FACTORS CONTROLLING THE DEVELOPMENT AND DISTRIBUTION OF POROSITY IN THE LANSING-KANSAS CITY "E" ZONE, HITCHCOCK COUNTY, NEBRASKA

by
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ABSTRACT

In southwest Nebraska, oil is produced from thin (15 to 30 foot, 4.5 to 9 meters thick) limestones of the Lansing and Kansas City groups (Upper Pennsylvanian), which are interbedded with marine and nonmarine terrigenous rocks. Oil entrapment was both stratigraphically and structurally controlled. Porosity in 30 cores of the Lansing and Kansas City limestones from the Meeker Canal Field and surrounding areas in Hitchcock County, Nebraska, is predominantly secondary. The distribution of porosity, which is far from uniform, is related to paleotopography, which influenced texture and movements of ground and surface waters during subaerial exposure.

During the deposition of the Lansing and Kansas City "E" zone, the area of Hitchcock County had a relatively flat to mildly undulating topography with a maximum relief across the county on the order of 30 to 60 feet (9 to 18 meters). Small positive areas, with a local relief of 15 to 30 feet (4.5 to 9 meters), dotted the landscape. Most porous rocks are coincident with these small positive features.

Oil production is from carbonate packstones and grainstones that were deposited during shallow water episodes of a complex marine-nonmarine sedimentary cycle. Porous packstones and grainstones were best developed on positive features of the seafloor, which were subjected to more wave agitation than the surrounding, low lying areas.

During subaerial exposure shortly after deposition of the marine carbonate sediments, fresh, meteoric, ground and surface waters, that were responsible for the development of secondary porosity, were concentrated by the slight variations in topography. The topographically lowest areas were catchment basins for surface runoff and groundwater

and were nearly always in a freshwater phreatic environment. Here, intense weathering that produced large scale dissolution accompanied by infiltration of silt and clay totally destroyed any reservoir potential the rocks may have had prior to subaerial exposure. Percolating meteoric waters dissolved aragonitic skeletal grains and intergranular carbonate mud in the vadose zone on the topographically highest areas. The dissolved calcite was apparently carried into the freshwater phreatic zone where it was precipitated as cement below the water table.

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INTRODUCTION

The Porosity Problem

The seemingly unpredictable distribution of porosity in thin (15 to 30 feet, 4.5 to 9 meters) limestone reservoirs of the Lansing and Kansas City groups (Upper Pennsylvanian) (Fig. 1) has hampered oil exploration and production efforts in southwestern Nebraska and northwestern Kansas. The objective of this research is to identify the factors controlling the development and distribution of porosity in the Lansing and Kansas City rocks thereby facilitating the defining of potentially productive areas in southwestern Nebraska and northwestern Kansas or other areas with a similar geologic setting.

It has long been recognized that oil entrapment in these rocks is not simply a function of structure, but, rather, is due to a combination of both structural and stratigraphic factors. Larson (1962) attributed the occurrence of good reservoir rock to organic buildups on topographic highs on the seafloor with relief of 3 to 10 feet (1 to 3 meters). He believed these high areas may be related to present day structures, but noted that many structures tested by drilling were not productive due to lack of porous rocks. My research confirms Larson's supposition that paleotopography was a major factor in controlling the distribution of potentially porous rocks. I have also found, however, that paleotopography had a profound influence on postdepositional processes and subsequent enhancement, preservation, or destruction of porosity. Furthermore, methods have been outlined that can be used to identify areas that were topographically high during the deposition of Lansing and Kansas City sediments.

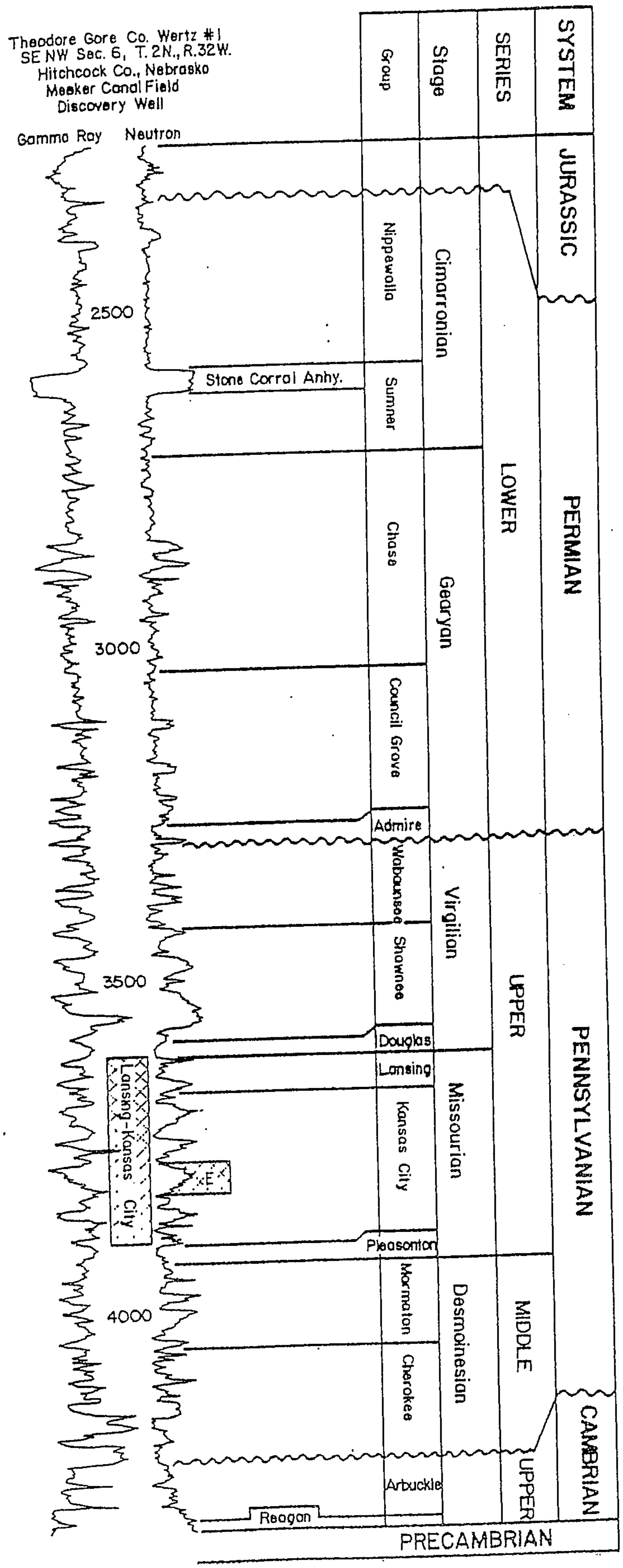


Figure 1. Stratigraphic section in Hitchcock County, Nebraska, correlated with the Rawlins County, Kansas, Type Log (Kansas Geological Society, 1966).

Informal Stratigraphic Classification

Several schemes of informal classification have been applied to the limestones of the Lansing and Kansas City groups herein called Lansing-Kansas City, in Nebraska and Kansas. Letter classification systems are used by most oil operators because they are more convenient than the formal rock formation and member names that have been assigned to these rocks where they crop out in eastern Kansas. Six letters (A-F) were assigned by Kincaid, Trimble, and Larson (in Packer, ed., 1961) to the six uppermost limestone units of the Lansing-Kansas City (Fig. 2). I have added a seventh letter (G) for the unassigned interval just above the base of the Kansas City. The fifth limestone from the top, the "E" zone is the subject of my research. The six or seven letter classification system is used by most oil operators in southwestern Nebraska, and the seven letter classification system will be used here.

Other classification systems are used in Kansas because there are quite often more than seven limestone units. The limestone unit of the "E" zone of the seven letter system is the same as Morgan's (1952) "J" zone (W.L. Watney, 1979, personal communication) and what some operators term the "180 foot" zone (M.J. Brady, 1979, personal communication). Parkhurst (1961) correlated Morgan's "J" zone with the outcropping Winterset Limestone Member of the Dennis Formation in eastern Kansas. A host of other classification systems of the Lansing-Kansas City limestones are used, but those mentioned above are the most common.

Study Area, Development History, Production

Hitchcock County (Fig. 3) is located in the northern portion of the Hugoton Embayment of the Anadarko Basin in southwestern Nebraska. It is

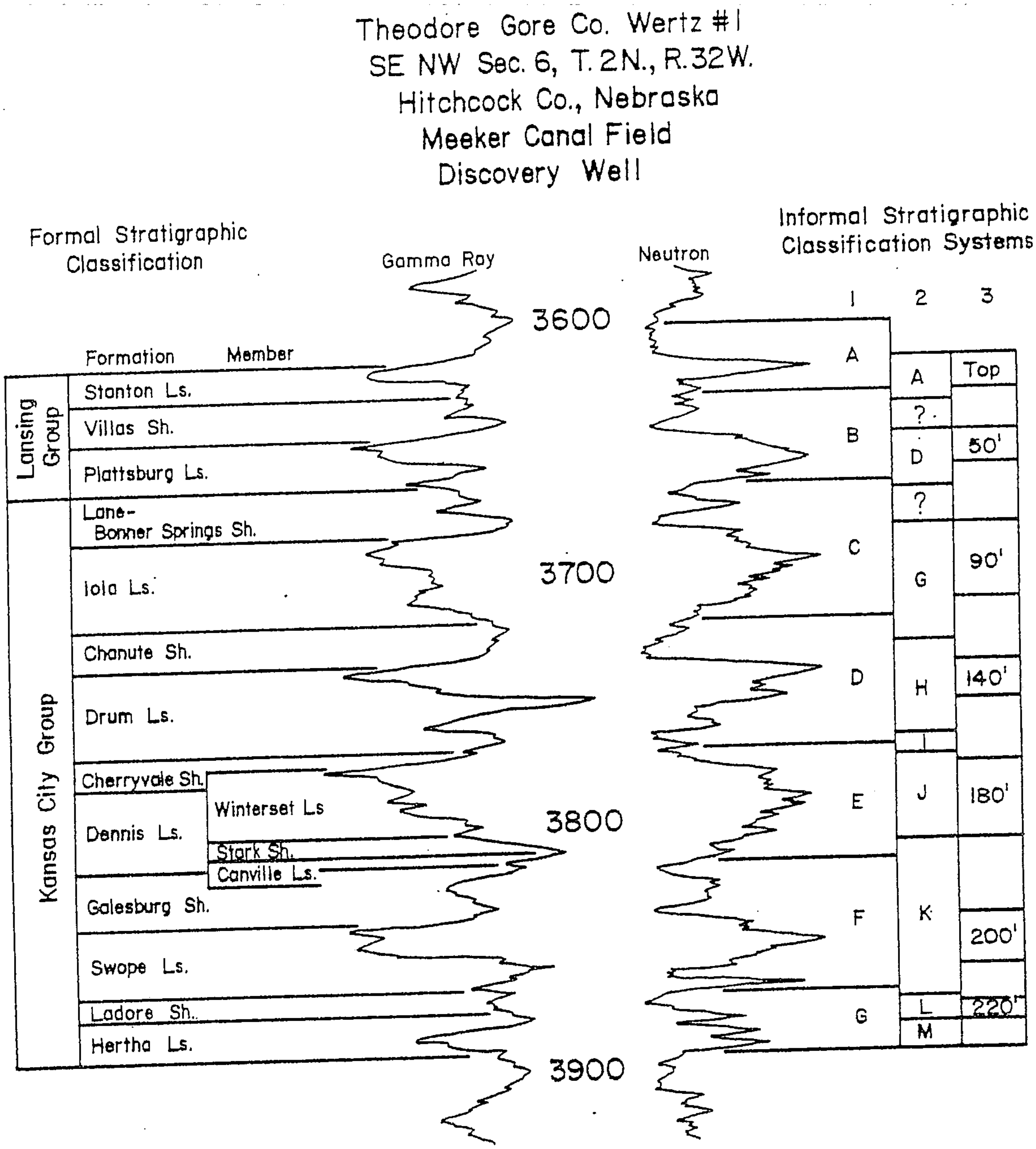


Figure 2. Stratigraphic classification schemes for the Lansing-Kansas City Groups. Informal classification systems: 1 letter designations commonly used in southwest Nebraska, modified after Kincaid, Trimble, and Larson (in J.M. Parker, ed., 1961); 2, Morgan's (1952) classification system, based on correlations with Watney's (1977) work in northwest Kansas; 3, system based upon depths below the top of the Lansing, used by some operators in central Kansas (W.L. Watney and M.J. Brady, 1979, personal communication). The formal stratigraphic classification is based on Parkhurst's (1961) work. He traced the Lansing-Kansas City into the subsurface from the outcrop and correlated the formation and members with Morgan's (1952) letter designations. The thicker carbonate of the "E" zone is also Morgan's "J" zone, the "180 foot" zone and the Winterset Limestone.

situated on the western flank of the Cambridge Arch and is on trend with the axis of the Las Animas Arch. An unusual abundance of cores has made possible a detailed petrographic study of the Lansing-Kansas City "E" zone of this county. Thirty cores were studied, twenty-one from the Meeker Canal Field. The nine other cores included one each from the Republican River, Dry Creek, and Reiher Fields and six dry hole wildcats, one just a few miles east of Hitchcock County in Red Willow County. All but four of the cores were from wells drilled by the Theodore Gore Company since 1975.

Exploratory drilling in the early 1950's in Hitchcock County met with little success. Drilling activity was accelerated in the early 1950's following the discovery of significant fields like the Reiher in 1958, and in adjacent Red Willow County, Ackman in 1959, and Sleepy Hollow in 1960. Five oil fields were discovered in Hitchcock County in 1960 (Svoboda, 1962). Drilling activity lessened in the late 1960s and early 1970s, but has been brisk since the rise in price of new oil following the 1973 Arab oil embargo. Ten new fields have been discovered since 1975, the two most significant being the Meeker Canal and Republican River Fields. Not all areas have been fully tested, and more fields will undoubtedly be discovered before Hitchcock County is fully developed.

Nearly all the oil produced in Hitchcock County comes from the Lansing-Kansas City. Production in a field may be from any one of the seven zones, and most fields produce oil from two, or more zones, The bulk of the production, however, is usually from only one or two limestones. The Meeker Canal Field presently produces oil from both the "E" and "F" zones. The "E" zone in most wells remains behind pipe, and will be perforated as the "F" zone is depleted.

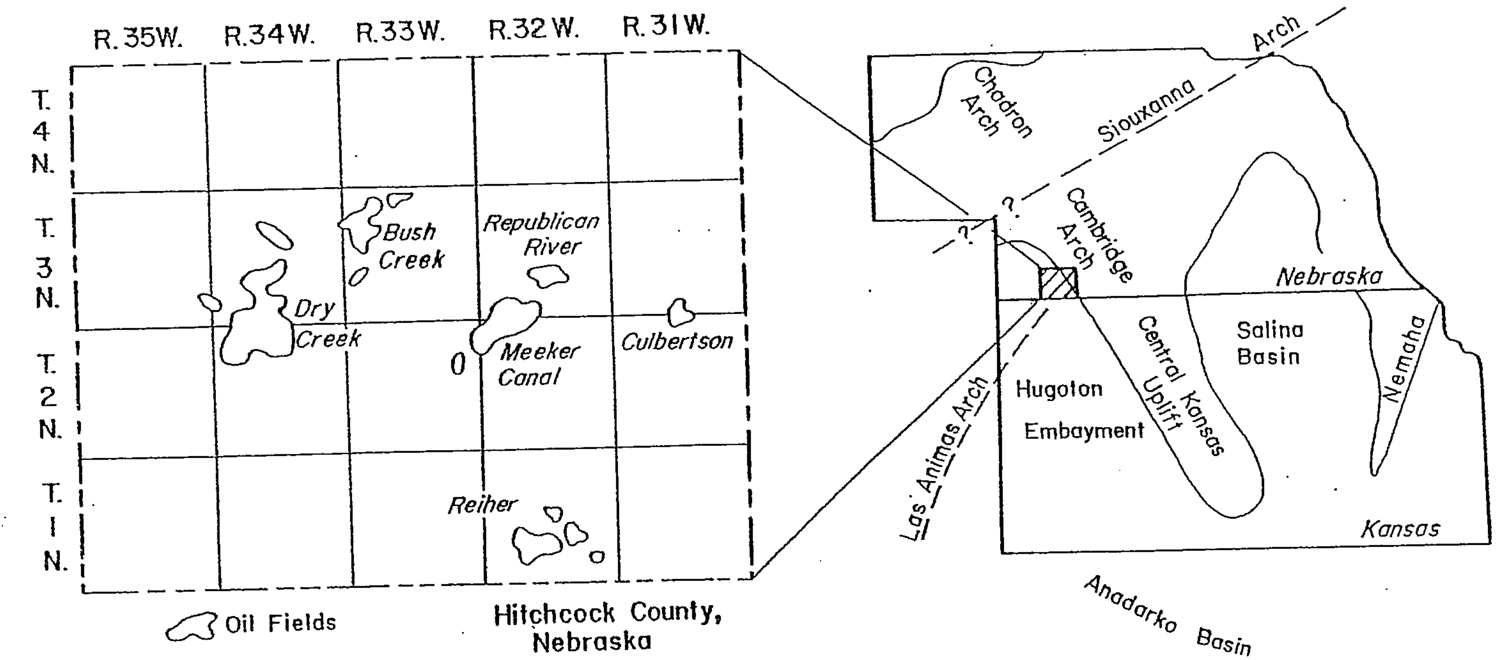


Figure 3. Index map showing location of Hitchcock County, Nebraska in relation to major tectonic features.

Reserves are not large enough to be of interest to most major oil companies, but are substantial enough to be profitably exploited by independent oil operators because of the shallow depths to the reservoirs (3500 to 4000 feet, 1077 to 1230 meters). Ultimate recovery, both primary and secondary, varies considerably from well to well depending on the quality of the reservoir and the number of productive zones, but usually averages 40-50 thousand barrels per well when developed on 40 acre tracts (J.E. Rakaskas, 1979, personal communication). In this area, a one-million barrel oil field is considered a good field.

GEOLOGIC FRAMEWORK

Configuration of the Platform

During deposition of Lansing-Kansas City sediments, southwestern Nebraska was situated in the northern, shoreward portion of an extensive, low-relief, gently southward-dipping platform. The platform's margin was near the Kansas-Oklahoma border (Rascoe, 1962) and the platform had paleoslopes as little as 0.1 meter per kilometer (0.5 feet per mile) in the area of study (Watney and Ebanks, 1978). The paleogeographic position of Hitchcock County corresponds to Heckel's (1977) northern shoreward facies belt. During deposition of the Lansing-Kansas City "E" zone Hitchcock County probably had a relatively flat to mildly undulating surface with maximum relief on the order of 30 to 60 feet (9 to 18 meters. Local positive features having a relief of 15 to 30 feet (4.5 to 9 meters) dotted the landscape. It is on these local positive features that the best "E" zone porosity is found.

Tectonic History

The present structural configuration of the Lansing-Kansas City rocks is considerably different than it was during deposition (Fig. 4). It is a combination of many elements, including drape over a pre-Pennsylvanian unconformity surface, later folding along previously existing pre-Pennsylvanian structures, post-unconformity and pre-Lansing-Kansas City regional tilting and post-Lansing-Kansas City regional tilt.

Regional structural features resulting from post-Mississippian, pre-Pennsylvanian tectonism provided a relatively stable framework for deposition throughout the Pennsylvanian and Permian. The Cambridge Arch and Central Kansas Uplift had their greatest movement at this time (Lee and Merriam, 1954). They provided the eastern margin for the Hugoton

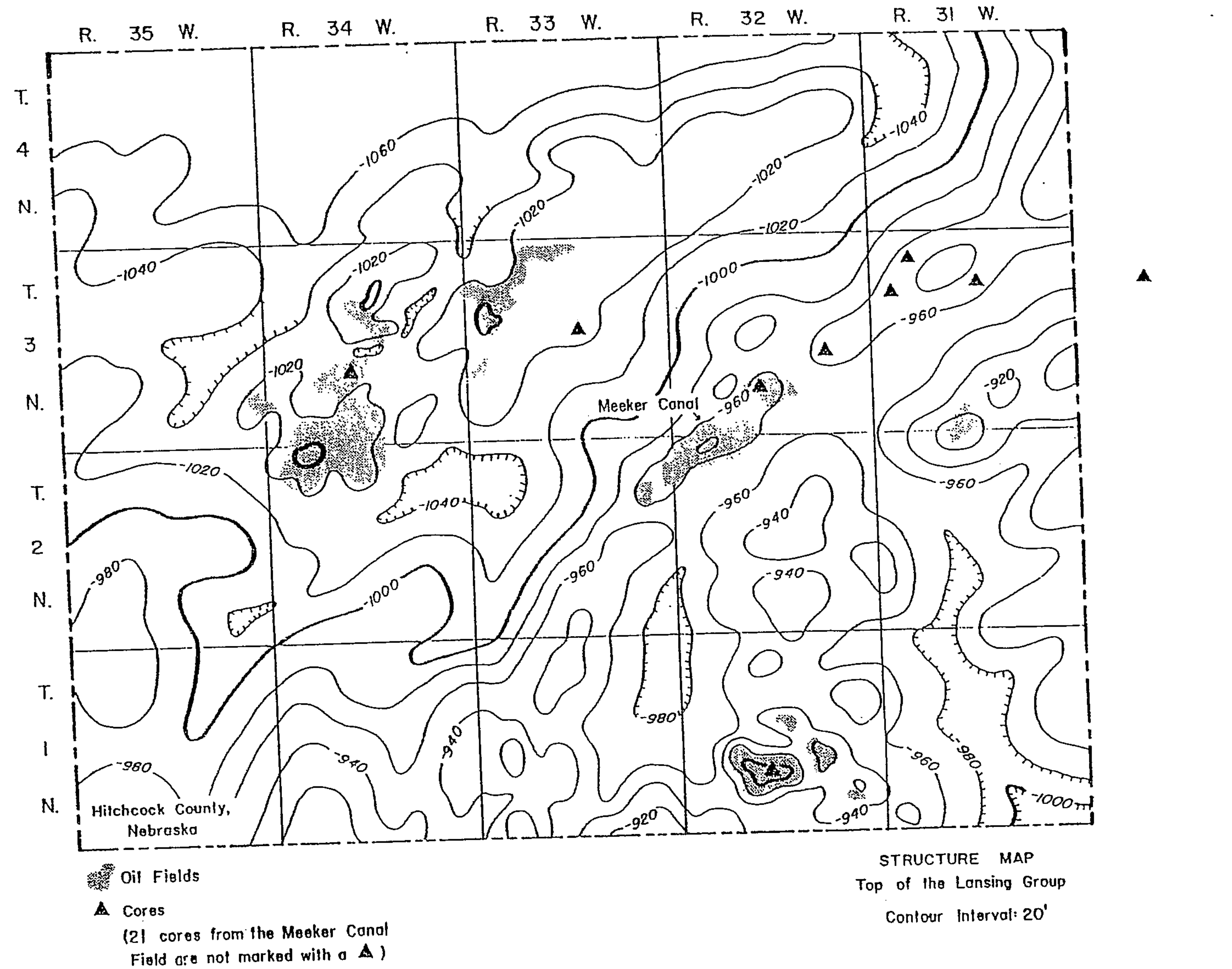


Figure 4. Lansing structure map of Hitchcock County. Tops from approximately 475 wells were used to prepare this map, most of them being operator-released tops.

Embayment of the Anadarko Basin (Maher and Collons, 1948). Pennsylvanian rocks overlie progressively older rock units from west to east across Hitchcock County and directly overlie Precambrian granite on top of the Cambridge Arch in adjacent Red Willow County (Fig. 5).

There was moderate relief on this surface as a result of structural movement and erosion. An isopach map between the top of the Lansing and the unconformity indicates the amount of relief on this surface which may have been as much as 150 feet (45 meters) (Fig. 6). The Reiher Field in south-central Hitchcock County is situated atop a major structural feature with Pennsylvanian sediments directly overlying Precambrian granite. This structure is similar to the buried Precambrian hills in Barton County, Kansas (Walters, 1946). The low areas of this surface were filled by Middle Pennsylvanian sediments, and most of the topography was removed by the time Lansing-Kansas City sediments were deposited. The topography at the time of Lansing-Kansas City deposition was a combination of structure caused by compaction and drape of sediments over topographic highs on the pre-Pennsylvanian surface, recurrent movement along previously existing structures, and regional tilting.

Tectonism after the deposition of Lansing-Kansas City sediments was predominantly in the form of regional tilting. An isopachous map of the interval from the Stone Corral Anhydrite to the Lansing-Kansas City "B" zone in adjacent Red Willow County consistently thickens to the southeast at a rate of approximately six feet per mile (1.13 meters per kilometer) (Busch, 1977). This is interpreted to represent regional tilting in that direction by that same amount. A structure map of the Stone Corral Anhydrite in Hitchcock County (Fig. 7) shows that the anhydrite has a NE-SW strike and dips to the northwest approximately nine feet per

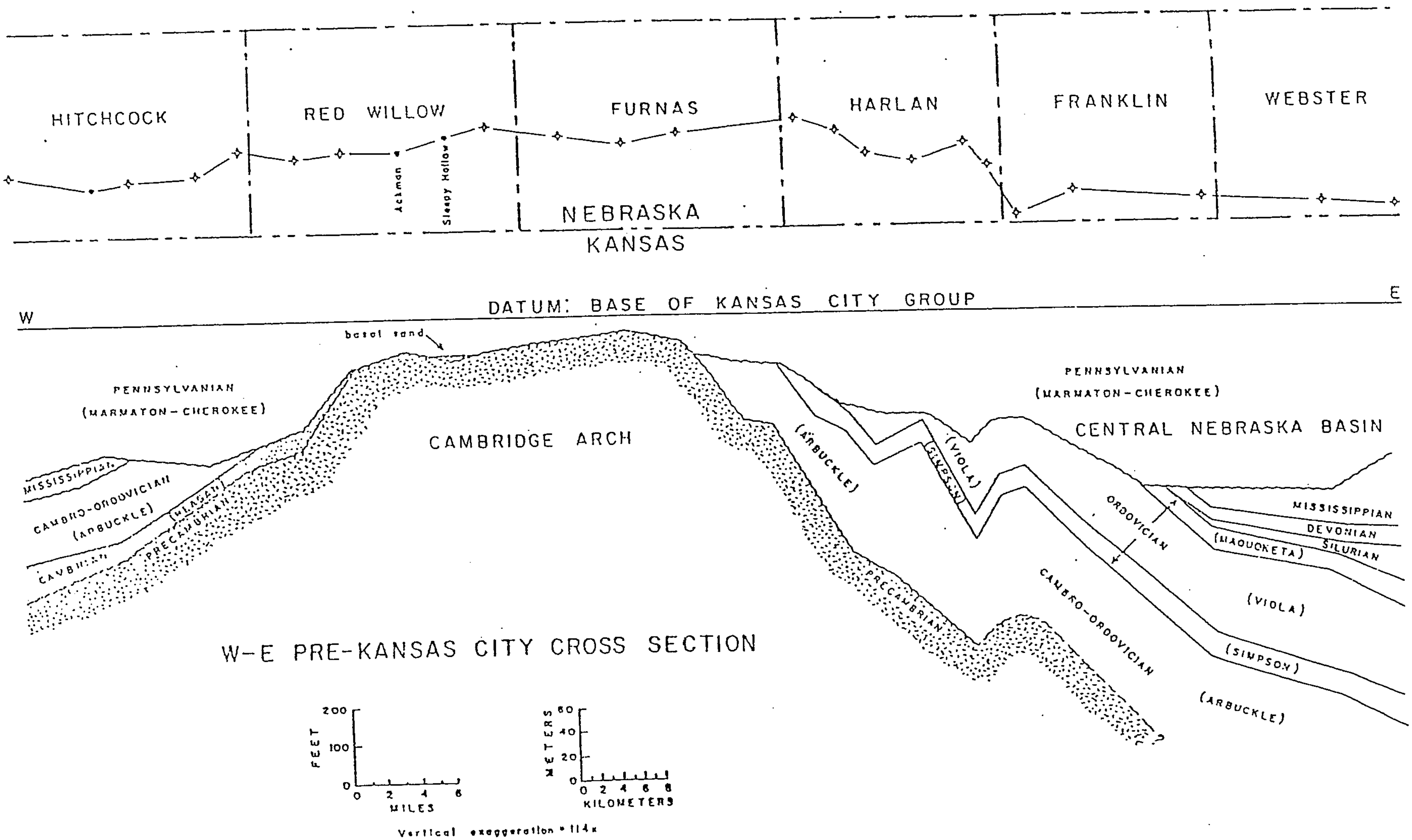


Figure 5. West to East regional cross section in southern Nebraska showing the structure of pre-Pennsylvanian rocks at the beginning of Kansas City deposition (from Busch, 1977, after Larson, 1962).

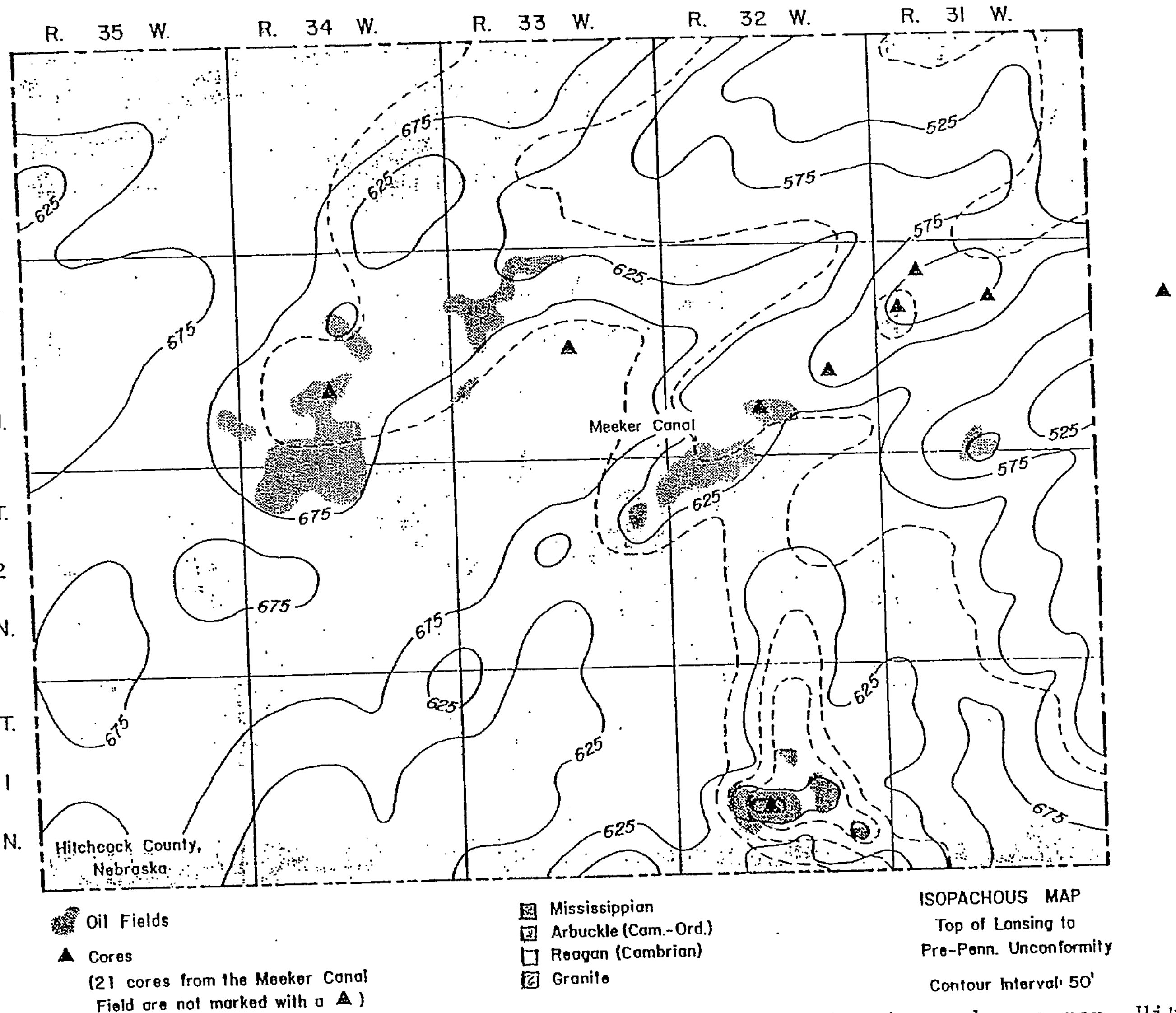


Figure 6. Lansing to pre-Pennsylvanian isopach and pre-Pennsylvanian subcrop map, Hitchcock County. Data from approximately 90 wells that penetrated the pre-Pennsylvanian rocks were used, most formation tops used were those released by the operators.

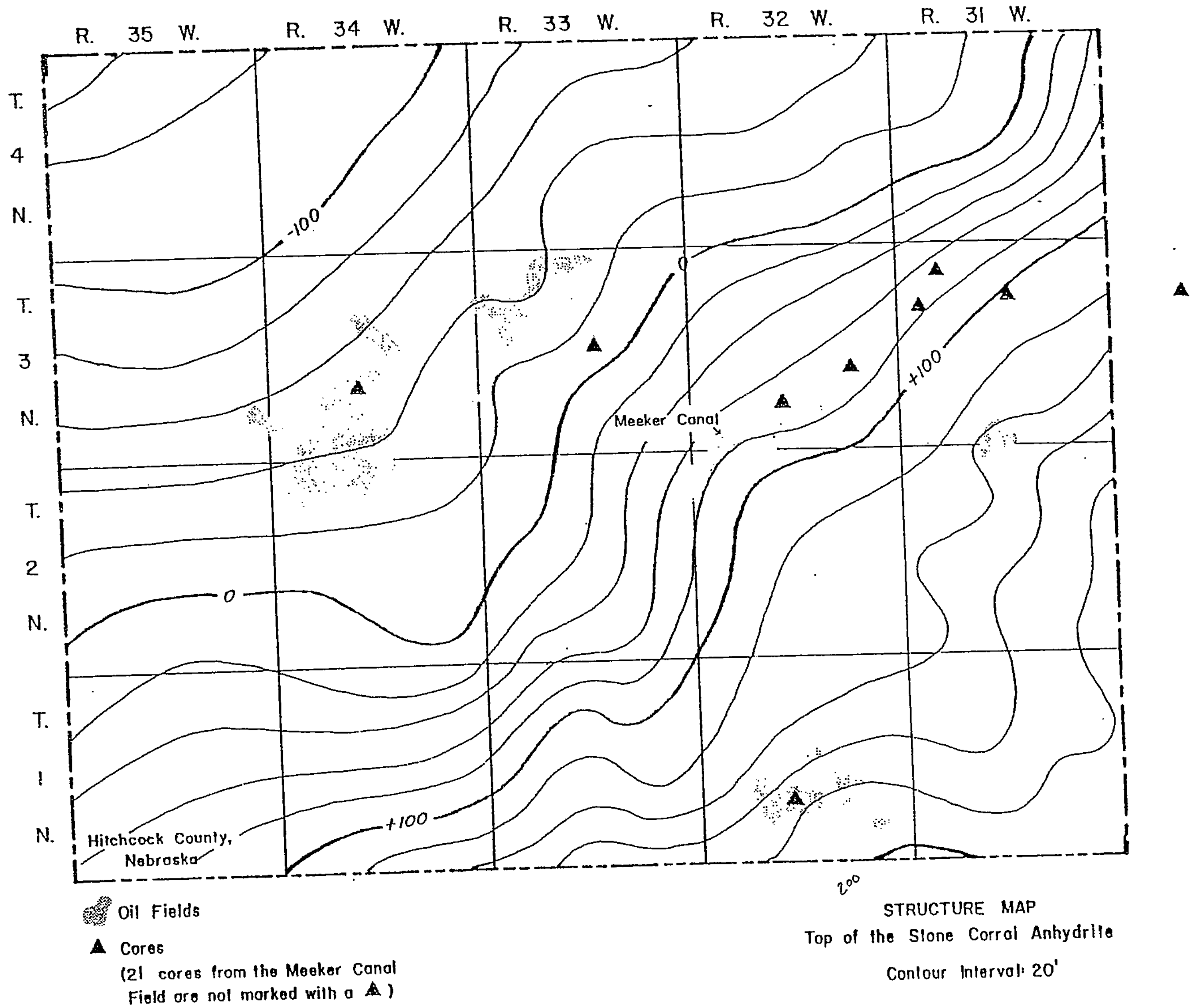


Figure 7. Stone Corral Anhydrite (Permian) structure map Hitchcock County. Formation tops released by the operator from approximately 200 wells were used to construct this map.

mile (1.7 meters per kilometer), supporting Merriam and Atkinson's (1955) suggestion of northwestward regional tilting during the Mesozoic. It is interesting to note the correspondence between the Stone Corral Anhydrite and the Lansing-Kansas City (Fig. 4) structural contours that trend northeastward diagonally across the centers of the maps. The increases of densities of contours on both maps represent a monoclinal flexure and are roughly in line with the axis of the Las Animas Arch (Fig. 3), a predominantly post-Cretaceous structural feature (Lee and Merriam, 1954). This structure may, in fact, be an extension of the Las Animas Arch.

Restoration of the Lansing-Kansas City Topography

The Lansing-Kansas City depositional topography can be estimated by removing post-Lansing-Kansas City structure from the present day Lansing structure using methods outlined by Lee (1954). Before attempting to restore the Lansing-Kansas City structure, two assumptions must be made:

1. The Stone Corral Anydrite was deposited on a horizontal surface, and any variation from the horizontal is a result of tectonism (regional tilting to the northwestward of nine feet per mile, 1.7 meters per kilometer).

2. Thickness change in the Stone Corral Anhydrite to Lansing-Kansas City "B" zone interval indicates regional tilting that took place between the times of deposition of the two units (regional tilting of three feet per mile, 1.13 meters per kilometer, to the southeast).

The summation of the two episodes of regional tilting yields a net tilting of three feet to the mile (1.13 meters per meter) to the northwest, or nearly 100 feet (30 meters) from the southeastern corner to the northwestern corner of Hitchcock County. When 100 feet is added to the Lansing-Kansas City structure (Fig. 4) in the northwestern corner of the map and progressively less is added in a southeasterly direction to the southeastern corner where nothing is added, the Lansing-Kansas City structure is considerably flattened. This reconstruction is of regional scale, and its purpose is to illustrate that the Lansing-Kansas City surface had much lower relief than the present day structure map indicates.

THE "E" ZONE CYCLE

Previous Work

Before the discussion of topography and its influence on the distribution of porosity can proceed, an understanding of the cyclical conditions under which the "E" zone sediments were deposited is necessary. A vast amount of literature deals with Pennsylvanian cyclothems of the Midcontinent. Early workers recognized the transgressive-regressive nature of Pennsylvanian rock sequences (Moore, 1936; Elias, 1937; Weller, 1958). Later work on the Lansing-Kansas City along the outcrop belt in eastern Kansas by Harbaugh (1959), Harbaugh and others (1965), Crowley (1969), Frost (1975), and Heckel (1975a, b, 1977) supported and refined the basic cyclothem theory applied to Kansas by Moore (1936). Watney (1977) and Watney and Ebanks (1978) applied the principles of cyclothemic theory in their work on the subsurface Lansing-Kansas City rocks in northwestern Kansas and southwestern Nebraska. Other than their work, no petrographic work so distant from the eastern Kansas outcrop belt has been published.

General Statement

In Hitchcock County, "E" zone oil is produced from two distinct reservoirs consisting of shallow-water, relatively high-energy carbonate packstones and grainstones that are separated stratigraphically by low-energy, deeper-water marlstones and silty shales. The reservoir rocks were deposited during shallow water episodes in the marine phase of the complex "E" zone cycle. At least three transgressions and three regressions occurred during the marine phase of this cycle. (Transgression and regression are used here to mean the lateral migration of the shoreline in response to an absolute rise or fall in the sea level.) The final

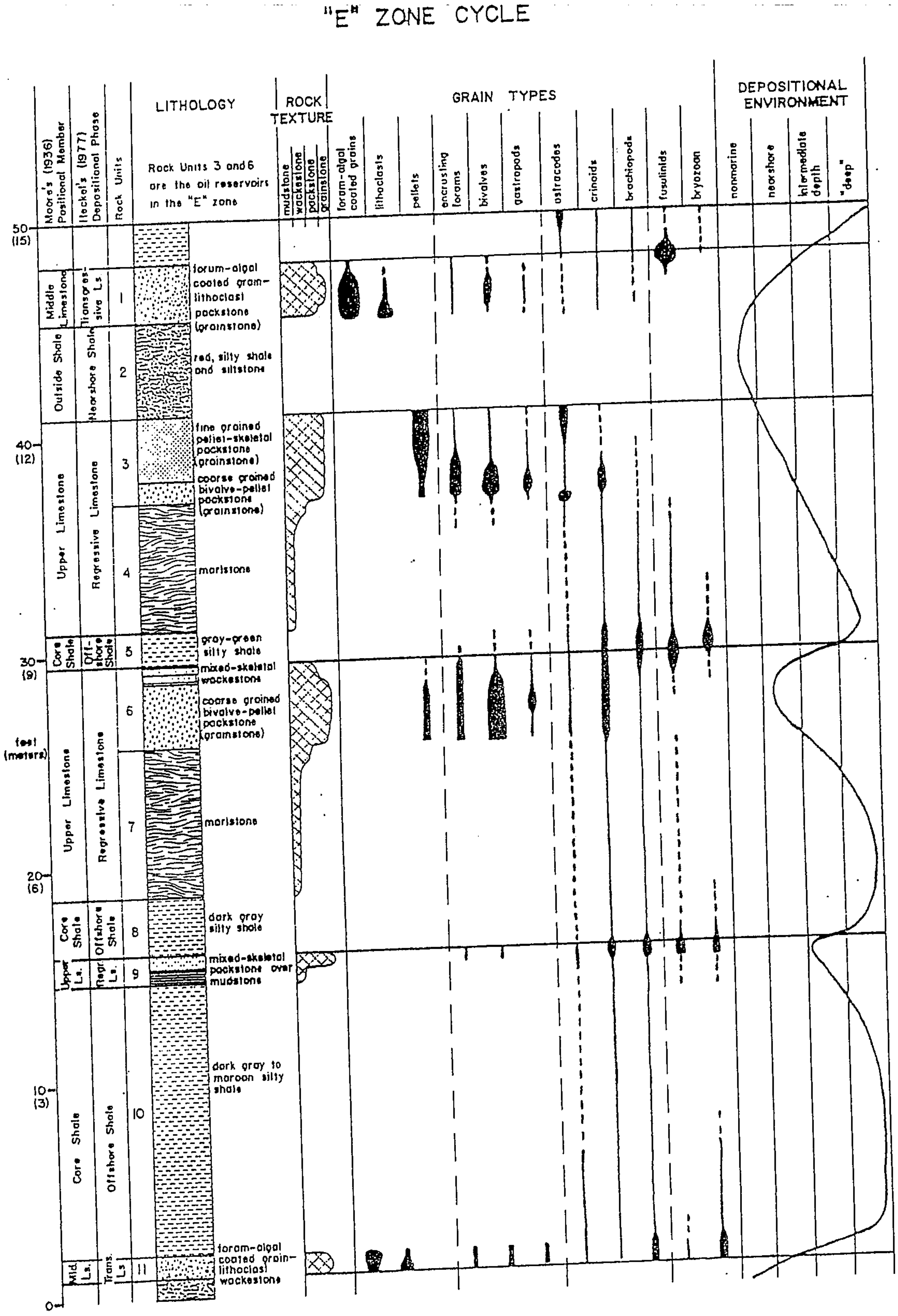


Figure 8. "E" zone cycle of the Meeker Canal Field.

regression culminated in subaerial exposure and deposition of nonmarine terrigenous sediments. An examination of the "E" zone sedimentary cycle (Fig. 8) and its resultant vertical sequence of lithologies is essential for the understanding of the differences between the two reservoirs.

Summary of the "E" Zone Cycle

The rock types and their sequence described in Figure 8 are somewhat different from those of Heckel's (1977) basic cyclothem. Different geographic position on the Midcontinent platform is probably the cause of these variations. The following is a summary of the events that occurred during the deposition of the "E" zone in Hitchcock County:

1. A relatively rapid marine transgression and ensuing deposition of a marine transgressive limestone (Unit 11) was followed by an influx of terrigenous sediment (Unit 10). No black, phosphatic shale, common in the core shales of eastern Kansas (Heckel, 1977) was deposited.

2. This transgression was interrupted by a minor regression and deposition of Unit 9, followed by another transgression.

3. A slow regression was accompanied by a slowdown of terrigenous influx, clearing of the water, and carbonate production resulting in the deposition of marlstone (Unit 7).

4. Further regression and cessation of terrigenous influx resulted in prolific carbonate grain production in a shallow, moderately agitated environment producing the packstones and grainstones in Unit 6.

5. Another relatively rapid transgression ensued, resulting in the deposition of "deeper" water wackestones at the top of Unit 6 and the terrigenous influx and deposition of a silty shale (Unit 5).

6. The marlstone (Unit 4) represents another regression, similar to the one previously described.

7. As the regression continued and terrigenous influx ceased prolific carbonate grain production in a shallow, moderately agitated environment resulted in the deposition of the packstones and grainstones in Unit 3.

8. Further regression resulted in subaerial exposure and deposition of nonmarine sediments. Enhancement of porosity by freshwater leaching of Units 3 and 6 produced the porous reservoir rocks of the "E" zone.

9. Nonmarine deposition ended abruptly with marine transgression and deposition of a transgressive limestone (Unit 1).

A single transgression followed by a slow, continuous regression is an alternative to the interpretation given. The interbedding of terrigenous and carbonate rocks might be explained by the waxing and waning of terrigenous influx. Carbonate production may have occurred during less turbid periods and inhibited during times of increased terrigenous influx. It does appear that carbonate production was curbed by the increased turbidity that must have accompanied the deposition of Rock Units 5, 8, and 10. However, terrigenous influx is thought to have been a result of marine transgression.

The existence of three shoaling upward sequences within one cycle is evidence that there were three distinct regressions. The upper two of the regressive sequences (Rock Units 3, 4, and 5, and Rock Units 6, 7, and 8) are nearly identical. At the base of each is a silty shale which grades upward into a low-energy marlstone. The marlstone increases upward in carbonate mud content and is truncated by shoal-water packstones and grainstones, on what were once positive seafloor features.

Faunal changes that accompany the vertical lithologic changes further support a fluctuating sealevel explanation for the complexities in the "E" zone. Rock Units 3 and 6 are dominated by a shallow-water, slightly restricted faunal assemblage consisting of bivalves, gastropods, and tubular encrusting forams. They also contain substantial amounts of pellets, commonly found in shallow-water carbonate sediments. Deeper-water, normal marine fauna are found in the marlstones and silty shales. Here existed numerous genera of brachiopods, crinoids, bryozoans and fusulinids.

The vertical transition from carbonate rock to terrigenous rock is more rapid than is that from terrigenous rock to carbonate rock. Silty shales are separated from nearly pure carbonate above by marlstones of intermediate composition. On the other hand, the silty shales directly overlie nearly pure carbonate without a transitional marlstone between them. This supports the idea of multiple, rapid transgressions which were followed by slow regressions, assuming that terrigenous sediments were deposited after a transgression and carbonate production was eclipsed as in eastern Kansas cyclothems.

Stratigraphic complexity as a result of changes in sealevel is recognized in rocks equivalent to the "E" zone where they crop out in eastern Kansas. Frost (1975) reported that the Winterset Limestone Member of the Dennis Formation consists of two algal mounds, one on top of the other, separated by an ooid grainstone. He attributed the vertical change from an ooid grainstone, deposited in a shallow, agitated environment, to an algal mound, deposited in a deeper, quiet-water environment, to deepening as a result of subsidence or [absolute] change in sea level.

Conodont distribution in the Lansing-Kansas City at its eastern-Kansas outcrop appears to indicate three distinct transgressions within the Dennis Formation. Heckel and Baesmann (1975) found that the abundance of Idiognathodus was maximum in the core shales and those parts of the middle and upper limestones immediately adjacent to the core shale, all interpreted to be deep water sediments. Furthermore, they found that the black shale facies of the core shale was characterized by the nearly exclusive presence of Gondollela and the less exclusive presence of Idioprioniodus lexingtonensis (Gunnell). Their data shows three distinct peaks of conodont abundance, one in the black shale facies of the core shale and the other two in the lower half of the Winterset Limestone. The peaks of abundance primarily reflect the abundance of Idiognathodus, and Idioprioniodus l. was found only in those intervals corresponding with the three peaks. Gondollela was only found in the black shale facies, the interval corresponding with the lowest peak of abundance. Their illustration implies that they interpreted the three peaks as comprising a single core. It is my contention that these three peaks indicate three separate cores representative of three distinct transgressions within the Dennis Formation.

Idealized Facies Belts

The vertical lithologic sequence is the result of lateral migration of facies belts in response to fluctuations of sea-level. Walther (1894) first linked vertical lithologic change to the lateral migration of depositional environments, a concept that has been applied extensively in the study of cyclic sedimentation. An idealized sequence of facies belts is shown in Figure 9. This is a modified version of models proposed by Irwin (1965) and Wilson (1970, 1974, 1975).

As in Irwin's model, most wave agitation, of the sea floor is concentrated in a narrow belt some distance from the shoreline. This is

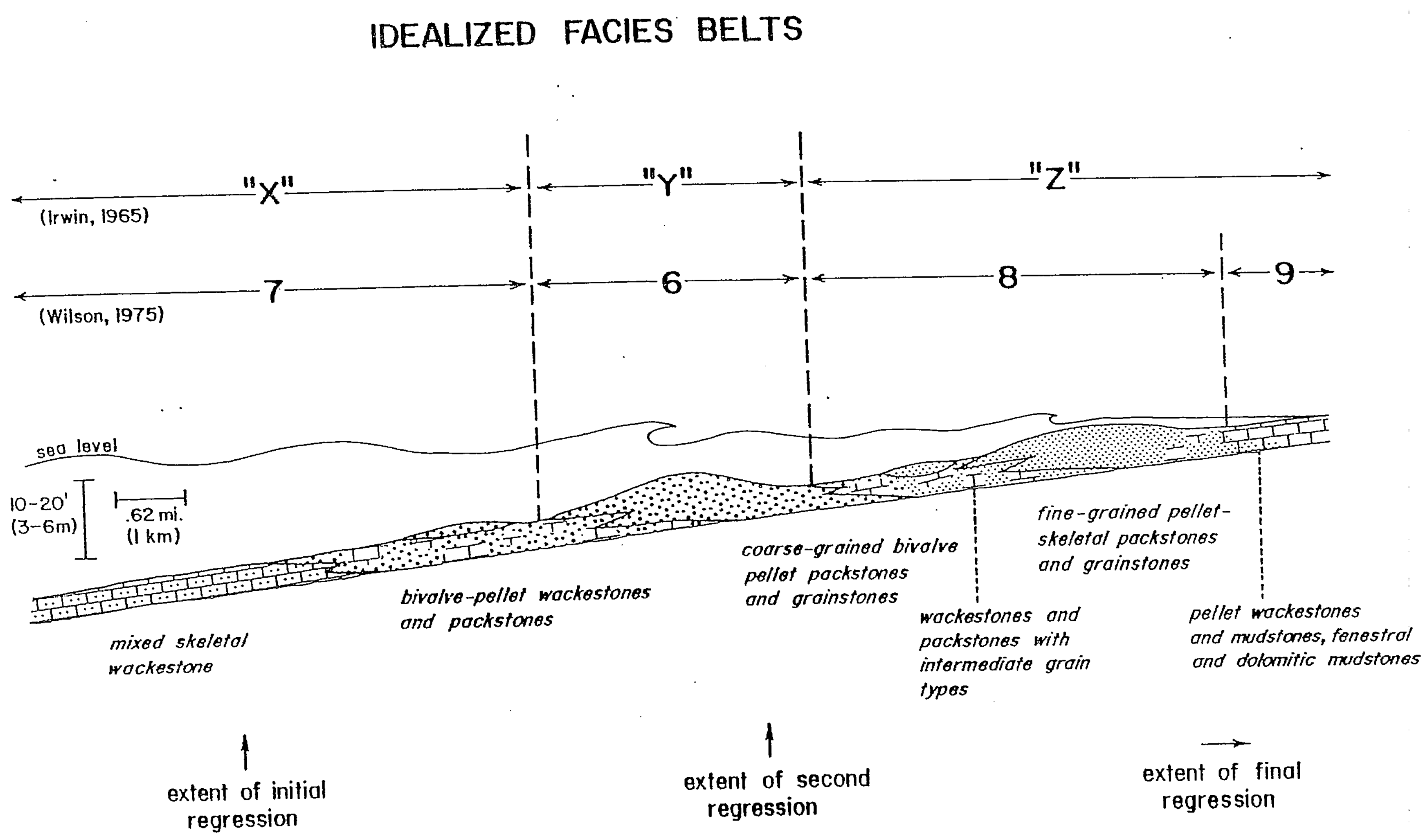


Figure 9. Idealized facies belts envisioned to have been present in Hitchcock County, Nebraska, during the deposition of the Lansing-Kansas City "E" zone.

where maximum organic activity and grain production occur and well-washed carbonate sands are deposited, the environment in which the coarse-grained packstones and grainstones of Unit 3 and Unit 6 presumably were deposited. Landward, the fauna is slightly restricted. The fine-grained packstones of Unit 3 were believed to have been deposited at or near the shoreline as a moderately washed lagoon-beach or shoal deposit with its sediment (pellets and fine-grained skeletal material) being derived from the area immediately seaward.

The model illustrated in Figure 9 is idealized and could only have existed if the sea floor had only low relief and was sloping. If the regression was gradual and continuous, one could expect to find a nearly perfect vertical sequence of lithologies as the result of laterally migrating facies belts. In Hitchcock County, the necessary conditions for an ideal vertical sequence did not occur. The model is complicated by the effects of topography on water depth and energy conditions and the complexity of the cycle, interruption of regression by minor transgressions. The result is a less than ideal, complex vertical sequence of lithologies.

PALEOTOPOGRAPHY

Paleotopography is used here to mean the relative difference in elevation between two points, whether it be on the seafloor, where paleobathymetry would be a more correct term, or on an exposed land surface, where paleotopography is the correct term. I have chosen to use paleotopography alone to avoid confusion that may have come about had I chosen to use both terms.

Thickness of nonmarine sediment, rock Unit 2, is used here as an indicator of relative topography. Eolian silt and clay was carried by sheetwash, more wind, and intermittent alluvial streams into topographic lows. Accumulation of sediment in relatively low areas resulted in a reduction of topographic relief. The difference in thickness over a distance of up to a few miles is presumed to be an accurate estimate of the minimum relief between two points.

Porosity and oil production from the "E" zone correspond well with the topographically high areas, indicated by thin areas on the isopachous map of the nonmarine sediments (Fig. 10). All significant "E" zone production is within the area enclosed by the 10 foot contour, and most is confined to areas with less than five feet of nonmarine sediments. The "E" zone is one of the major producing zones in the Dry Creek, North Dry Creek, Meeker Canal, and Culbertson Fields (see Fig. 3 for location of fields). Not all areas within the 10 foot thickness contour are productive, the Republican River Field which produces "F" zone oil is an example, but the correspondence between thinning of the nonmarine sediments and "E" zone production appears to be more than a mere coincidence.

Similar occurrences of thinning in this same interval have been recognized by Watney (1979, personnel communication) in Rawlins County,

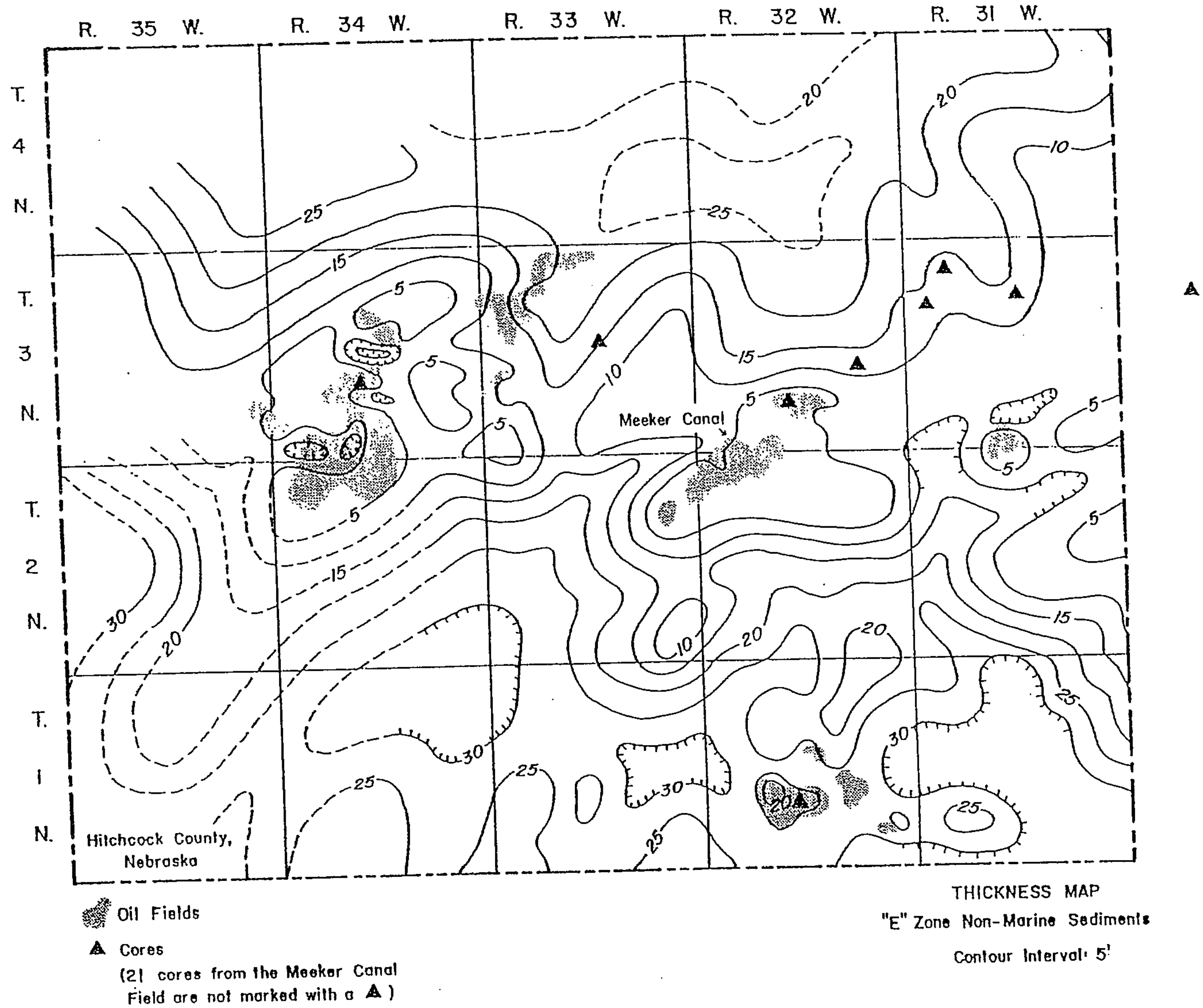


Figure 10. Nonmarine sediment thickness map, Hitchcock County. Data from 30 cores and 220 mechanical well logs (mostly radio-activity logs) were used in constructing this map. All significant "E" zone production falls within the 10 foot contour, most within the 5 foot contour.

Kansas, adjacent to Hitchcock County on the south. There are two thin areas: one in the Cahoj Field, northern Rawlins County, which is situated atop a prominent structure similar to that in the Reiher Field, and one in the southern part of the county over what is interpreted as a phylloid algal mound. W.L. Watney (personal communication, 1978) believed the topography was a result of structure in the Cahoj Field, but was related to depositional topography where thinning occurred over a carbonate mound. Separating structural from depositional relief is difficult because the second is often related to the first and the total topographic relief is usually a combination of both kinds of relief. It is conceivable that only minor thickening (10 feet, 3 meters) of the marine sediments would have a profound influence on topography in a setting where total relief is on the order of 20-30 feet (6-9 meters).

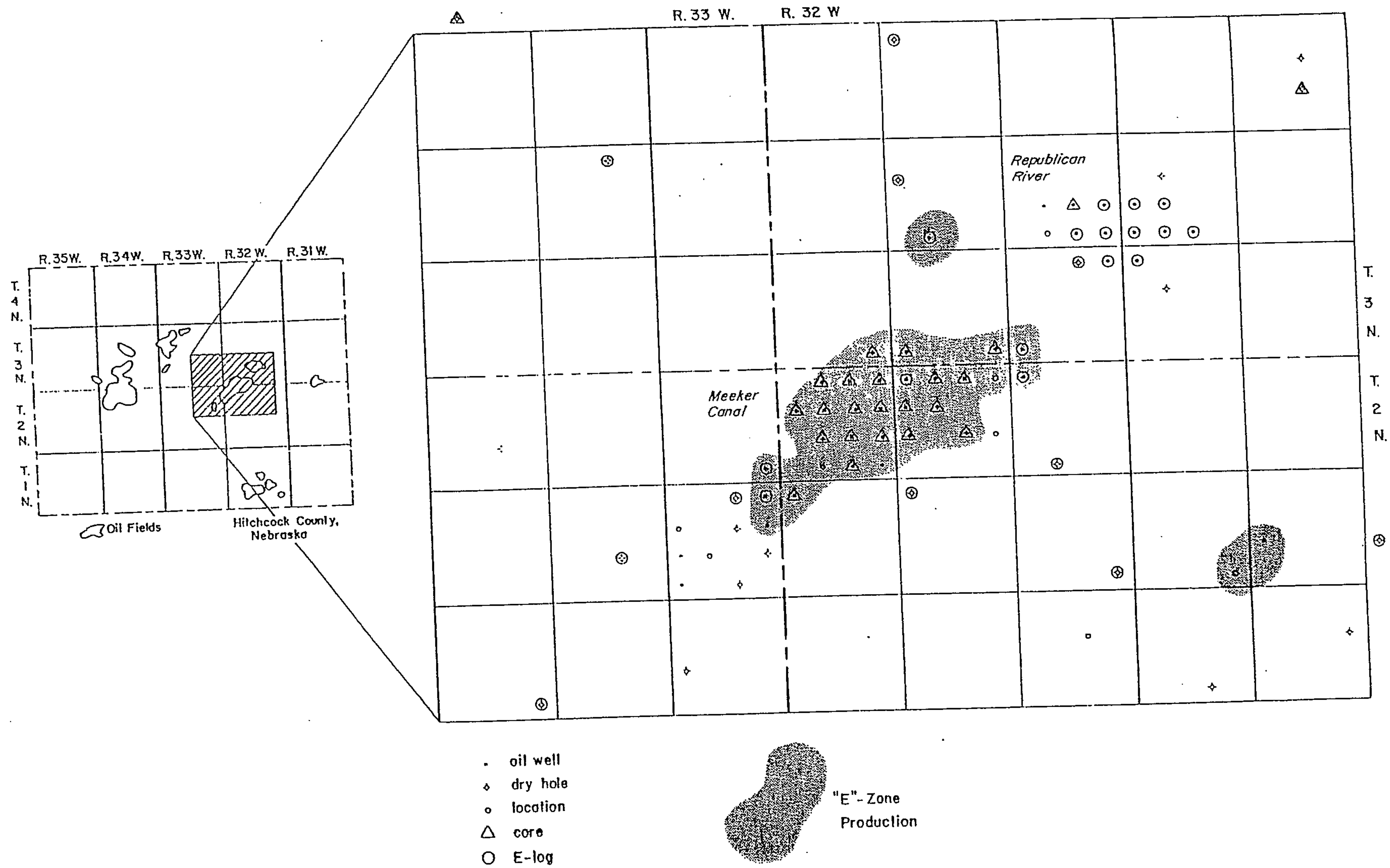


Figure 11. Index map showing area of Hitchcock County covered by maps in Figures 12 through 17.

RELATION OF FACIES TO PALEOTOPOGRAPHY

General Statement

The following is a discussion of the facies changes in the three upper regressive carbonate units of the "E" zone (Units 3, 6, 9). Units 3 and 6 will be discussed in more detail than Unit 9 because they are the oil productive intervals. The discussion will be centered around the Meeker Canal Field because of the abundant core control (Fig. 11). Production of oil from the "E" zone in this area is restricted to the Meeker Canal Field and two 1978 discovery wells (1 mile north and 2-1/2 miles southeast of the Meeker Canal Field). Figure 12 is a thickness map of the nonmarine sediments in the area and should be compared with later thickness, porosity, and facies maps.

Units 3 and 6, the two oil producing intervals in the "E" zone, were deposited in shallow water during two separate marine regressions in the complex "E" zone cycle. They show considerable facies changes in contrast with the other marine rock units deposited in deeper marine water, which show very little lateral variation. Since rock Units 3 and 6 were deposited in relatively shallow water, topography had a considerable influence on the prevailing energy conditions. During the deposition of the deeper-water rock units the seafloor was below wave base even on topographically high areas.

Thickness, Porosity, and Facies Maps

Rock Unit 6 is more variable and, in many wells, more porous than rock Unit 3. Unit 6 thickens and thins rather abruptly in the Meeker Canal Field (Fig. 13), where it thickens from two to six and one-half feet (0.6 to 2 meters) in less than a mile (1.6 kilometers). The

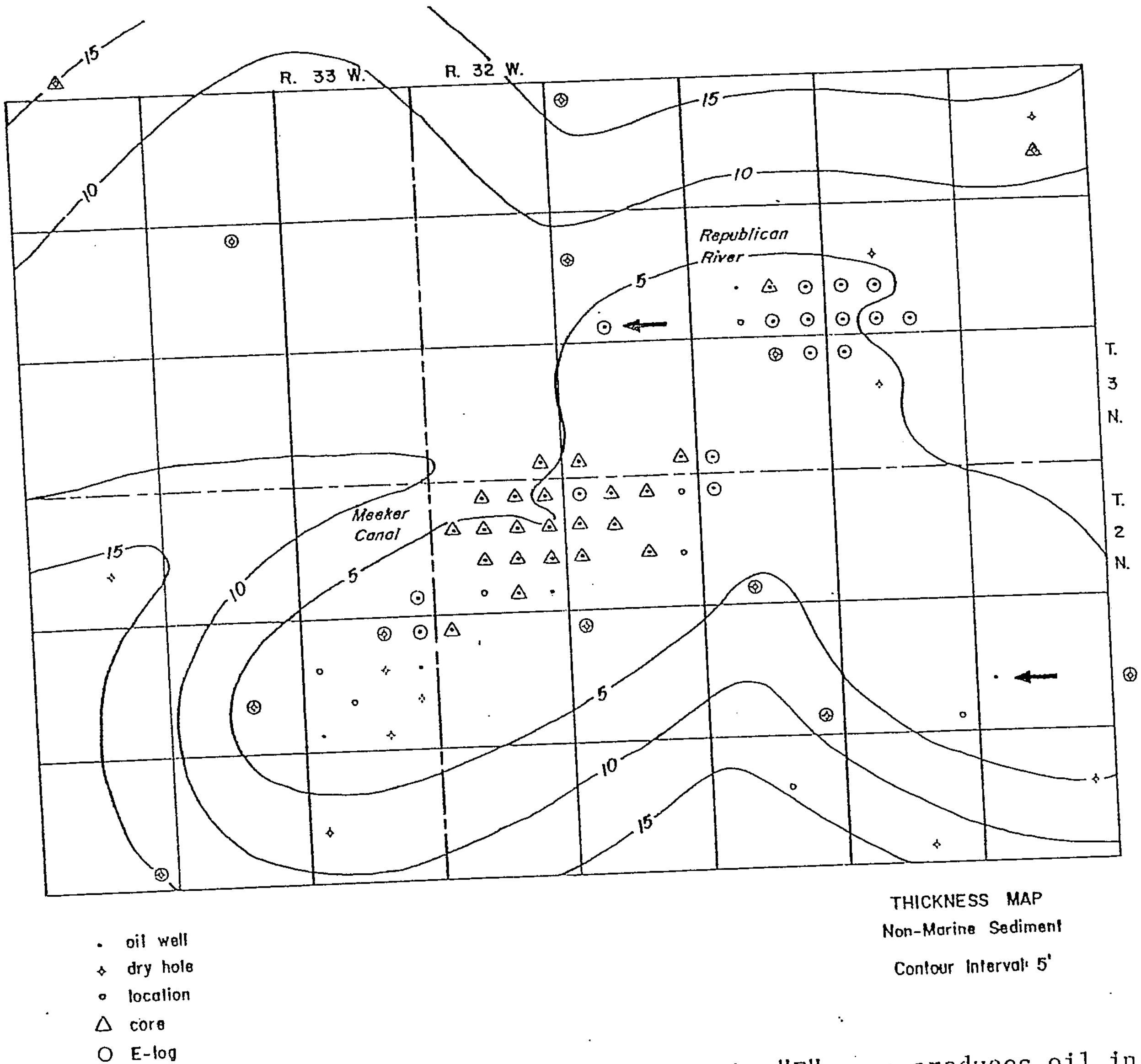


Figure 12. "E" zone nonmarine sediment thickness map. The "E" zone produces oil in the Meeker Canal Field and two recent unnamed discoveries (arrows). The Republican River Field produces oil from the "F" zone.

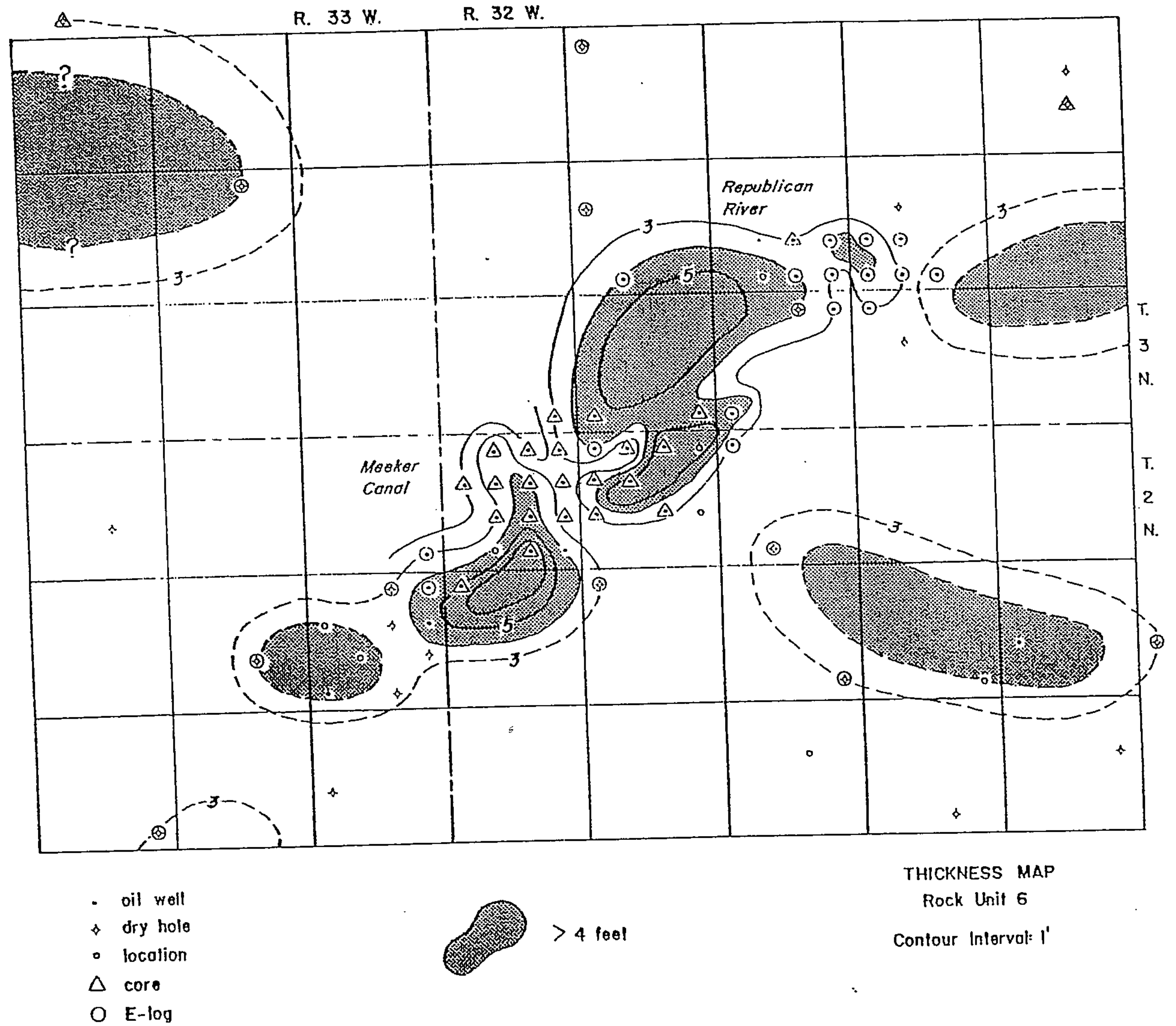

R. 33 W.
R. 32 W.
T. 3 N.
T. 2 N.
Republican River
Meeker Canal
3
5
?
oil well
dry hole
location
core
E-log
> 4 feet
THICKNESS MAP
Rock Unit 6
Contour Interval: 1'

Figure 13.

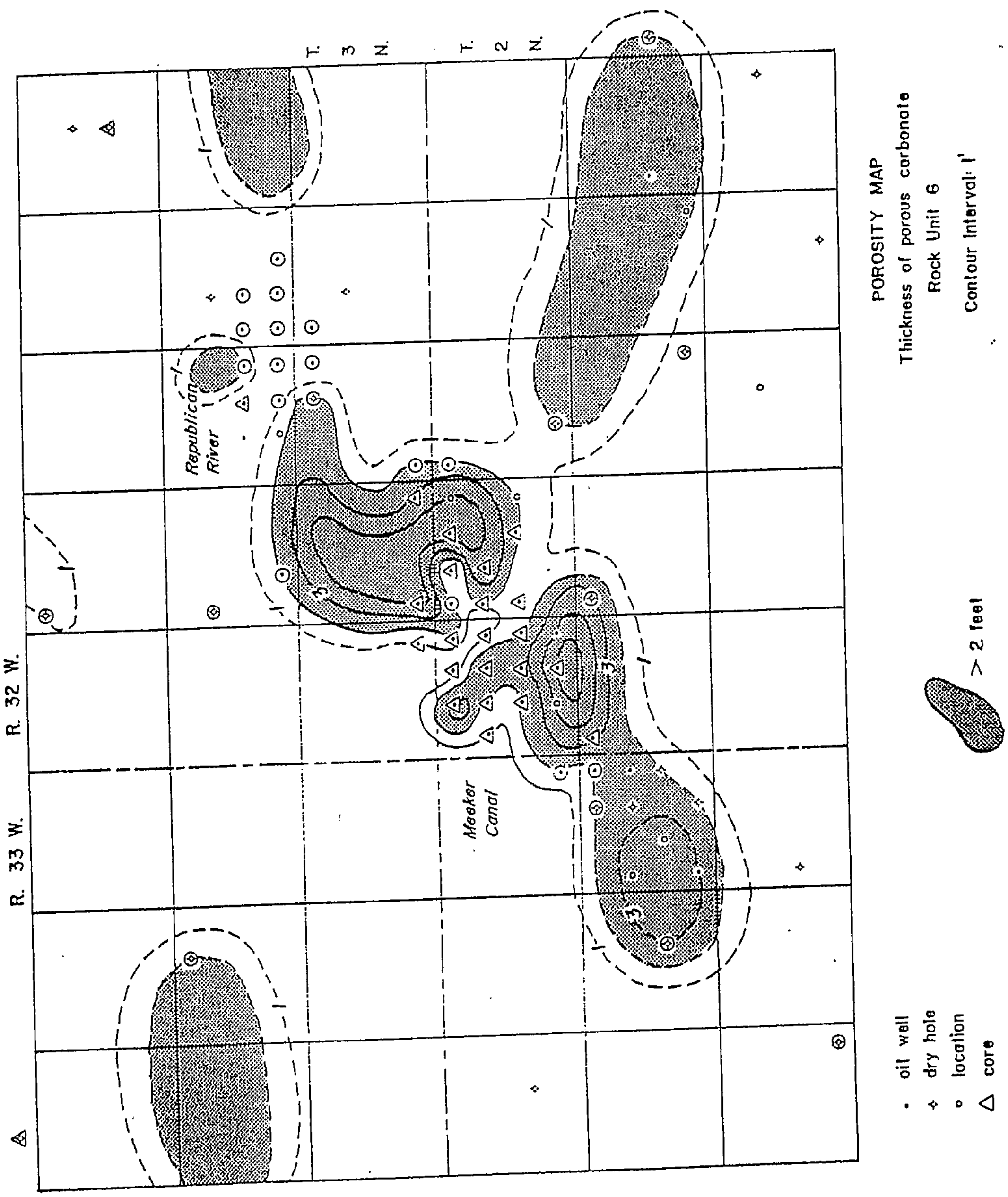

R. 33 W.
R. 32 W.
T. 3 N.
T. 2 N.
Republican River
Meeker Canal
oil well
dry hole
location
core
E-log
> 2 feet
POROSITY MAP
Thickness of porous carbonate
Rock Unit 6
Contour Interval: 1'

Figure 14.

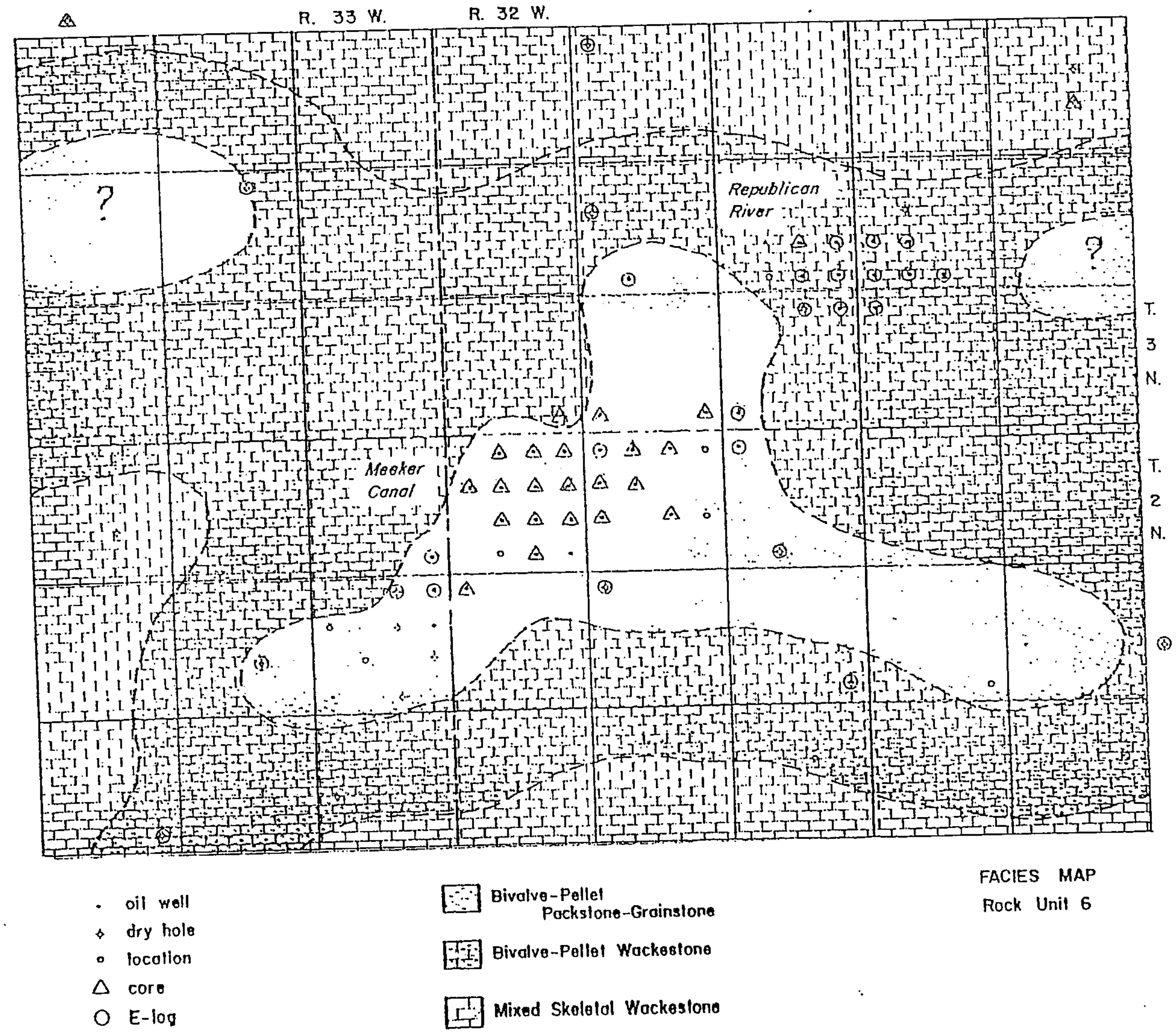

R. 33 W.
R. 32 W.
T. 3 N.
T. 2 N.
Republican River
Meeker Canal
?
?
oil well
dry hole
location
core
E-log
Bivalve-Pellet Packstone-Grainstone
Bivalve-Pellet Wackestone
Mixed Skeletal Wackestone
FACIES MAP
Rock Unit 6

Figure 15.

thickest areas consist of porous packstones and grainstones (see Figs. 14 and 15). The thickening is a result of the accumulation of coarse skeletal grains, primarily bivalves, and, to a lesser extent, pellets, in a shallow water, moderately high-energy environment. It is believed that these grains accumulated essentially in place as a biostromal deposit on topographic highs. These topographic highs were better agitated and more suitable environments for organic productivity than surrounding lows. Carbonate mud was washed from these sediments by wave action resulting in a grain-supported texture.

Thickening in rock Unit 3 (Fig. 16) is less dramatic than in Unit 6, and two things must be considered when attempting to interpret this thickening. First, the upper surface has been eroded. Second, Unit 3 is quite often deeply weathered, particularly in lows, and the expression of this weathered zone on radioactive logs is very much like that of the overlying nonmarine rocks, making the contact between these two difficult to decipher. For these reasons, the thickness of this unit, as recognized on radioactive logs, is to be considered a minimum thickness. As is the case with rock Unit 6, the thickness of porous limestone (Fig. 17) corresponds well with the thickness of the rock (Fig. 16). There is less lateral variation in facies in this unit than in Unit 6 within the area covered by previous maps so no facies map is shown. It is predominantly a fine-grained pellet-skeletal packstone. The local thickening of this unit may be due to piling of sediment on a beach or in a very nearshore shoal environment, a result of more rapid production of carbonate grains production locally or was a function of time, assuming the highest areas topographically would have been exposed to higher energy conditions for a longer period than low areas would. Whatever the reason for this

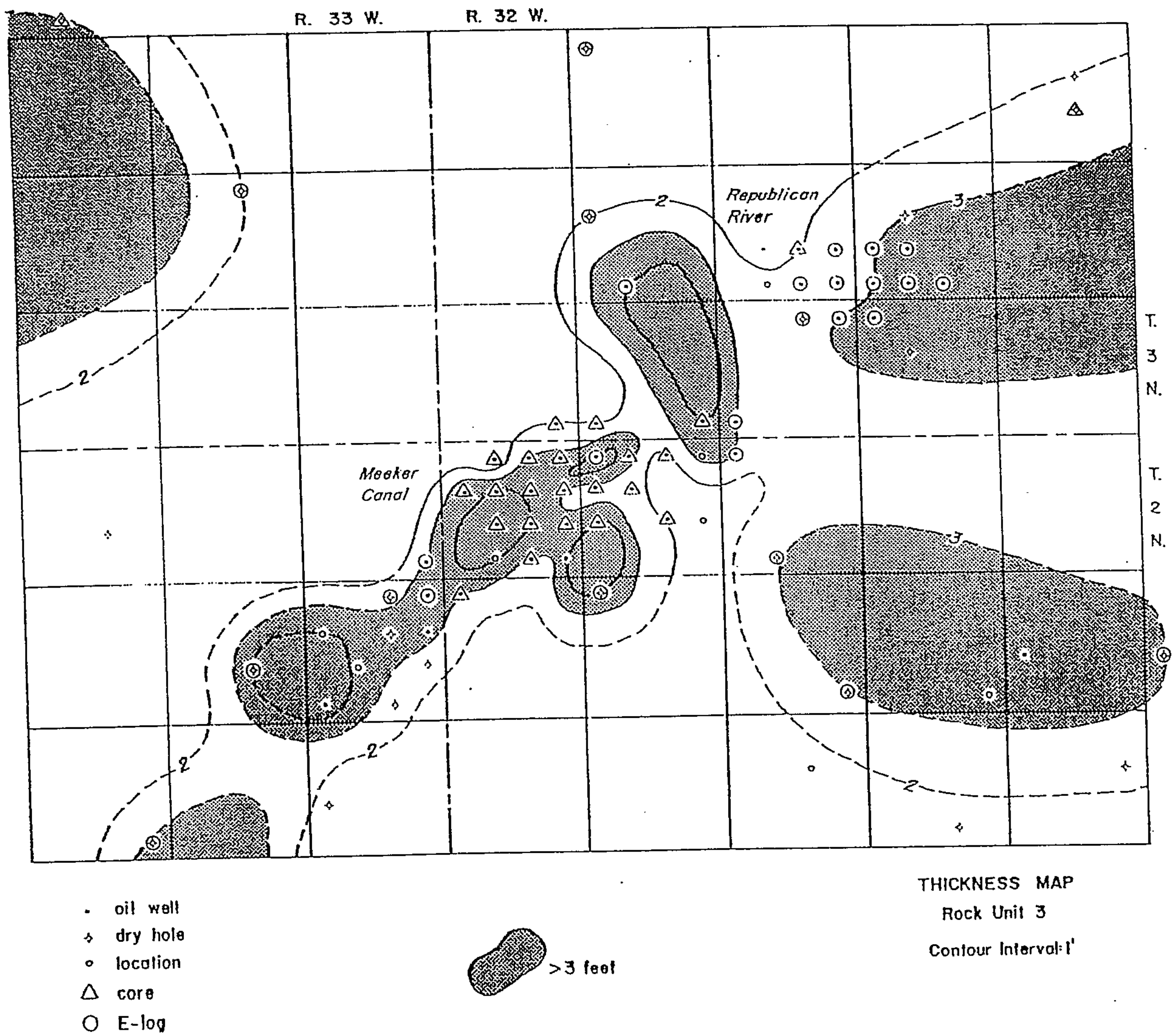

R. 33 W.
R. 32 W.
T. 3 N.
T. 2 N.
Republican River
Meeker Canal
2
3
oil well
dry hole
location
core
E-log
>3 feet
THICKNESS MAP
Rock Unit 3
Contour Interval: 1'

Figure 16.

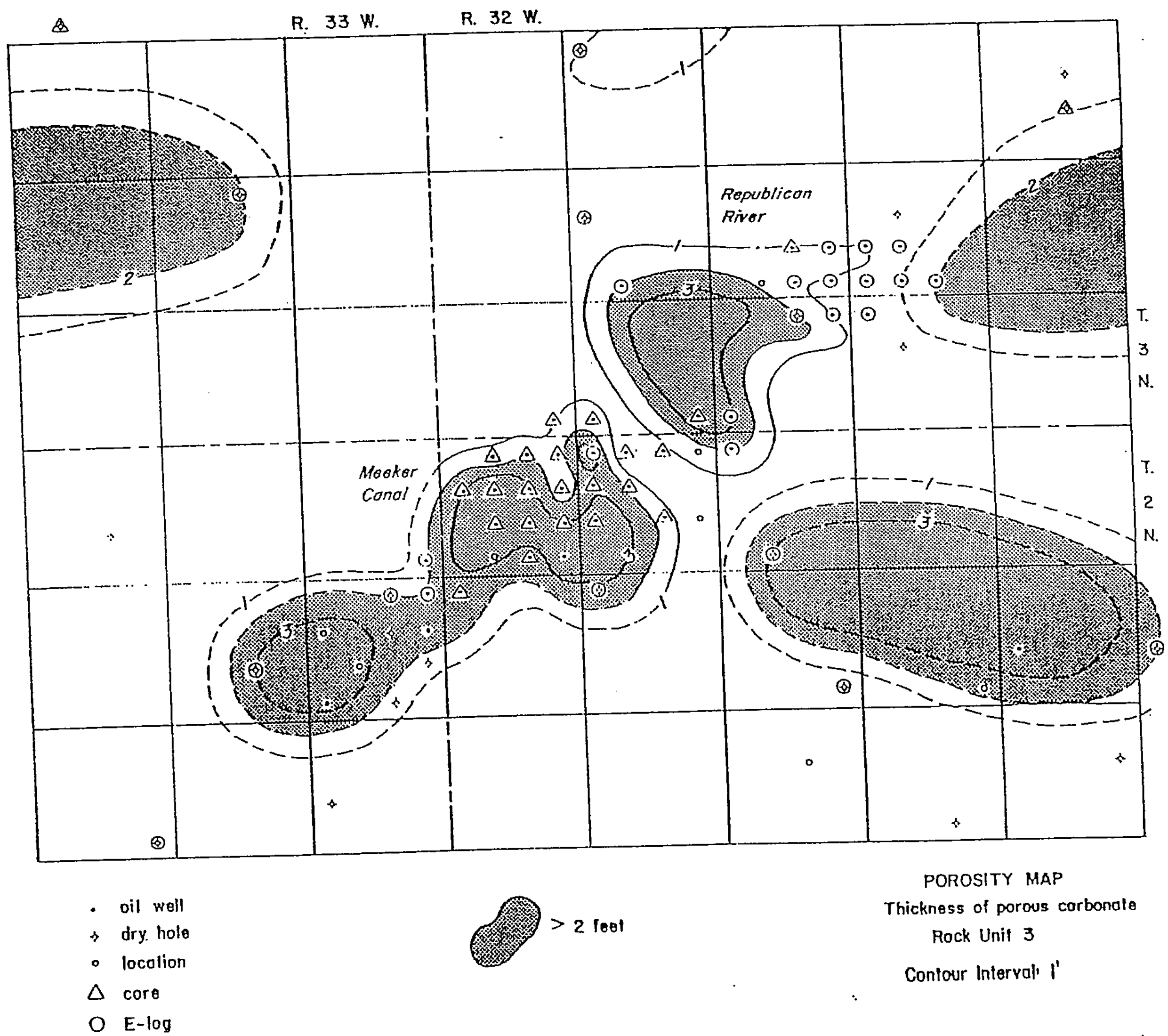

R. 33 W.
R. 32 W.
T.
3
N.
T.
2
N.
Republican
River
Meeker
Canal
oil well
dry hole
location
core
E-log
> 2 feet
POROSITY MAP
Thickness of porous carbonate
Rock Unit 3
Contour Interval 1'

Figure 17.

thickening, topography (illustrated in Fig. 12) was evidently the controlling factor.

Facies Changes

An east-west stratigraphic cross section illustrates the complexity of the "E" zone (Fig. 18). Interpretations are most reliable in areas of close core control, Meeker Canal Field and areas to the northeast. The datum for this cross section, the base of Unit 1, was chosen because this presentation is believed to illustrate the minimum topography of the marine sedimentary rocks.

Unit 3 has the least lateral variability of the three upper regressive limestone units (Units 3, 6 and 9). The widespread distribution of a single facies, fine-grained pellet-skeletal packstone-grainstone, is a result of lateral migration of environments during the regression of the Midcontinent sea, and to a lesser extent progradation. The fine-grained pellet-skeletal packstone (locally grainstone) (Figs. 19A, B) varies considerably in carbonate mud content and in the ratio of pellets to fine skeletal grains. The ratio ranges from nearly all pellets to nearly all skeletal grains. The difference in relative abundance of the two graintypes is attributed to minor paleoecological differences that are not easily interpreted or documented. It is convenient to lump all fine-grained packstones together and to interpret them as having been deposited in shallow, slightly restricted, moderately agitated lagoonal-beach or shoal environments. Wackestones accumulated in areas that were agitated less by waves. Fenestral mudstones (Fig. 19C) and dolomitic mudstones in a few cores were probably deposited in tidal pools or on mud flats.

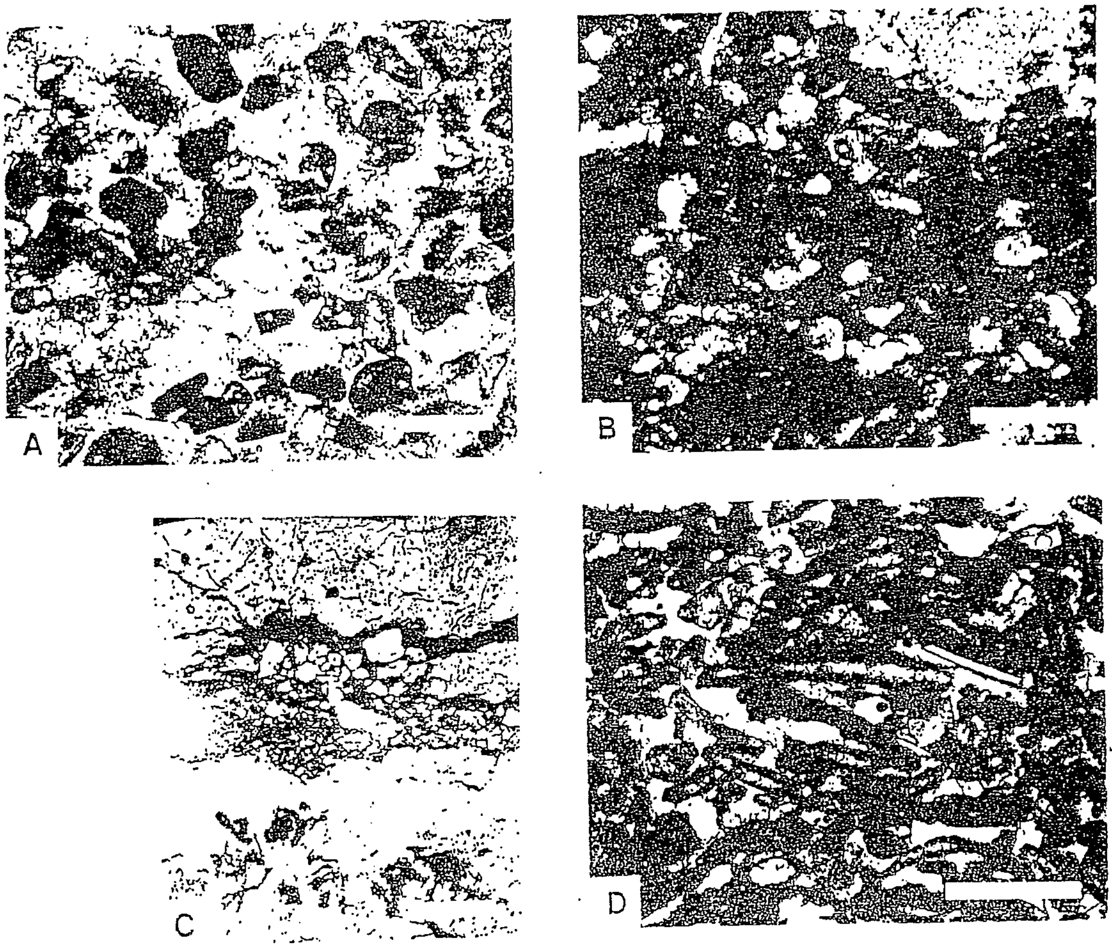
Figure 19. Facies of Rock Unit 3. See Appendices for sample identification.

A. Fine-grained pellet-skeletal grainstone. Dark grains are pellets, light grains are skeletal fragments. (Scale is 0.2 mm. plane light)

B. Fine-grained sandy pellet packstone. Most light grains are fine quartz sand. (Scale is 0.2 mm. plane light)

C. Slabbed core of fenestral mudstone and collapse breccia. Green shale fills areas between breccia fragments. (Scale is 2 cm.)

D. Coarse-grained bivalve-pellet grainstone. Elongate grains are bivalve fragments. (Scale is 1 mm. cross-polarized light)


A
B
C
D

In the Meeker Canal Field area and to the west along the cross-section in Figure 18, the fine-grained packstone of Unit 3 grades rapidly downward into a coarse-grained bivalve-pellet packstone-grainstone (Fig. 19D). This coarse-grained facies is very similar to the coarse-grained reservoir rock in Unit 6 and is interpreted to have been deposited in a moderately high energy environment in somewhat deeper water than the fine-grained rocks above it were deposited.

The coarse-grained packstones and grainstones of Unit 6 (Fig. 20A) in well number 3 of the east-west cross section, grades laterally into a wackestone (Fig 20B) with similar slightly restricted fauna, such as bivalves, gastropods, and encrusting forams, which in turn grades laterally, downslope, into a mixed skeletal wackestone (Fig. 20C) containing normal-marine fauna, such as brachiopods, fusulinids, and ramose bryozoan. This same facies onlaps the coarse-grained packstones and grainstones in well number 3 in a fashion indicative of a rise in sea level. Mixed skeletal wackestone is also the dominant facies of the very thin Unit 6 in the Reiher #2 well.

Unit 9 is thin, yet laterally persistent. In wells to the west and south it consists of thin mudstone overlain by mixed skeletal wackestone-packstone (Fig. 21A, B). An abrupt, scoured surface separates the two rock types, whose total thickness is as little as one foot (0.3 meters). To the east, this unit grades rapidly into a phylloid algal wackestone (up to three feet, 1 meter thick) (Fig. 21B). Unit 9 in well number 8 has some mixed skeletal packstone and in well number 9 it consists of a silty carbonate mudstone.

The contacts between higher-energy, grain-supported rocks of Units 3 and 6 and lower-energy, mud-supported rocks below (Fig. 22) and the

Figure 20. Facies of Rock Unit 6. See Appendices for sample identification.

A. Coarse-grained bivalve grainstone. Cement is quartz druse. (Scale is 1 mm. cross-polarized light)

B. Bivalve-pellet wackestone. Bivalve molds are filled with calcite cement. (Scale is 1 mm. cross-polarized light)

C. Slabbed core of mixed skeletal wackestone with whispy green shale laminae. (Scale is 2 cm.)

D. Photomicrograph of C (mixed skeletal wackestone). (Scale is 1 mm. plane light)

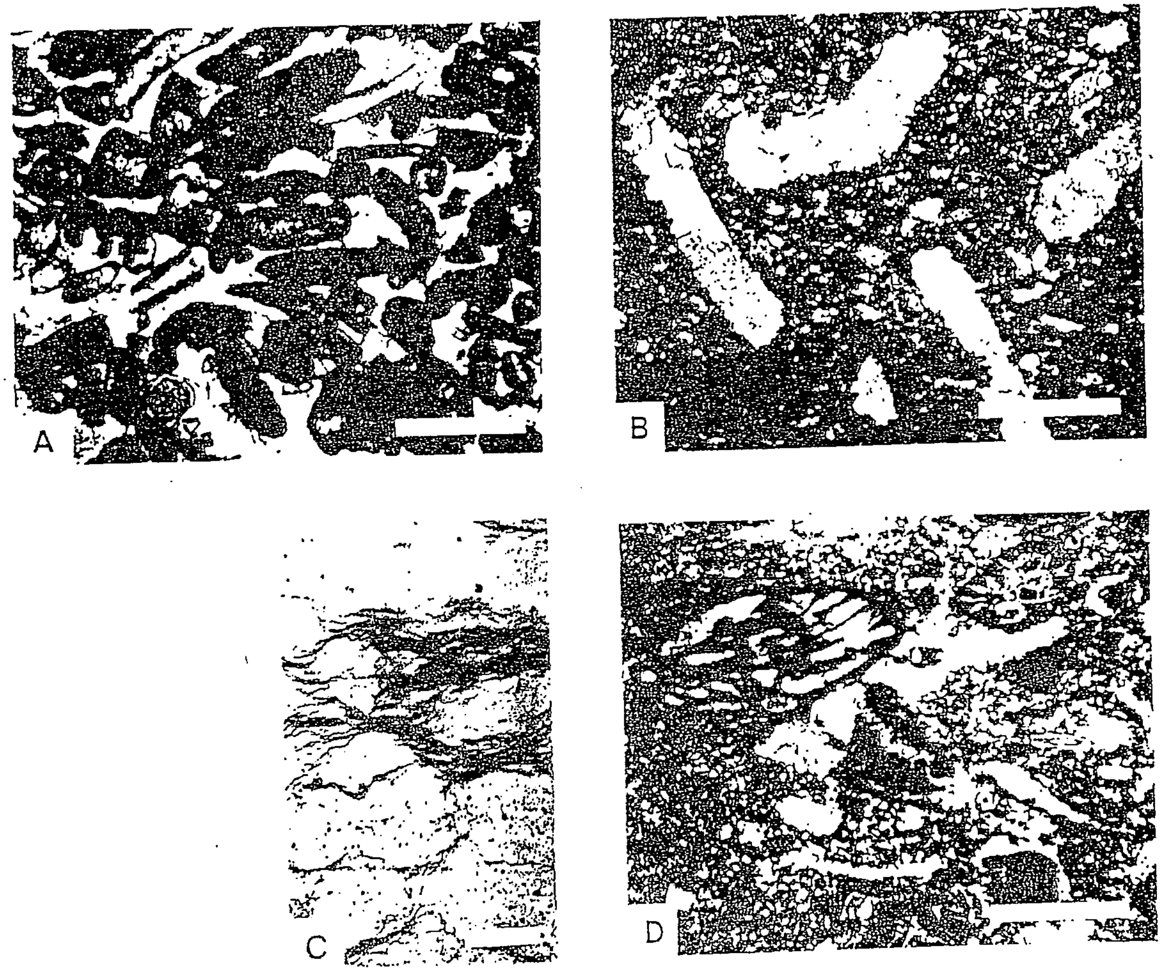

A
B
C
D

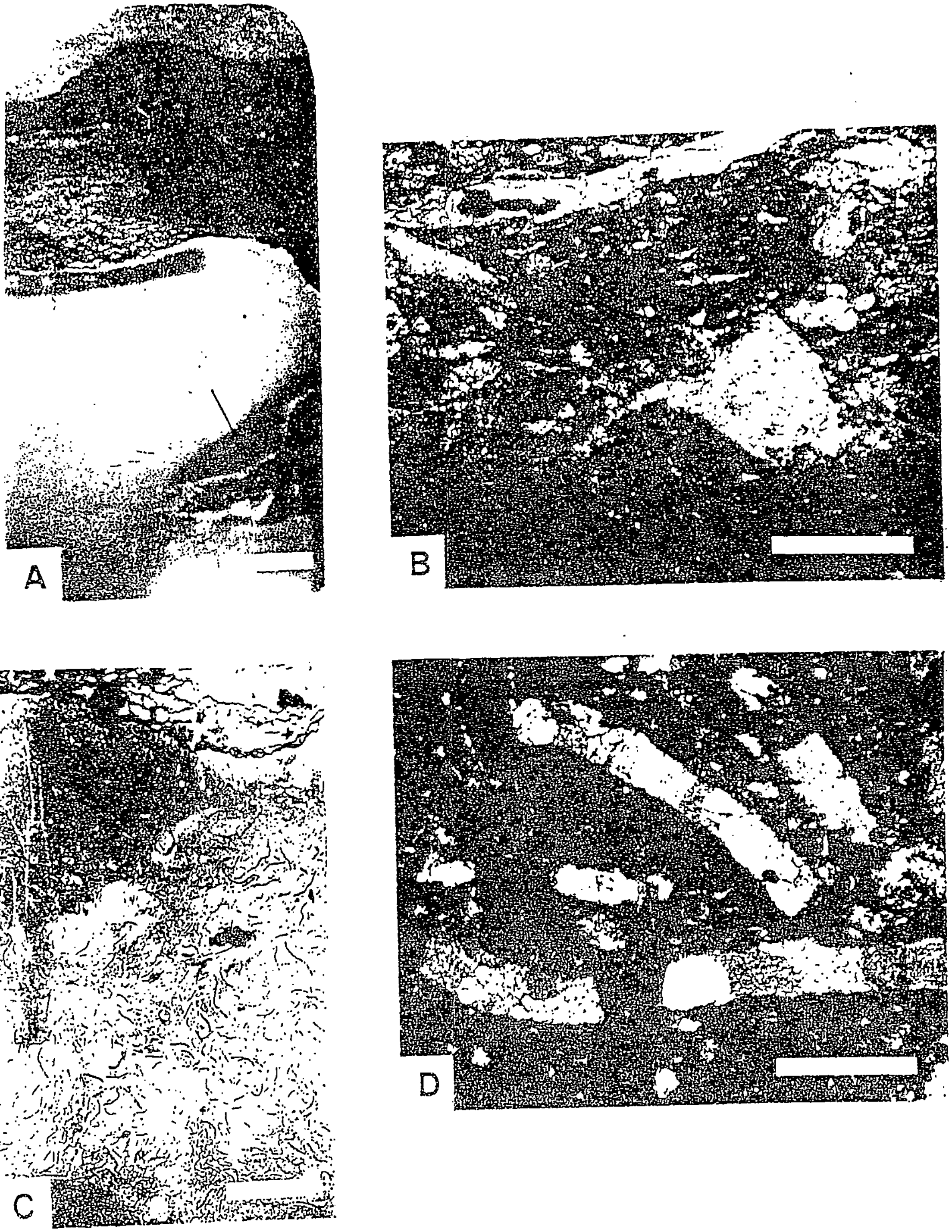
Figure 21. Facies of Rock Unit 9. See Appendices for sample identification.

A. Slabbed core of mixed skeletal wackestone (darker) overlying a silty mudstone (lighter). A burrow (arrow) in the mudstone is filled with skeletal material from the overlying mixed skeletal wackestone. (Scale is 2 cm.)

B. Photomicrograph of A at the contact between wackestone and mudstone. (Scale is 1 mm. plane light)

C. Slabbed core of phylloid algal wackestone. (Scale is 2 cm.)

D. Photomicrograph of C. Algal blade molds are filled with calcite cement. (Scale is 1 mm. cross-polarized light)


A
B
C
D

contact between the wackestone and underlying mudstone in Unit 9 (Fig. 21A, B) indicate a rapid environmental change and possibly a rapid drop in sea level. The contacts are scoured surfaces with vertical burrows that extend into the underlying mud-supported sediments and are filled with skeletal grains derived from the overlying carbonate sands. The carbonate sands deposited in relatively high-energy environments which migrated laterally over areas previously dominated by low-energy environments. The migration of the high energy environment is presumed to be in response to lowering of sea level during the regressive phases of the complex "E" zone cycle.

The deeper water marine rock units (4, 5, 7, 8 and 10) vary little in facies but thicken and thin. Units 7 and 8 thicken considerably westward, and this thickening is coincident with thinning in the nonmarine rock Unit 2. This thickening may have contributed to the topography at the time of deposition of the overlying carbonate rock units. Thickening in this interval is also apparent on radioactive well logs north and south of the Meeker Canal Field. Note the thinning of this interval in the Reiher #2 well.

Rock Unit 10 thickens eastward, and the combined interval of rock units 4 and 5 thickens to the west. This particular interval thickens even more to the southwest of well #1.

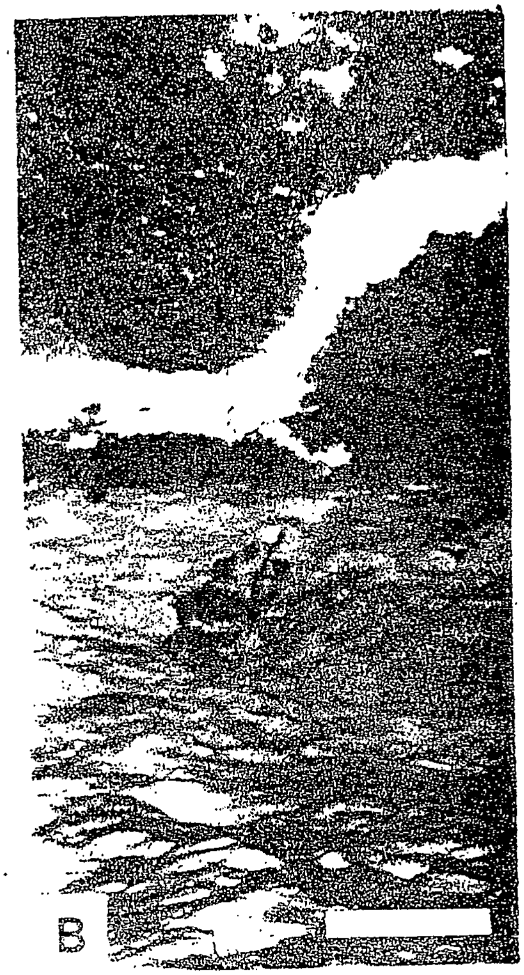
The trend of thickening of the deeper marine rocks is to the southwest from the bottom to the top. That is, the thickest accumulations of rock unit 10, combined rock units 7 and 8, and combined rock units 4 and 5 occur progressively southwest of the other, respectively. This is also thought to be the direction of overall regression of the "E" zone cycle.

Figure 22. Basal contacts of the packstones-grainstones of Rock Units 3 and 6 in the Meeker Canal Field area. See Appendices for sample identification.

A. Slabbed core of burrowed contact at base of Rock Unit 3. Porous packstone (oil stained) fills large, mostly vertical or high-angle, burrows in a carbonate mudstone (light). (Scale is 2 cm.)

B. Slabbed core of abrupt, scoured contact at the base of Rock Unit 6. Packstone (oil stained) overlies marlstone. (Scale is 2 cm.)

A



B

Correlation of Radioactivity Logs

Correlations of radioactivity logs of wells is difficult because the rock units are thin and log characteristics change as a result of secondary minerals. With good core control, however, it is possible to make accurate correlations of the 11 rock units with other wells that were not cored by using radioactive logs. The radioactive logs are particularly useful in mapping the paleorelief on the "E" zone carbonate as indicated by the thickness of nonmarine sediment. This interval is readily recognizable where there is sufficient core control to identify the transgressive limestone (Unit 1) on the mechanical logs. It is nearly beyond the limit of resolution of the logs to detect lateral facies changes, but thicknesses of individual rock units, especially Units 3 and 6, can be mapped and facies changes inferred from these maps.

RELATION OF FRESHWATER DIGENESIS TO PALEOTOPOGRAPHY

General Statement

Freshwater diagenesis during subaerial exposure of the "E" zone was as important in the generation of porous reservoir rock as the original texture. The development or destruction of porosity can be related to the movement of freshwater through the "E" zone carbonates (Fig. 23). Most porosity is secondary, a result of leaching of aragonitic skeletal grains and carbonate mud in the vadose zone on topographic highs. Deep weathering, large scale dissolution accompanied by clay and silt infiltration, was prevalent in topographic lows where freshwater phreatic processes dominated. This deep weathering destroyed any reservoir potential the original rock may have had. There was a moderate amount of porosity occlusion by cements, most of which were precipitated in the freshwater phreatic environment. The areal distribution of the vadose and freshwater phreatic diagenetic environments and the movements of freshwater through them were functions of topography and the availability of freshwater.

Availability and Movement of Freshwater

Caliche soil textures found in the red nonmarine rocks (Unit 2, Fig. 18) are keys to the interpretations of the prevailing climatic conditions that prevailed during subaerial exposure. Caliche soil horizons, termed k-Horizons (Gile and others, 1965), usually indicate subtropical to tropical, semiarid climate (Reeves, 1970). Rainfall in such a climate is seasonal and is usually in the form of short intense periods of precipitation separated by long dry spells. During storms, rainwater tends to run off instead of soaking in, and collects in lows.

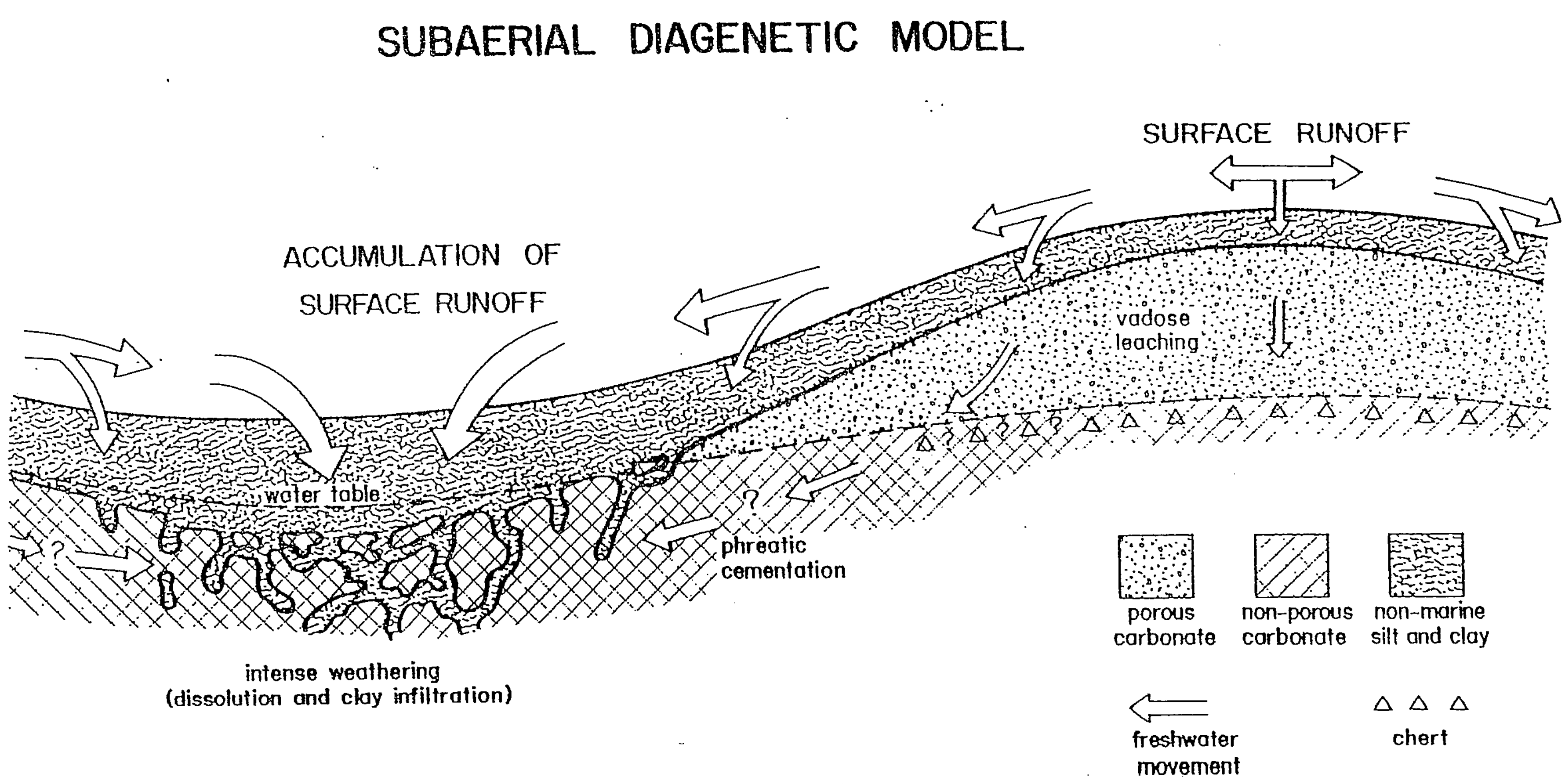


Figure 23. Subaerial diagenetic model of the Lansing-Kansas City "E" zone in Hitchcock County, Nebraska.

Infiltration is greatest in low-lying areas where surface runoff collects. Under these conditions, underlying rock units may experience either vadose or phreatic conditions depending upon the intensity and duration of the rainfall, the amount of runoff, percolation rates, and topography.

Movement of groundwater downslope depends on permeability and slope. Slopes present during subaerial exposure of the "E" zone may not have been adequate to move groundwater downslope. With such low slopes, water tables are likely to be perched where vertical or lateral permeability barriers exist.

The following discussion applies to the upper reservoir rock unit (Unit 3). Unit 3 is the most laterally homogeneous of the two "E" zone pay intervals, and its distribution of porosity can be explained by the different diagenetic environments that prevailed. Favorable rock textures, packstones and grainstones, in Unit 6 are present only on the most positive topographic features where vadose conditions most likely dominated. Lateral variability of diagenetic environments is coincident with facies changes into unfavorable rock textures in Unit 6, preventing meaningful comparisons of distribution of porosity as a function of freshwater diagenesis.

Development of Secondary Porosity by Leaching in the Vadose Zone

The highest portions of topographically positive features were dominated by vadose conditions during subaerial exposure of the "E" zone. Much of the rainwater probably flowed into lower areas, but that which entered the underlying carbonate rocks was responsible for the development of secondary porosity in packstones and grainstones on these high areas.

Except for a minor amount of primary intergranular porosity the porosity in the "E" zone is secondary (Fig. 24A). Much of it, especially in the pellet-skeletal packstone facies of the upper pay zone, is secondary intergranular porosity (Fig. 24B). Much of the aragonitic mud that once filled the interstices has been dissolved. However, it is difficult to say how much mud was dissolved since the resultant pores appear very much like primary intergranular voids that are partially filled with carbonate mud. Moldic porosity (Fig. 24C) prevails where bivalve grains are abundant, their aragonitic shell structure being easily dissolved by freshwater percolating through the vadose zone. Molds and other voids are frequently enlarged to form vugs (Fig. 24D), especially in packstones that originally had a high content of carbonate mud.

The transformation of high-magnesium calcite and aragonite to rock composed of stable low-magnesium calcite is well documented (Friedman, 1964; Bathurst, 1966; Land, 1966, 1967; Gavish and Friedman, 1969). The order of stability of carbonate minerals in freshwater environments, from least to most stable, is high-magnesium calcite, aragonite, and low-magnesium calcite. High-magnesium calcite usually inverts to low-magnesium calcite without notable fabric change (Land's, 1966, Stage III). The transformation of aragonite to low-magnesium calcite usually involves dissolution of aragonitic grains and precipitation of low magnesium calcite as a cement (Land's, 1966, Stage IV).

Most of the sediment in Units 3 and 6 was probably aragonitic at the time of deposition. Bivalves and gastropods were aragonitic ostracodes and encrusting forams were composed of low-magnesium calcite, and crinoids were composed of high-magnesium calcite (Scholle, 1978).

Figure 24. Porosity types found in the "E" zone. See Appendices for sample identification.

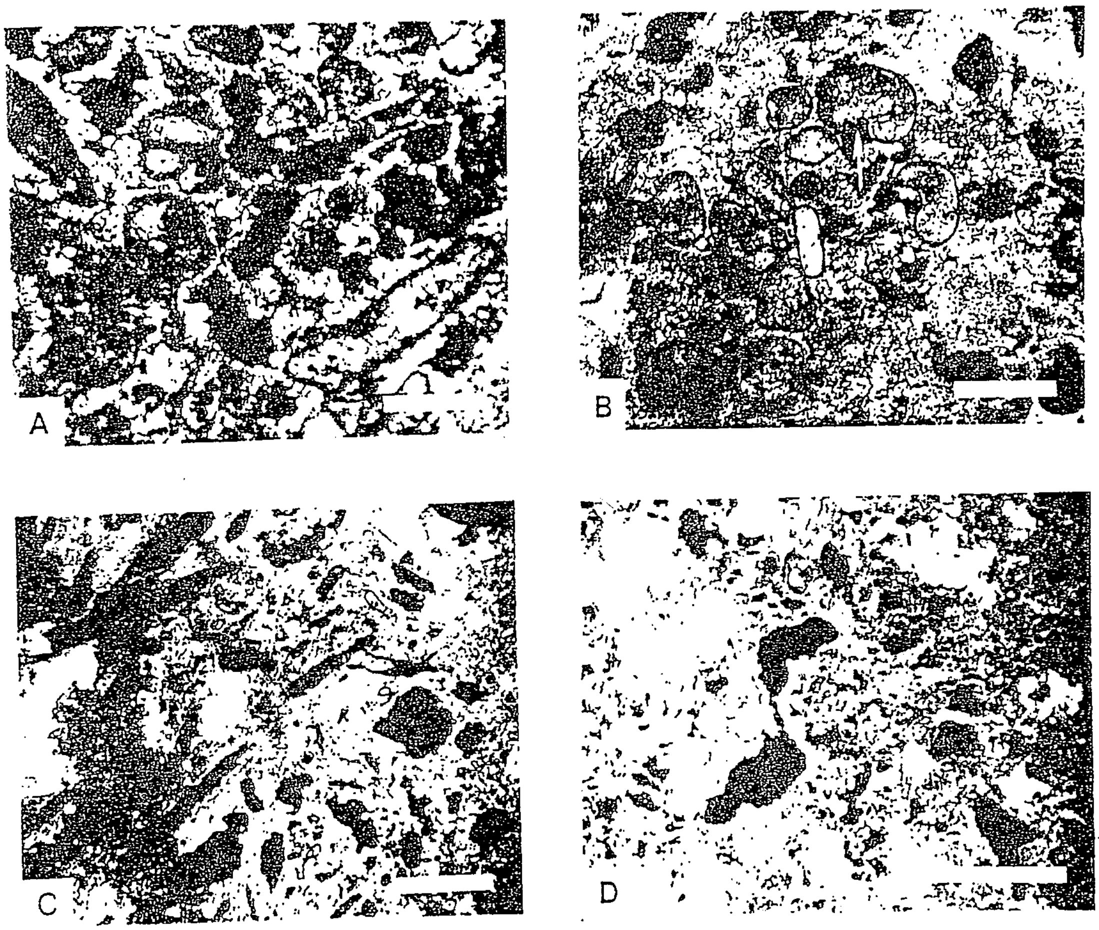
A. Primary intergranular porosity, partially occluded by an early fine blocky rim cement. (Scale is 0.2 mm. cross-polarized light)

B. Secondary intergranular porosity. Porosity is most likely a result of dissolution of carbonate mud between grains (encircled), or at least enlargement of primary pores not entirely filled with carbonate mud. Grain corrosion (arrow) is a result of pore enlargement. Remaining intergranular mud has been recrystalized to microspar. (Scale is 0.2 mm. cross-polarized light)

C. Moldic porosity. Pores are molds of bivalves. (Scale is 2 mm. cross-polarized light)

D. Vuggy porosity. (Scale is 1 mm. cross-polarized light)

Note the lack of cements in B, C, and D.


A
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C
D

There has been much discussion in the geologic literature over the origin of carbonate mud (Lowenstam and Epstein, 1955; Wells and Illing, 1964; Matthews, 1966; Stockman and others, 1967). Whether the mud originated from mechanical breakdown of skeletal grains or by inorganic precipitation, most workers are in agreement that the mineralogy of carbonate mud is usually aragonite. The pellets that make up the largest proportion of the grains in Unit 3 and to a lesser extent in Unit 6 are composed of compacted carbonate mud and their mineralogy was most likely aragonitic. Rock Unit 3, predominately pellets, and, to a lesser extent, carbonate mud, bivalves, gastropods, encrusting forams, crinoids and ostracodes, and Rock Unit 6, predominately bivalves and, to a lesser extent carbonate mud, gastropods, pellets, encrusting forams, crinoids, and ostracodes, were, therefore, predominantly aragonite at the time of deposition.

During subaerial exposure, percolating vadose groundwater selectively dissolved intergranular mud and aragonitic skeletal grains, bivalves and gastropod fragments, producing the porous reservoir rocks in Units 3 and 6. Pellets were not as easily dissolved due to their compact internal structure. Friedman (1964) stated that pellets are more stable than skeletal grains having aragonite composition, and it is also my belief that pellets are more stable than intergranular muds since meteoric waters would more easily dissolve loosely consolidated mud than the compacted mud in pellets. The grain supported textures, packstones and grainstones, provided a structural framework resulting in interconnected, secondary, intergranular and moldic voids that were instrumental in promoting percolation of fresh ground water through the sediment, continuation of dissolution, and removal of calcite. Considerably less porosity occurs in wackestones and mudstones where percolation was inhibited by the lack of connected pore space. Leaching of aragonitic grains and carbonate mud in the vadose zone is compatable with earlier works on this subject by Land (1966, 1967), Harris and Matthews (1968), Semeniuk (1971), and Friedman (1975).

Solution compaction, calichification, and absence of cements further support a vadose interpretation. The upper 5 to 20 centimeters of Unit 3 in the Meeker Canal Field usually consists of a dense, non-porous cap rock (Fig. 25). In the upper portions of Unit 3, usually directly below the contact between nonmarine and marine sediments, calichification of the limestone occurs. Here, the rocks are characterized by clotted (grumelous) (Fig. 25C) textures, circumgranular cracking, and caliche breccias (Fig. 25C, D) usually attributed to exposure to freshwater diagenesis in the vadose zone (Wilson, 1975). Dolomitization is common where the original rock texture was mud supported (Fig. 25A, B). Vadose solution compaction and calichification may occur in the same core. When this does occur the calichified interval is on top of the compacted interval. In many cores of the Meeker Canal Field the porous portions of Unit 3 have little or no cement in their pores. Cementation in the vadose zone is typically quite slow (Land, 1970), and a lack of cements may be indicative of high rates of percolation through the vadose zone and transportation of dissolved calcite to the water table (Harris and Matthews, 1968).

Destruction of Porosity by Deep Weathering

Freshwater phreatic conditions prevailed in the "E" zone carbonate rocks in topographically low areas. A relatively high water table was maintained by surface runoff and, to a lesser extent, the downslope movement of groundwater. The upper part of rock Unit 3 was usually nearly obliterated in this regime. The exposed carbonate surface

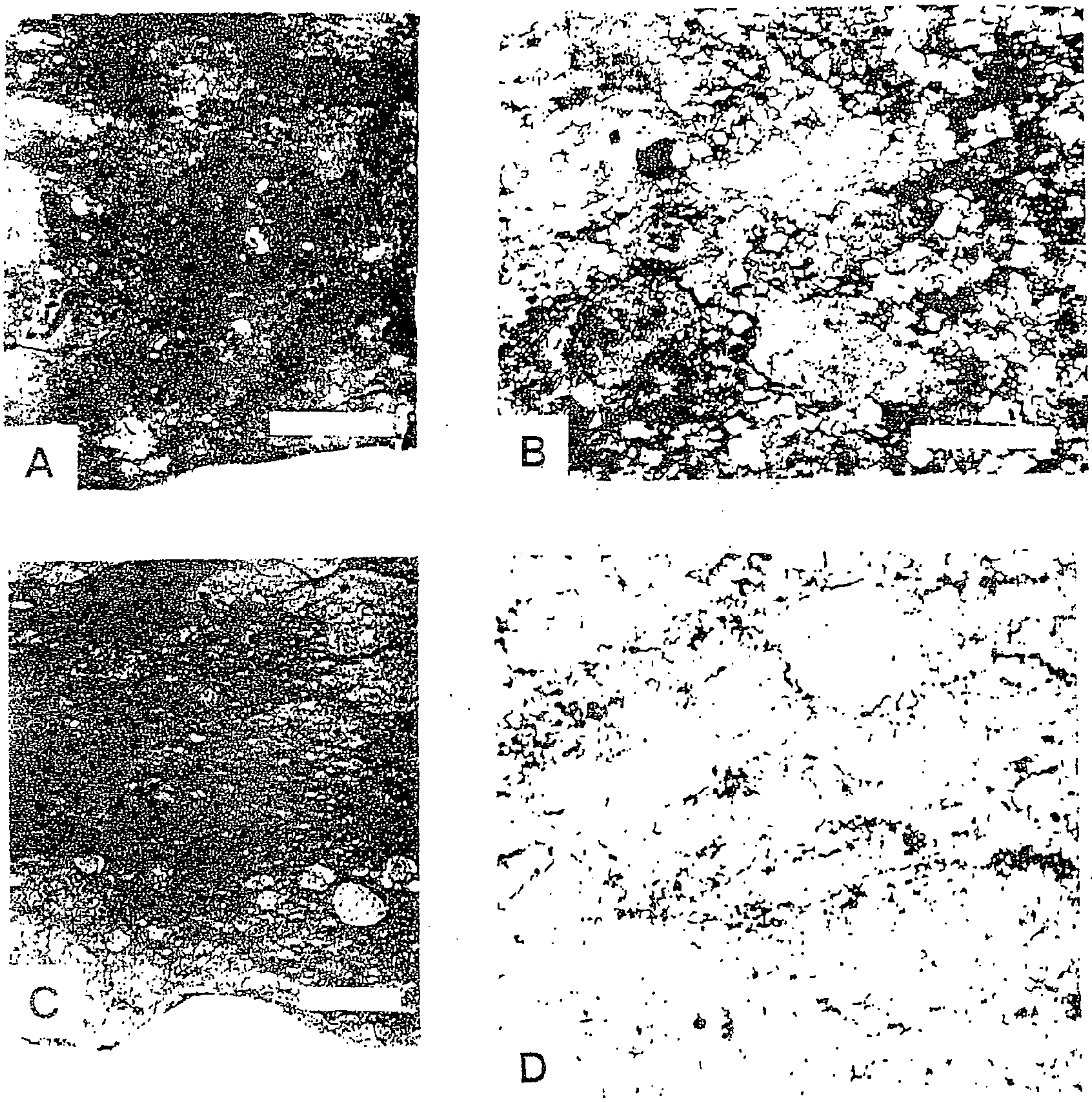
Figure 25. Alteration of carbonate directly below the subaerially exposed surface on paleotopographic highs. See Appendices for sample identification.

A. Slab of a core. Infiltrated silt and clay give the weathered carbonate a light reddish-brown cast. Lighter areas contain more carbonate. (Scale is 2 cm.)

B. Photomicrograph of A. Dolomite rhombs in an infiltrated silt and clay and carbonate mud matrix. Darker areas are richer in silt and clay. (Scale is 0.2 mm. plane light)

C. Slab of a core of a caliche breccia. "Grains" are essentially in place. (Scale is 1 cm.)

D. Photomicrograph of C. Brecciated appearance is the result of the calichification process. The original texture appears to have been a mudstone. (Scale is 1 mm. cross-polarized light)


A
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consists fragments of limestone, weathered in situ, enclosed in a red silt and clay matrix (Fig. 26A, B, C). Pores in these limestone fragments are filled with red silt and clay. The amount of silt and clay that infiltrated from the overlying soils varies from 30 to 80 percent of the total volume of rock and is usually highest towards the top of the weathered zone. This weathered zone extended to depths up to six feet (1.8 meters) and completely destroyed any reservoir potential the original rock may have had. Vertical solution fissures are associated with this type of weathering, some of which were least six feet in length (two meters) and were found at depths up to thirty feet (9 meters) below the exposed carbonate surface. Solution fissures of this sort were rarely found on the topographically high areas, but where present they are not nearly as wide nor as long as those in low areas. Enlargement of these fissures to the size of small caverns (Fig. 26D, E) is common in topographic lows and nonexistent on highs. Red silt and clay and occasional clasts of wallrock fill these fissures and small caverns. Most of the silt and clay was derived from the overlying nonmarine sediments, but some is probably insoluble residue.

The extensive dissolution of limestone probably occurred in the freshwater phreatic zone. Davis (1930), Bretz (1942), and Davies (1960) believed that most dissolution of limestones resulting in development of caverns takes place below the water table. Thrailkill (1968) showed that the slight reduction of temperature as vadose waters enter the phreatic zone is sufficient to increase the solubility of $CaCO_3$ and believed this increased solubility is sufficient to initiate cavern development in the shallow phreatic zone.

Figure 26. Deep weathering in topographic lows. (All photographs are of slabbed cores.) See Appendices for sample identification.

A. Weathering profile in the exposed carbonate rock. The amount of original rock (light) increases downward; red infiltrated silt and clay from overlying soils is dark. (Scale is 10 cm.)

B. Enlarged portion of A. Altered, but recognizable carbonate remains essentially in place despite solution and infiltration of red silt and clay. (Scale is 2 cm.)

C. Enlarged portion of A. Carbonate mudstone that was brecciated by weathering. Red silt and clay fill fine solution channels and larger, diagonally oriented, fissure. (Scale is 2 cm.)

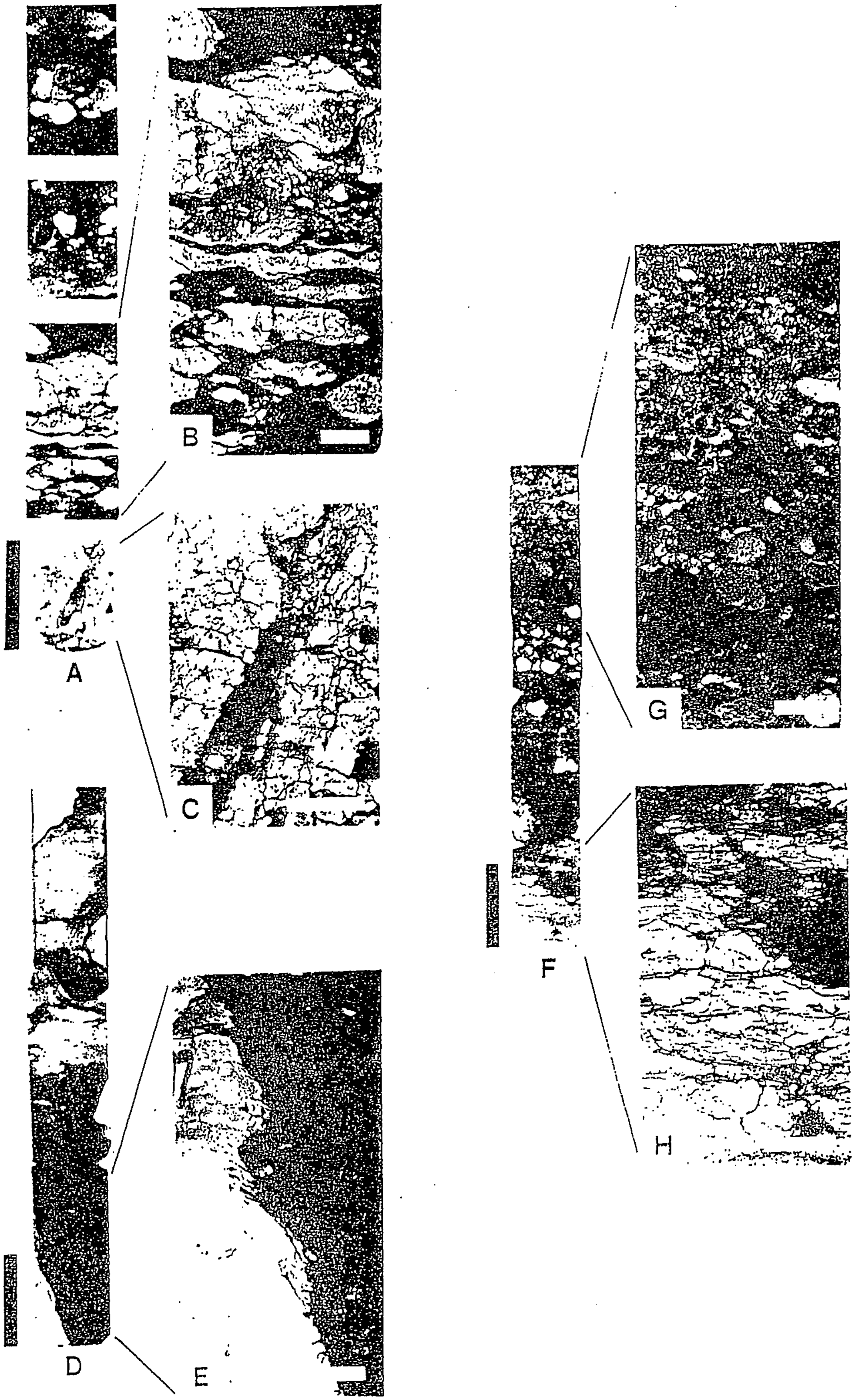
D. Enlarged solution fissure in the same core as A, B, and C, five feet below C. Nearly vertical fissure is filled with red silt and clay in the lower half and green silt and clay (reduced) in the upper half. Lines border the fissure. (Scale is 10 cm.)

E. Enlarged portion of D. Fragments of wall rock incorporated in the fissure fill material are light in color. (Scale is 2 cm.)

F. Channel conglomerate (upper part) on a deeply weathered carbonate surface. (Scale is 10 cm.)

G. Enlarged portion of F. Channel conglomerate consisting of subrounded limestone clasts derived from Rock Unit 3 in a sandy matrix. (Scale is 2 cm.)

H. Enlarged portion of F. Weathered marlstone (Rock Unit 4). No _in situ_ Rock Unit 3 is present. (Scale is 2 cm.)


A
B
C
D
E
F
G
H

The implacement of silt and clay transported downward from overlying soils occurs under vadose conditions (Dunham, 1969A). In topographic lows phreatic conditions dominated, but periodic dry spells, consistent with climatic interpretations, may have led to periods of low water table. When the water table was low, silt and clay was carried into the cracks and fissures by vadose waters on their way to the water table. There was a balance between infiltration of silt and clay when vadose conditions existed and enlargement of solution features when phreatic conditions existed, as evidenced by the lack of open caverns and fissures.

Only a slight amount of actual erosion and transport of material from the upper carbonate surface was evident in most wells. Most of the alteration of the upper "E" zone carbonate was caused by in situ weathering, but extensive erosion was observed in one well (well #8, Fig. 19). In this well, approximately 9 feet (3 meters) of section is missing from the upper part of the "E" zone regressive carbonate. In its place is about three feet (1 meter) of limestone pebble conglomerate (Fig. 26F, G, H) the clasts of which can be identified as belonging to the fine-grained pellet-skeletal packstone facies of rock Unit 3 and marlstone of rock Unit 4. This feature is a channel, most likely an arroyo, and the conglomerate a channel deposit consisting of locally derived sediments.

It is conceivable that packstones and grainstones which were below the zone of intense weathering (as is rock Unit 6) could be potential oil reservoirs, if they were not tightly cemented. However, packstones and grainstones are almost nonexistant in Unit 6 in low areas. Secondary void spaces, molds and vugs, found in wackestones below the weathered zone are filled with phreatic calcite cements. It is highly probable that any packstones and grainstones that might occur in this topographic setting would also be tightly cemented.

Occlusion of Secondary Porosity by Phreatic Cement

Distribution of Cement

Cement was not as important in the determination of ultimate porosity in the "E" zone as were vadose leaching, and deep weathering, and the original rock texture. However, cementation is the reason there is no porosity in a small, yet significant, portion of the packstones and grainstones in and around the Meeker Canal Field and in topographic low areas where reservoir potential was not already destroyed by weathering.

In the porous reservoir rocks in the Meeker Canal Field, cement is nearly absent. The only place that cement is pervasive is just above the packstone-marlstone boundary in the lower portions of rock Units 3 and 6. The interface, a partially effective aquiclude, together with minor variations in topography and horizontal permeability, resulted in localized, perched water tables. The occurrence of cement at this position, while absent above, supports my interpretation of cement precipitation occurring in the freshwater phreatic environment.

Cement in packstones and grainstones down dip from the Meeker Canal Field, whose reservoir potential was not already destroyed by weathering, could have been precipitated beneath a water table of more regional extent. This water table would have been related to the down-slope movement of surface runoff and groundwater. In topographic lows, pores not already plugged with silt and clay were cemented. The secondary pores may have resulted from vadose leaching during times of low water table or from dissolution under freshwater phreatic conditions.

Calcite Cement

Only two stages of calcite cement are common in these rocks. An early, fine, blocky rim cement is followed by coarse, void filling spar (Fig. 27A, B). The fine, blocky rim cement always precedes the coarser cement when the two are found in the same pore space. Crystals vary in size from one pore to another, but little problem exists in distinguishing the fine, blocky, rim cement from the coarser, second-stage cement. Where pores are small, the early rim cement may fill the entire pore (Fig. 27C, D). Where pores are larger, the early rim cement may only partially occlude porosity with much of it remaining open or filled with the second-stage coarse spar. The early rim cement is believed to be a freshwater phreatic cement for the following reasons:

1. It occurs as the first cement lining secondary voids that probably likely resulted from freshwater dissolution.

2. The crystal habit is blocky (equant) rather than fibrous or bladed, as are marine cements (Folk, 1973).

3. Lining of the entire void space by the rim cement, indicating phreatic conditions (Bathurst, 1975; Badiozamani and others, 1978).

4. Absence of vadose cement features described by Dunham (1971), Muller (1971).

5. The areal and vertical distribution of the cement suggests deposition below the water table.

The second-stage, coarse, void-filling spar fills only the larger voids that were not filled by the early rim cement. The timing of this cementation is not as easily documented, but it is thought to be predominantly a shallow, near surface, freshwater phreatic cement. Evidence that support this interpretation includes 2, 3, 4, and 5 (above) and the following:

1. Cement is clear, whereas marine cement is typically cloudy (Meyers, 1974).

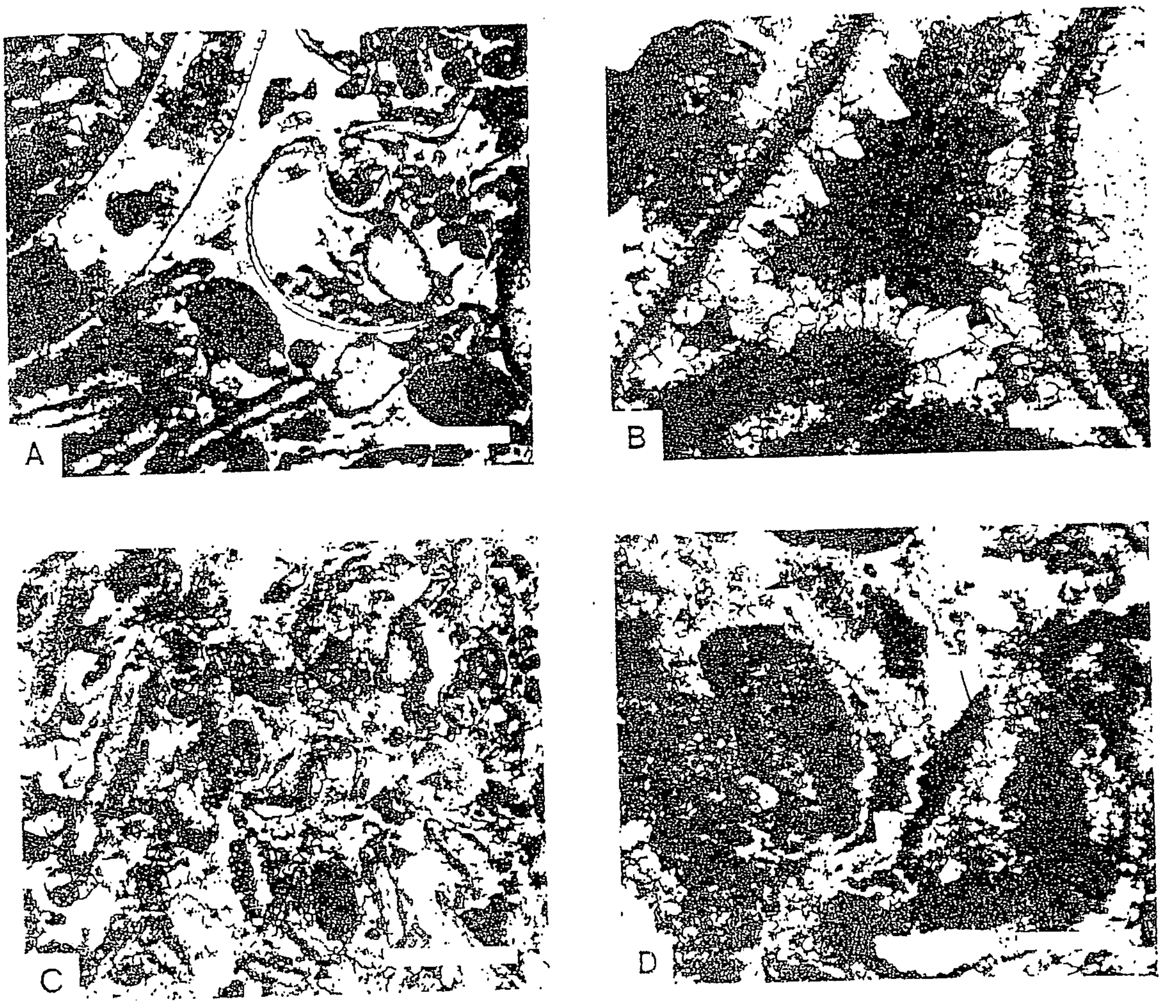
Figure 27. Calcite Cements. See Appendices for sample identification.

A. Two distinct generations of cement are present. Fine, equant rim cement lines primary and secondary voids and is followed by a coarse void-filling spar. (Scale is 1 mm. cross-polarized light)

B. An enlarged view of A illustrates the blocky habit of the rim cement on micrite envelopes of dissolved bivalve and gastropod fragments. (Scale is 0.2 mm. cross-polarized light)

C. Tightly cemented grainstone from well number 4, Figure 18. Most of the cement is the first stage, fine-grained cement due to the small pore sizes. (Scale is 1 mm. cross-polarized light)

D. Enlarged portion from center of C. Arrows point to pores filled with fine-grained cement. (Scale is 0.2 mm. cross-polarized light)


A
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2. Most of the second-stage cement is non-ferroan whereas deeper subsurface phreatic conditions often lead to ferroan-calcite cement (Oldershaw and Scoffin, 1967; Folk, 1973).

3. The timing of certain fractures indicates that much of the cement preceded compaction, which accompanied burial (Fig. 28A).

Other lines of evidence seem to indicate that some of the coarse, second-stage cement may have been deposited in a subsurface freshwater phreatic environment.

1. Experimental data by Badiozomani and others (1977) indicates that as temperature or NaCl content of groundwaters increase the grain size of the cement increases. An increase of salinity could occur as a result of dewatering of shales during compaction following burial.

2. A significant yet relatively small amount of the coarse cement is ferroan calcite.

3. The timing of a fracture in one brachiopod with coarse internal cement (Fig. 28B) indicates that the precipitation of the early rim cement preceded and the precipitation of the coarse cement postdated fracturing which most likely occurred during burial.

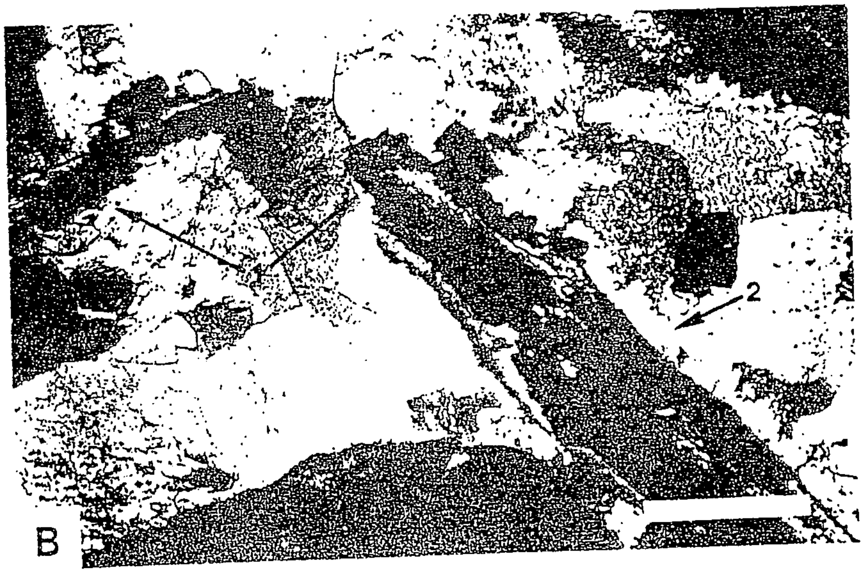
To summarize the preceding discussion, an initial fine, blocky, calcite rim cement lined larger voids and filled the smaller pores. The first stage cement was followed by a coarser second-stage cement consisting of coarse, void filling, sparry calcite. The first stage was precipitated in the freshwater phreatic environment. Most of the second stage is believed to have been precipitated in the freshwater phreatic environment, but some of it may have been precipitated in the subsurface freshwater phreatic environment. The source of the calcite in both stages of cement was most likely calcium and carbonate released by dissolution of aragonitic grains and carbonate mud in the vadose zone. Calcium and carbonate ions were carried in solution to the water table where they were precipitated as low magnesium calcite cement.

Figure 28. Photomicrographs illustrating the sequence of calcite cement formation. See Appendices for sample identification.

A. Both first and second stage cements precipitated prior to fracturing which most likely occurred during burial. Coarse-grained calcite cement (second stage) is in contact with the matrix along a fracture (arrow). The cement had filled a shelter void of a brachiopod prior to the fracture. (Scale is 1 mm. cross-polarized light)

B. First stage cement preceeded and second stage cement post-dated fracturing. There is no first stage fine, blocky calcite cement along the fractured brachiopod shell (arrows at one) while it does occur along the unfractured surface (arrow at two) where the first stage cement lined the original void. Coarse second stage calcite cements are in contact with the fractured surfaces (arrows at one) and the first stage cement (arrow at two). (Scale is 1 mm. cross-polarized light)

A



B

Quartz Cement and Silicification

The most notable occurrence of silicification is a 15 to 35 centimeter band directly above the contact between the packstones of Unit 6 and the underlying marlstones of rock Unit 7 in twelve of the twenty-one cores from the Meeker Canal Field. A similar occurrence is at the base of Unit 3 in one core. Silicification is in the form of red chert replacing the limestone matrix (Fig. 29A) and void filling by several stages of chalcedony cement followed by a quartz druse cement (Fig. 29B). Quartz druse fills only the largest voids that are not completely filled by earlier chalcedony. This type of silicification grades rapidly upward over a few centimeters first into rock where chert replaced grains are cemented with quartz druse (Fig. 29C, D), and second, into rock where grains remain calcareous but voids are filled with a quartz druse cement. Quartz druse cement in turn passes rapidly upward into calcite cement.

Silicification or the formation of chert nodules is sometimes used as a criterion for recognizing the level of ancient water tables (Wilson, 1975). The conspicuous silicified interval in the "E" zone is interpreted to have formed at or directly below a permanent or perched water table. The discontinuous lateral distribution of this silicified interval indicates the latter. Alternating vadose and phreatic conditions may be responsible for the numerous stages of chalcedony cement deposited in a phreatic environment.

Reeves (1970) explained the occurrence of amorphous silica in older caliche below younger caliche horizons in west Texas and eastern New Mexico. The pH of groundwater increases when cation exchange with certain clays take place. The increased pH causes deposition of caliche and dissolution of silica, which is transported downward and

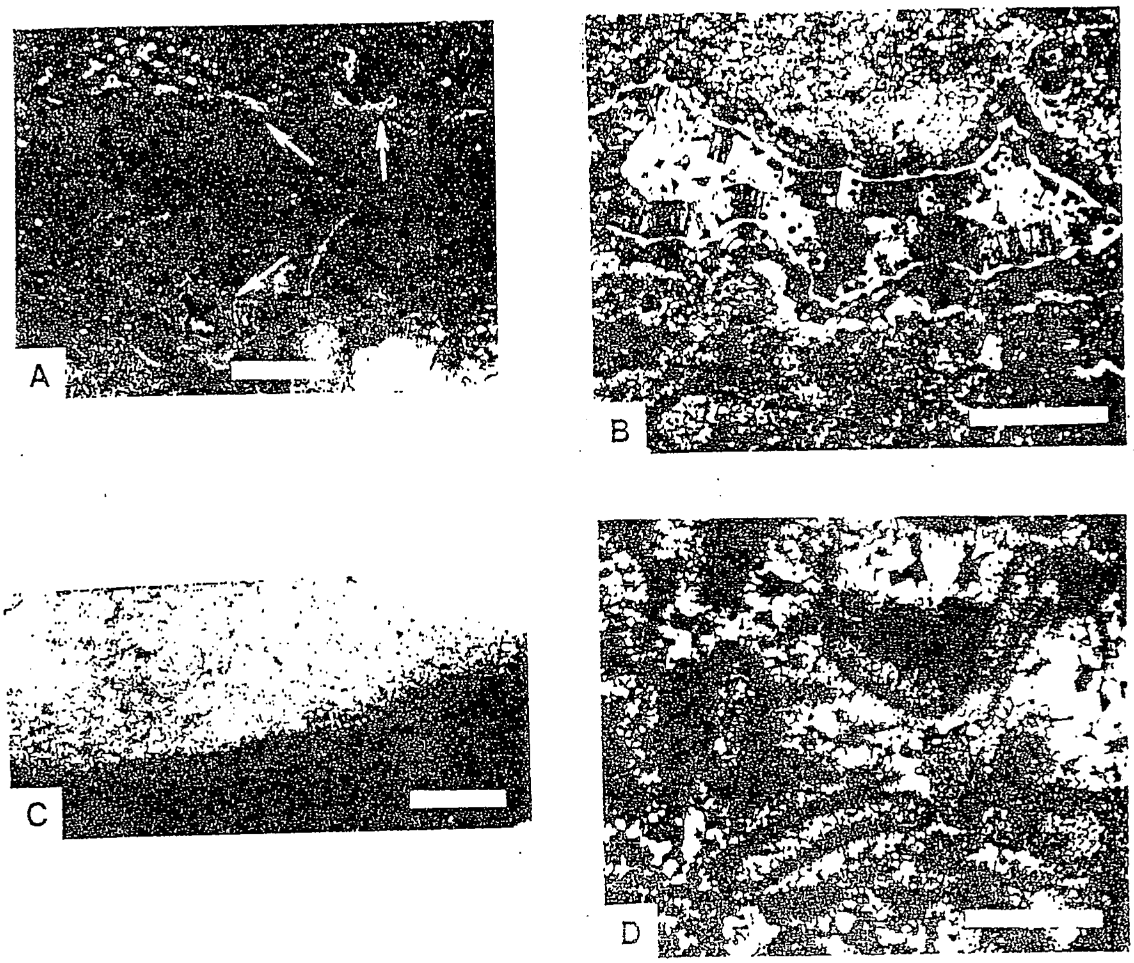
Figure 29. Silicification in the "E" zone carbonate. See Appendices for sample identification.

A. Core slab of red chert which totally replaces the carbonate at the base of Rock Unit 3 in a well in the Meeker Canal Field. Chalcedony filled vugs (arrows) and large dolomite rhombs are common in the chert. (Scale is 1 cm.)

B. Photomicrograph of a portion of a vug (upper right arrow) from A. Several stages of chalcedony followed by a quartz druse cement fill the vug. (Scale is 1 mm. cross-polarized light)

C. Core slab of silicified carbonate at base of Rock Unit 6 in the Meeker Canal Field. The lower portion is totally replaced by red chert similar to that in A and B in this figure. The lower portion (lighter) consists of silicified and unsilicified skeletal grains cemented by a quartz druse cement. (Scale is 1 cm.)

D. Photomicrograph of a portion of the upper part of core slab in C. Bivalve grains are replaced by chert and cemented by a quartz druse cement. (Scale is 1 mm. cross-polarized light)


A
B
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D

deposited as amorphous silica. Since the soil cover on top of the exposed "E" zone carbonate unit is so thin, it is conceivable that any silica dissolved from the soil in the calichification process could be transported into the underlying carbonate unit where changes in temperature, pH, or pCO_2 could result in silicification of the carbonate unit and deposition of silica cement.

CONCLUSIONS

Detailed multidisciplinary studies, core examinations, thin section petrography, and subsurface correlation of well logs, can define the factors controlling the development and distribution of porosity in the Lansing-Kansas City limestones. This facilitates the definition of potentially oil productive areas. As a result of studying 30 cores of the Lansing-Kansas City "E" zone in Hitchcock County, Nebraska, I have reached the following conclusions:

1. Oil production is from carbonate packstones and grainstones that were deposited during shallow water episodes in the marine phase of a complex marine-nonmarine sedimentary cycle.

2. Significant quantities of oil are produced only from areas interpreted to have been topographically (bathymetrically) high during the deposition of the "E" zone sediments.

3. The thickness of nonmarine sediments deposited on top of the "E" zone regressive carbonate sequence is believed to be inversely proportional to the paleotopography of the subaerially exposed carbonate surface. This interval is easily mapped by using mechanical well logs, provided there is sufficient core control to identify the rock units on the logs.

4. Favorable rock textures, packstones and grainstones are best developed on paleotopographic high areas where the sea floor was subjected to wave agitation that was more vigorous and of longer duration than in paleotopographic lows, and where production of carbonate grains was greatest.

5. Most porosity is secondary, the result of freshwater dissolution of aragonitic skeletal grains and intergranular carbonate mud. Topography was the main influencing factor in the development of two distinct freshwater diagenetic environments:

   A. Freshwater leaching of packstones and grainstones in the vadose zone on topographically high areas resulted in secondary porosity and development of good reservoir rock.

   B. Intense weathering, limestone dissolution accompanied by clay and silt infiltration, occurred in topographic lows, which were dominated by freshwater phreatic conditions. The processes acting on the rocks totally destroyed any reservoir potential the rocks may have had prior to subaerial exposure.

6. Because of 4 and 5 (above), paleotopographically high areas, indicated by localized thin areas on maps of nonmarine sediment thickness, have the best potential for future oil production from the Lansing-Kansas City "E" zone in Hitchcock County, Nebraska.

REFERENCES

Badiozamani, K., McKenzie, F.T., and Thorstenson, D.C., 1977, Experimental carbonate cementation: Salinity, temperature, and vadose-phreatic effects, Jour. Sed. Pet., v. 47, no. 2, pp. 529-543.

Bathurst, R.G.C., 1966, Boring algae, micrite envelopes and lithification of molluscan biosparites, Geol. Jour., v. 5, pp. 15-32.

________, 1975, Carbonate sediments and their diagenesis, Elsevier Publishing Co., 658 pp.

Bretz, J.H., 1942, Vadose and phreatic features of limestone caverns, Jour. Geol., v. 50, p. 675-811.

Busch, K.M., 1977, Structure and stratigraphy of the B zone (Lansing-Kansas City Groups) in Red Willow County, Nebraska, Univ. of Nebraska, unpublished M.S. thesis.

Clark, D.N., 1979, Patterns of porosity and cement in ooid reservoirs in Dogger (Middle Jurassic) of France: Discussion, Am. Assoc. of Petroleum Geologists Bull., v. 63, no. 4, p. 676.

Crowley, D.J., 1969, Algal-bank complex in Wyandotte Limestone (Late Pennsylvanian) in eastern Kansas, Kansas Geol. Survey Bull. 198, 52 pp.

Davies, W.E., 1960, Origin of caves in folded limestone, Natl. Speled. Soc. Bull., v. 22, pp. 5-18.

Davis, W.M., 1930, Origin of limestone caverns, Geol. Soc. America Bull., v. 41, pp. 475-628.

Dickson, J.A.D., 1969, A modified staining technique for carbonates in thin section, Nature, v. 205, p. 587.

Dunham, R.J., 1962, Classification of carbonate rocks according to texture, in: Ham, William (ed.), Classification of carbonate rocks, Am. Assoc. of Petroleum Geologists Memoir 1, pp. 108-121.

________, 1969a, Early vadose silt in the Townsend Mound (reef), New Mexico, in: G.M. Friedman (ed.), Depositional environments in carbonate rocks, Soc. Economic Paleontologists and Mineralogists Spec. Publ. 14, pp. 182-191.

________, 1971, Meniscus cements, in: O.P. Bricker (ed.), Carbonate cements, John Hopkins Univ. Studies in Geology, no. 19, pp. 297-300.

Elias, M.K., 1937, Depth of deposition of the Big Blue (late Paleozoic) sediments in Kansas, Geol. Soc. America Bull., v. 48, pp. 403-432.

Folk, R.L., 1973, Carbonate petrography in the post-Sorbian age, in: Evolving concepts in sedimentology, John Hopkins Press, pp. 118-158.

Friedman, G.M., 1964, Early diagenesis and lithification in carbonate sediments, Jour. Sed. Pet., v. 34, no. 4, pp. 777-813.

________, 1975, The making and unmaking of limestones, or the ups and downs of porosity, Jour. Sed. Pet., v. 45, no. 2, pp. 379-398.

Frost, J.G., 1975, Winterset algal-bank complex, Pennsylvanian, eastern Kansas, Amer. Assoc. of Petrol. Geol. Bull., v. 59, pp. 265-291.

Gavish, E. and Friedman, G.M., 1969, Progressive diagenesis in quaternary to late tertiary carbonate sediments: Sequence and time scale, Jour. Sed. Pet., v. 36, pp. 143-152.

Gile, L.H., Peterson, F.F., and Grossman, R.B., 1965, The K horizon: A master soil horizon of carbonate accumulation, Soil Science, v. 99, no. 2, pp. 74-82.

Harbaugh, J.W., 1959, Marine bank development in Plattsburg Limestone (Pennsylvanian), Neodesha-Fredonia area, Kansas, Kansas Geol. Survey Bull. 134, pt. 8, pp. 289-331.

________ and others, 1965, Field conference guide to Pennsylvanian marine banks, southeastern Kansas, <u>in</u>: Pennsylvanian marine banks in southeastern Kansas: Geol. Soc. America, Ann. Mtg., Kansas City Field Conf. Guidebook, pp. 1-46.

Harris, W.H. and Matthews, R.K., 1968, Subaerial diagenesis of carbonate sediments; efficiency of the solution-reprecipitation process, Science, v. 160, pp. 77-79.

Heckel, P.H., 1975a, Field guide to Stanton Formation (Upper Pennsylvanian) in southeastern Kansas, Kansas Geol. Soc. 31st Regional Field Conf. Guidebook, pp. 2-71.

________, 1975b, Stratigraphy and depositional framework of the Stanton Formation in southeastern Kansas, Kansas Geol. Survey Bull. 210, 45pp.

________, 1977, Origin of phosphatic black shale facies in Pennsylvanian cyclothems of the Mid-Continent North America, Amer. Assoc. of Petrol. Geol. Bull., v. 61, no. 7, pp. 1045-1068.

________ and Baesemann, J.F., 1975, Environmental interpretation of conodont distribution in Upper Pennsylvanian (Missourian) mega-cyclothems in eastern Kansas, Amer. Assoc. of Petrol. Geol. Bull., v. 59, pp. 486-509.

Irwin, M.C., 1965, General theory of epeiric clear water sedimentation, Amer. Assoc. of Petrol. Geol. Bull., v. 49, pp. 445-459.

Kansas Geological Society, 1966, Type logs of Kansas, 2 volumes.

Land, L.S., 1966, Diagenesis of metastable skeletal carbonates, Marine Science Center, Lehigh Univ., M.S. thesis, 141 pp.

Land, L.S., 1967, Diagenesis of skeletal carbonates, Jour. Sed. Pet., v. 37, pp. 914-930.

________, 1970, Submarine lithification of Jamaican reefs, Jour. Sed. Pet., v. 40, pp. 457-462.

Larson, W.S., 1962, Ackman field and environs, southwestern Nebraska, Amer. Assoc. of Petrol. Geol. Bull., v. 26, no. 11, pp. 2079-2089.

Lee, W., 1954, Thickness maps as criterion of regional structural movement, Kansas Geol. Survey Bull. 109, pt. 5, 80 pp.

________ and Merriam, D.F., 1954, Preliminary study of the structure of western Kansas, Kansas Geol. Survey, Oil and Gas Investigations No, 11, pp. 1-23.

Lowenstam, H.A. and Epstein, S., 1957, On the origin of sedimentary aragonitic needles of the Great Bahamas Bank, Jour. Geol., v. 65, p. 364-375.

Maher, J.C. and Collins, J.B., 1948, Hugoton Embayment of the Anadarko Basin in southwestern Kansas, southeastern Colorado and Oklahoma panhandle, Amer. Assoc. of Petrol. Geol. Bull., v. 32, p. 813-819.

Matthews, R.K., 1966, Genesis of recent lime mud in southern British Honduras, Jour. Sed. Pet., v. 36, p. 428-454.

Merriam, D.F. and Atkinson, W.R., 1955, Tectonic history of the Cambridge Arch in Kansas, Kansas Geol. Surv., Oil and Gas Invest. No. 13.

Moore, R.C., 1936, Stratigraphic classification of the Pennsylvanian rocks of Kansas, Kansas Geol. Surv. Bull. 169, 256 p.

Morgan, J.V., 1952, Correlation of radioactive logs of the Lansing and Kansas City groups in central Kansas, Pet. Transactions, AIME, v. 195, p. 111-118.

Muller, G., 1971, Gravitational cement: An indicator for the vadose zone of subaerial diagenetic environment, in: O.P. Bricker (ed.), Carbonate cements, John Hopkins Univ. Studies in Geology, no. 19, pp. 185-188.

Oldershaw, A.E. and Scoffin, T.P., 1967, The source of ferroan and non-ferroan calcite cements in the Halkin and Wenlock Limestones, Jour. Geol., v. 5, pp. 309-320.

Parker, J.M., ed., Rocky Mountain Association of Geologists, 1961, Oil and gas field volume, Colorado-Nebraska, R.M.A.G. Denver, Colo., 390 p., 8 maps.

Parkhurst, R.W., 1961, Surface to subsurface correlations and oil entrapment in the Lansing and Kansas City groups (Pennsylvanian) in northwest Kansas, Unpub. Master's Thesis, Univ. of Kansas, 71 p.

Rascoe, B., 1962, Regional stratigraphic analysis of Pennsylvanian and Permian rocks of the western Mid-continent, Colorado, Kansas, Oklahoma, Texas, Amer. Assoc. of Petrol. Geol. Bull., v. 46, no. 8, pp. 1345-1370.

Reeves, C.C., 1970, Origin, classification and geologic history of caliche on the southern High Plains, Texas and eastern New Mexico, Jour. Geol., v. 78, pp. 352-362.

Scholle, P.A., 1978, Carbonate rock constituents, textures, cements, and porosities, Amer. Assoc. of Petrol. Geol. Memoir 27, 241 p.

Semeniuk, V., 1971, Subaerial leaching in the limestones of the Bowan Park Group (Ordovician) of Central Western New South Wales, Jour. Sed. Pet., v. 41, no. 4, pp. 939-950.

Stockman, K.W., Ginsburg, R.N., Shinn, E.A., 1967, The production of lime mud by algae in South Florida, Jour. Sed. Pet., v. 37, pp. 633-648.

Svoboda, R.F., 1962, Sleepy Hollow action sets off southwest Nebraska drilling push, Oil and Gas Jour., v. 60, no. 29, pp. 132-137.

Thrailkill, J., 1968, Chemical and hydrologic factors in the excavation of limestone caves, Geol. Soc. Amer., v. 79, pp. 19-46.

Walters, R.F., 1946, Buried Pre-Cambrian hills in northeastern Barton County, Central Kansas, Amer. Assoc. Petrol. Geol. Bull., v. 30, no. 5, pp. 660-710.

Walther, J., 1894, Lithogenesis der Gegenwart, Jena, Gustav Fischer, 1055 p.,

Watney, W.L., 1977, Lithofacies of Upper Pennsylvanian Lansing-Kansas City Groups in northwest Kansas - southwest Nebraska (abs.), Amer. Assoc. of Petrol. Geol.. Bull., v. 61, p. 879.

________ and Ebanks, W.J. Jr., 1978, Early subaerial exposure and fresh-water diagenesis of Upper Pennsylvanian cyclic sediments in northern Kansas and southern Nebraska (abs.), Amer. Assoc. of Petrol. Geol. Bull., v. 62, p. 510-511.

Weller, J.M., 1958, Cyclothems and larger sedimentary cycles of the Pennsylvanian, Jour. Geol., v. 66, p. 195-207.

Wells, A.J. and Illing, L.V., 1964, Present day precipitation of calcium carbonate in the Persian Gulf, Developments in Sedimentology, v. 1, Deltaic and Shallow Marine Deposits, pp. 429-439.

Wilson, J.L., 1970, Depositional facies across carbonate shelf margins, Trans. Gulf Coast Assoc. Geol. Soc., v. 20, pp. 229-233.

________, 1974, Characteristics of carbonate platform margins, Amer. Assoc. of Petrol. Geol. Bull., v. 58, pp. 810-824.

________, 1975, Carbonate facies in geology, Springer-Verlag, 471 pp.

APPENDICES

VERTICAL LITHOLOGIC SEQUENCE OF THE "E" ZONE

The complexity of the "E" zone cycle is illustrated in Figure 8 of the main text. A brief description of the various rocks in this sequence is given below. These descriptions, unless otherwise stated, are based on examinations of cores in the Meeker Canal Field. Rock unit numbers correspond to those in Figure 8 of the main text.

Unit 1

This thin limestone is at the base of the marine phase of the "D" zone cycle. It is a coarse-grained grainstone (locally packstone). The dominant grain types are encrusting foram-algal coated grains ("Osagia") and lithoclasts of caliche from the underlying nonmarine sediments (Fig. 30A, B). The uppermost part is fusulinid rich and shaly (Fig. 30C, D). The lower contact is either an abrupt scoured surface or it is burrowed, where there is a thin intertidal siltstone below. In places this unit is a reservoir rock of fair quality with primary intergranular porosity ranging from eight to twelve percent. It varies in thickness from one to three feet (0.3 to 1 meter).

Unit 2

Three of four stages (I, II, III) of the K soil horizon (Gile and others, 1965) are recognized in this interval. The K-horizon is a soil horizon that has been indurated with calcite (caliche). The caliche occurs as small isolated nodules (Fig. 31B) or may replace nearly 100 percent of the matrix (Fig. 31C). Pedotubules (Fig. 31D) are recognized throughout, but are especially abundant when in association with the caliche. Other than a few blackened carbonate pebbles, there are few

Figure 30. Rock Unit 1. See Appendices for sample identification.

A. Oil stained core slab of encrusting foram-algal coated grain-lithoclast grainstone. Large caliche lithoclast (arrow) was derived from an underlying paleosol. (Scale is 1 cm.)

B. Photomicrograph of the same facies as in A. Encrusting forams and algae, possibly the blue-green algae Girvanella, coat rounded bivalve and caliche lithoclast grains. (Scale is 1 mm. cross-polarized light)

C. Core slab of shaly fusulinid packstone. Fusulinids are light colored and green shale is dark. (Scale is 1 cm.)

D. Photomicrograph of a portion of C. Scattered reworked caliche lithoclasts (dark grains) are among whole fusulinids. (Scale is 1 mm. plane light)

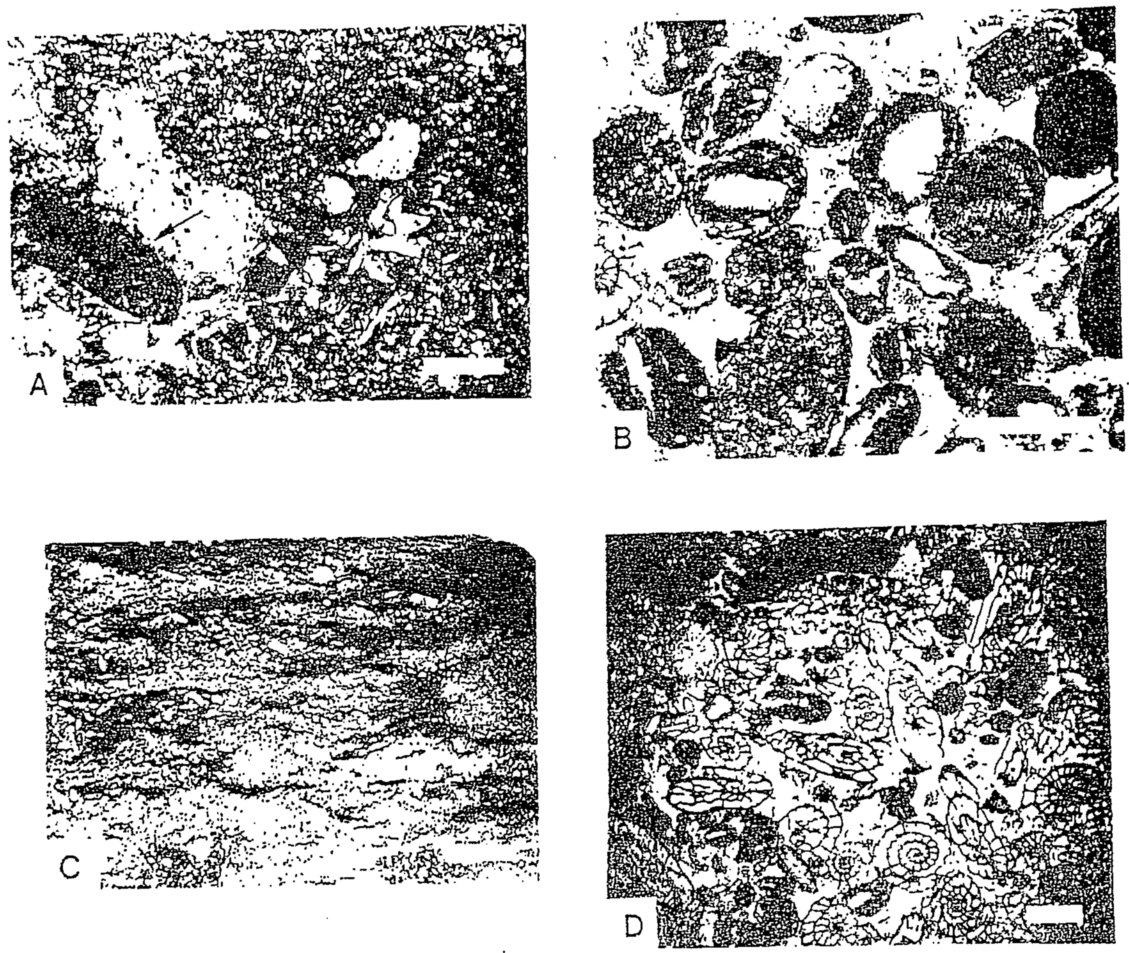
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Figure 31. Rock Unit 2. See Appendices for sample identification.

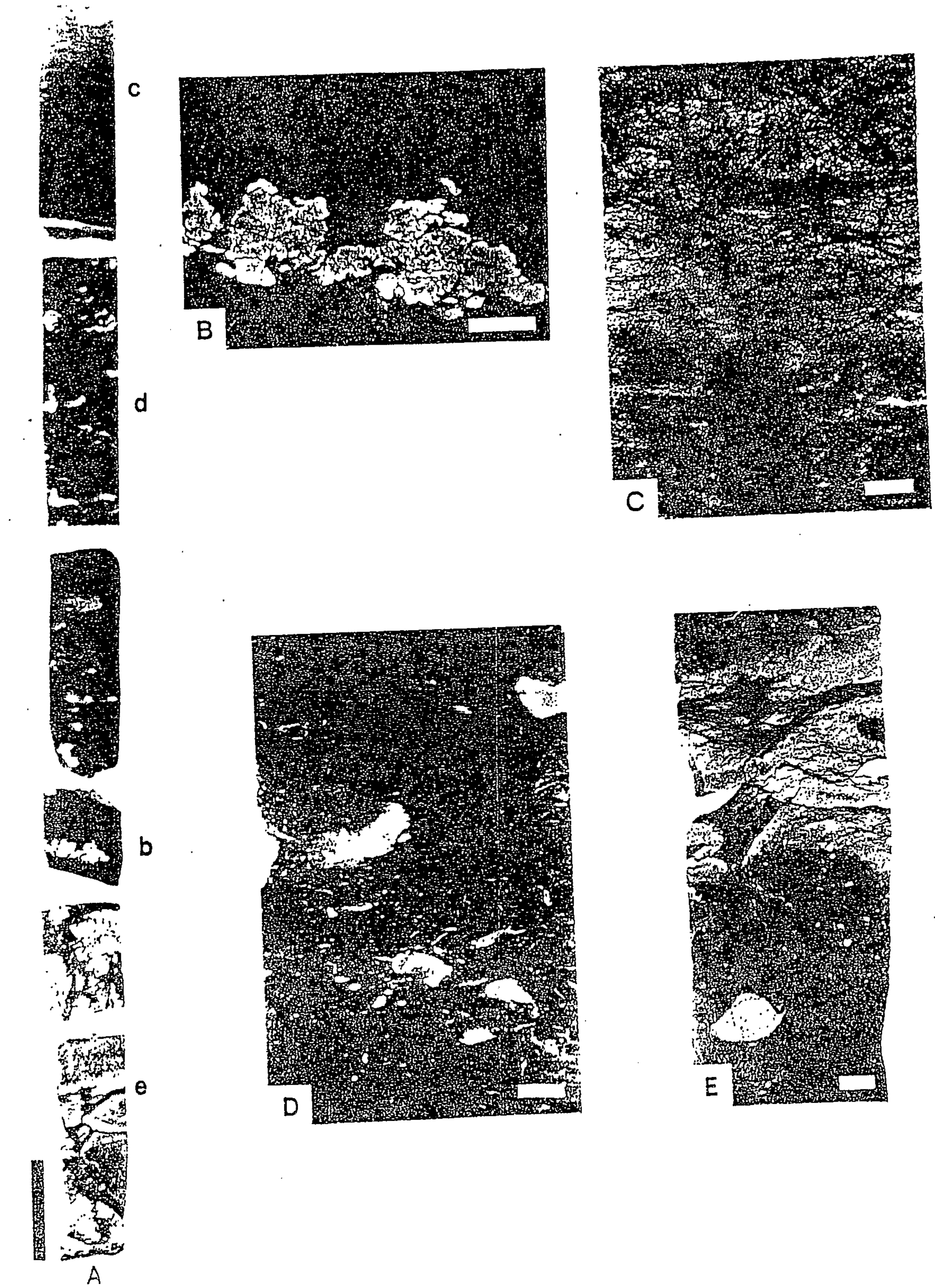
A. Representative core slabs from a fourteen foot nonmarine section in well number 2, Figure 18. The lighter areas are carbonate enriched while darker areas are red siltstone and shaly siltstone. The lower case letters to the right of the core slabs correspond with other core slabs in the figure. (Scale is 1 cm.)

B. Core slab of isolated caliche nodules in a silty shale. (Scale is 1 cm.)

C. Core slab of caliche carbonate disseminated throughout the matrix. (Scale is 1 cm.)

D. Core slab of a red siltstone containing calcite filled root tubes (smaller light blebs) and caliche nodules. (Scale is 1 cm.)

E. Core slab of upper, deeply weathered portion of the "E" zone marine carbonate. Red silt and clay (dark) from the overlying soil has infiltrated into the carbonate. (Scale is 1 cm.)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grains larger than very fine sand. The sediment is red and consists mostly of silt and clay. Unit 2 thins and thickens more than any other rock unit in the "E" zone. Intense weathering (Fig. 31E) sometimes makes it difficult to determine the precise contact with the carbonate unit below.

Unit 3

There are three distinct rock types in this unit. Fine-grained packstones-grainstones, coarse-grained packstones-grainstones and mudstones-wackestones, occur in the same sequence from top to bottom. The fine-grained packstone (Fig. 32A, B) usually makes up the bulk of the unit and grades into the underlying coarser-grained packstone (Fig. 32C, D) which abruptly truncates a thin (10 to 20 centimeter) mudstone-wackestone. This contact is erosional and burrowed with coarse grained sands having filled vertical burrows in the mudstone that are five centimeters or longer.

The fine-grained packstones-grainstones that dominate the upper part consist of moderately washed, well sorted pellets and fine, rounded, skeletal debris of a restricted faunal assemblage. The skeletal constituents include encrusting forams, presently detached from their substrate, ostracodes, and small gastropods and bivalves. The ratio of pellets to skeletal grains and grains to intergranular carbonate mud vary considerably. Usually there are more pellets than skeletal grains, and the rock is usually grain supported. The underlying coarse-grained packstones-grainstones consist of moderately to poorly sorted, broken and rounded skeletal grains of bivalves, and to a lesser extent, crinoids, gastropods, ostracodes and encrusting forams. It also contains moderate amounts of pellets. The amount of carbonate mud is variable, but usually

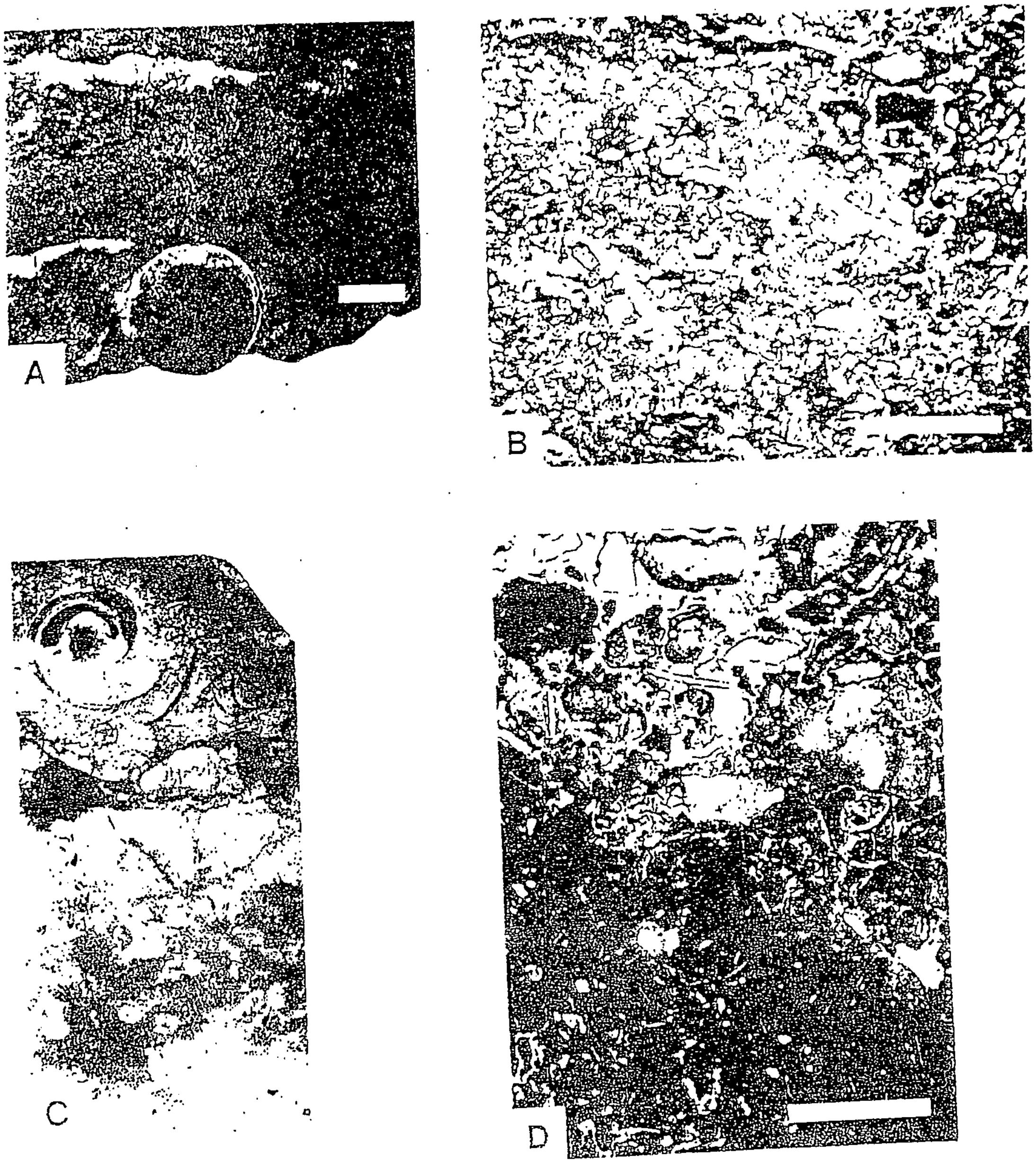
Figure 32. Rock Unit 3. See Appendices for sample identification.

A. Core slab of an oil stained fine-grained pellet-skeletal grainstone-packstone. The circular feature is a cross section through an orthocone cephelopod, one of the rare megafossils found in this rock unit. Light areas are tightly cemented with calcite cement. (Scale is 1 cm.)

B. Photomicrograph of one of the tightly cemented (lighter) portions of A. Most smaller grains are pellets and most larger grains are bivalve fragments. (Scale is 1 mm. cross-polarized light)

C. Core slab of the contact between coarse-grained grainstone and wackestone at the base of Rock Unit 3. Porous grainstone (oil stained) fills a large burrow (on the left) in the wackestone. Some of the wackestone is oil stained where bivalve molds and small vugs occur. A large gastropod in the grainstone must have been rapidly buried by carbonate sands. (Scale is 1 cm.)

D. Photomicrograph of the contact between grainstone and wackestone in C. Most grains in the grainstone are bivalve and gastropod fragments and those in the wackestone are mostly sponge spicules. (Scale is 1 mm. cross-polarized light)


A
B
C
D

is less than in the fine-grained packstone above. The mudstone below the coarse-grained packstone contains sponge spicules, gastropods, and ostracodes.

Unit 3 is light tan in color and ranges in thickness from less than two feet to five feet (0.6 to 1.6 meters). The packstones and grainstones make excellent reservoir rock with average porosity ranging from 10 to 15 percent, but with porosities up to 25 percent. Most porosity is secondary as a result of dissolution of intergranular carbonate mud, and bivalve and gastropod shells.

Unit 4

Unit 4 is a marlstone (Fig. 32A) consisting of a mixture of carbonate mud, silt, and clay. The ratio of carbonate mud to terrigenous material is highly variable over a short distance (centimeters) but generally decreases downward. Silt and clay is concentrated in discrete laminae as well as disseminated throughout the matrix. The carbonate mud is concentrated in nodule-like masses (5 to 20 centimeters) whose form is enhanced by mini-stylolites in a manner described by Scholle (1977). These nodules are separated by silt and clay laminae, but contain variable amounts of silt and clay in their matrix. There appears to have been carbonate enrichment of small (1 to 2 centimeter diameter) horizontal burrows. Carbonate mud-rich areas are typically light gray while silt and clay-rich laminae are usually light green to maroonish-green. In outcrop this unit would most likely appear to be a nodular limestone with a silty shale matrix. A sparse normal marine faunal assemblage consisting of brachiopods, crinoids, and a few fusulinids is found in this unit.

Figure 33. Rock Units 4 and 6. See Appendices for identification.

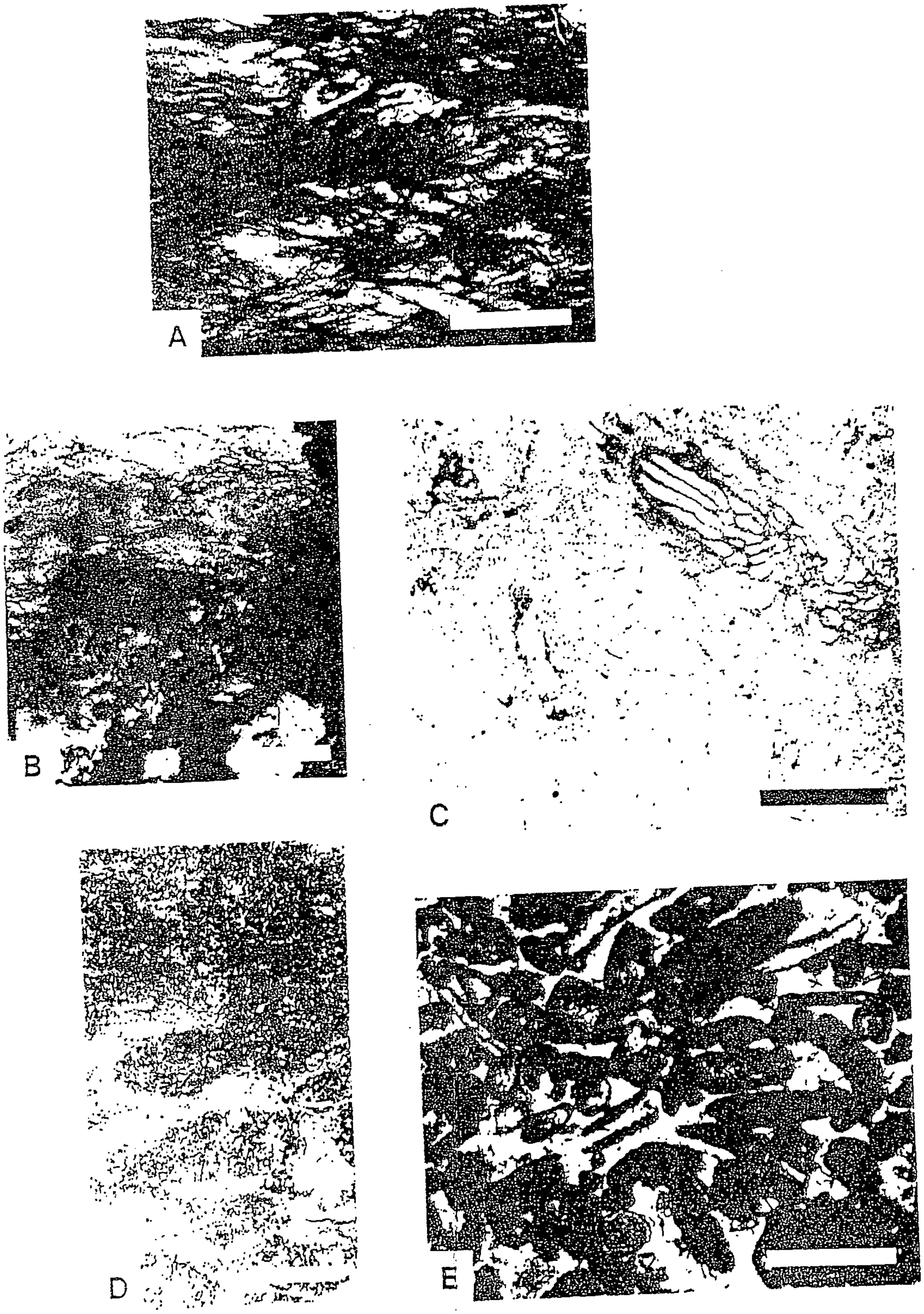
A. Core slab of Rock Unit 4-marlstone. Carbonate mud-rich areas are lighter than the green, shaly siltstone. (Scale is 2 cm.)

B. Core slab of upper Rock Unit 6-mixed skeletal wackestone. Oil stained areas have moldic porosity. (Scale is 2 cm.)

C. Photomicrograph of a portion of B. Fusulinids, bivalves, brachiopods, encrusting forams, bryozoans, and ostracodes are found in this unit. (Scale is 1 mm. cross-polarized light)

D. Core slab of Rock Unit 6-coarse-grained grainstone. Uncemented areas are oil stained. (Scale is 2 cm.)

E. Photomicrograph from the lower part of D. Rounded bivalve fragments are cemented with a quartz druse cement. (Scale is 1 mm. cross-polarized light)


A
B
C
D
E

Unit 5

The greatest faunal diversity in the entire "E" zone cycle is found in this shale interval. Fossils include ramose bryozoans, several genera of brachiopods, fusulinids, crinoids, ostracodes, and bivalves. The shale is silty throughout and sandy locally. The color is dark green-gray. Both upper and lower contacts are gradational.

Unit 6

Two distinct rock-types with a gradational boundary between them make up this interval. The lower one is the thickest (1.5 to 5 feet, 0.5 to 1.6 meters) and is a coarse-grained skeletal packstone or grainstone (Fig. 33D, E), that is nearly identical to the coarse-grained packstone (grainstone) of Unit 3. The upper part of Unit 6 is a mixed-skeletal wackestone (Fig. 33B, C) with normal marine faunal assemblage similar to that of Unit 5. The lower contact of Unit 6 is an abrupt, scoured, erosional surface.

Unit 6 is light tan in color and ranges in thickness from two to six and one-half feet thick (0.6 to 2 meters). The packstones and grainstones of this unit are excellent oil reservoir rock. Porosity averages 10 to 15 percent but is as great as 25 percent. Porosity is secondary, predominantly moldic, and resulted from dissolution of bivalve shell fragments.

Unit 7

This unit is marlstone (Fig. 34A) that is nearly identical to the rock of Unit 4. The color of the carbonate-rich areas is light, but the color of the clay and silt laminae changes gradually in a downward direction from light green, to maroonish-green, to dark maroonish gray.

Unit 8

A dark, maroonish-gray, silty, calcareous shale with sparse normal marine fauna makes up the bulk of this unit (Fig. 34B).

Unit 9

Within the Meeker Canal Field area rock unit 9 consists of a mixed-skeletal wackestone-packstone abruptly overlying a mudstone (Fig. 34D). The contact appears to be a scoured, erosional surface with some burrows penetrating the mudstone and filled with skeletal grains from the over-lying wackestone. This unit has considerable lateral variation to the northeast of the Meeker Canal Field, which was discussed in the main text. This unit is considerably darker, being a dark gray color, than are Units 3 and 6.

Unit 10

This shale unit (Fig. 34E) is similar to the shale of Unit 8. It does vary, however, in that the color becomes maroonish-brown towards the base and there are locally abundant fossils such as bryozoan, crinoids, and brachiopods near the base.

Unit 11

Since no cores of this interval were taken in the Meeker Canal Field, the following description is based on cores from surrounding areas. It consists of tan, silty limestone nodules of irregular form (5 to 10 centimeters in diameter) and thin discontinuous limestone lenses (2 to 5 centimeters thick) in a yellowish-brown siltstone matrix (Fig. 35A, B). The limestones are wackestones containing foram-algal coated grains ("Osagia"), whole fossils (brachiopods, bivalves, bryozoan, gastropods,

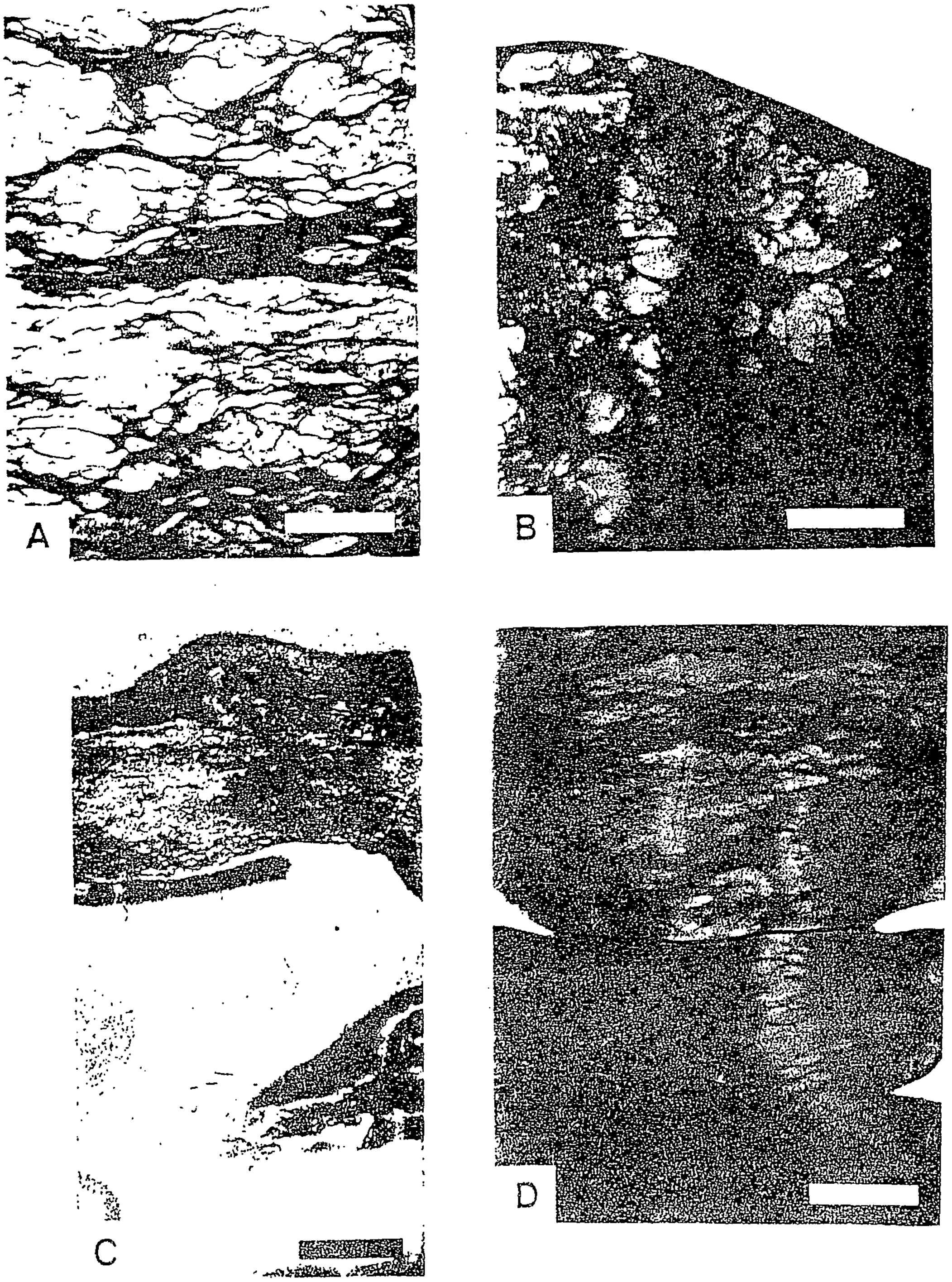
Figure 34. Core slabs of Rock Units 7, 8, 9, and 10. See Appendices for sample identification.

A. Rock Unit 7-marlstone. Dark areas are gray shaly siltstone and light areas are carbonate mud-rich. (Scale is 2 cm.)

B. Rock Unit 8-gray silty shale. This unit contains less carbonate mud than Rock Unity 7. (Scale is 2 cm.)

C. Rock Unit 9-mixed skeletal wackestone overlying a silty mudstone. The wackestone is dark (silicified) and fills a large burrow in the underlying mudstone. (Scale is 2 cm.)

D. Rock Unit 10-gray silty shale. Lighter areas are secondarily enriched with carbonate where permeability was greatest. These areas are generally along fractures and what appear to be burrows. (Scale is 2 cm.)


A
B
C
D

fusulinids) most of which are foram-algal coated, and a moderate amount of caliche lithoclasts, also coated. This nodular limestone overlies a horizontal laminated siltstone (Fig. 35C, D) which in turn overlies nonmarine sediments (Fig. 35E, F) as in Unit 1.

Figure 35. Rock Unit 11. Core slabs A, D, and E are from a transgressive sequence that is 50 cm thick.

A. Encrusting foram-algal coated-grain-skeletal wackestone. (Scale is 2 cm.)

B. Photomicrograph of a portion of a portion of A. Dark coats of forams and algae, possibly Girvanella, encrust skeletal grains of several types and caliche lithoclasts. Forams are tubular and appear (in section) as small calcite-filled voids (arrow). (Scale is 1 mm. plane light)

C. Horizontal laminated intertidal rock comprised of thin silty sandstone laminae (dark) and carbonate mud-rich siltstone laminae (light). Lower few centimeters is a caliche nodule conglomerate, the caliche being derived from the underlying paleosol. (Scale is 2 cm.)

D. Photomicrograph of the caliche nodule conglomerate from C. Nodules are dark and contain fine quartz sand grains (light), and are in a quartz sand matrix. (Scale is 1 mm. plane light)

E. Caliche nodule conglomerate overlying a caliche-indurated paleosol. Below the conglomerate, caliche is disseminated throughout a sandy matrix as well as concentrated in nodular masses. (Scale is 2 cm.)

F. Photomicrograph of a portion of E. Darker areas are caliche nodules which are in place. (Scale is 1 mm. plane light)

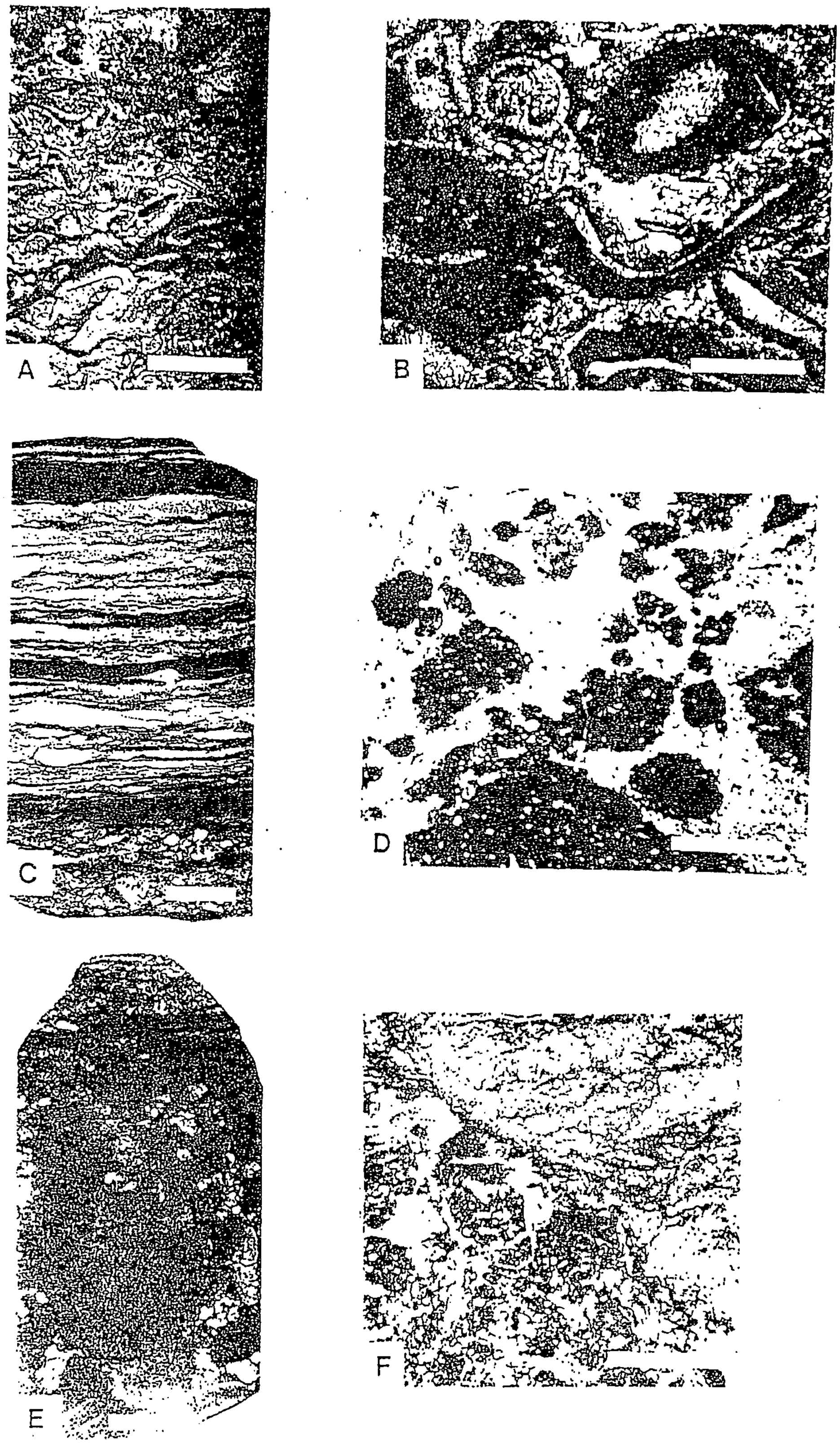

A
B
C
D
E
F

TABLE OF DATA USED IN CONSTRUCTION OF FIGURES 13 THROUGH 17

Well Name (Operator, Lease)	Location (Sec.-Twp.-Rng.)	Rock Unit 3: Total Thickness	Rock Unit 3: Packstone (Grainstone) Thickness	Rock Unit 3: Porosity Thickness	Rock Unit 3: Intense Weathering Thickness*	Rock Unit 6: Total Thickness	Rock Unit 6: Packstone (grainstone) Thickness	Rock Unit 6: Porosity Thickness	Rock Unit 6: Chert Thickness**	Rock Unit 6: Total "E" Zone Porosity Thickness	Cored Interval Examined
1. Theodore Gore Co., Fleming #1	SE SE 31-3N-32W	2.5	2	1	1	3	1	1	0.5	2	3750-3780
2. Theodore Gore Co., George #1	NW SE 5-2N-32W	2.5	2	1.5	0.5	3.5	3	2.5	0.5	4	3796-3814
3. Theodore Gore Co., Hutt #1	NW NW 7-2N-32W	3.5	2.5	2.5	0.5	5	4	2	1	5.5	3827-3863
4. Theodore Gore Co., H.V. Farms #1	SW SW 32-3N-32W	3	3	1.5	1.5	4.5	4	4	0	5.5	3758-3792
5. Theodore Gore Co., H.V. Farms #B-1	NW NE 5-2N-32W	3	5	0.5	0.5	5.5	4	4.5	0	5	3772-3811
6. Theodore Gore Co., Mundy #1	NW SE 6-2N-32W	5	2	3.5	1	4	2.5	2.5	0.5	6	3766-3798
7. Theodore Gore Co., Mundy #2	NE SE 6-2N-32W	4.5	4.5	3	1	2.5	1.5	2	0	5	3754-3800
8. Theodore Gore Co., Mundy #3	SE SE 6-2N-32W	3.5	3.5	2.5	1	6.5	5	5	5	7.5	3773-3800
9. Theodore Gore Co., Poindexter #1	SW NW 5-2N-32W	3	1.5	2.5	0	3.5	2	2	0.5	4.5	3774-3813
10. Theodore Gore Co., Poindexter #3	NE NW 5-2N-32W	2	0	0	0	2.5	2	1	0.5	1	3777-3806
11. Theodore Gore Co., Poindexter #4	SE NW 5-2N-32W	2.5	2	1.5	0.5	5	4.5	3.5	1	5	3766-3803
12. Theodore Gore Co., Schaffert #B-1	SE SE 32-3N-32W	5	4.5	3.5	1	4.5	2	3	0	6.5	3761-3792
13. Theodore Gore Co., Wertz #1	SE NW 6-2N-32W	4.5	4	3.5	0	3.5	3	2	1	5.5	3768-3814
14. Theodore Gore Co., Wertz #2	NW NE 6-2N-32W	4	3	2	1	2	1.5	0.5	0	2.5	3756-3793
15. Theodore Gore Co., Wertz #3	SW NW 6-2N-32W	4	3.5	3	0.5	2	1	1	0	4	3790-3814
16. Theodore Gore Co., Wertz #4	NE NW 6-2N-32W	1.5	1.5	1.5	0	3.5	3	3	0	4.5	3752-3786
17. Theodore Gore Co., Wertz-Brown #1	NE SW 6-2N-32W	5	4.5	3.5	1	3	2	2	0.5	5.5	3778-3805
18. Theodore Gore Co., Wertz-Fleming #1	SW NE 6-2N-32W	3.5	3	3	0	4	3.5	2.5	1	5.5	3768-3813
19. Theodore Gore Co., Wertz-Fleming #2	SE NE 6-2N-32W	4	1	1.5	2	2.5	1.5	1	0	2.5	3764-3791
20. Theodore Gore Co., Wertz-Fleming #3	NE NE 6-2N-32W	2.5	3	2	1	3	2.5	2	0.5	4	3748-3783
21. Theodore Gore Co., Williamson #B-1	NW SW 5-2N-32W	5	4	3.5	1	3	2	1.5	1	5	3774-3812
22. Empire Drilling Co., Blackwood Farms #1	NW SW 10-3N-31W	Absent due to erosion				1	0.5	0	0	0	3706-3746
23. Ladd Petroleum Co., Dry Creek #2-3A	SW SE 21-3N-34W	2	1	1.5	0	3	1	1.5	0	3	4080-4246
24. Theodore Gore Co., Hidy #1	SE SW 15-3N-34W	5	2	0	3	3	3	0	0	0	4021-4090
25. Theodore Gore Co., McDonald #1	NW SE 26-3N-32W	3	2	1	1	3	0	0	0	1	3736-3768
26. Theodore Gore Co., Hustion #2	NW SE 23-3N-32W	2.5	1.5	1	0	2	0.5	0	0	1	3838-3878
27. Theodore Gore Co., Poore #1	SW SE 7-3N-31W	4	1	0	2	1	0.5	0	0	0	3768-3805
28. Empire Drilling Co., Katne #1	NW SW 9-3N-30W	4	2	0	0	2	0	0	0	0	3737-3780
29. Skelly Oil Co., Reiher #2	NW NE 26-1N-37W	3.5	0	1	0	0.5	0	0	0	1	3847-3916
30. Theodore Gore Co., Sitzman #1	SW SW 5-3N-31W	2	0	0	0.5	1.5	0.5	0	0	0	3794-3820
31. Theodore Gore Co., Schaffert #B-2	SW SW 33-3N-32W	3		3		4.5		2		5	
32. Theodore Gore Co., Poindexter #2	NW NW 5-2N-32W	4		3		4		2		5	
33. Theodore Gore Co., Wertz-Williams #1	NE NE 29-3N-32W	4		2		4		2		4	
34. Theodore Gore Co., Bauerle #1	SW SW 27-3N-32W	3		0		4		0		0	
35. Theodore Gore Co., Bauerle #2	NW NW 34-3N-32W	Absent due to erosion				3		0		0	
36. Theodore Gove Co., Bauerle #4	SE SW 27-3N-32W	3		1		3		0		1	
37. Theodore Gove Co., Grothius #1	SW SE 27-3N-32W	3		2		3.5		0		2	
38. Theodore Gore Co., Watson #1	NE NE 33-3N-32W	3		1		3		0		1	
39. Theodore Gore Co., Watson #2	NW NE 33-3N-32W	3		2		3		2		4	
40. Theodore Gore Co., Nichols-Bauerle #1	NW SW 27-3N-32W	3		1		3.5		0		1	
41. Theodore Gore Co., Nichols-Bauerle #2	NE SW 27-3N-32W	3		0		2.5		0		0	
42. Theodore Gore Co., Schaffert #1	SE SE 29-3N-32W	2		1		3		0		1	
43. Theodore Gore Co., Schaffert #2	SW SE 26-3N-32W	2.5		1		4		0		1	
44. Theodore Gore Co., Schaffert #3	NE SE 28-3N-32W	2.5		1		4		2		3	
45. Theodore Gore Co., Wimer #1	SE NE 14-2N-32W	3		0		3		0		0	
46. Ackman, Schulein and Associates; Brew, Stecker #1	SE SW 4-2N-32W	3		3		4		2	1	5	
47. Ackman, Schulein and Associates; Brew, Stecker #2	NW NW 4-2N-32W	3		2		3.5		3	0.5	2.5	
48. Ackman, Schulein and Associates; Brew, Shackelford Feed Lots #1	NW NW 6-2N-32W	4		3		3.5		2		5	
49. W.F. Carr, Hay #1	NW NE 26-3N-32W	2		2		4		2	1	4	
50. Edminston and Shields, Williams #1	SW NW 29-3N-32W	2		0		3		0		0	
51. Lincoln Haggard and Murfin Drilling Co., Conter #1	NW SW 12-2N-32W	3		2		5		3		5	
52. Oxford Petroleum Co., Cobb #1	NE NE 20-3N-32W	2		1		3		0		1	
53. S & W Drilling Co., Carmody #B-1	SE SE 15-2N-33W	3		0		2.5		0	1	0	
54. S & W Drilling Co., Carmody #C-1	NW SE 11-2N-33W	4		3		5		3	0.5	6	
55. S & W. Drilling Co., Coleman #1	NE NE 12-2N-33W	3		2		4.5		2	1	4	
56. S & W Drilling Co., Coleman #2	SE NE 12-2N-33W	3		2		4.5		2		4	
57. S & W Drilling Co., Coleman #3	SW NE 12-2N-33W	3		2		3.5		1.5		3.5	

*Portion of Rock Unit 3 porosity was precluded by intense weathering.

**Portion of Rock Unit 6 where porosity was destroyed by silicification and quartz cement.

TABLE OF WELLS AND DEPTHS THAT CORRESPOND TO

PHOTOGRAPHS OF CORE SLABS AND THIN SECTION PHOTOMICROGRAPHS

Figure	Operator	Lease	Depth	"E" Zone Status
19 A	Theodore Gore Co.	Hutt #1	3836	+
B	Empire Drilling Co.	Rathe #1	3745	*
C	Theodore Gore Co.	Poindexter #3	3788.5	+
D	Theodore Gore Co.	George #1	3800.5	+
20 A	Theodore Gore Co.	Wertz-Fleming #1	3789	+
B	Theodore Gore Co.	McDonald #1	3754	*
C	Theodore Gore Co.	Poore #1	3782	*
D	Theodore Gore Co.	Poore #1	3782	*
21 A	Theodore Gore Co.	Mundy #2	3797	+
B	Theodore Gore Co.	Mundy #2	3797	+
C	Theodore Gore Co.	Mustion #2	3866	*
D	Theodore Gore Co.	Mustion #2	3866	*
22 A	Theodore Gore Co.	Schaffert B-1	3770	+
B	Theodore Gore Co.	Schaffert B-1	3781	+
24 A	Theodore Gore Co.	Wertz-Fleming #3	3759	+
B	Theodore Gore Co.	Wertz-Fleming #3	3759.5	+
C	Theodore Gore Co.	Hutt #1	3851	+
D	Theodore Gore Co.	Wertz #4	3766.5	+
25 A	Theodore Gore Co.	H. V. Farms #1	3766	+
B	Theodore Gore Co.	H. V. Farms #1	3766	+
C	Theodore Gore Co.	Schaffert B-1	3767	+
D	Theodore Gore Co.	Schaffert B-1	3767	+
26 A	Theodore Gore Co.	Poore #1	3769-72	*
B	Theodore Gore Co.	Poore #1	3771	*
C	Theodore Gore Co.	Poore #1	3772	*
D	Theodore Gore Co.	Poore #1	3775-77	*
E	Theodore Gore Co.	Poore #1	3777	*
F	Empire Drilling Co.	Blackwood Farms #1	3710-12	
G	Empire Drilling Co.	Blackwood Farms #1	3711	*
H	Empire Drilling Co.	Blackwood Farms #1	3712	*
27 A	Theodore Gore Co.	George #1	3800.8	+
B	Theodore Gore Co.	George #1	3800.8	+
C	Theodore Gore Co.	McDonald #1	3743	*
D	Theodore Gore Co.	McDonald #1	3743	*
28 A	Theodore Gore Co.	H. V. Farms B-1	3798	+
B	Theodore Gore Co.	Hidy #1	4086	*
29 A	Theodore Gore Co.	Wertz #1	3780	+
B	Theodore Gore Co.	Wertz #1	3780	+
C	Theodore Gore Co.	Wertz #1	3791	+
D	Theodore Gore Co.	Wertz #1	3791	+
30 A	Theodore Gore Co.	Williamson B-1	3778	+
B	Theodore Gore Co.	Poindexter #3	3781	+
C	Theodore Gore Co.	Williamson B-1	3777.5	+
D	Theodore Gore Co.	Williamson B-1	3777.5	+
31 A	Theodore Gore Co.	Hidy #1	4056-70	*
B	Theodore Gore Co.	Hidy #1	4065	*
C	Theodore Gore Co.	Hidy #1	4056	*
D	Theodore Gore Co.	Hidy #1	4059	*
E	Theodore Gore Co.	Hidy #1	4070	*
32 A	Theodore Gore Co.	Williamson B-1	3784	+
B	Theodore Gore Co.	Williamson B-1	3784	+
C	Theodore Gore Co.	George #1	3801	+
D	Theodore Gore Co.	George #1	3801	+
33 A	Theodore Gore Co.	Sitzman #1	3805	*
B	Theodore Gore Co.	Poindexter #3	3797	+
C	Theodore Gore Co.	Poindexter #3	3797	+
D	Theodore Gore Co.	Wertz-Fleming #1	3789	+
E	Theodore Gore Co.	Wertz-Fleming #1	3789	+
34 A	Theodore Gore Co.	Williamson B-1	3802	+
B	Ladd Petroleum Co.	2-3A Dry Creek	4174	*
C	Theodore Gore Co.	Mundy #2	3797	+
D	Ladd Petroleum Co.	2-3A Dry Creek	4192	*
35 A	Skelly Oil Co.	Reiher #2	3904	*
B	Skelly Oil Co.	Reiher #2	3904	*
C	Skelly Oil Co.	Reiher #2	3904.5	*
D	Skelly Oil Co.	Reiher #2	3904.5	*
E	Skelly Oil Co.	Reiher #2	3905	*
F	Skelly Oil Co.	Reiher #2	3905	*

* Non-productive
+ Produces oil or most likely will produce oil when perforated

METHODS OF STUDY

Core Data Availability

The conclusions of this study were drawn from data gathered from 29 cores from wells in Hitchcock County, Nebraska, one from adjacent Red Willow County, and other operator-released well information. All but four cores are from wells drilled by the Theodore Gore Company since 1975. The highest concentration of cores is in the Meeker Canal Field, from which 21 cores were studied. Six cores from dry hole wild-cat wells, all but one located northeast of the Meeker Canal Field, were examined. The three other cores, one of which is productive and two that are not, came from the Reiker, Republican River, and the Dry Creek Field (produces oil).

Core Descriptions

Detailed descriptions of slabbed cores were made with the aid of a binocular microscope and data was recorded both written and graphically on a lithologic log. Particular attention was paid to porosity, rock texture, terrigenous sediment content, grain types, and diagenetic features. Dunham's (1962) textural classification for carbonate rocks was used. These data were visually estimated and later verified or adjusted by petrographic work.

Petrography

Three-hundred-and-forty thin sections of samples from 30 cores were examined. The objectives of the petrographic work were to:

1. Verify or adjust data recorded from observations of the slabbed cores;
2. Determine and relative abundances of various kinds of pores; and

3. Study the results of diagenetic processes that affected porosity.

All 11 rock units of the "E" zone were sampled. Most thin sections, at least two but usually three, came from samples from each of the rock Units 3 and 6, the oil producing units. Approximately 50 of the thin sections were stained for ferroan and non-ferroan calcite and dolomite using Dickson's (1965) staining technique.