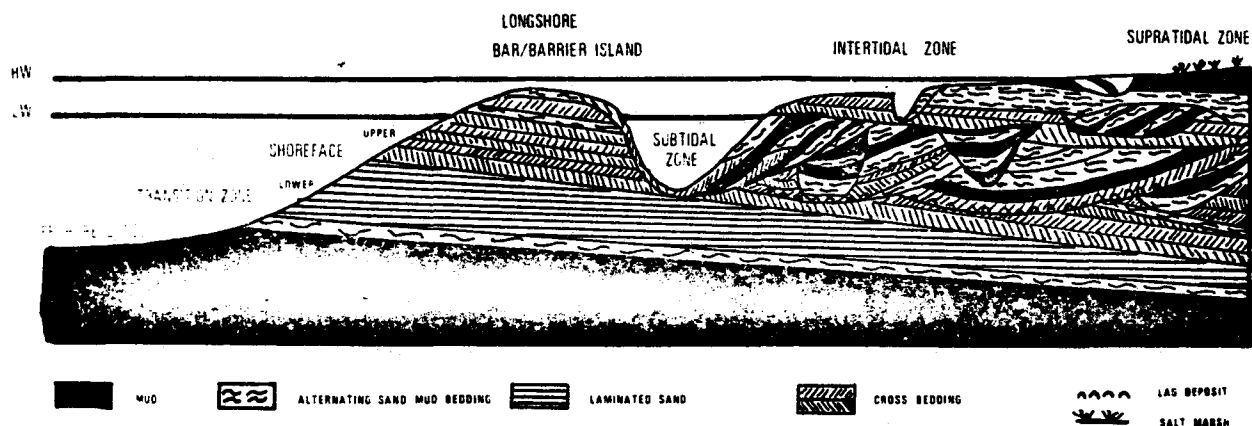


Fig. D-5a.

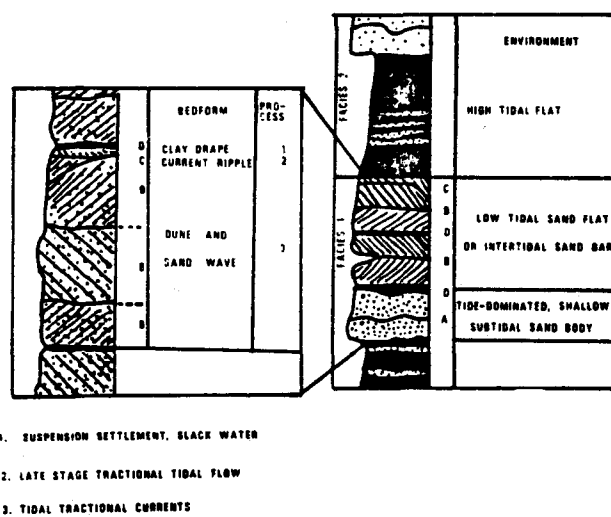


Fig. D-5b.

Figure D-6. - Barrier Bar System  
(Both figures are adopted from Reineck  
and Singh, 1975)

Figure D-6a. - Vertical sequence of sedimentary structures developed in a prograding barrier bar. The sedimentary structures show a multiplicity of directions. Also note the coarsening upward sequence in grain size distribution.

Figure D-6b. - Cross section of Galveston Island showing transitional lower boundary and grain size distribution.

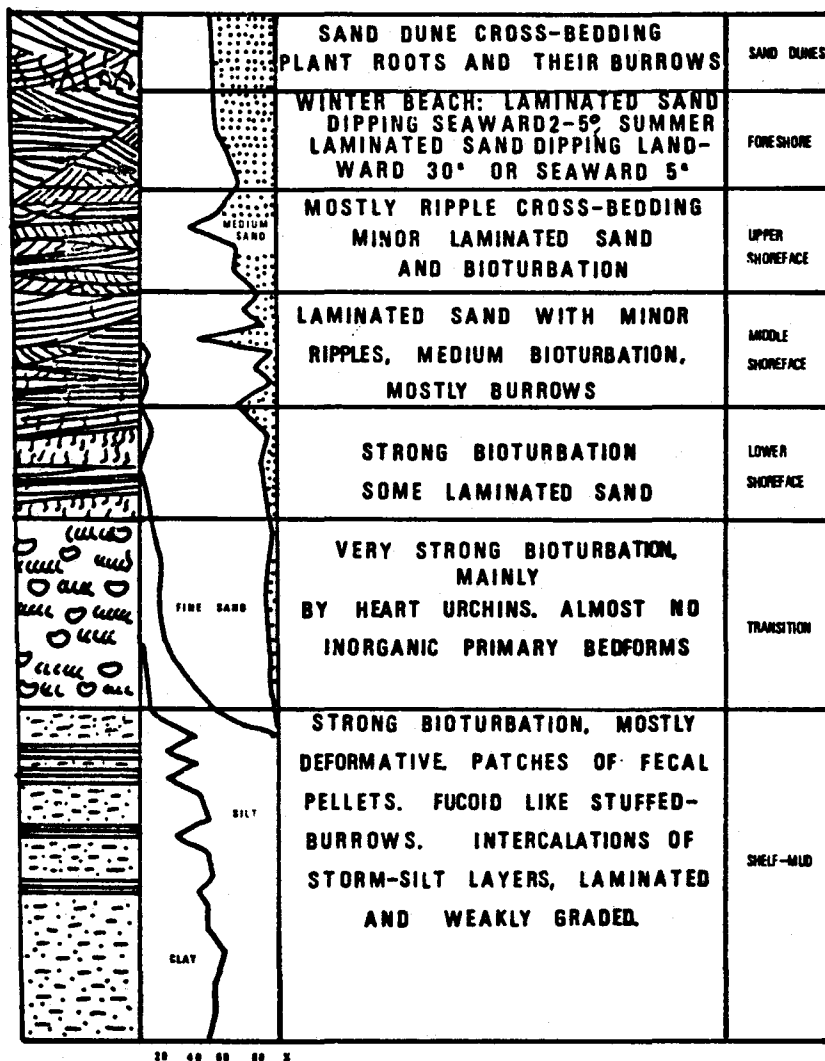


Fig. D-6a.

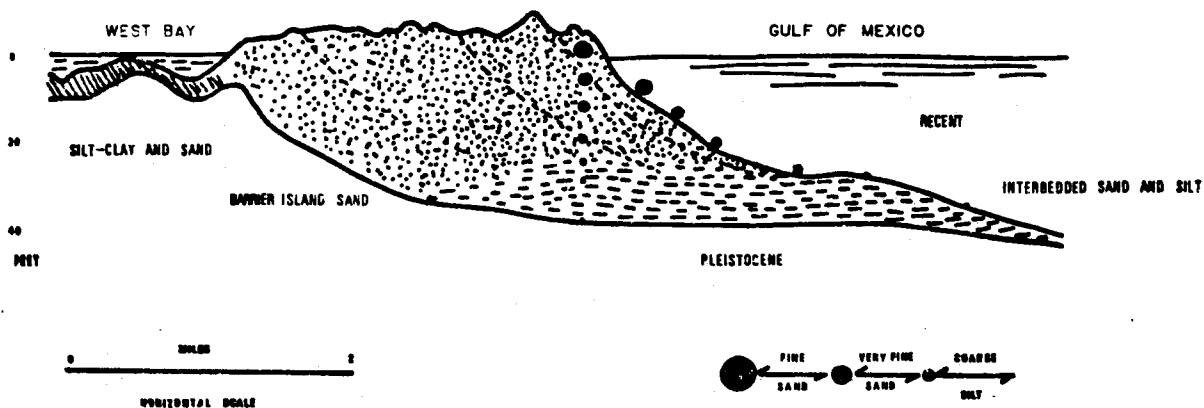


Fig. D-6b.

## Figure D-7. - Shallow Marine Sand Systems

Figure D-7a. - Differing geometric shapes of shallow marine sandstone bars. (After Reineck and Singh, 1975).

Figure D-7b. - Postulated helical flow as one mechanism for formation of shallow marine sand bars. (After Spearing et. al., 1975).

Figure D-7c. - Cross section of a tidal sand bar showing the types of stratification and its orientation. (After Reineck and Singh, 1975).

Figure D-7d. - Vertical sequence of sedimentary structures of an interpreted shallow marine tidal sandstone bar: St. Peter Sandstone. (After Spearing et. al., 1975).

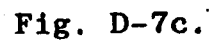
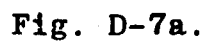
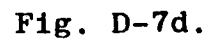


Fig. D-7b.



## APPENDIX E

### Cumulative Permeability Curves for Selected Cores in the Sallyards Field Area

Figure E-1.- Teichgraber #4

Figure E-2.- Crew #21

Figure E-3.- Barrier #34

Figure E-4.- Hendrickson #1

Figure E-1. - Teichgraber #4. Notice that that the ripple forms have lower permeabilities than the large scale cross-beds. Permeabilities of the large scale cross-beds vary from 9.5 to 110 md. This is due to variations in the amount of cement. The very low permeability values (.1) of some of the ripple cross-bedding is due to the high amount of silt in the sample. One other aspect of this core is that the permeability values are highest at the base of the core (Fig. 53) while large scale cross-beds in the middle of the core have lower values and the ripple zones have the lowest values. This supports the idea of a current with decreasing velocity as the depositing agent. The initial dune beds formed under the highest flow velocity conditions. As the point bar built up the depositing currents were of less velocity and the permeabilities are correspondingly lower. Finally, the ripples were formed under currents of low velocities.

Fig. E-1

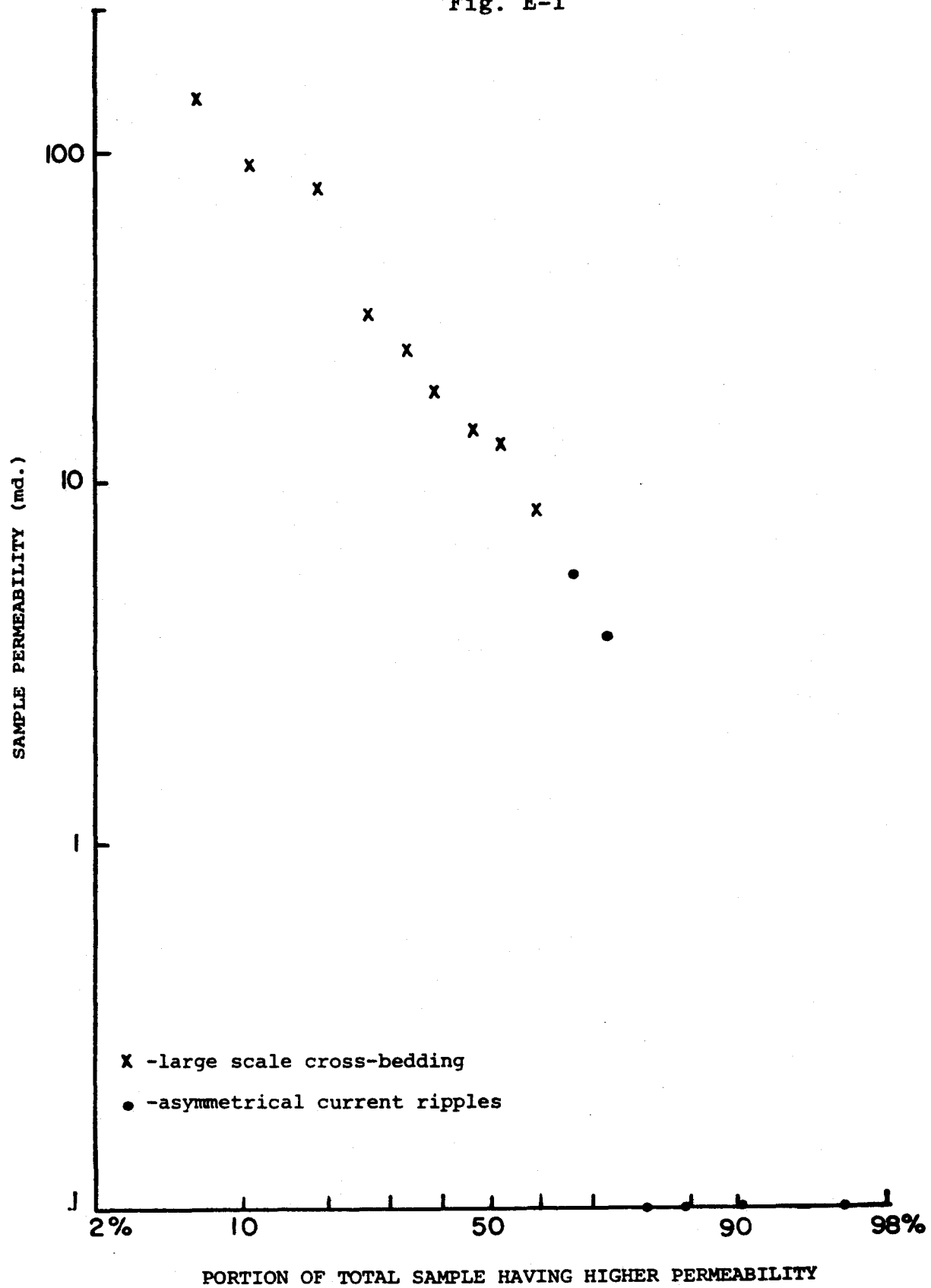


Figure E-2. - Crew #21. This core also shows that large scale cross-bedding is the dominant bed form with permeabilities greater than 10 md. Also permeability variations within both ripples and large scale cross-bedding range up to 20 times. This core overall was deposited under relatively high energy conditions and the variations in permeability depend on the amount of silt present and on the amount of cement.

Fig. E-2

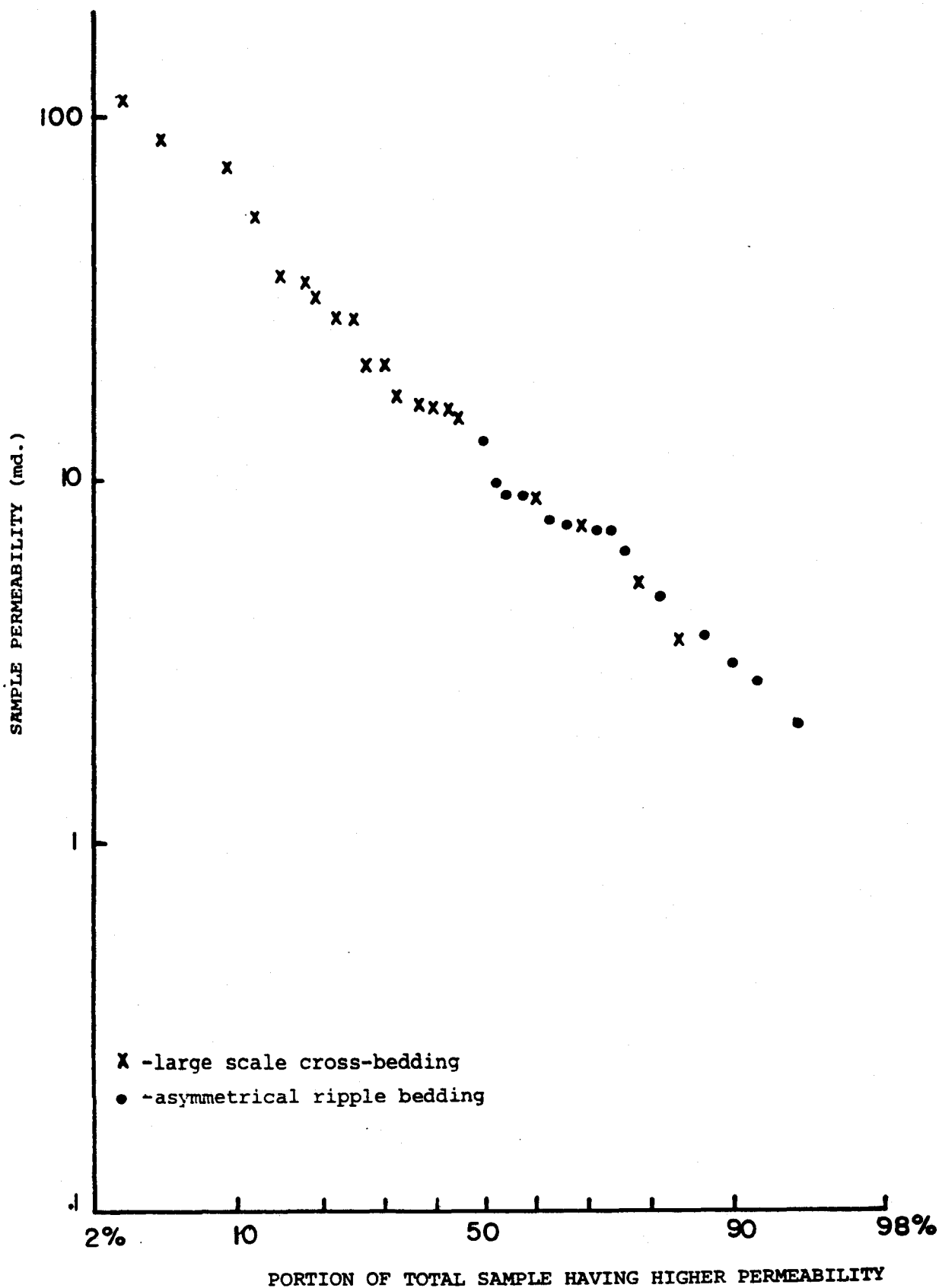


Figure E-3. - Barrier #34. This sandstone was deposited under the highest energy conditions of any of the cores studied. The dominant bed form is large scale cross-bedding. Observations of the core indicated that the large scale cross-beds are outlined with varying amounts of silt laminae. Also, the grain size distribution (Fig. 54) shows that the grain size in large scale cross-beds varies from 8.5 to 11.5 units. The smaller grains were probably deposited under lower energy conditions with larger amounts of silt.

Fig. E-3

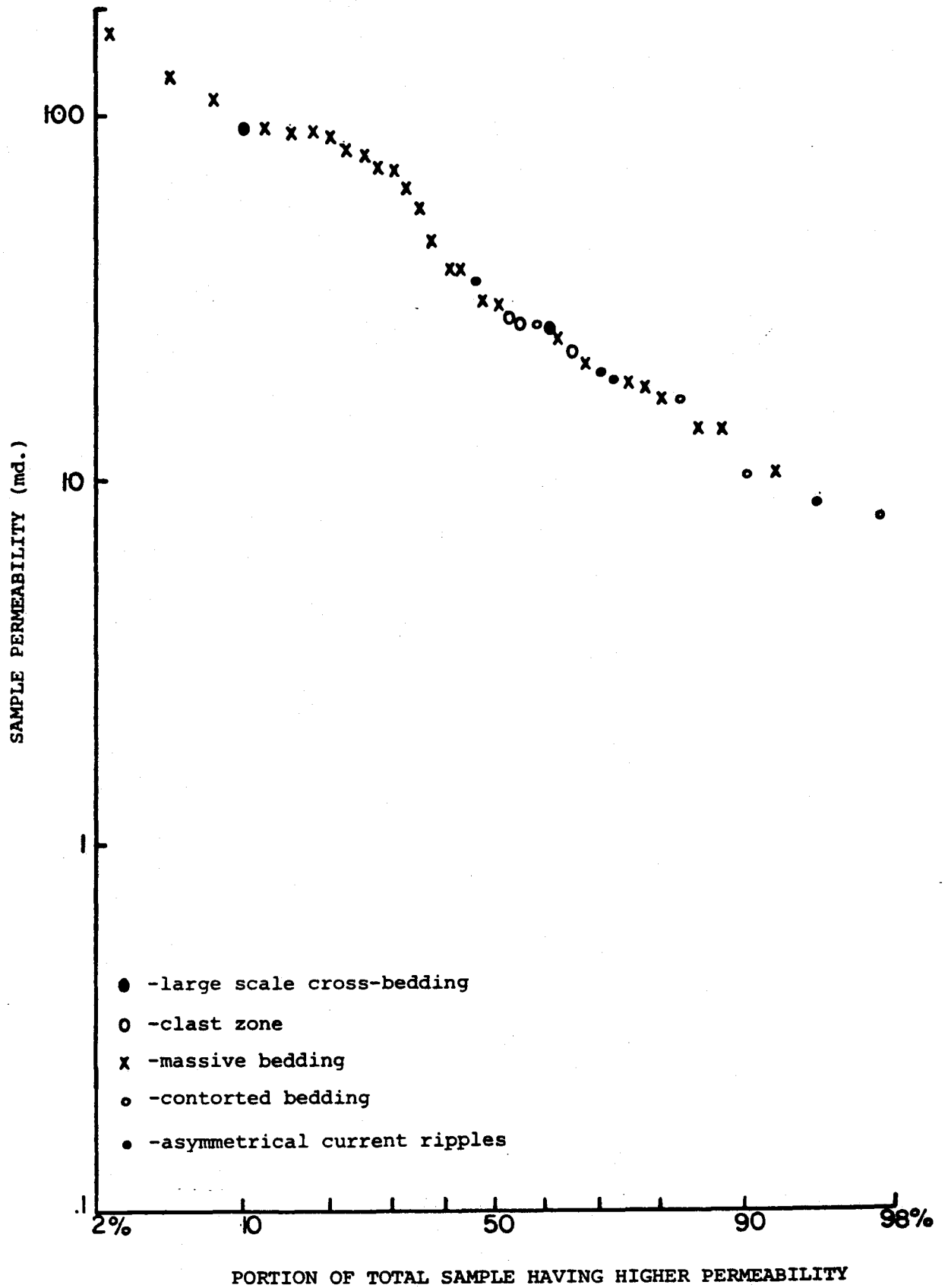


Figure E-4. - Hendrickson #1. This core is ripple dominated. The lower permeability values are due to the high amounts of cement and silt in both the large scale cross-bedding and ripple zones. Many of the ripples have permeabilities under 1 md. and probably act as barriers to flow.

Fig. E-4

