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Petrology and Diagensis of the Lower Mississippian,
Osagean Series, Western Sedgwick Basin, Kansas

by

Mark A. Thomas

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PETROLOGY AND DIAGENESIS OF THE LOWER MISSISSIPPIAN, OSAGEAN SERIES, WESTERN SEDGWICK BASIN, KANSAS

A Thesis

Presented to

the Faculty of the Graduate School

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of the Requirements for the Degree

Master of Arts

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by

Mark A. Thomas

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Dr. Tom Freeman   Thesis Supervisor

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INTRODUCTION

The lower Mississippian Osagean Series of Kansas has been a prolific oil and gas reservoir since its exploitation in the mid-1940's. This study proposes to document the petrography of the Osagean Series and to illuminate controls of hydrocarbon occurrence. The investigation focused on two oil fields producing from Mississippian rocks, Rhodes and Hardtner, which are in extreme southern Barber County, Kansas. These fields are on the western margin of the Sedgwick Basin and off the southern flank of the Pratt Anticline.

In summary, the goals of this study are: (1) to describe the lithology and to interpret the depositional environments of the lower Mississippian Osagean Series rocks, (2) to determine the paragenesis of authigenic minerals, including the genesis of porosity, and (3) to analyze the structure and trapping mechanisms of some typical Mississippian producing, oil fields.

AREAL GEOLOGY

The Sedgwick Basin is a northern shelf-like extension of the Anadarko Basin. Like other pre-Desmoinesian structural elements, the Sedgwick Basin is defined by the subsurface distribution of Mississippian rocks (the Mississippian crops out only in extreme southeastern Kansas) (Fig. 1). The Nemaha Anticline bounds the basin on the east, and the Pratt Anticline and Central Kansas Uplift serve as its western boundaries. An indistinct structural saddle separates the Sedgwick from the Salina Basin to the north, whereas thickening and facies changes occur southward into the Anadarko Basin (Merriam, 1963, p. 182).

In Barber County, an angular unconformity separates the Osagean Series from the Pennsylvanian System, so that progessively younger Mississippian rocks subcrop toward the basin center. Similarly, Paleozoic subcrops are progressively older as one approaches the Pratt Anticline and central Kansas Uplift. Structural strike in the area ranges from N 15° E to N 20° E and dip is 57 ft. per mile to the southeast for the Osagean Series. For the overlying Pennsylvanian Cherokee Formation, strike is N 85° E to N 90° E, and dip is 33 ft. per mile to the south.

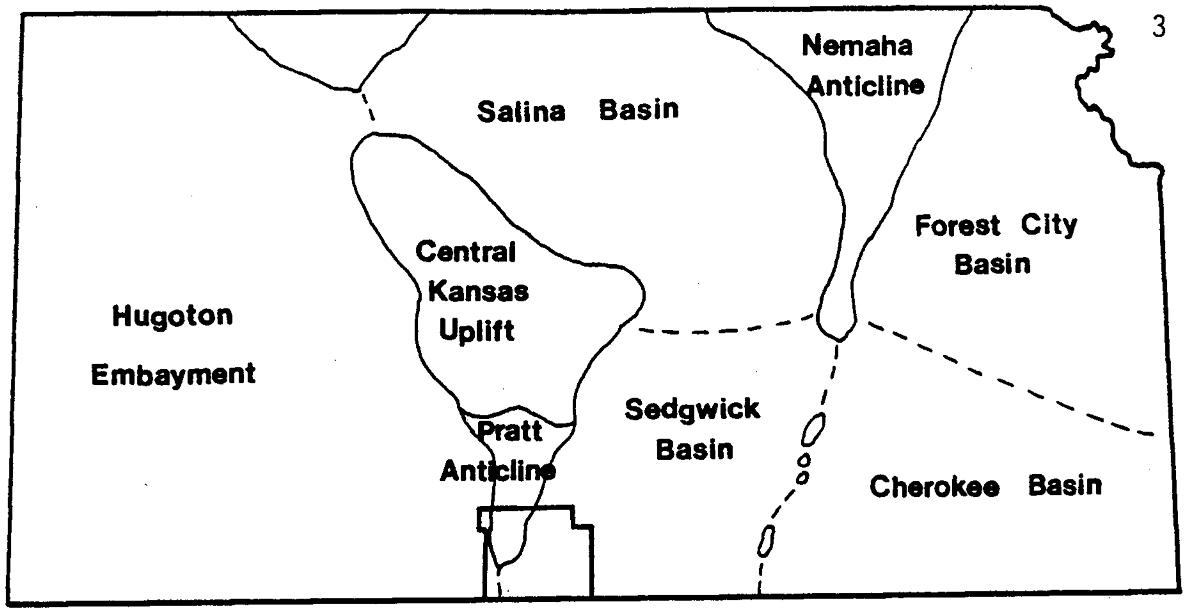


Fig. 1. Major post-Mississippian, pre Desmoinesian structural elements of Kansas (after Merriam, 1963, p. 178).

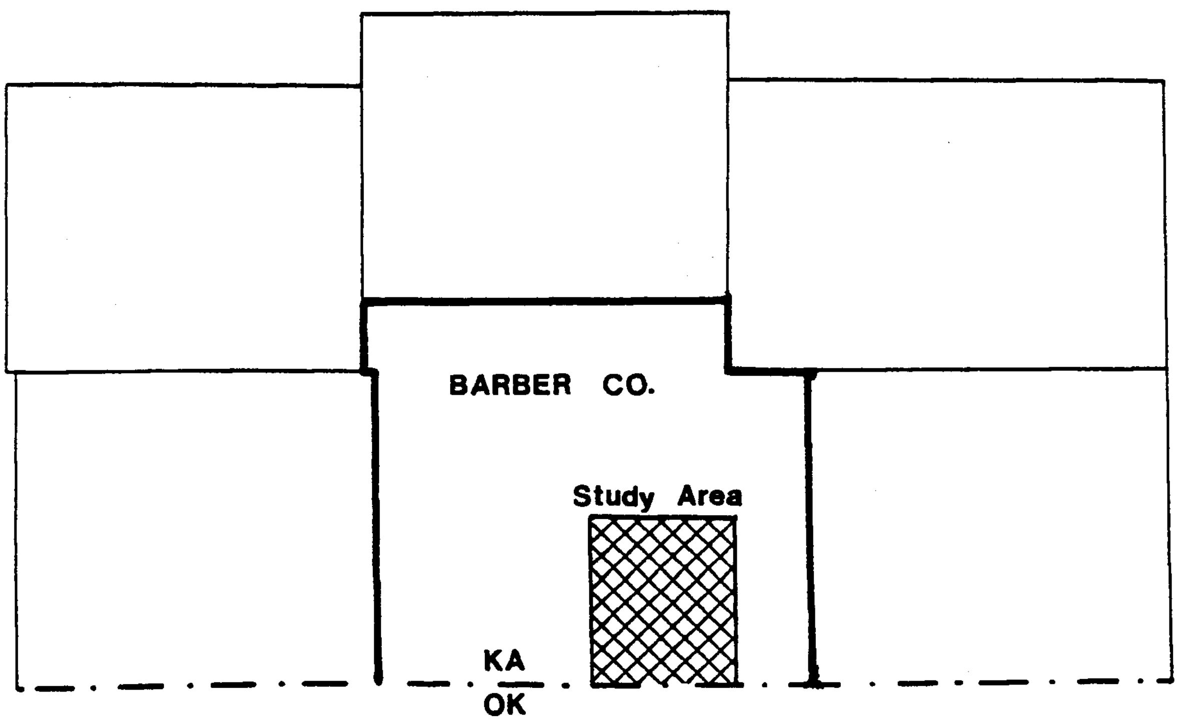


Fig. 2. Location of study area in Barber County.

PETROLEUM GEOLOGY

Oil fields producing from the Osagean Series are typically stratigraphic traps (Clark, 1956, Zajic, 1956, Curtis, 1968, Euwer, 1968, Fernsley and Darmstetter, 1968, and Young, 1968,) with production coming from the top of the Mississippian at the Pennsylvanian (pre-Desmoinesian) unconformity, The producing zone is called the Mississippian "Chat" by oil company geologists. Porosity genesis has been attributed to in situ weathering (Duren, 1960), to reworking of Mississippian rocks, 1966), and to channel deposition in topographic lows (Cruz, 1966). The lithology of the "Chat" is variable and includes limestone, brecciated chert, and tripolitic chert. This is not surprising inasmuch as the low dip of the angular unconformity allows for subcrop of all lithologies within the Osagean Series.

The Rhodes field discovery well is the Barbara Oil Company #1 Page Estate (sw sw sw, 15, T33S, R11W) which was completed November 7, 1949 with an initial potential of 146 barrels of oil per day. Cumulative production, as of December 1980, for the Rhodes field and its extension was 10,324,553 barrels of oil (Paul and Bahnmaier, 1981).

The discovery well for the Hardtner field is the #1 Rathgeber (c ne se, 31, T34S, R12w), which was completed

November 19, 1954 by the Aurora Gasoline Company and the Barbour Drilling Company. As of December 1980, Hardtner field and its extensions have produced 1,859,149 barrels of oil (Paul and Bahnmaier, 1981).

In cases of both the Rhodes field and the Hardtner field, production is limited updip by the the truncation of the porous facies at the unconformity, with Pennsylvanian shales forming the seal. Downdip, production is usually limited by increasing water saturation.

METHODS OF STUDY

The study area was selected on the basis of the availability of Mississippian well cores. Within the following townships: T33S, R11W; T34S, R11W; T35S, R11W; T33S, R12W; T34S, R12W; and T35S, R12W, (Fig. 2) there were eleven, three and a half inch diameter cores cut and stored at the Kansas Geological Survey's facilities in Lawrence, Kansas. The cores were described and sampled for thin-sectioning, and scanning electron microscope specimens were taken at significant changes in lithology. A few cores had been so heavily sampled by previous workers that several inches of core would represent a two to three foot interval.

Thin-sections were examined using a Lietz petrographic microscope. Staining with Alizarin Red-S and impregnation with blue epoxy aided in identifying mineralogy and porosity. One hundred randomly selected points were counted for estimating bulk composition (Appendix 2)

Scanning electron microscope specimens were mounted on aluminum stubs, blown free of dust, and sputter-coated with gold to an approximate thickness of 200 Å. The specimens were examined and photographed using JEOL JSM-S1 and/or JEOL JSM-35 scanning electron microscopes. A Kevex energy dispersive spectrometer was used in conjunction with the JEOL JSM-35 to qualitatively determine elemental composition, where crystal morphology was ambiguous.

Over 180 geophysical well logs and scout tickets were studied, including those from cored wells (Plate 1) (Appendix 1). The laterally focused induction and gamma ray combination seemed best suited for correlating from well to well. Thickness and depth information derived from these logs was used to construct isopach maps, structural contour maps, and cross-sections. To substantiate the correlation of geophysical logs, rotary drill cuttings from five wells in the area were examined (Appendix 1).

STRATIGRAPHY

Introduction

Mississippian rocks in the study area range in age from Kinderhookian, through Osagean, to possible early Meramecian. The subject of this thesis, the Osagean, extends from the base of the Fern Glen Formation, upward through the Burlington Formation to the top of the Keokuk Formation. The Osage Series lies unconformably on the Kinderhook Series, and is truncated above by a Pennsylvanian (Desmoinesian) uncomformity. The lower Meramecian Warsaw Formation locally occurs between the Osage Series and the Pennsylvanian unconformity. The stratigraphic relationship between the Osage and the Warsaw is uncertain, and the assignment of the Warsaw to the Meramec Series is questioned by some.

Nomenclatorial History

The name Osage was first used by Williams (1891, p. 169) to designate a group containing the Burlington and Keokuk Formations in his subdivision of the Mississippian Series in southeastern Iowa. Moore (1928, p. 143) included the Fern Glen at the base and the Warsaw at the top of the Osage in his discussion of the Mississippian. Moore (1928, p. 230) based his classification on the similarity of faunas in the Keokuk and Warsaw Formation.

When Weller and St. Clair (1928) described the geology of Ste. Genevieve County in southeastern Missouri, they too included the Fern Glen at the base of the Osage, but assigned the Warsaw to the lower Meramercian. Although no unconformity was observed at the base of the Warsaw, they believed that the Warsaw was lithologically similar to rocks of the Meramecian Series.

Surface Formation Extended to the Subsurface of Kansas

Lee (1940) used Weller and St. Clair's classification, because of its lithologic emphasis' to differentiate subsurface Mississippian formations by examining cuttings from cable-tool wells. Lee recognized the strictly subsurface occurence of a unit that he had named the Cowley Formation, which he believed had filled a basin eroded into Osagean rock of south-central Kansas. Cowley lithology is characterized by dark silty dolostones, dark dolomitic cherts, and a basal glauconitic zone (Lee, 1940, p. 66).

Clair (1948, p. 9) undertook a similar study of Mississippian well cuttings, and suggested that Lee's Cowley Formation is a basin facies ranging in age from Kinderhookian through early Meramecian. In addition, Clair (1948, p.8) cited the occurence of tripolitic chert (weathered chert) at the top of the undifferentiated Burlington-Keokuk as evidence of a pre-Meramecian unconformity.

Goebel (1966) compared conodont fauna recovered from Mississippian cores with conodont biostratigraphic zones of the type Mississippian in southeastern Iowa. Conodonts from a core of the "Cowley Formation" lithology indicated a late Meramecian age and corroborated Clair's interpretation of the Cowley as a basin facies (Goebel, 1966, p. 102). Yet, in that same paper, Goebel designated the *Bactrognathus* - *Polygnathus communis* Assemblage Zone, a biostratigraphic zone common to both the Burlington and Fern Glen Formation in their type sections, as the boundary between lithostratigraphic units, the Burlington and Keokuk Formation (Goebel, 1966, p. 76).

Clearly, consistency in using lithologic criteria to define lithostratigraphic units must be maintained, but the imprecise nature of rotary cuttings allows for only gross delineation of stratigraphic units. By correlating depositional facies with geophysical log response (admittedly, commonly equivocal themselves), a better understanding of Osagean deposition and stratigraphy should result.

Depositional Model for the Osagean Series

The Burlington shelf model of Lane (1978) is an eloquent synthesis of biostratigraphy and sedimentology regarding early and middle Osagean deposition. Lane describes three

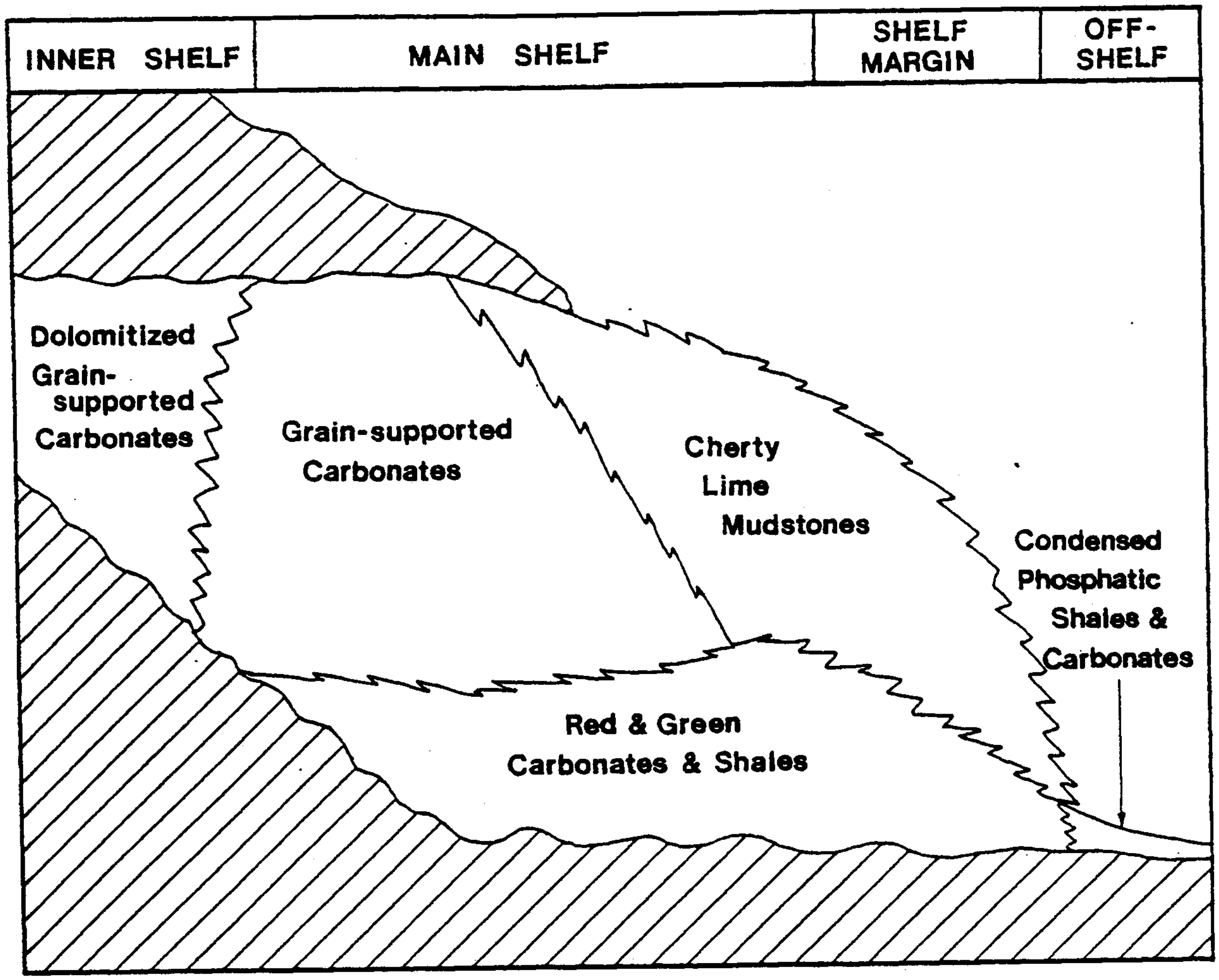


Fig. 3. Burlington shelf model. Schematic cross-section across Missouri into southern Illinois. (after Lane, 1978, p. 171).

onshelf facies and one offshelf facies, whose boundaries approximate those of lithostratigraphic formations of the midcontinent (Fig. 3).

Lane (1978, p. 168) suggested that the shelf trend continues into the subsurface of Kansas. It does appear that lithofacies analogous to certain facies of the Burlington shelf model can be recognized in the study area.

Subsurface Lithofacies of the Osagean Series

Lithofacies are stratigraphic subdivisions reflective of particular depositional environments. Environmental interpretations presented here are based on structural, textural, and compositional features observed in cores and in thin-sections, as well as on comparisons made with lower Mississippian lithofacies described from other areas. Earlier studies especially useful in this regard are those of Wilson (1975), Lane (1978), and King (1980).

Inasmuch as no single core includes the entire Osagean Series, lithofacies must be correlated with geophysical log responses in order to evaluate their lateral and vertical relationships.

Elements of the Burlington shelf facies present in the study area are those of the main shelf and shelf margin. The main shelf facies is subdivisible into the shelf flank facies, which consists of grainstones and wackestones, and the open shelf facies, which consists of cherty lime mudstones.

The shelf margin also contains cherty lime mudstone of the open shelf facies, in addition to the basinward, distal open shelf facies, which is characterized by cherty lime mudstones and cherty shales.

Shelf Flank Facies

The shelf flank facies is approximately equal to the combined Fern Glen and Burlington Formation of Lee (1940) and Goebel (1966). and corresponds to the grain-supported carbonates in figure 3. This facies is analogous to Wilson's (1975, p. 25) deep shelf margin facies and to King's (1980, p. 13) resedimented facies. Although texturally and compositionally similar, the deep shelf margin facies implies a shoreward position at the base of a carbonate platform, whereas the resedimented facies is proximal to carbonate bioherms on the main shelf. Differentiating the two on the basis of present subsurface information is not possible. Lee (1940, p. 51) did suggest that thickness variation in the Fern Glen Formation could be accounted for by bioherms like those described by Laudon (1939, p. 326).

Interbedded lime grainstones and lime mud and/or wackestones are characteristic of the shelf flank facies. The grainstones are light to dark grey, thin bedded (5 cm), and locally graded bedded. The graded bedding is expressed by the upward decrease in size of crinoid fragments, with the uppermost part displaying clay-rich laminations. The basal contact is sharp, and the lower portion contains clasts of the underlying mudstone (Fig. 4a). These structures imply deposition of turbidite-like flows below wave base. King (1980, p. 35) suggested that a carbonate buildup complex could attain topographic relief sufficiently great to serve as a source for these deposits.

Major constituent particles of the grainstones are crinoid and bryozoan debris (Fig. 4b). There are lesser amounts of brachiopods and solitary corals. Endothyrid foraminifers and trilobites are rare. Both chalcedony and syntaxial overgrowths on crinoid fragments occur as primary cements. Where micritic matrix occurs, it is commonly silicified or dolomitized.

The lime mudstones and wackestones occur in thin, graded beds (Fig. 4c). Some clay-rich beds are horizontally burrowed. Crinoids and bryozoans are the most abundant bioclasts. The micritic matrix is locally recrystallized to pseudospar. Here again, silicification and dolomitization have been selective for the matrix (Fig. 4d). Detrital clays are common in some beds.

Judging from point counts of bulk composition (Appendix 2), the shelf flank facies consists of 16% chert or less. Chert in this facies generally is nodular and distributed along bedding planes (King, 1980, p. 29).

Figure 4

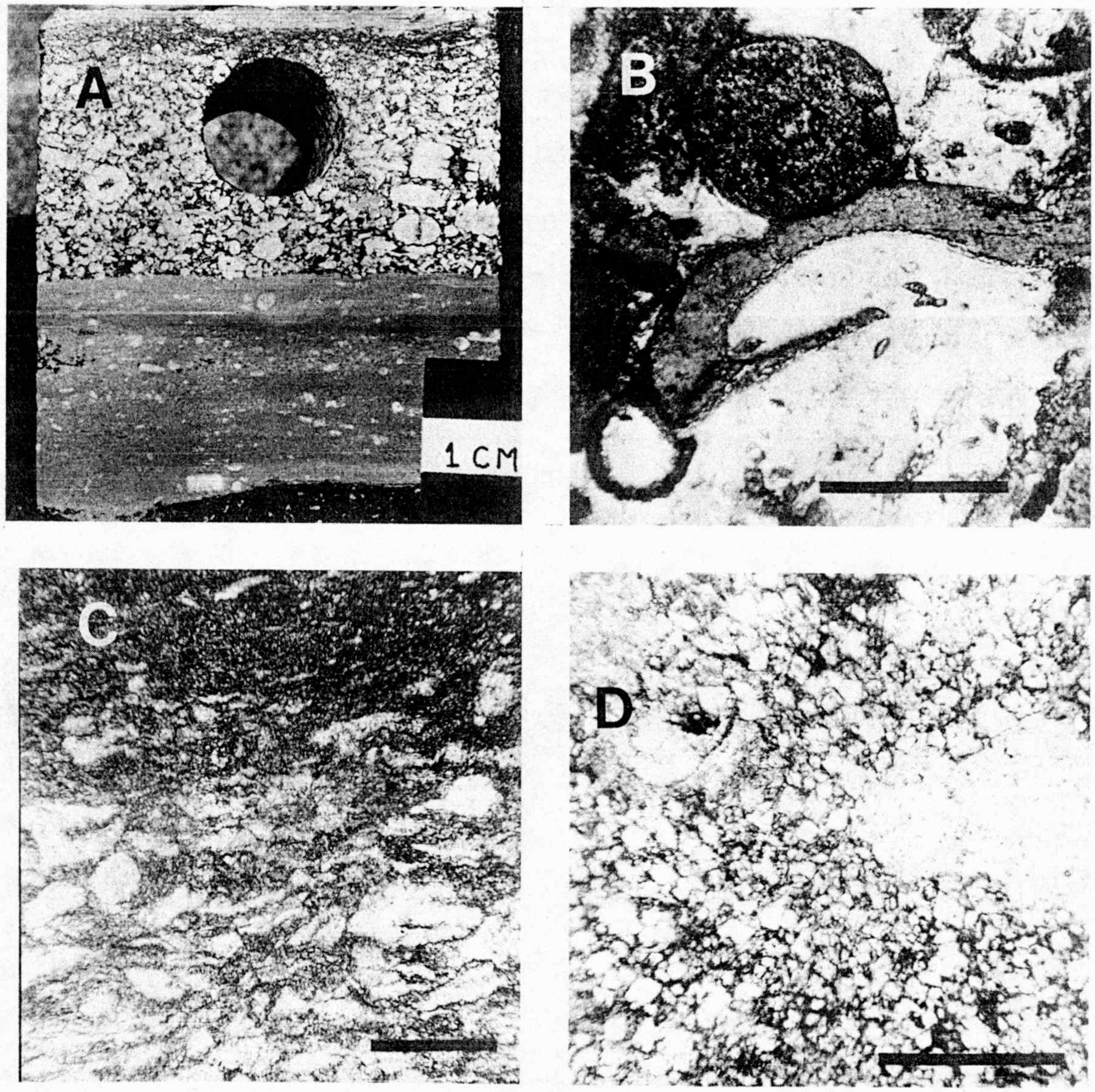
Shelf flank facies

A. Graded bedding (upper half of core), interbedded lime grainstone and lime wackestone/mudstone. Sinclair #10 Newkirk, 4430'.

B. Bioclasts - crinoid, bryozoan, and trilobite debris. Plane light, bar equals 0.20 mm, SC 4562.

C. Micrograded bedding, lime wackestone. Plane light, bar equals 1.0 mm, SC 4551.

D. Selective dolomitization of matrix. Plane light, bar equals 0.20 mm, SN 4426.


A
B
C
D
1 CM

The shelf flank facies, which represents a sub-wave base deposit, consists of carbonate sediment eroded from a local carbonate build-up complex or from a shoreward carbonate platform.

Open Shelf Facies

Cherty lime mudstones of the open shelf facies are approximately equal to the combined Burlington and Keokuk Formations of Lee (1940). This facies is equivalent to the open shelf facies of both Wilson (1975, p. 25) and King (1980, p. 15). Referring to figure 3, the open shelf facies corresponds to the cherty lime mudstone of the main shelf - shelf margin.

The medium to dark brown lime mudstone and local wackestones of the open shelf facies are typically both vertically and horizontally burrowed (Fig. 5a). Recognizable bioclast constituents are broken crinoids, calcitized monaxon sponge spicules, and rare trilobite carapaces. Local lime wackestones have been recrystallized to pseudospar. Detrital quartz silt, 0.050 - 0.25 mm in size, distinguished by straight extinction and monocrystaline habit, occurs in vague laminae where not disrupted by burrowing.

Silicification has been pervasive, but reflects some selectivity for micritic matrix (Fig. 5b). Very few bioclasts and pseudospar patches have been replaced. The bulk composition averages an estimated 50% chert, and ranges from 37%-

100% chert in the open shelf facies. The selective occurrence of chert in this facies has been reported by Wilson (1975, p. 15) and by King (1980, p. 13).

The depositional environment of the open shelf facies was deep marine (below wave base) and characterized by a relatively slow sedimentation rate.

Distal Open Shelf Facies

The distal open shelf facies represents a basinward, shelf margin facies (see Fig. 3). This facies is analogous to Wilson's basin and lower slope deposits (1975, p. 64). The distal open shelf facies is approximately equal to the Cowley Facies of both Clair (1948, p. 9) and Goebel (1966, p. 99).

The distal open shelf is characterized by detrital constituents, with detrital clays exceeding 10% and quartz silt 1%-5% in bulk compsition estimates. Distinctive "sedimentary boudinage" has resulted from dewatering and compaction of clay-rich layers alternating with relatively competent carbonate and chert laminae (Fig. 5c). Monaxon sponge spicules are the most common type of bioclast. These spicules are locally so abundant that they have the "matted chert texture" (Fig. 5d) that Lee cited as typical of his Cowley Formation (1940, p. 73).

The amount of micritic matrix is variable. Associated with greater matrix content are finely broken crinoids

Figure 5

Open shelf - distal open shelf facies

A. Burrowed, cherty lime mudstone. S7 4530.

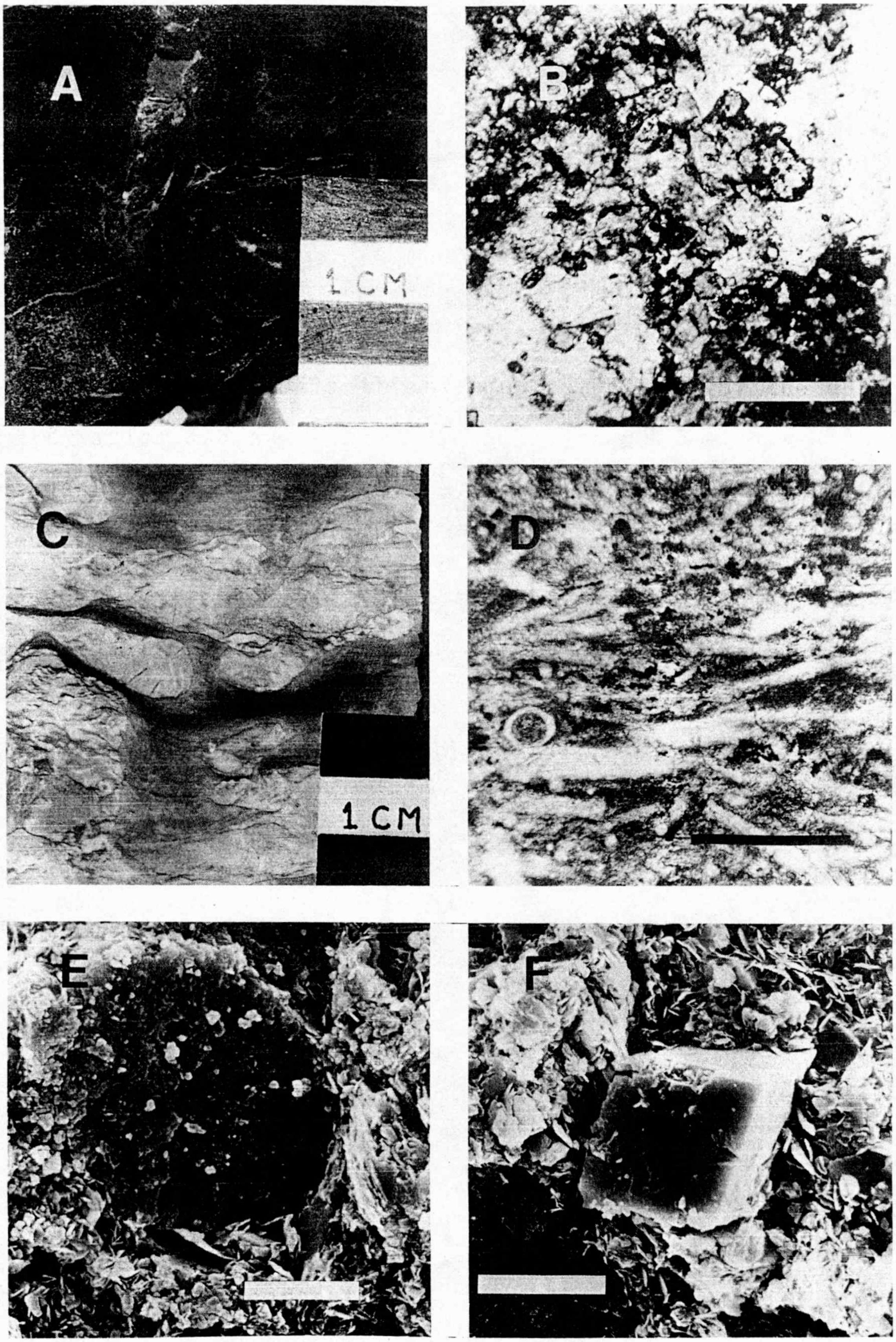
B. Selective silicification of matrix. Plane light, bar equals 0.20 mm, SC 4573.

C. Sedimentary boundinage in cherty shale. CH 4560.

D. Siliceous sponge spicules in detrital clay. Plane light, bar equals 0.20 mm, SO 4841.

E. SEM micrograph, detrital clays deformed around spicules. Bar equals 10 μm, SO 4845.

F. SEM micrograph, dolomite in detrital and authigenic clay matrix. Bar equals 10 μm, SO 4845.


A
1 CM
B
C
1 CM
D
E
F

and other unidentifiable bioclasts. Both dolomitization and silicification have been selective for the matrix. In clay-rich samples, silicification appears to have been coincedent with more spiculitic intervals. Chert percentage in the distal open shelf facies ranges from 15% to 84%, and averages approximately 46%.

Textural similarities among components of the open shelf facies and the distal open shelf facies suggest gradation between the two. Detrital clay is more common in the distal open shelf facies and appears to be the principal difference in constituent particle compositions of the two facies (Fig. 5e,f). Evidence of deeper water as a setting for the distal open shelf facies is the pre-dominance of epifaunal, siliceous biota, e.g. Hexactinellida, and the lack of bioturbation.

Correlation of Lithofacies to Geophysical Log Response

Geophysical logs and cores used in this study date from the mid-1950's. State-of-the-art logging techniques produced combined gamma-ray and laterally-focused resistivity logs. Neither of these log components allows for the quantitative determination of lithology. Gamma-ray logs, which detect radiation emitted by clays, can be used to estimate the argillaceous content ("shaliness") of a formation. Laterally-focused resistivity logs measure the resistivity of a formation, which is controlled by porosity and pore-fluid composition. For example, dense nonporous formations have a high resistivity while porous formations, such as a well sorted sandstone, exhibit low resistivity.

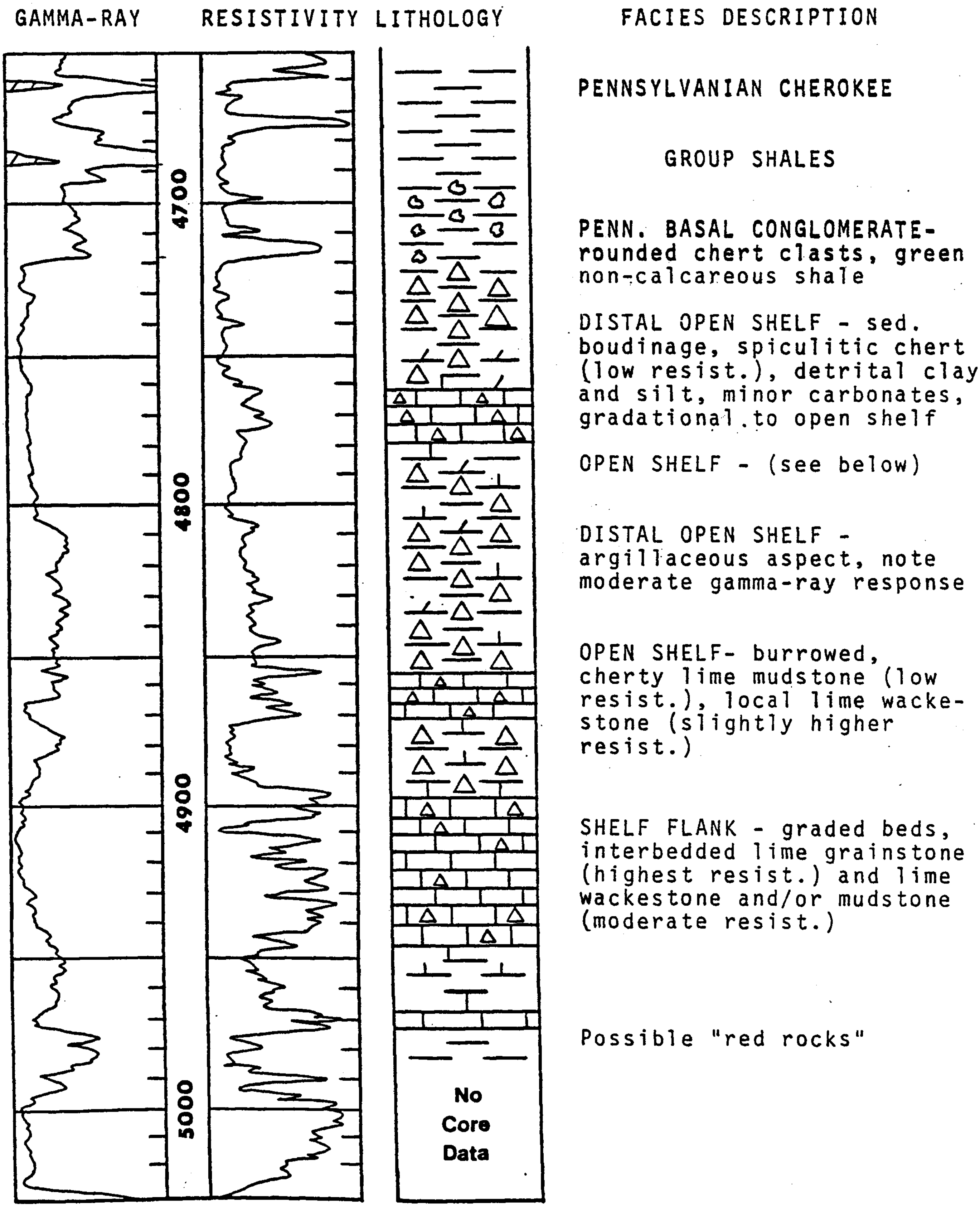
Comparison of cores with geophysical logs allowed for direct matching of lithology with log response (Appendix 3). Some general qualitative conclusions can be made: (1) lime grainstones are nonporous and exhibit high resistivity and moderate to low gamma-ray response; (2) interbedded lime mudstones/wackestones exhibit lower resistivity and a higher gamma-ray response than grainstones; (3) chert-rich lime mudstones exhibit the lowest resistivity and a low gamma-ray response; and (4) shaley chert exhibits a low resistivity, similar to that of the cherty lime mudstones, but the gamma-ray response is commonly higher and varies depending on the amount of clay constituents.

One would expect a typically dense, nonporous rock like chert to have a high resistivity, yet chert-rich rocks exhibit low resistivities. This can be explained in two ways. First, competent chert-rich rocks may deform brittly during compaction, relative to the more ductile deformation of adjacent shales and limestones. Fractures would permit circulation of fluids that tend to lower formation resistivity. Second, chert-rich rocks may have intergranular porosity, which is certainly true of rocks that subcrop beneath the Pennsylvanian unconformity.

Duren (1960) examined the petrophysical aspects of Mississippian tripolitic chert from Kiowa County, Kansas. He concluded that the extremely low resistivities exhibited by the chert resulted from high porosity (26% to 51%) and high water saturations.

Figure 6 illustrates a composite stratigraphic section of the Osagean Series. Geophysical log-core lithology relationships, as established in appendix 3, were employed to discriminate lithofacies. The type well, the KBW Oil Property Management #1 McCracken, was not cored, but is used here because it demonstrates the usual vertical variation in lithofacies. An attempt was made to correlate these lithofacies with rotary cuttings from the #1 McCracken well, but no reliable distinctions were possible. However, pinkish red grainstone was observed in cuttings from both the #1 McCracken and the Sinclair #1 Olsson from a stratigraphic position below that of the shelf flank facies. These red grainstones may be similar to Lee's (1940, p. 49), St. Joe Member of the Fern Glen, King's (1980, p. 22), mud build up core facies and/or Lane's red and green argillaceous limestones of the main shelf - shelf margin (1978, p. 170). No cores penetrate this interval, therefore one can only speculate as to whether or not these "red rocks" represent a carbonate mud mound facies in the study area.

Fig. 6. Composite stratigraphic section of the Osagean Series. Lithology versus geophysical log response. Type well KBW Oil Property Management, #1 McCracken.



Summary of Osagean Deposition

The petrology and sedimentary structures observed in cores of Osagean rocks indicate lithofacial elements of Lane's Burlington shelf model (1978) and imply subsurface extension of the Burlington shelf into south-central Kansas. Discernable lithofacies are those of the shelf flank, the open shelf, and the distal open shelf. These facies represent a deep marine (below wave base) main shelf - shelf margin deposits, with local sources of coarse-grained carbonate sediment. The vertical succession of open shelf and distal open shelf facies overlying shelf flank facies suggests an Osagean transgression. Lane reported evidence of such a transgression as it occurs in outcrops near St. Louis, Missouri (1978, p. 172). Stratigraphic cross-section D to D' (Plate 8) illustrates the facies changes that occur eastward into the Sedgwick Basin. Thinning of the shelf flank facies supports a shelf margin setting for the Osagean rocks in the study area.

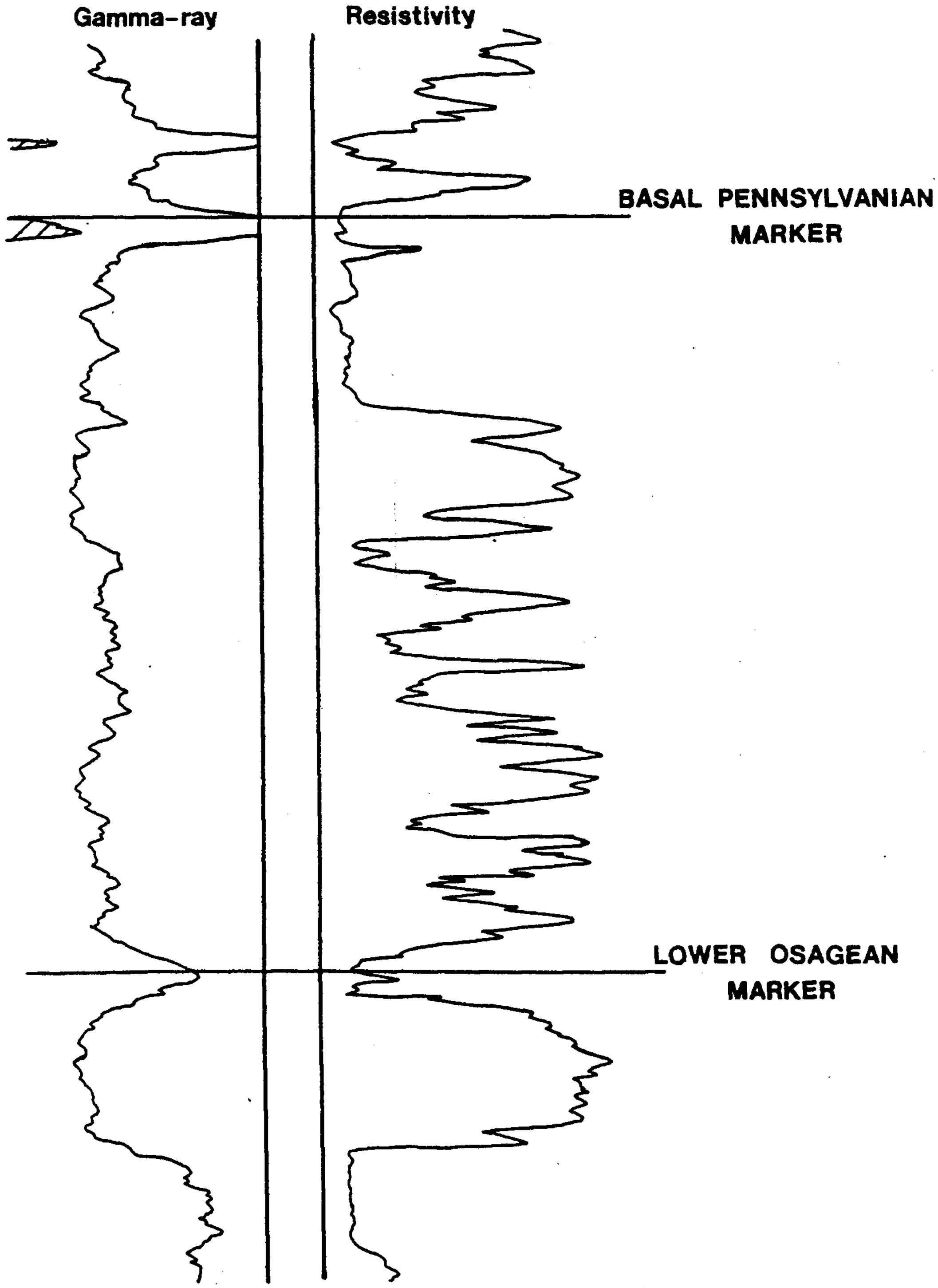
STRUCTURAL GEOLOGY

To determine whether or not geologic structures control hydrocarbon production in the area of report, a series of cross-sections, structural contour maps, and isopach maps was constructed. Precise identification of the Pennsylvanian unconformity on geophysical logs is difficult, because both the uppermost Mississippian and the lowermost Pennsylvanian are variable. A thin, persistant, radioactive shale that marks the base of the Desmoinesian Cherokee Group was used to approximate the base of the Pennsylvanian (Fig. 7). A structural contour map of this marker reduces apparent erosional relief on the top of the Mississippian (this is attributed to the basal Pennsylvanian conglomerate filling topographic lows), but such a map does serve to illustrate any post-Desmoinesian deformation.

The structural contour of the basal Pennsylvanian marker map (Plate 2) illustrates a uniform, monoclinal surface with an inclination of 33 feet per mile. A comparison of this map with the distribution of production (Plate 1) shows that no major post-Desmoinesian structures have influenced Osagean production.

An exception to the uniform, monoclinal surface is a triangular depression in the northwest corner of township T34S, R12W. Its shape suggests a solution-

Figure 7. Expression of principle stratgraphic markers on geophysical log.



collapse feature, yet two lineaments extend beyond the immediate area of the depression. Most likely this a fault-related feature that has been enlarged by solution of associated carbonate rocks. Geophysical logs reveal a thickness of the basal Pennsylvanian conglomerate in excess of 60 feet within the "downthrown" block, indicating that locally high relief influenced deposition.

Because the Pennsylvanian shale marker is so thin and persistent, it is assumed to be essentially isochronous throughout the study area. It therefore serves as a datum for assessing the magnitude of pre-Pennsylvanian structural features. A second important stratigraphic marker is a thin interval of limestone within a radioactive shale section above the base of the Osagean Series. Where this limestone is absent the top of the enclosing shale is used in its place (Fig. 7).

The horizontal datum for cross-section A-A' (Plate 3) is the basal Pennsylvanian marker. Plotting of the lower Osagean marker, relative to this datum, reveals a subtle anticline that has been truncated by the Pennsylvanian unconformity.

A structural contour map of the lower Osagean marker (Plate 4), and an isopach map of the interval between the basal Pennsylvanian marker and the lower Osagean marker, were constructed in an effort to assess the magnitude and orientation of post-Osagean, pre-Desmoinesian structures.

Assuming that the basal Pennsylvanian marker was deposited on an essentially horizontal surface, thinning of a subjacent interval is believed to reflect pre-Pennsylvanian structural highs. The isopach map (Plate 5) indicates a series of southwest plunging, anticlinal noses, one of which is coincident with Rhodes Field. The Osagean Series also thins northward (up dip) where it is locally truncated.

Although anticlinal noses are less apparent on the lower Osagean structural contour map (Plate 4), there is general agreement with the isopach map. For example, lower Osagean rocks dip steeply on the southeastern flank of the anticline coincident with Rhodes Field, but less steeply on the northwestern limb, which suggests folding either preceding or concomitant with regional tilting.

Plates 4 and 5 offer supportive evidence of the occurrence of fault and/or solution features in the northwestern part of township T34S, R12W. The lower Osagean marker is deeper and the interval isopach is thicker in the area of the "downthrown" block.

The trend of anticlinal structures, approximately N 40° E, agrees with Merriam's (1963) compilation of orientation of post-Mississippian, pre-Desmoinesian structural elements. Merriam stated that:

> "smaller structures superimposed on these uplifts (Nemaha Anticline and Central Kansas Uplift) or adjacent to them are either parallel or prependicular to the larger structures".

The trend of structures in the study area is subparallel to, and probably genetically related to, the Pratt Anticline.

Structural cross-section B - B' (Plate 6) and C - C' (Plate 7) indicate that hydrocarbons are not restricted to structural highs as one would expect from an anticline-related oil field. Comparison of Plate 1 with Plate 5 shows that many productive Mississippian wells are not coincident with structures.

Generally, the productive zone is at or near the top of the Osagean Series, just beneath the Pennsylvanian unconformity. This suggests that Pennsylvanian shales serve as seals for stratigraphic traps and that porosity development might have been related to Carboniferous near-surface processes. Whatever the process of porosity development, it was only locally effective, as indicated by the patchy occurrence of hydrocarbons.

The correlation between lithofacies and porosity is demonstrated on cross-section B - B' (Plate 6). The southernmost well produces from a chert-rich facies, probably open shelf in origin, just beneath the Pennsylvanian unconformity. Below the producing interval is a high resistivity zone, which probably marks lime wackestones and/or grainstones of the open shelf facies or possibly of the shelf flank facies. Below this limestone facies is another chert-rich zone of the open shelf facies.

Northward, the upper cherty open shelf facies is truncated so that the limestone facies abuts the unconformity, yet production at this point is from the still lower cherty facies, rather than from the higher subcropping limestone. This lower cherty facies continues to be productive updip, to a point where it too is truncated by the unconformity. In the northernmost dry well the still deeper shelf flank facies subcrops beneath the unconformity.

In an effort to recognize this Mississippian limestone and to substantiate correlation of it, rotary cuttings were examined, but were less than definitive. However, light colored grainstones with fresh chert, are believed to represent the Osagean limestone in cross-section B - B'. Mikkelson (1966), in studies of tripolitic chert in northern Oklahoma, proposed a model where local Pennsylvanian limestones were deposited on structural (topographic) highs above the weathered chert zone. However, Pennsylvanian limestones are typically dark, micritic, and chert free, in contrast with Mississippian limestones described above.

Porosity development appears to have been selective for chert-rich facies, either open shelf or distal open shelf in origin. This distribution of porosity can be ascribed to brittle deformation of chert-rich facies relative to that of the adjacent limestones and shales. The resulting fractures and high permeabilities would enhance surface water circulation, weathering, and porosity development. The occurrence of Rhodes Field over an anticline may reflect this relationship of intense fracturing, thereby localizing porosity and accounting for hydrocarbon occurrence.

Variation in depositional facies within the Osagean Series explains the difficulty in prospecting for chert-rich facies along depositional strike. Lateral changes to a more argillaceous facies, such as that within the distal open shelf facies, may be critical for the entrapment of hydrocarbons.

To summarize, structural analysis of the study area indicates that (1) Osagean production is principally from stratigraphic traps, (2) hydrocarbon production is associated with chert-rich facies where they subcrop beneath the Pennsylvanian unconformity (suggesting that porosity within the chert facies was produced by near-surface processes), and (3) structural deformation might account for fractures that led to pervasive porosity development.

DIAGENESIS OF THE OSAGEAN SERIES

Diagenesis is the physical and chemical changes in sediments that occur following deposition. Regarding the Osagean Series, these changes have been produced by (1) burial by younger Mississippian rocks (Meramecian and probably Chesterian), (2) exposure to surface weathering, and (3) subsequent burial to at least 4,500 feet. In this study special attention has been given to diagenesis as it relates to the development of porosity, and inasmuch as chert-rich facies appear to correlate with porosity, specific attention has been given to the process of silicification. Diagenetic interpretations are based on the study of cores and petrographic thin-sections, and on scanning electron microscope (SEM) examination of selected specimens.

Silicification

Keller (1978), in his report on tripolitic chert from Seneca, Missouri, questioned whether the parent rock was a siliceous limestone or whether it was a calcareous chert. Perhaps a more pertinent question is whether the chert developed as discreet nodules or whether silicification was pervasive. Both of these processes appear to have occurred in the Osagean Series of Kansas.

Nodular chert occurs in all three Osagean lithofacies, but it is rare in the open shelf facies. Chert in the shelf flank facies is like nodules described by McQuillan (1979) from the Burlington Formation near Columbia, Missouri. That is, the nodules are elliptical, with their long axis parallel to bedding, and they are concentrated along bedding planes within the finer-grained facies. McQuillan concluded that silicification occurred before lithification of the host sediment and that the elliptical shape of nodules is a primary developmental feature, rather than a product of compaction.

Chert in the distal open shelf facies also appears to be nodular (Fig. 5C), but here the nodular shape might reflect silicification of sedimentary boudins. The original morphology of the chert cannot be determined from the available information.

Nodular chert is rare in the open shelf facies, but a more pervasive variety of silica, which is selective for the micritic matrix, occurs here. The texture of burrowed lime mudstones is unaltered, so products of silicification are not obvious (Fig. 5a).

Silica Paragenesis

Even though the mode of silicification of Osagean rocks was varied, mesoscopic and microscopic evidence suggests that silicification was predominantly early.

McQuillan's study (1979) provided criteria for distinquishing early silicification, although his criteria are not equally applicable to all depositional facies; grain size is a limiting factor.

Mesoscopic Evidence

Even though core data are spacially restricted, it seems clear that silicification was not related to major faults and other structural features. The occurrence, in the Pennsylvanian basal conglomerate, of chert clasts suggestive of Osagean lithology indicate that silicification was pre-Desmoinesian. The association of chert with certain lithofacies suggests an origin linked to depositional environment. Wilson (1972, p. 26), and King (1980, p. 13) also recognized that silicification can be facies dependent, but this correlation might only reflect a selectivity for finer (more reactant?) grained carbonate sediments.

Namy (1974) documented unconformity related silicification in the Pennsylvanian Marble Falls Group of central Texas. The bulk of Osagean Series silicification is not associated with the Pennsylvanian unconformity, although undoubtably some redistribution of silica occurred under surface weathering conditions. Two observations refute the silicified unconformity model as it might apply here. First, assuming that the matching of geophysical log response and core lithology is valid, subcropping chert-rich lithofacies can be traced to depths where surface-related silicification should be ineffective. Second, only nodular chert was observed where shelf flank facies subcrop. Namy reported that silica associated with the Marble Falls unconformity occurred as a 1 to 2 centimeter crust, with partial silicification of oncolites and pore space below that (Namy, 1974, p. 1263). No such crusts occur in cores from the study area.

The temporal relationship of silicification to compaction could be evaluated best in the distal open shelf facies, where sedimentary boudinage structures are prevalent. Flowage of argilloceous sediments around more competent chert boudins reflects early lithification of the boudins. The occurrence of local calcareous boudins allows for the possibility of this chert having been a post-compaction replacement of calcite.

Microscopic Evidence

Discrimination of quartz textures facilitates the determination of silica paragenesis. Three quartz textures occur in the Osagean Series: microquartz, chalcedony, and megaquartz. The textural terminology applied is that described by Folk and Weaver (1952) and by Wilson (1966). Microquartz is nonclastic, with interlocking equant crystals 1-4 microns in size, and is commonly a replacement fabric (Folk and Weaver, 1952, p. 506; Wilson, 1966, p. 1036; and

McQuillan, 1979, p. 9). In Osagean rocks the occurrence of calcite inclusions in microquartz and of relict skeletal grains and dolomite rhombs (Fig. 8a-e) indicate the microquartz is a replacement product.

Chalcedony, which occurs as botryoids of radiating fibers, is most usually a pore filling precipitate (Folk and Weaver, 1952, p. 506; Wilson, 1966, p. 1038; McQuillan, 1979, p. 16). Megaquartz consists of interlocking equant crystals generally greater than 20 microns in width. McQuillan (1979, p. 16) reported that megaquartz in the Burlington Limestone is a pore-fill cement that developed after chalcedony cement.

Pore-fill chalcedony fabrics, which are best observed in lime grainstones, coat skeletal grains and are followed by a younger generation of mosaic megaquartz cement (Fig. 9a, b). Neither the chalcedony nor the megaquartz contain calcite inclusions or skeletal "ghosts". Megaquartz also occurs as a cement druse that is succeeded by mosaic megaquartz (Fig. 9c). Pore-fill fabrics are only locally developed in the cherty lime mudstones and in argillaceous carbonates. Figure 9d shows chalcedony cement in a detrital clay-rich distal open shelf facies.

Samples from 4,900 feet in the Gulf #13 Newkirk well exhibit features believed to be the result of the recrystallization of chalcedony to microquartz. A precursor chalcedony cement is suggested by the following: (1)

Figure 8

Replacement Features

A. "Ghost" of siliceous spicule in chert. Plane light, bar equals 0.04 mm, SO 4818.

B. Microquartz, note larger crystal size of replaced skeletal grains and recrystallized spicules. Crossed polars, bar equals 0.04 mm, SO 4818.

C. "Ghost" of dolomite rhomb. Plane light, bar equals 0.01 mm, CH 4532.

D. Same field of view as 8c, microquartz replacement of dolomite. Crossed polars, bar equals 0.01 mm, CH 4532.

E. SEM micrograph of silicified dolomite rhomb, note larger crystal size preserving original fabric. This coarser microquartz also occurs in recrystallized siliceous spicules and in replaced skeletal grains. Bar equals 10.0 μm, SO 4818.

F. Calcitized sponge spicule (q - microquartz, c - calcite). Plane light, bar equals 0.015 mm, SC 4573.

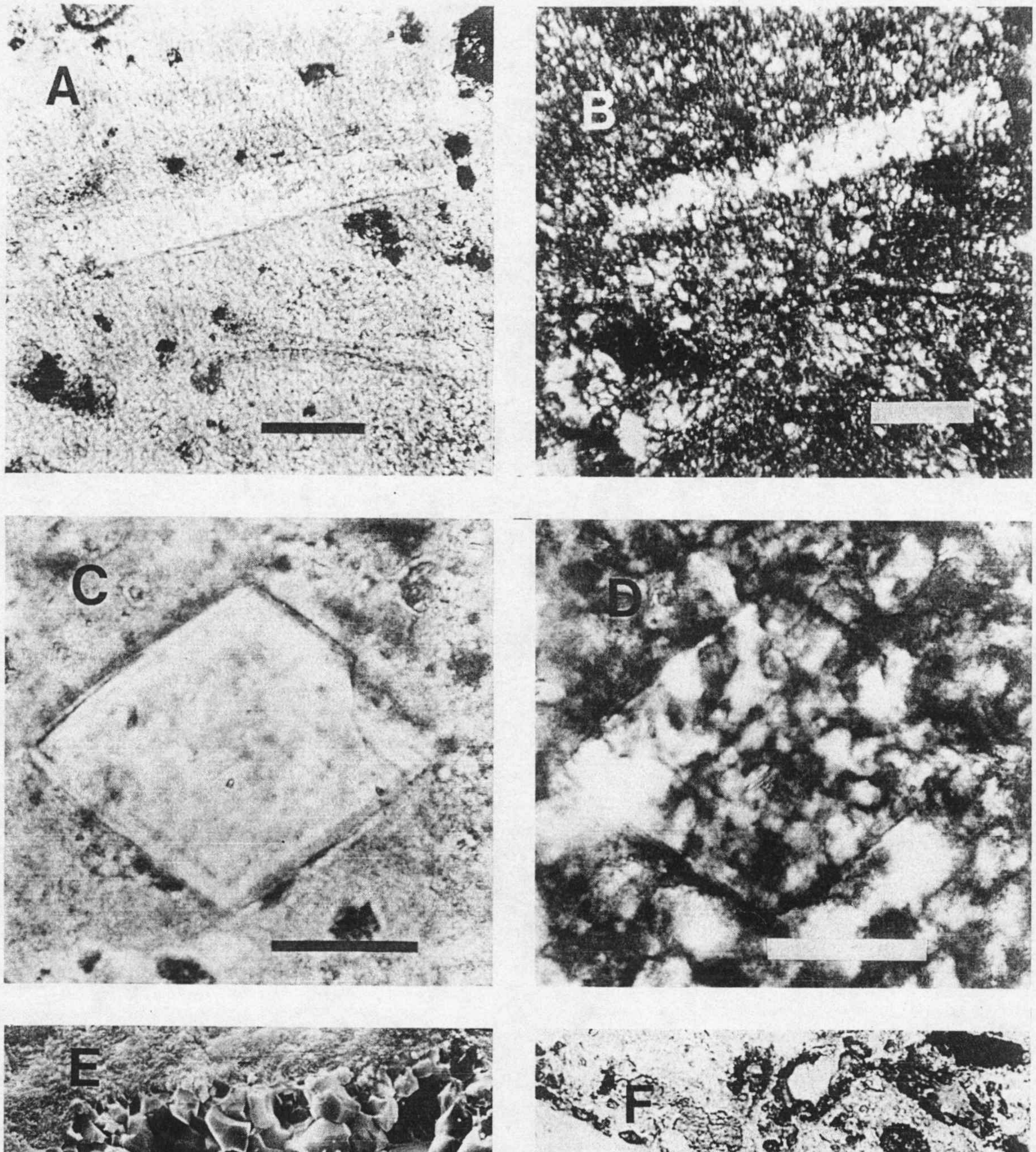

A
B
C
D
E
F
C

Figure 9

Chalcedony cements

A. Chalcedony botryoids on skeletal grains and subsequent megaquartz. Plane light, bar equals 0.04 mm, SN 4415.

B. Higher magnification of 9a, megaquartz (m) after chalcedony (c). Crossed polars, bar equals 0.01 mm, SN 4415.

C. Megaquartz pore-fill and geopedal micrite. Crossed polars, bar equals 0.04 mm, SC 4562.

D. Chalcedony in distal open shelf facies sample. Plane light, bar equals 0.003 mm, CH 4597.

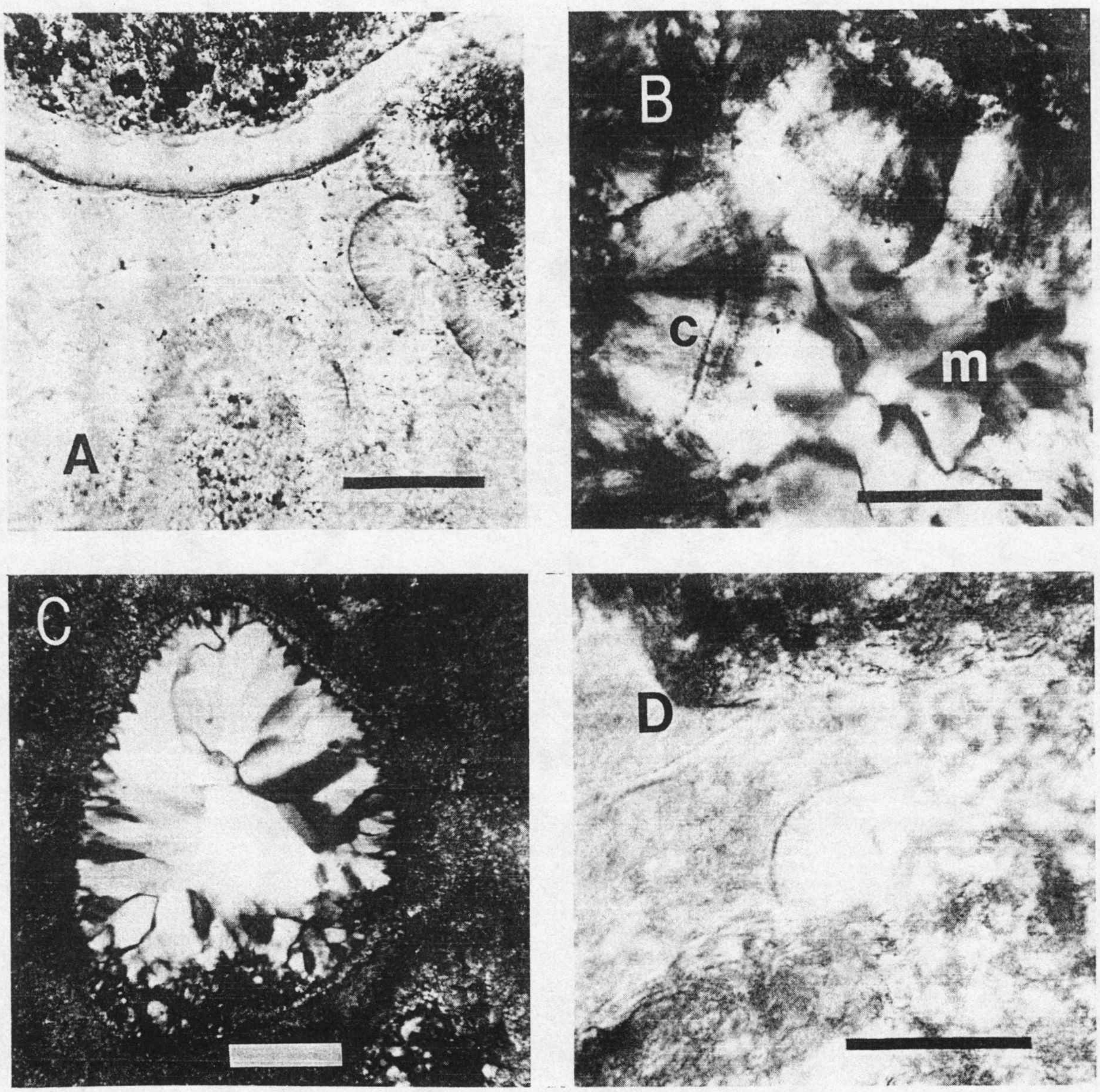

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Figure 10

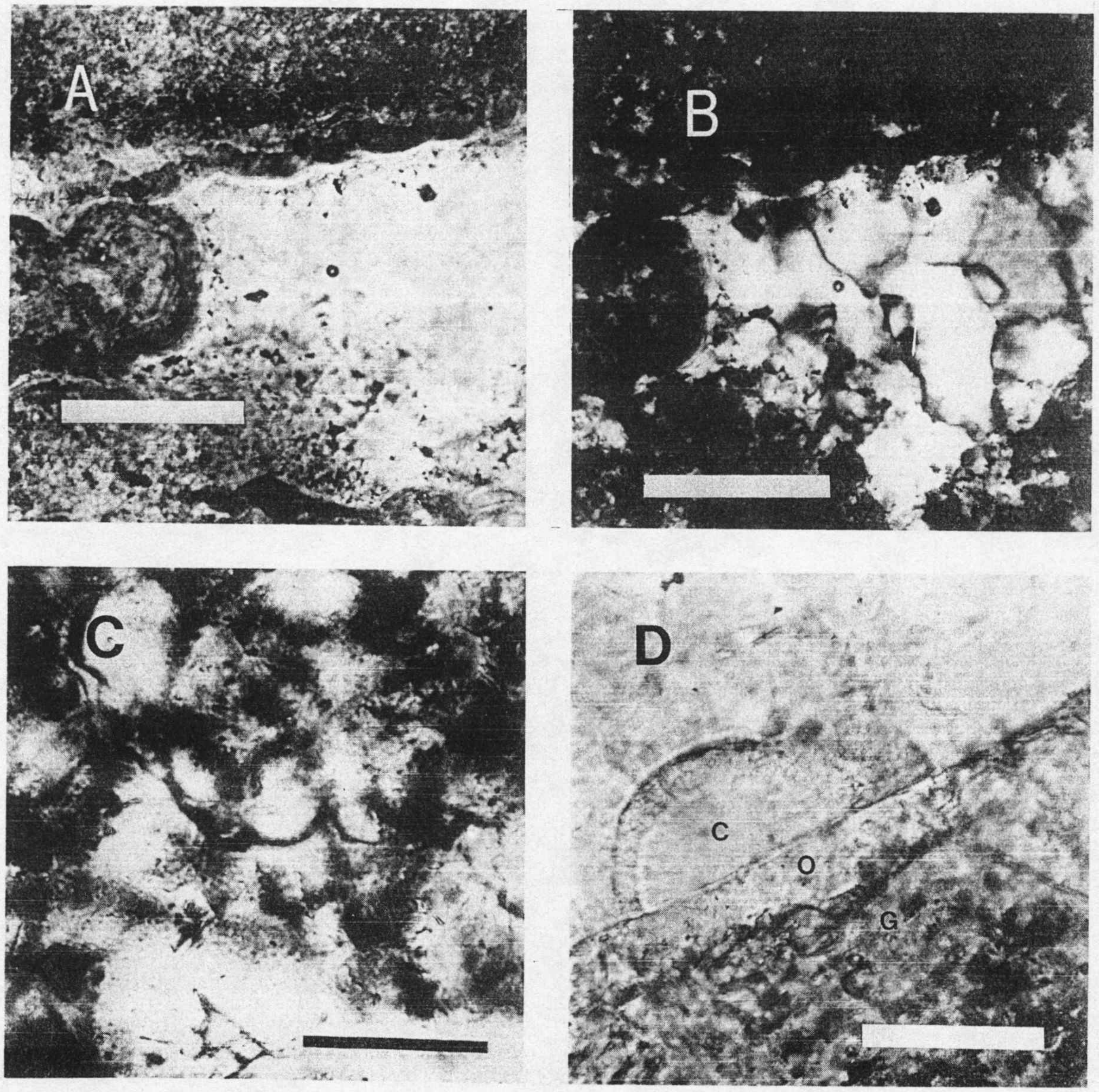
Recrystallized chalcedony

A. Chalcedony botryoids. Plane light, bar equals 0.01 mm, GN 4490.

B. Figure 10a crossed polars, megaquartz after chalcedony. Bar equals 0.01 mm, GN 4490.

C. Undulose extinction of botryoids. Crossed polars, bar equals 0.003 mm, GN 4490.

D. Chalcedony cement on syntaxial calcite overgrowth (c-chalcedony, O-overgrowth, G-skeletal grain). Plane light, bar equals 0.01 mm, SN 4415.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skeletal-grain substrates, (2) botryoidal ghosts, and (3) a post "chalcedony" generation of mosaic megaquartz (Fig. 10a, b). These botyroids exhibit undulose extinction typical of microquartz, rather than the sweeping extinction of chalcedony fibers (Fig. 10c).

The temporal relationship of silicification to calcite cementation is variable. At any one place, the apparent relationship depends on the position relative to the site of silica nucleation. McQuillan (1979) described chert diagenesis as it is recorded from the center of chert nodules to their margins. Some grainstones of this study display chalcedony that has developed directly on crinoid grains (Fig. 9a), which indicates that the chalcedony was the primary intergranular cement. Other grains exhibit chalcedony cement that has grown on syntaxial overgrowths on crinoid grains, which indicates that the chalcedony post-dates some calcite cementation (Fig. 10d). Some micrite recrystallization preceded silicification as indicated by local pseudospar patches that occur as residual calcite in microquartz (Fig. 5b).

Dolomite is locally abundant in lime mudstones, wackestones, and argillaceous lime mudstones. Evidence regarding the temporal relationship between dolomitization and silicification is inconclusive. Dolomite rhombs "floating" in chert reflect differing degrees of silification, ranging from unaltered rhombs, through partially silicified rhombs with remnant dolomite, to totally replaced rhombs (Fig. 8c-e). Generally, where silicification has been most prevasive, dolomite has been replaced. Still, the possibility of post-silicification dolomitization cannot be ruled out. Dedolomite (revealed by staining with Alizarin Red-S) is rare. Locally, dedolomite appears to be associated with fractures and high porosity, suggesting that the invasion of meteoric water during near-surface exposure supplied Ca^{++} ions for calcitization.

Other authigenic minerals are chlorite, kaolinite, and halite. Chlorite occurs as coatings on skeletal grains that formed simultaneous with silicification (Fig. 11a-c). Kaolinite lines some secondary pores indicating a late origin (Fig. 11d). Halite, which is also a pore-fill mineral, was precipitated when the connate brines (254, 946 milligrams/liter total dissolved solids) evaporated during storage at the Kansas Geological Survey (Fig. 11e).

To summarize, silicification was primarily early; that is, pre-lithification in origin. Dolomitization, for the most part, appears to have preceded silicification. The occurrence of both silica and calcite intergranular cements suggests that silicification and calcite cementation were coeval. Chlorite formed simultaneous with silicification. Porosity development was post-silicification, and kaolinite precipitation was later still.

Figure 11

Authigenic clays and halite

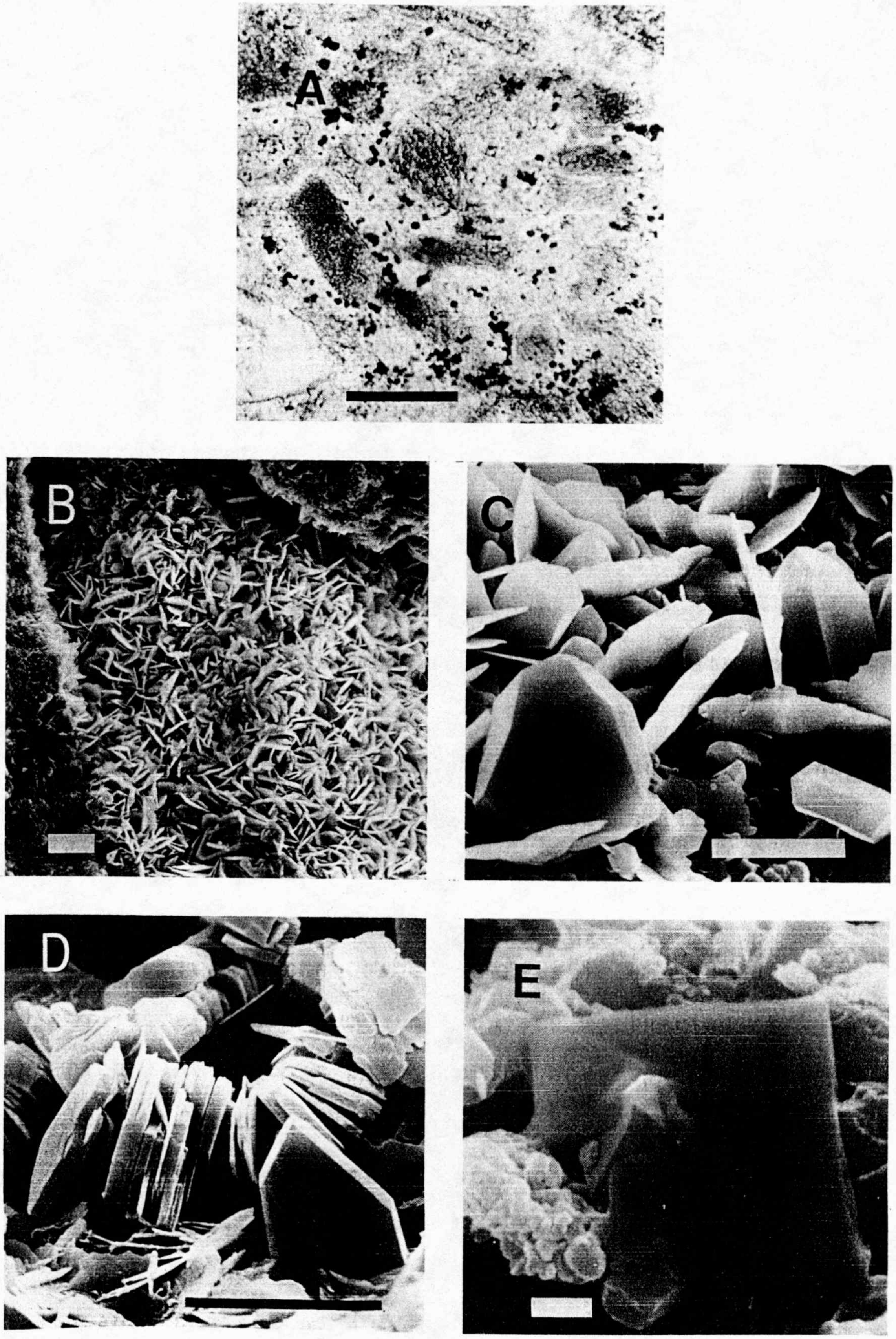
A. Chlorite coating skeletal grains. Plane light, bar equals 0.04 mm, GN 4490.

B. SEM micrograph, chlorite coating skeletal grain. Bar equals 4.0 µm, GN 4490.

C. SEM micrograph, intergrown quartz and chlorite. Bar equals 5.0 µm, GN 4490.

D. SEM micrograph, kaolinite on chlorite and quartz. Bar equals 5.0 µm, GN 4490.

E. SEM micrograph, halite on quartz. Bar equals 1.0 µm, S7 4526.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Silica Source

The simplest and most probable silica source is the dissolution of biogenic silica from sponge spicules. Chert-rich rocks contain numerous ghosts of sponge spicules, whereas the host limestone is apparently barren of spicules. This spicule-deficient aureole may be similar to the silica deficient aureoles that Chilingar (1956) described from limestone adjacent to chert nodules in the Joana Limestone. The occurrence of calcitized sponge spicules attests to their dissolution (Wilson, 1966, p. 1046; Wilson, 1975, p. 414). Calcitization of spicules appears to be a "solid-to-solid" replacement process, as indicated by the lack of void-fill calcite cement (Fig. 8f). In the distal open shelf facies, where detrital constituents are abundant, quartz silt might have been an additional silica source.

Porosity Genesis

Porosity in the Osagean Series is of secondary origin. It resulted from near-surface weathering of chert-rich limestones exposed during development of the Pennsylvanian unconformity. The weathered chert, such as that near Seneca, Missouri, has commonly been described as "tripolitic chert" because it resembles chert that occurs near Tripoli in north Africa. Ore-grade tripoli contains no calcite and consists of a more or less friable mass of quartz. Lamar (1953) in his report on tripoli in southern Illinois, concluded that those deposits were the residue after leaching of carbonate minerals from siliceous Devonian limestones.

In south-central Kansas the relationship between porous zones and the Pennsylvanian unconformity is apparent from cores (Appendix 3). Generally, porosity is greatest at the top of the Osagean Series and decreases downward to a point where porous rock grades, apparently abruptly, into nonporous parent rock. This transition has not been observed within a single core sample, probably because cores tend to break at such lithic contacts.

Secondary porosity types can generally be characterized as either fracture porosity, fabric selective (moldic) solution porosity, and non-fabric selective solution porosity. Porosity types are varied within the study area and within individual cores. Determinants of porosity type are the parent rock lithology (i.e., subcropping lithofacies) and the degree of dissolution of the lithofacies.

The Sinclair #1 Olsson well exhibits porosity that developed in a distal open shelf facies that subcrops below the Pennsylvanian unconformity. This facies consists of spiculitic cherts, detrital clays, and minor carbonate constituents such as dolomite. Fracturing resulted in porosity that was later enhanced by solution along the fractures. The close fit among angular chert clasts indicates that they are not detrital in origin (Fig. 12a). Fabric-controlled porosity is most common at clast margins (Fig. 12b, 14a). The matrix among clasts contains clay, small chert clasts, and finely fragmented chert. Higher in the core (closer to the unconformity) dissolution has been so extensive that chert clasts grade imperceptively into matrix, and the petrographic distribution of porosity is obscured. A decrease in porosity with depth suggests that infiltration of meteoric waters in the vadose zone was probably responsible for porosity development. Still, no corroborative evidence of a vadose zone environment, such as pendant or meniscus cements, is evident.

There is inconclusive evidence as to what type of minerals were dissolved to generate the porosity. Clearly, dolomoldic chert reflects the dissolution of dolomite (Fig. 12c). Spicule-moldic porosity suggests dissolution of siliceous sponge spicules. Perhaps silica dissolution was selective for the smaller crystal size (the microquartz) of silicified skeletal grains. The enlargement of secondary pores also suggests that some silica dissolution occurred.

However, quartz solution features were not observed with the scanning electron microscope. Euhedral quartz occurs at present pore boundaries, but this could have resulted from the partial replacement of carbonate with euhedral quartz, followed by dissolution of the residual

Figure 12

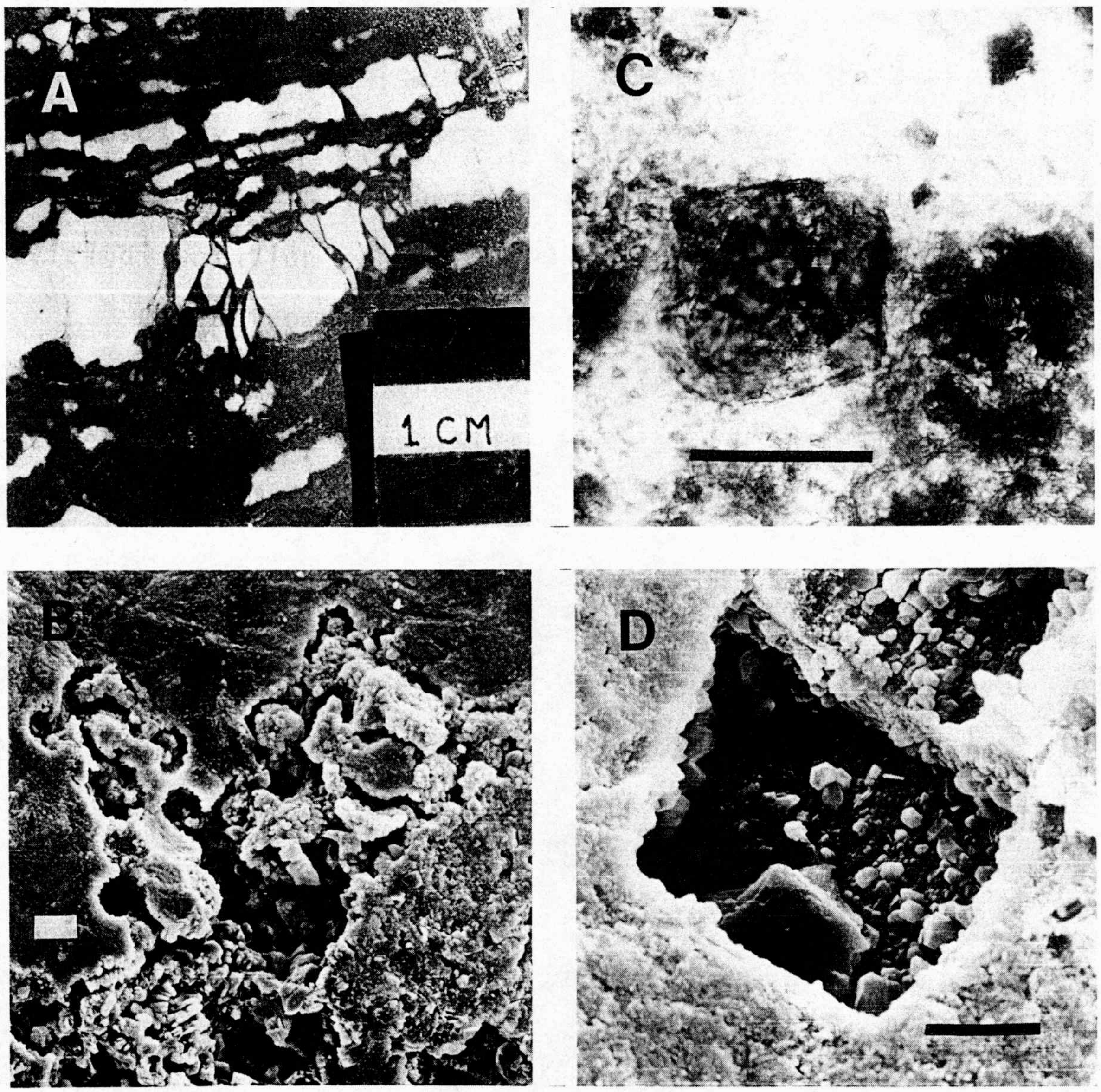
Porosity-Distal Open Shelf Facies

A. *In situ* porosity development in fractured chert, note embayed fragment margins, SO 4818.

B. SEM micrograph, fabric selective porosity at chert fragment margin. Bar equals 20.0 μm, SO 4818.

C. Dolomoldic porosity, dark areas - blue stained epoxy. Plane light, bar equals, 0.01 mm, SO 4818.

D. SEM micrograph of dolomold, note euhedral microquartz that lines present pore. Bar equals 10.0 μm, SO 4818.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carbonate (Fig. 12d). No pore-filling fabrics, such as that of chalcedony or drusy megaquartz, were observed in thin-section. Moreover, it is difficult to explain the dissolution of silica with water that has equilibrated with atmospheric CO_2. Therefore, the simplest explanation is that porosity resulted from the dissolution of residual carbonate minerals in chert, although the possibility of silica dissolution can not be dismissed.

Cores from the Gulf #13 Newkirk exhibit porosity within a subcropping open shelf facies. Lithologically this facies consists of cherty lime mudstones. The degree of silicification differs within this core, but generally silicification has been selective for the micritic matrix rather than for coarsely crystalline skeletal grains and pseudospar. Locally the core is fractured, but fracture porosity was not observed in thin-section. Almost pure chert occurs within the upper few feet of this core. Here an unusual porosity distribution occurs: The larger pores are clearly skelmoldic, but impregnated blue epoxy also follows boundaries of chalcedony botryoids (Fig. 14b). The moldic porosity is apparent in standard SEM specimens (Fig. 13a), but porous botryoid zones are not evident. A pore cast of this sample did contain botryoid-like structures (Fig. 13b), as well as casts of skeletal grains (Fig. 13c). This evidence suggests that the apparent botryodial porosity is real and that it is not an artifact of thin-section preparation.

Lower in the core, where silicification was less thorough, the type of porosity is different. Coarsely crystalline calcite, which occurs as "islands" within microquartz, has been only slightly affected by silicification and porosity development (Fig. 13d, 13e). The calcite is not poikilotopic cement inasmuch as it does not contain microquartz inclusions. Porosity is locally skelmoldic (Fig. 14c), whereas elsewhere its development appears to have been independent of fabric (Fig. 15a, b). The distribution of residual micritic matrix and calcitized sponge spicules appears to have controlled porosity genesis and pore morphology. Figure 13f shows a partially leached calcitized spicule.

Core from the Gulf #13 Newkirk does not display a systematic vertical variation in porosity, so solution by infiltration processes does not seem to apply here. If fracturing controlled fluid migration and local dissolution, then inhomogeneity in porosity distribution reflects inhomogeneity in fracturing. Ultimately, fracturing was controlled by lithology; that is, cherty rock deformed brittlely relative to less siliceous limestones and shales. For example, a chert-deficient horizon (approximately 7% chert) at 4,500 feet has low porosity (Appendix 2). Even

Figure 13

Porosity-Open Shelf Facies

A. SEM micrograph of skelmoldic porosity. Bar equals 50 µm, GN 4490.

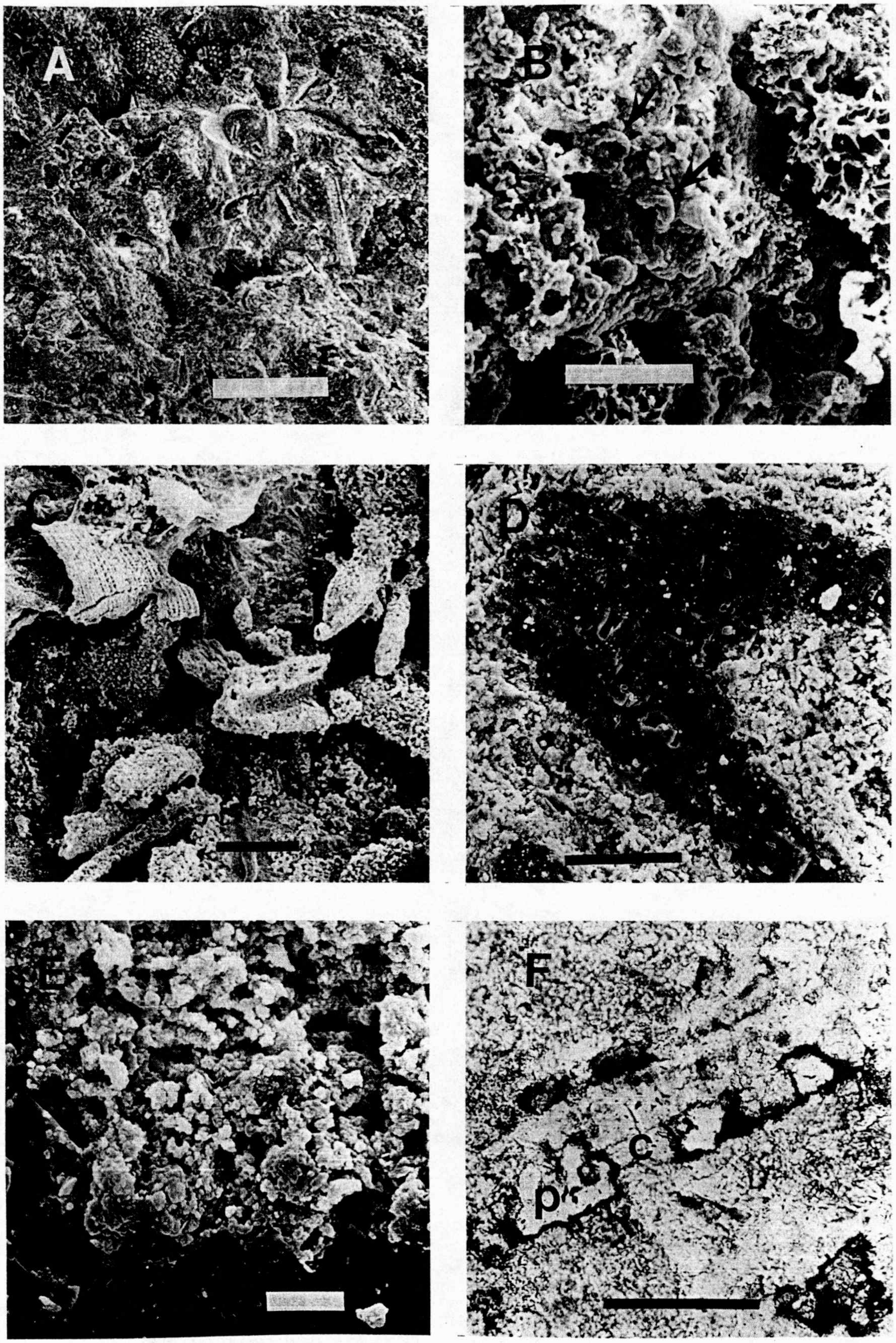
B. SEM micrograph of casts of botryoidal pores (arrows), honeycomb structures are casts of euhedral quartz. Bar equals 100 µm, GN 4490.

C. SEM micrograph of casts of skelmoldic pores. Bar equals 100 µm, BN 4490.

D. SEM micrograph of coarsely crystalline calcite (possibly a crinoid fragment) in tripolitic chert matrix. Bar equals 50 µm, S7 4526.

E. A portion of Figure 13d, porosity resulted from dissolution of residual micritic matrix. Coarse calcite was largely unaffected by silicification or dissolution. Bar equals 10 µm, S7 4526.

F. Partially leached calcitized spicule, oil lines pores (p-porosity, c-calcite). Plane light, bar equals 0.01 mm, S7 4534.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p
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Figure 14

Fabric Selective Porosity

A. Porosity, indicated by dark blue epoxy, outlines sponge spicules. Also note dolomoldic pores. Plane light, bar equals 0.50 mm, SO 4818.

B. Porosity (dark blue) traces chalcedony-like botryoids. This suggests silica dissolution unless a generation of carbonate cement was present. Yellow - megaquartz and microquartz (q), orange brown - chlorite coating skeletal grains (c). Plane light, bar equals 0.04 mm, GN 4490.

C. Spicule-moldic porosity (blue), both transverse and longitudinal sections. Plane light, bar equals 0.01 mm, GN 4490.

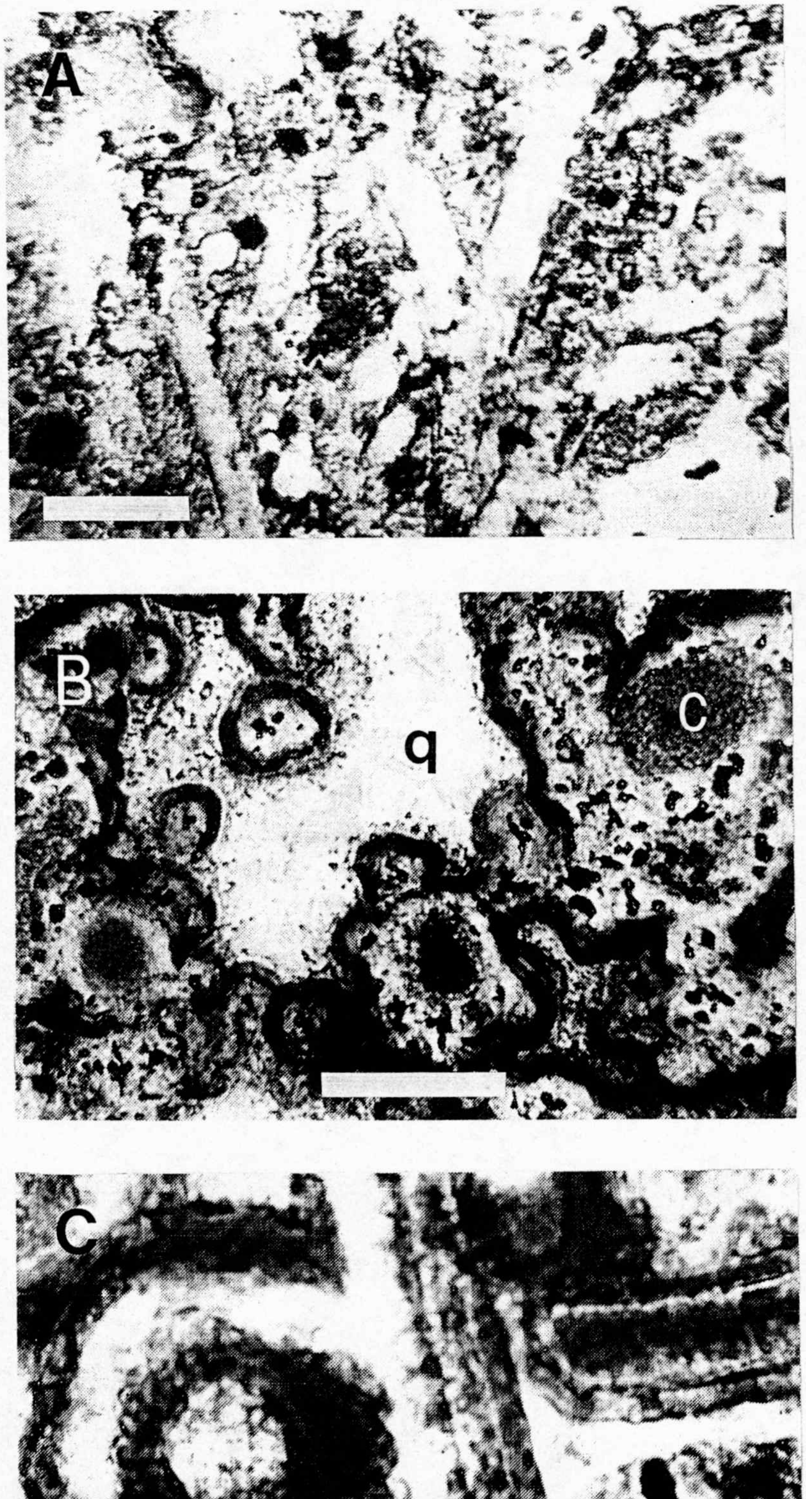
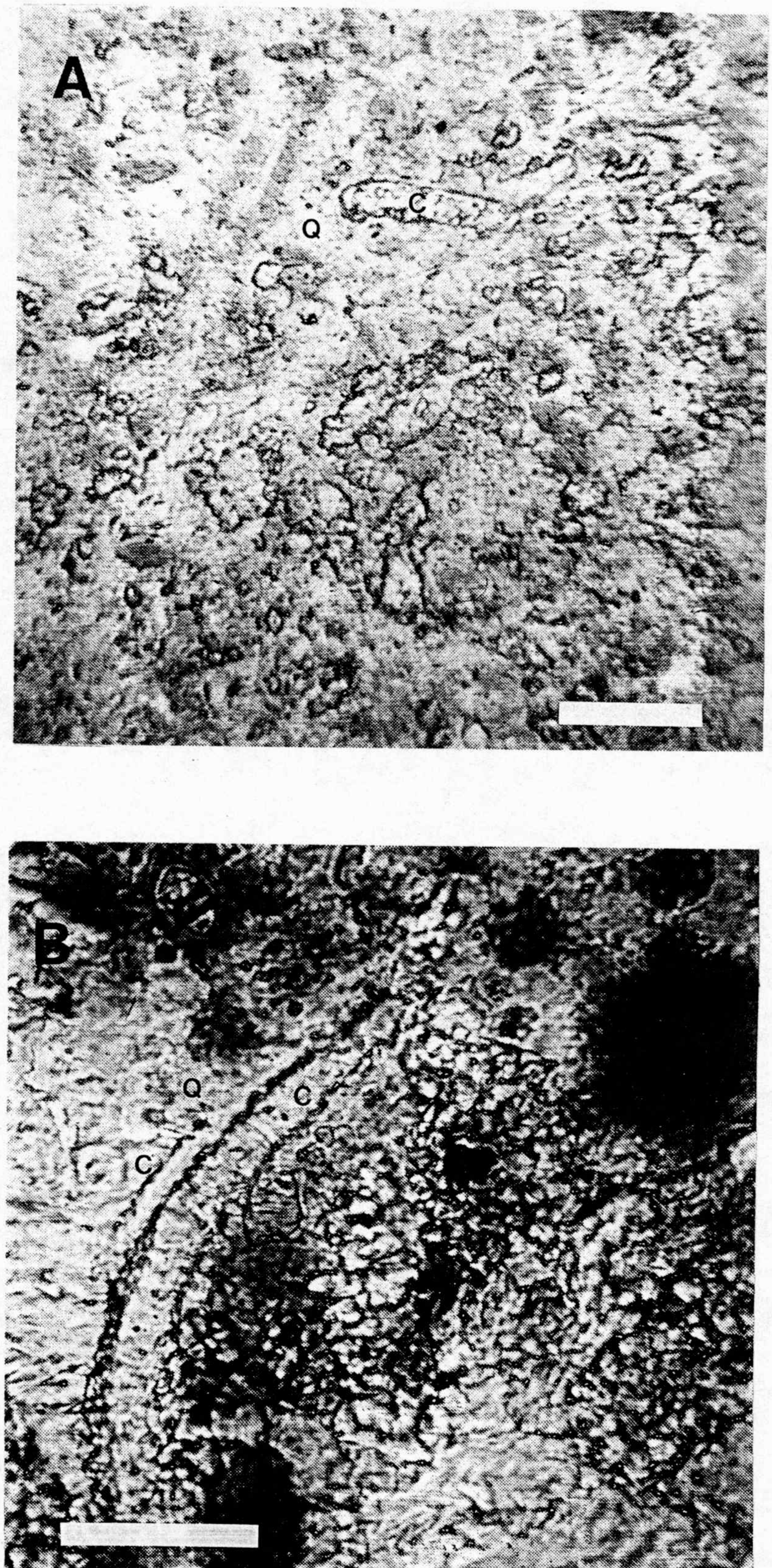

A
B
q
c
C

Figure 15

Non-Fabric Selective Porosity

A. Porosity (blue) distribution is not exclusively fabric dependent, porosity within microquartz (Q) may reflect dissolution of residual micritic matrix. Residual coarsely crystalline calcite (C) distinguished by high relief. Plane light, bar equals 0.50 mm, GN 4530.

B. Same sample as 15a, porosity within microquartz, coarsely crystalline calcite largely unaffected by dissolution. Plane light, bar equals 0.01 mm, GN 4530.


A
C
Q
B
Q
C
C

so, there is no petrographic evidence reflective of vadose or phreatic conditions.

In the lower portion of the core porosity resulted from dissolution of residual micritic matrix and selected skeletal grains. Locally, coarsely crystalline calcite exhibits solution features. On the other hand, the upper portion of this core does not contain any residual carbonate. This implies that either (a) some skeletal grains escaped silicification and were later completely leached, or (b) silica dissolution was selective for replaced grains (finer crystal size of microquartz). The occurrence of botryoid-like porosity suggests silica dissolution, but as in the Sinclair #1 Olsson core, quartz that lines pores is euhedral and displays no effects of solution. Still, a geochemical setting where silica and calcite both dissolve is difficult to envision.

Petroleum Migration and Source Rocks

A final consideration in this study was investigating the source and migration of hydrocarbons. Although no chemical analysis of the oil or measurements of thermal maturity were undertaken, some general observations concerning time of migration and possible source rocks can be made.

Certainly, hydrocarbon migration occurred after porosity development, establishing that the time of migration was Desmoinesian or later. Maximum depth of burial probably occurred during the late Pennsylvanian or early Permian. Even so, it is doubtful that the organic-rich source rocks in stragraphic proximity to the Osagean Series (the Pennsylvanian Cherokee shales above and the upper Devonian-lower Mississippian Chattanooga Shale below) were buried deep enough to generate hydrocarbons. Assuming a geothermal gradient of 1°C/40 m (Freeze and Cherry, 1979, p. 507) and an estimated maximum depth of burial of 1,828 m (6,000 ft.), the source rocks may have reached approximately 46°C, which is well below the lower temperature limit of liquid hydrocarbon generation (75°C). An alternate hypothesis is that hydrocarbons were generated in the deep Anodarko Basin and migrated up onto the shelf (Jeff Hall, personal communication). Possible source rocks in the Anadarko Basin are the Morrowan shales and the Woodford Shale.

CONCLUSIONS

1. The Osagean Series in Barber County, Kansas can be subdivided into three lithofacies: the shelf flank facies, the open shelf facies, and distal open shelf facies. The shelf facies is characterized by graded bedded lime grainstones interbedded with lime wackestones and mudstones. The open shelf facies is characterized by burrowed, cherty lime mudstone. The distal open shelf facies is characterized by sedimentary boudinage structures and detrital clay and silt components.

2. The Osagean Series represents deep marine (below effective wave base) main shelf - shelf margin deposits.

3. Silicification favored lime mudstone and was predominantly early (pre-lithification).

4. Osagean hydrocarbon production is principally from stratigraphic traps.

5. Local structures might account for fractures that led to porosity deveopment.

6. Hydrocarbon production is associated with chert-rich lithofacies where they subcrop beneath the Pennsylvanian unconformity.

7. Porosity is secondary and resulted from near - surface processes associated with development of the Pennsylvanian unconformity.

8. Tripolitic chert resulted primarily from leaching of residual carbonate minerals, although some silia dissolution might have occurred.

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APPENDIX 1

LIST OF WELLS

Cored*

Rotary Samples+

T33S-R11W

Section	Well Name	Location
1	Gulf #1 Schiff	SE NW NW
2	Gulf #1 L Davis	E2 W2 SW
3	Gulf #1 Wortman 'B'	C SE SE
4	Musgrove Pet. #1 Early	SE SE SW
7	K&E Drilling #1 Fitzgerald	E2 SE SW
7	Armer Drilling #1 Fitzgerald	SE SE SE
8	Sinclair #2 Newkirk	NE SW SE
8	Sinclair #10 Newkirk	NE SW SW*
9	Barbara Oil #1 Colborn	SE NW SW
9	Sinclair #1 Arthur Colborn	SW SW SE
9	Sinclair #1 Colborn 'A'	NE SW NE*
9	Sinclair #11 W.A. Newkirk	SE NW NW*
10	Gulf #1 Wortman	SE NW SE
10	Gulf #1 Colborn	NE SW NW
11	O.W. Parker #1 Davis Ranch	NW SW SW
12	K&E Drilling #1 Davis 'A'	C NE NW
12	K&E Drilling #1 'C' E. Davis	C SE NW

Section	Well Name	Location
13	Petroleum Inc. #1 Circle 'B'	NW NW SE
14	Sinclair #1 Circle	SW SW SW*
14	Sinclair #2 Circle	SW NW SW
15	Barbara Oil #7 Page 'A'	SW SE NW
16	Sinclair #7 Newkirk	NW NW SW*
16	Kewanee Oil #11 Rhodes Page 'C'	NE SW SE+
17	Gulf #1 W. A. Newkirk	SE NE SE
17	Gulf #13 W. A. Newkirk	NW NE SE*
18	Armer #2 Fitzgerald	SE NE SW
19	Bowers Drilling #2 Gilmore-Chapin	S/C SW
19	Conoco #1 Harbaugh	SE NE NE
20	Conoco #14 W. A. Newkirk	SE NW NW
20	Conoco #23 Newkirk	W2 W2 SE
21	Superior Oil #7 Gilmore	SW SW SW
21	Barbara Oil #10 Page 'B'	SW SW NW
21	Barbara Oil #6 Page 'B'	SW SW NE+
22	Barbara Oil #1 Rake	SW SW SE
22	Barbara Oil #4 Page 'D'	NE NE NE
24	Todd Drilling #1 Burns	NE NE NE
28	Aurora Gasoline #1 Harbaugh	SW NW SE
29	National Association Pet. #1 Harbaugh	NE NW SW
30	Bowers Drilling #1 Pendley	C SW SE
30	Skelly #1 Fitzgerald	SE SE NE
32	Conoco #9 Harbaugh	NE NE NE*

Section	Well Name	Location
32	Conoco #13 Harbaugh	W2 W2 NE
33	San Diego Oil #1 Harbaugh	SE SE NE+
34	Magnolia Pet. #1 D.Forester	SE NW NW
36	Rupp-Ferguson #1 Powell	SW SW SW
T33S-R12W		
1	Skelly #1 Kenney	NW NW SW
1	Okmar Oil #1 Kenney 'B'	NW NW SE
1	Okmar Oil #1 Kenney	S2 S2 SW
2	Skelly #1 Boggs 'E'	NW NW SW
2	Okmar #1 Barthalow	SW SW NE
3	Conoco #1 Colborn	NW NW SE
3	Texaco #1 E. Meadows 'B'	C NE NE
5	Skelly #2 Boggs 'D'	C SW NW
6	K&E Drilling #1 M. Hospital 'A'	C NW
8	Bowers Drilling #1 Boggs Estate	C NE SE
9	Monsanto #1 Jargian	SW SW NE
9	Bowers Drilling #1 Boggs Estate 'C'	NE SW NW
11	Honaker-Davis #1 Balmer	NE NE SW
11	Jones-Gebert #1 Hindman	C SE NE
12	Graham-Michaels #1 Harbaugh	C SE SE
12	Okmar Oil #1 Warren	C W2 W2
14	Okmar Oil #1 Groendycke	C NE NE
16	Skelly #1 Boggs 'F'	SW NW SE

Section	Well Name	Location
16	Bowers Drilling #1 Boggs Estate 'A'	SW NE NW
17	Skelly #19 Boggs 'C'	N2 NE SW
17	Skelly #21 Boggs 'C'	N2 SE NE
18	Skelly #1 Boggs 'G'	NW NW SE
18	Skelly #1 Bartholow	NE NE NE
19	Skelly #1 Boggs 'H'	NW SE SW
19	Petroleum Inc. #1 Coppinger	SE SW NE
24	Superior Oil #1 Harbaugh-Unit	NE SW SE
24	Trans Era #1 Long	SE SE SW
25	Honaker-Davis #1 Fitzgerald	C SE SE
25	Bachus Oil #1 McKanna	C N2 NW
26	Aurora Gasoline #1 Long 'A'	SE SE SE
26	Carter & Mandel #1 Long	C NW SE
27	Sinclair #1 Groendycke	NW NE SE
27	Bower Drilling #1 Groendycke	SW SW SE
30	Trans Era #1 McCullough	NW NW NE
30	Rupp-Ferguson #1 Page McCullough	NW SE SW
31	Petroleum Inc. #1 Hall-Page Unit	SW NW NW
31	Rupp-Ferguson #1 Hall	NE NW NE
32	Petroelum Inc. #1 McCracken	NW SW SW
32	Skelly #1 V. Smith	C NW NW
33	Jones, Shelburne, & Farmer #1 Warwick	C SW SW

Section	Well Name	Location
34	Sinclair #1 Wright	C NE NE
34	Bowers Drilling #1 Wright-Bevans	E2 NE SE
35	Sinclair #1 Charles Berans	NE NE NW
35	Beardmore Drilling #1 Berans	SE SE NW
36	Sands Drilling #1 Nurre Berans	C SE SE
T34S-R11W		
1	Mack Oil #1 Swartz	C SW NE
5	Cirmer Drilling #1 Groendycke	SE SE NE
6	Gulf #1 Groendycke	NW NW NW
7	Nichols Drilling #1-7 Michel	C NE SW
8	Nichols Drilling #1-8 Michel	C NE SE*
8	L.C. Smitherman #1 Groendycke	NW NW NW
10	Petroleum Inc. #1 Zimmerman 'D'	NW NW NW
11	Rupp-Ferguson #1 Koontz	NW NW NE
15	Woods Drilling #1 Schuplach	NZ NW NW
16	Nichols Drilling #1-16 Landis	C SE NW*
20	Edwards Energy Corp. #1 N.C. Short	SW NE NW
21	Purcell-Mull #1 Schupbach 'A'	SW NW NE

Section	Well Name	Location
26	D.R. Lauck Oil #1 Elliott	SE SE SW
26	Messman-Rinehart #1 Humphrey	C SW SW
32	Aurora Gasoline #1 Goldman	NW NW SW
T34S-R12W		
2	Conoco #1 Colson	N2 N2 NE
3	Shenandoah Oil #1 Virginia Wright	NW NW NE
5	K&E Drilling #1 Warwick 'A'	C N2 SE
5	Atlantic Refining #1 Donovan 'B'	C SW SW
6	Alyword Drilling Co. Donovan 'C'	NW SW SE
6	Skelly #1 Donovan 'A'	NE SW NW
7	Magnolia Pet. #1 Vestal Cook	C W2 SE
7	Atlantic Refining #2 Donovan	C SE NW
8	K.W.B. Oil Property Mgnt. #1 McCracken	C SW NE+
9	K.W.B. Oil Property Mgnt. #1 Cook-McCullough	C SW NW
12	Woodman and Iannitti #1 Zimmerman	C SE SE
15	Jones et. al. #1 Wright 'B'	NE NE NE
17	Mgnolia Pet. #1 R. Cook 'B'	E2 SE SW

Section	Well Name	Location
17	Atlantic Refining #1 V.L. Cook 'A'	NE NW SW
18	K.W.B. Oil Property Mgnt. R.B. Cook	SE NW SE
18	Carter Oil #1 V.L. Cook	SE NW NW
19	Carter Oil #2 R.B. Cook	NW SE NW
19	Magnolia Pet. #1 C. Olson 'B'	NE SW SW
20	Superior Oil #1 Olson	NE SW SE
20	Magnolia Pet. #2 R. Cook	SW NE NW
21	Petroleum Inc. #1 Cook 'F'	S2 N2 SE
21	Edwin Bradley #1 Cook	c SW NW
22	Rex et. al. #1 Cook	C NW NW
24	Aurora Gasoline #1 Humphrey	SE SE NE
26	Nichols Drilling #1-26 Stranathan	C SW SE*
27	Ram Petroleum #1 Richardson 'A'	SE NW NW
28	Magnolia Pet. #1 Wm. Graver	C NW SE
29	Superior Oil #1 Sterling 'A'	NW SE SW
30	Sinclair #1 Olsson	NW SE NE*+
30	Superior Oil $1 Sterling 'B'	NW SE SW
30	Aurora Gasoline #1 Sterling	C NE SE
31	Aurora Gasoline #1 Rathegeber	C NE SE
31	Atlantic Refining #1 Ed Sterling 'C'	SW NE SW
32	Atlantic Refining #1 Sterling	NE SW NW

Section	Well Name	Location
33	Atlantic Refining #2 Graves Unit	C NW NE
34	Nichols Drilling #1-34 Good	C SW NE
35	Sinclair #1 Sam Good	SE SE NE
36	DNB Drilling #1 Wetz	C NW SW
36	Nichols Drilling #1-36 Wetz	C SE NW
T35S-R11W		
4	DNB Drilling #1 Schooley	C NE SW
5	Molz Oil #1 Blong-Boldman	N2 NW NW
6	Molz Oil #A-2 Rathgeber	N2 NE SW
7	Molz Oil #1 Platt 'A'	C NW NW
10	Aurora Gasoline #1 Washburn 'B'	NW NW SW
T35S-R11W		
1	Robinson #B-1 Molz	C SE NE
1	Molz #1-A Yates	N2 NE NE
2	Barbara Oil #1 Mission	NE NE NW
3	Molz Oil #1 Lohmann	C SE NE
5	Barbara Oil #1 Bank Unit	N2 S2 NW
5	Barbara Oil #1 Bank Unit	SE NW NE
6	Aurora Gasoline #1 Platt	C NE SE
6	Sands Drilling #1 Ohlson 'B'	C NW NW

Section	Well Name	Location
7	E.K. Edmiston #1 Ohlson	C NW NE
8	Flynn Oil #1 Achenbach	SW SE SE
8	Aurora Gasoline #1 Ohlson 'C'	C NW NW
9	Beren Corp. #2 Lois 'B'	C NE NW
10	McGinness Oil #1 Ohlson 'A;	C NW SE
11	Molz Oil #1 Kessler	C SE NW
12	Rupp-Ferguson #1 College	SW SW NW
18	Petroleum Inc. #1 Stratzmann	C NW NW

APPENDIX 2

BULK COMPOSITION

FACIES: SAMPLE	Calcite	Dolomite	Authigenic Quartz & Chert	Detrital Quartz	Detrital Clay	Porosity	Authigenic Clay Hematite
PENN, BASAL CONGLOMERATE:							
CH 4490	0	0	0	55	45	0	0
NL 4578	0	0	0	42	58	0	0
SHELF FLANK FACIES:							
SN 4415	77	5	16	0	0	0	2
SN 4426	62	38	0	0	0	0	0
SC 4551	99	0	1	0	0	0	0
SC 4562	55	0	43	0	0	0	2
SC 4564	83	0	15	0	2	0	0
SC 4565	91	0	9	0	0	0	0
SC 4588	51	49	0	0	0	0	0
OPEN SHELF FACIES:							
S7 4526	15	0	76	2	0	7	0
S7 4532	90	0	3	1	0	2	4
SC 4481	0	2	68	1	1	24	4
SC 4486	11	0	73	2	0	6	8
SC 4571	0	0	100	0	0	0	0
SC 4572	12	0	74	1	0	11	2
SC 4573	58	0	37	0	0	2	3
NS 4744	0	0	61	1	0	37	1
GN 4490	0	0	70	0	0	28	2
GN 4500	89	0	7	0	0	3	1
GN 4530	72	0	13	0	0	15	0
GN 4540	93	0	6	0	0	0	1

DISTAL OPEN SHELF FACIES:	Calcite	Dolomite	Authigenic Quartz & Chert	Detrital Quartz	Detrital Clay	Porosity	Authigenic Clay Hematite
SC 4535	32	0	44	4	20	0	0
CH 4532	58	0	31	2	9	0	0
CH 4585	0	0	83	1	0	16	0
CH 4592	13	50	22	4	11	0	0
CH 4597	0	0	14	2	84	0	0
SO 4808	0	4	72	1	2	22	0
SO 4818	0	3	77	2	3	14	1
SO 4841	1	3	56	2	36	0	2
SO 4845	24	32	27	1	14	0	2
NL 4586	0	5	89	3	0	3	0

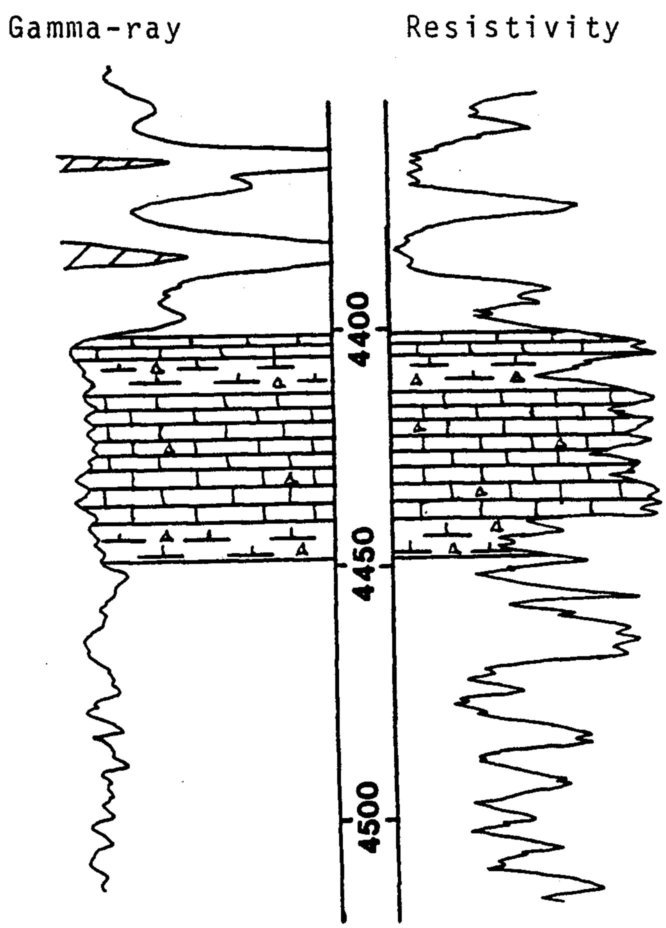
THIN SECTION KEY:

SN - Sinclair #11 Newkirk
S7 - Sinclair #7 Newkirk
SC - Sinclair #1 Circle
CH - Conoco #9 Harbaugh
SO - Sinclair #1 Olsson
NS - Nichols #1-26 Stranathan
NL - Nichols #1-16 Landes
GN - Gulf #13 WA Newkirk

APPENDIX 3

CORE DESCRIPTIONS

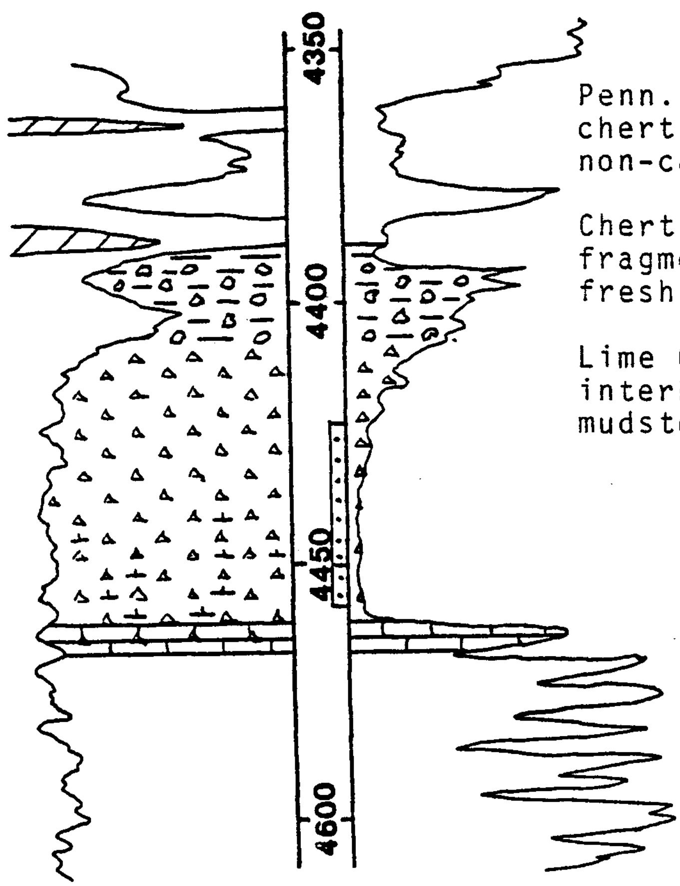
Sinclair Oil and Gas #11 Newkirk
SE, NW, NW, 9-33-11 W
Dry and Abandoned
Cored 4401' - 4448'



Lime grainstone-dark gray locally graded bedded, crinoids, brachiopods, interbedded with green lime mudstone, some dolomite, some nodular chert.

Sinclair Oil Gas #1 Colborn 'A'
NE, SW, NE, 9-33-11 W
Perforated 4422'-60', I.P. 4,700,000 CFG
Cored 4387-4468'

Gamma-ray Resistivity

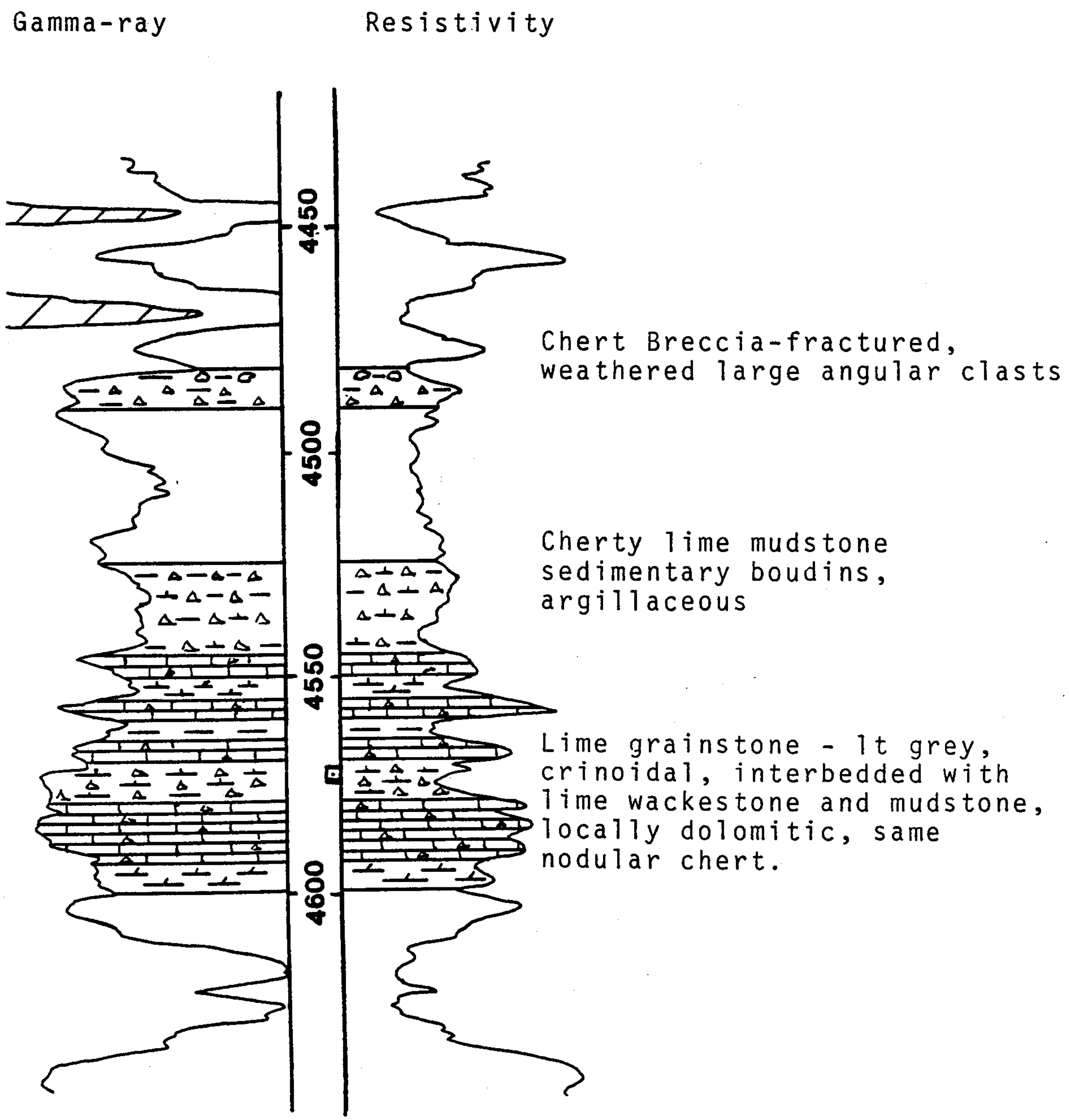


Penn. Conglomerate-subrounded chert clasts in lt-dk green non-calcareous shale

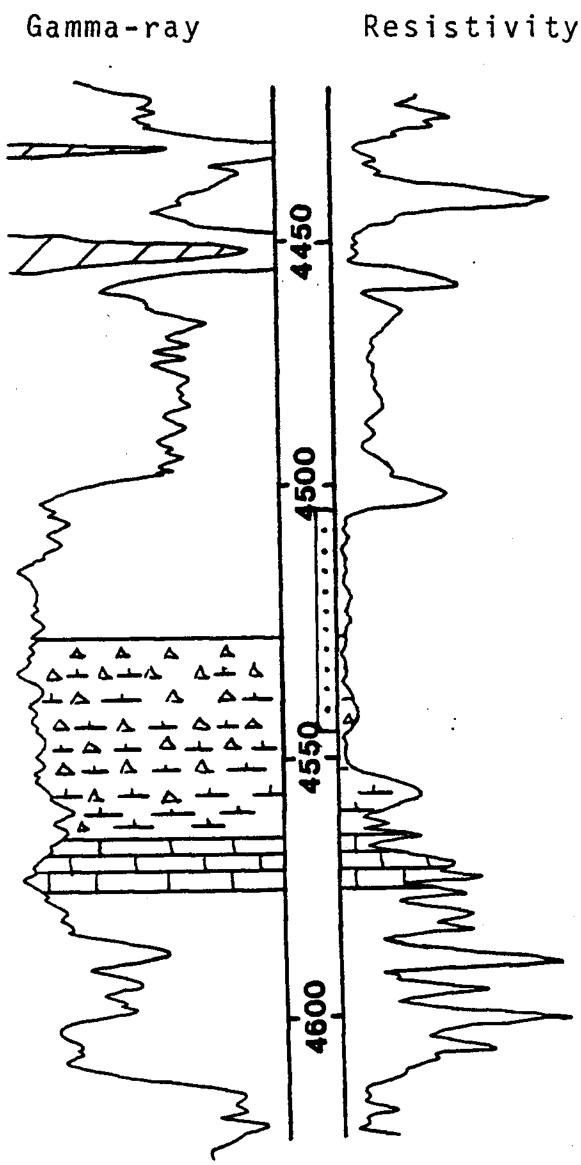
Chert - fractured, weathered fragment margins (lt brown-gray), fresh chert (white-tan).

Lime Grainstone-grey crinoidal, interbedded with lt green lime mudstone.

Sinclair Oil and Gas #1 Circle
SW, SW, SW, 14-33-11 W
Perforated 4572'-78   I.P. 112 BOPD
cored 4481'-89', 4525'-99'



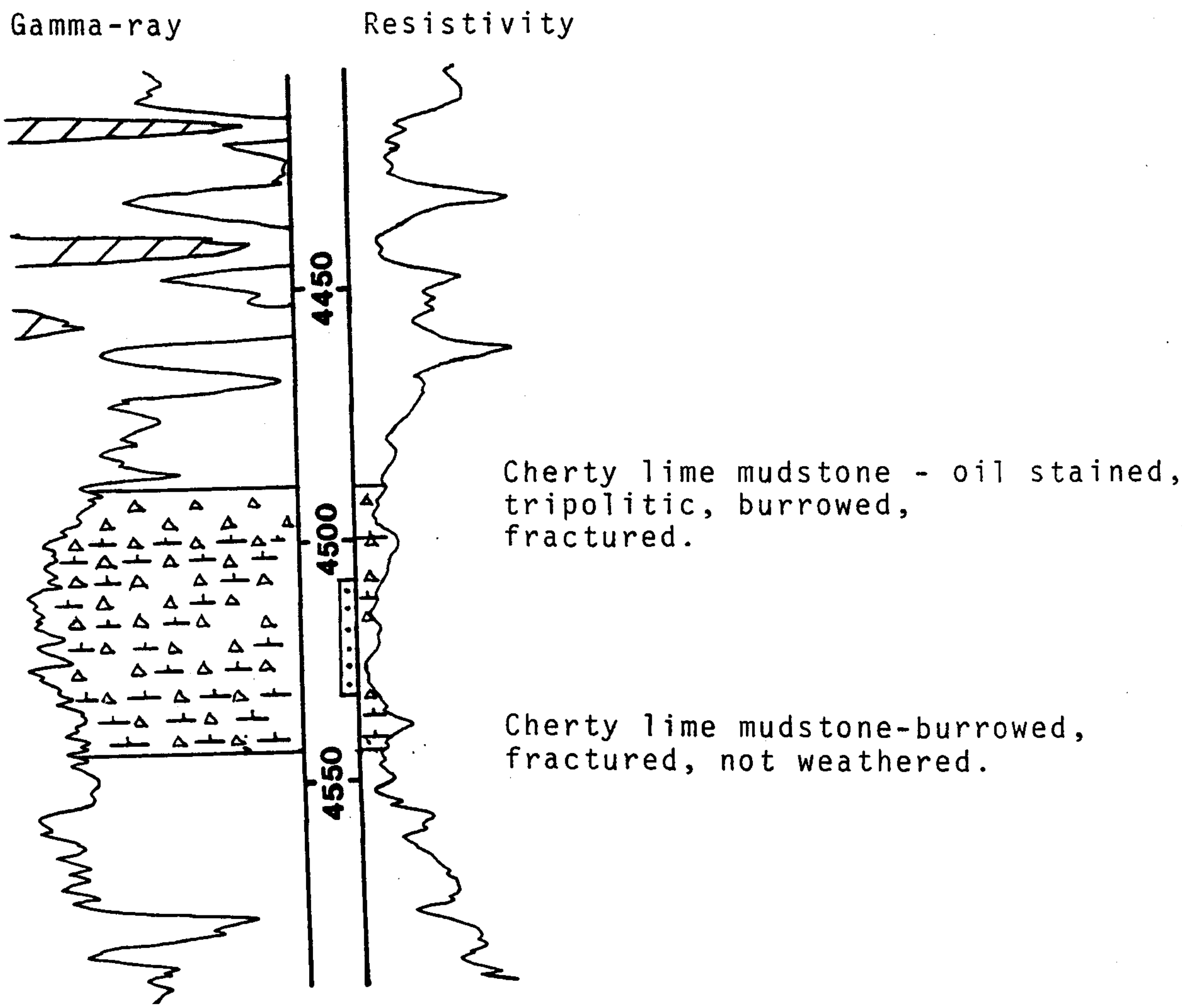
Sinclair Oil and Gas #7 Newkirk
NW, NW, SW, 16-33-11 W
Perforated 4506'-46' I.P. 208 BOPD
Cored 4526'-4575



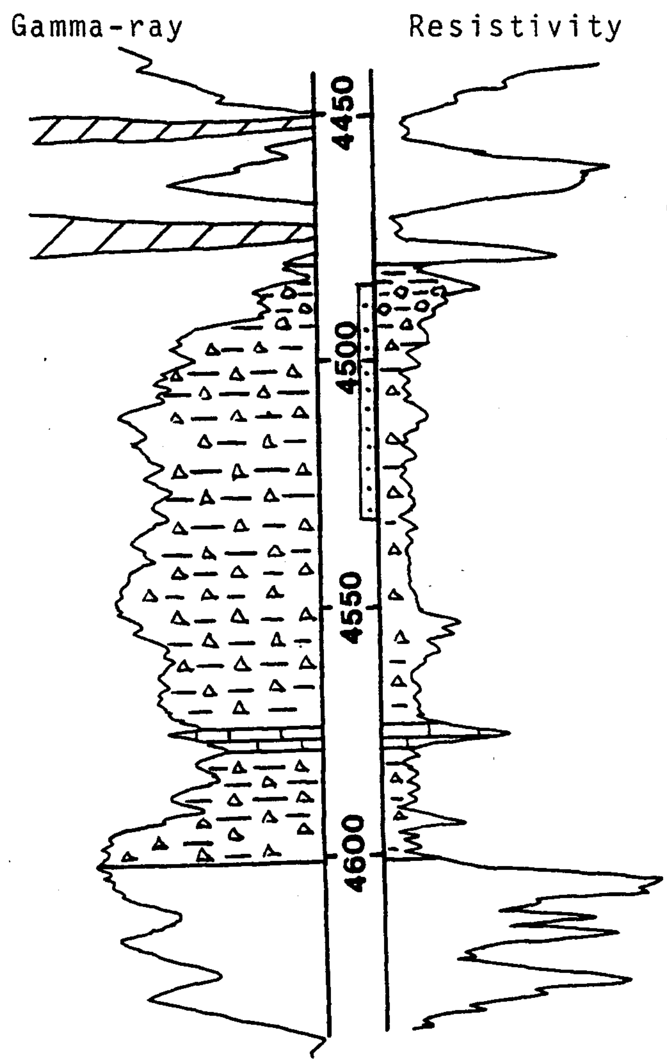
Cherty lime mudstone-burrowed, fractured, tripolitic

Lime grainstone-crinoidal, interbedded with light green lime mudstone.

Gulf Oil #13 W. A. Newkirk
NW, NE, SE, 17-33-11 W
Perforated 4510'-30'   I.P. 303 BOPD
Cored 4490' - 4543'



Conoco #9 Harbaugh
NE, NE, NE, 32-33-11 W
Perforated 4486'-4534'   I.P. 35 BOPD
Cored 4480'-4601'



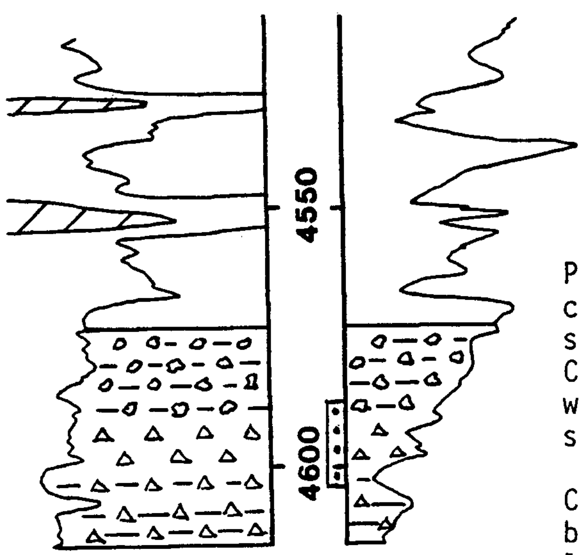
Penn. Conglomerate-subrounded chert clasts in dk green shale.

Cherty Shale-sedimentary boudinage, off-white chert in lt-dk green shale, local lime mudstone and wackestone, dolomite, spiculitic chert

Lime grainstone-grey crinoidal, thin bedded
Cherty shale-as above, increasing chert content.

Nichols Drilling Co. #1-8 Michel
C, NE, SW, 8-34-11 W
Perforated 4586'-4606'   I. P. 25 #BOPD
Cored 4572'-4617'

Gamma-ray   Resistivity

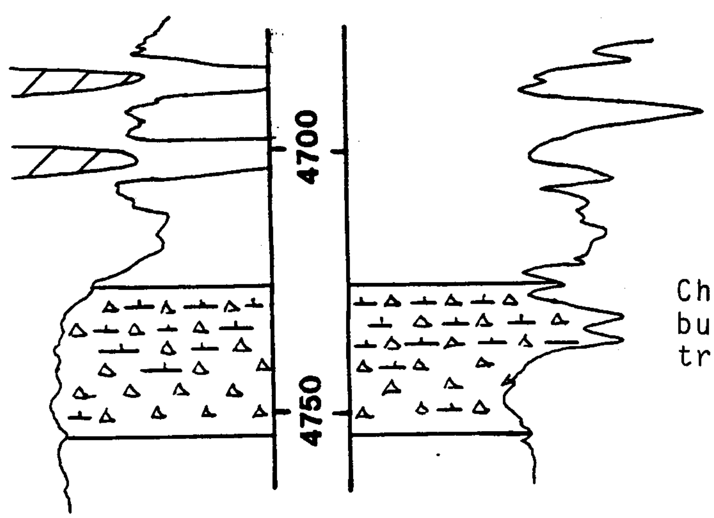


Penn. Conglomerate - angular cherty in non-calcareous, green shale
Chert Breccia-fractured chert weathered at margins, little shale matrix.

Cherty Shale-sedimentary boudins, blue-grey chert in lt green calcareous shale.

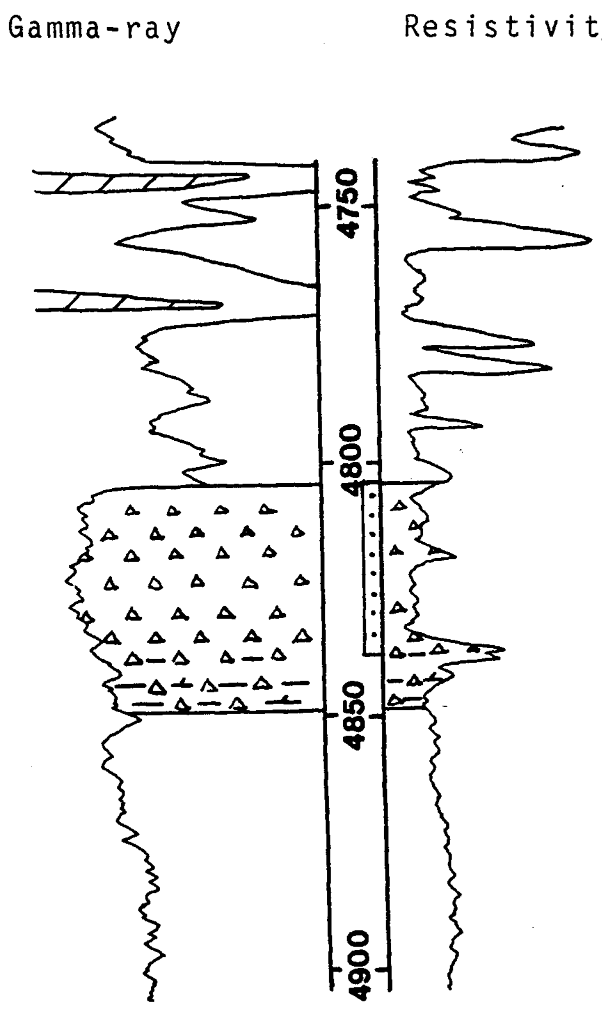
Nichols Drilling Co. #1-26 Stranathan
C, SW, SE, 26-34-12 W
Oil well, perforations, I. P. not shown
Cored 4725'-55'

Gamma-ray Resistivity



Cherty lime mudstone - burrowed, fractured, tripolitic

Sinclair Oil and Gas #1 Olsson
NW, SE, NE, 30-23-12 W
Perforated 4804'-36'   I. P. 7.8 MMCFGPD
Cored 4804'-49'



Chert Breccia-fractured, highly weathered, fresh chert-lt grey, white, tripolitic matrix-tan, lt brown, no residual calcite.

Cherty Shale-sedimentary boudinage, spiculitic chert in green shale and mudstone, local dolomite.

The undersigned, appointed by the Dean of the Graduate Faculty, have examined a thesis entitled:

Petrology and Diagenesis of the Lower Mississippian, Osagean Series, Western Sedgwick Basin, Kansas

presented by Mark A. Thomas

a candidate for the degree of Master of Arts

and hereby certify that in their opinion it is worthy of acceptance.