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DONALD A. MYERS, PHILIP T. STAFFORD,
AND ROBERT J. BURNSIDE

PREPARED IN CO-OPERATION WITH THE UNITED STATES
GEOLOGICAL SURVEY

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JOHN T. LONSDALE, *Director*

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The benefits of education and of useful knowledge, generally diffused through a community, are essential to the preservation of a free government.

SAM HOUSTON

Cultivated mind is the guardian genius of Democracy, and while guided and controlled by virtue, the noblest attribute of man. It is the only dictator that freemen acknowledge, and the only security which freemen desire.

MIRABEAU B. LAMAR

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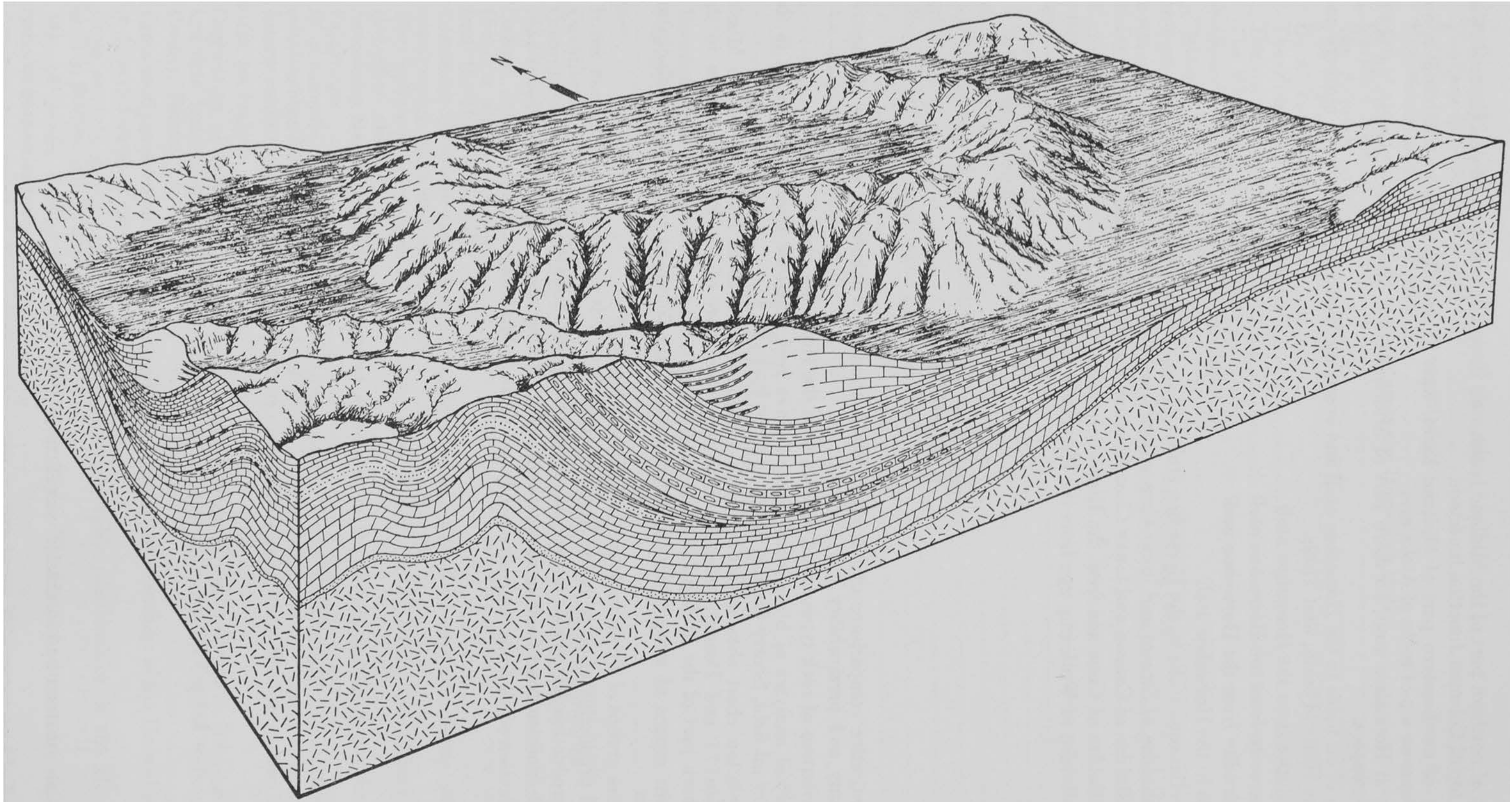
Contents

Illustrations

Tables



Reconstruction of the northern part of the Midland basin in late Pennsylvanian time (vertically exaggerated to emphasize the configuration of the Horseshoe atoll).

Geology of the Late Paleozoic Horseshoe Atoll in West Texas

DONALD A. MYERS,[1] PHILIP T. STAFFORD,[1] AND ROBERT J. BURNSIDE[1]

ABSTRACT

Regional geology.—The Horseshoe atoll is a subsurface accumulation of fossiliferous limestone which is as much as 3,000 feet thick and which was deposited during Pennsylvanian and early Permian time in the northern part of the Midland basin, in western Texas. It is a horseshoe-shaped mass about 90 miles across in an east-west direction and about 70 miles from north to south. The crest of the atoll is a series of irregular hills and depressions, and the flanks slope gently away to merge with a broad limestone platform on which the atoll rests. Large quantities of petroleum have been produced from reservoirs in the eastern and southern parts of the atoll.

The Midland basin is an asymmetric, subsurface structural and sedimentary basin, bounded by the Matador arch on the north, the Central Basin Platform on the west, and the Ozona "high" on the south. The sedimentary rocks in the Midland basin belong to the Quaternary, Tertiary, Cretaceous, Triassic, and Permian through Cambrian systems. The thickest and most complete sequence of sedimentary rock is found on the western side of the basin. In most of the Midland basin, rocks belonging to the Pennsylvanian system consist of a thin sequence of nonfossiliferous shale and siltstone, but in the Horseshoe atoll the Pennsylvanian rocks are many times as thick and include very little noncarbonate or nonfossiliferous material.

Characteristics of the reef rocks.—The limestone in the Horseshoe atoll is composed mainly of nonbedded clastic calcium carbonate debris of organic origin. It is bonded by lithified lime mud and by calcite cement. The limestone may be classed as calcilutite, calcarenite, and calcirudite according to the dominant size of the constituent grains; the calcirudite commonly contains large fragments of pre-existing reef rock indicating reworking of the materials that form the atoll. The only lithologically distinct units that are traceable from well to well in the atoll are thin beds of dark bituminous shale.

Porosity in the reef rocks is almost entirely secondary. Effective porosity ranges from almost nothing to 30 percent. Studies of cores and well logs have shown that the atoll contains zones of relatively high porosity (more than 4.5 percent) having little argillaceous material, alternating with zones of relatively low porosity (less than 4.5 percent) having considerable argillaceous material. Chemical analyses indicate the limestone generally contains more than 97 percent calcium carbonate. Insoluble residues average about 1.4 percent of the total limestone by weight.

Stratigraphy.—The rocks that form the Horseshoe atoll have been assigned to the Strawn, Canyon, and Cisco groups of the Pennsylvanian system and to the Wolfcamp series of the Permian system. Rocks of Strawn age in the atoll have a maximum thickness of 750 feet. They are generally overlain by rocks of Canyon age, but in many places they are overlain by rocks of Cisco or Wolfcamp age. Reef rocks of Canyon age have a maximum thickness of 800 feet and are generally overlain by rocks of Cisco age, although in some places they are overlain directly by rocks of Wolfcamp age. Reef rocks of Cisco age

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have a maximum thickness of 600 feet, and those of Wolfcamp age have a maximum thickness of 1,000 feet.

As a result of reworking of the reef rocks at several times during the growth of the atoll, the rocks of the different ages are distributed irregularly and discontinuously. Thus, reef limestone of Wolfcamp age is found in places high on the crest of the atoll; in places low on the flanks of the atoll; and in places extending tonguelike into shale of Wolfcamp age surrounding the atoll. Studies of the fusulinid faunas in the atoll as related to the porosity zones indicate that these porosity zones may have time-stratigraphical significance. Thin beds of shale appear to mark unconformities in the atoll.

The Horseshoe atoll is underlain by bedded limestone and shale of Strawn and Atoka ages. Throughout most of the area of the atoll these rocks rest on limestone of probable Mississippian age, but in eastern Mitchell County they rest directly on the Ellenburger.

Rocks overlying the atoll are of Wolfcamp age and consist of gray to black shale, siltstone, sandstone, and small amounts of limestone. The terrigenous rocks immediately overlying the atoll appear to have been deposited as a southwestward-transgressing delta, which progressively smothered the atoll and ended its growth.

Paleontology.—A study of faunal associations indicates that crinoids and fusulinids are the most abundant fossils in the reef rock. Brachiopods, bryozoans, corals, and mollusks are less abundant. Algae are believed to have been present, although little positive evidence of algae has been observed in the atoll.

The reef limestones of the atoll lie almost wholly within the zones of *Fusulina*, *Triticites*, and *Pseudoschwagerina*. Stratigraphic differentiation within the zone of *Triticites* was based on evolutionary development within the genus, as well as on first appearance of other genera.

Evidence of reworking was found in the Horseshoe atoll. Mixed fusulinid faunas were noted in many calcirudites. The fossils contained in the reef rock indicate that the atoll probably accumulated in tropical marine waters of normal salinity. Turbidity was slight during periods of maximum reef development.

Subsurface structure.—Complex stratigraphic relationships caused by reef and reeflike carbonate masses and abrupt facies changes in the rocks of Pennsylvanian and Permian ages tend to obscure the effects of tectonic movements in the area of the atoll, except for the major regional structures. Contours drawn on rocks younger than the Horseshoe atoll generally reveal structures resulting from draping and differential compaction rather than from actual tectonic movements. Contours drawn on rocks older than the Horseshoe atoll reveal a regional dip to the west and southwest ranging from about 20 to 200 feet per mile. Two major regional structural features, however, are present in the lower Pennsylvanian rocks on which the atoll rests—a syncline curving around the western and southern sides of the atoll and a regional nose plunging to the southwest in the lagoonal area. These features may have partly controlled the position and shape of the atoll.

Origin of the atoll.—Studies of the lithology, porosity, and fusulinid faunas suggest that several periods of erosion took place during the development of the Horseshoe atoll, alternating with periods of growth. It is believed that the alternation between growth and erosion is related to changes in sea level. The Midland basin was subsiding, probably with little interruption, during this time. Low slopes on the flanks of the atoll are mainly a result of reworking of the reef rock—particularly during periods when the sea level was low—and lateral spreading of the resulting detritus.

The shape of the atoll may be explained by the action of winds and currents. Simultaneous deposition of carbonate material in the atoll and noncarbonate material in immediately adjacent parts of the Midland basin indicates abrupt and important differences in characteristics of the water and currents in different parts of the basin.

Geologic history.—Carbonate sediments were deposited during most of Mississippian time in the area now occupied by the Horseshoe atoll. During Chester(?) time terrigenous muds entered the area and were deposited concurrently with the carbonate sediments. During Morrow(?) time the Matador arch underwent erosion, and arkosic sands and gravels were deposited in the northern part of the Midland basin. During Atoka time, carbonate and terrigenous sediments were deposited in the western part of the Midland basin. Near the Matador arch the arkosic sands and gravels were still being deposited. In late Atoka or early Strawn time the eastern part of the basin emerged, and rocks of Atoka and Mississippian ages were truncated by erosion. Deposition may have continued in the western part during this time. In early Strawn time, a biostromal limestone was deposited over the entire area. During Wolfcamp time, terrigenous muds encroached upon the atoll from the northeast and east, progressively smothering reef. The last of the atoll was buried in the late Wolfcamp time.

The history of the development of the atoll appears to be one of fluctuating sea level coupled with transgressing and regressing reef growth, erosion, and occasional incursions of terrigenous muds.

Oil and gas.—Oil was first produced from reef rocks in 1938; however, discoveries of large reservoirs were not made until 1948 when the part of the atoll underlying Scurry County was drilled. From January 1, 1939, to December 31, 1953, oil production from the Horseshoe atoll was 244,066,994 barrels. Production in the atoll is from reef rocks of Strawn, Canyon, Cisco, and Wolfcamp ages. The bituminous shales of Wolfcamp age surrounding the atoll are suspected to be the source of the oil.

The oil reservoirs and fields of the atoll are interconnected by the stratigraphically lower, more porous parts of the reef. They are also connected with the structurally high water-saturated parts of the reef. Because of the porosity zonation, a natural water drive will be effective only in those zones which have good porosity and permeability and which lie in direct contact with the oil-water interface. It is believed that the technique developed in correlating zones of different porosity will aid in the understanding of the porosity relationships in the atoll and in secondary recovery efforts.

INTRODUCTION

In recent years, many important investigations of both modern and ancient reefs have been made. Most students of reefs (including King, 1948; Teichert and Fairbridge, 1948; Adams and Frenzel, 1950; Fairbridge, 1950; Ladd et al., 1953; Newell et al., 1953; and MacNeil, 1954a and b) have investigated living reefs or fossil reefs exposed at the surface. Only a few workers, such as Lowenstam (1950), have undertaken comprehensive studies of reefs in the subsurface. Although these investigators have contributed much to the general knowledge of reefs, many problems remain, particularly in regard to the nature and origin of the ancient reefs, some of which are important deeply buried reservoirs of petroleum.

It has been estimated (Imbt, 1950) that more than half the world's petroleum reserves are contained in carbonate reservoirs. Of the carbonate reservoirs, rocks classed as "reefs" probably contain the largest volume of reserves. Detailed studies of some of these carbonate reservoirs for which abundant subsurface data are available may help to determine the significance of these reeflike masses and to solve some of the problems of exploring for petroleum in these rocks.

This paper summarizes the available information about one of the most productive and extensively drilled oil-bearing carbonate accumulations in North America. This carbonate mass—a horseshoe-shaped accumulation of limestone—called the "Horseshoe atoll" by Adams et al. (1951, fig. 1) is buried more than 6,000 feet beneath the plains of western Texas. In January 1948, oil was discovered in the atoll in Howard County, Texas. Later that year the largest limestone reservoir in North America, part of the Scurry oil field, was discovered in the Scurry County part of the atoll. Prior to March 1954, 42 fields had been found, mainly along the crest of the atoll. As a result of the extensive petroleum exploration, a large amount of subsurface information about the Horseshoe atoll is available in records of more than 5,000 wells drilled into the atoll. This information is summarized and interpreted in this paper in the hope that it will aid petroleum exploration and promote a better understanding of other reeflike carbonate masses.

The terms "atoll" and "reef" have been generally applied to this subsurface horseshoe-shaped accumulation of limestone, although, as noted by Heck, Yenne, and Henbest (1952a, p. 5), the limestone does not contain important amounts of readily recognizable frame-building reef organisms. However, this limestone mass likely had many characteristics of a reef during its growth.

It is possible that the Horseshoe atoll may have originated as an organic bank or shell bank, rather than as an organic reef, as these terms are commonly defined by students of modern reefs. This is suggested by the absence of identifiable reef core and by the scarcity of identifiable frame-building organisms in the cores from wells penetrating the atoll.

Whether the Horseshoe atoll originated as an organic reef or an organic bank is not conclusively indicated by the evidence now available; therefore, the terms "reef" and "atoll" are used throughout this paper with the realization that this limestone accumulation may not be an organic reef as defined by many geologists.

Location and Extent of the Horseshoe Atoll

The Horseshoe atoll underlies part of a 16-county area in western Texas (fig. 1) bounded by the 30° 00′ and 33° 30′ parallels and by the 100° 45′ and 102° 30′ meridians. It is 70 miles across from north to south and 90 miles across from east to west and, in some places, as much as 3,000 feet thick. The northern end of the atoll, in Lynn and Crosby counties, is open. The crest of the atoll is a series of mounds rising as much as 700 feet above the intervening parts of the atoll; the flanks are indented by irregular re-entrants, particularly along the eastern side.

Structurally, the Horseshoe atoll lies in the northern part of the Midland basin, a subsurface feature that was a topographic depression at the time the atoll was formed. It is south of the subsurface Matador arch (at the north end of the Midland basin) and east of the Central Basin Platform.

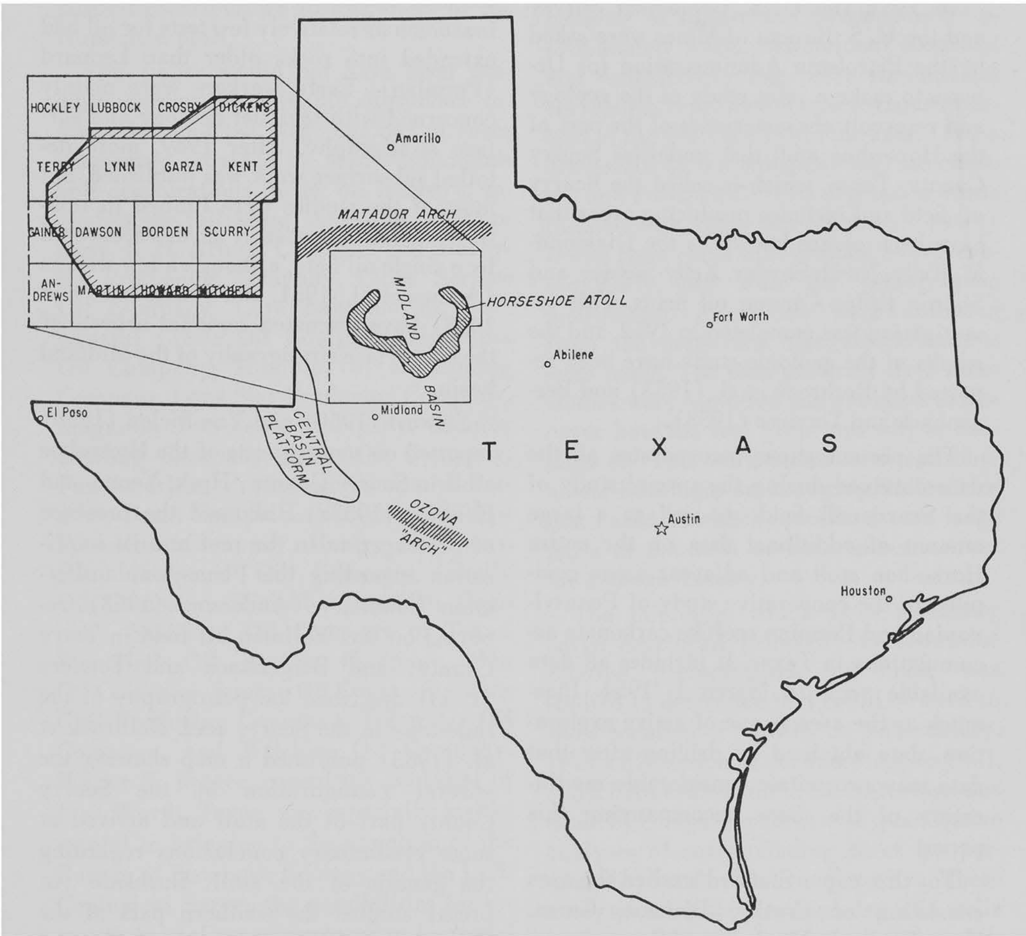


FIG. 1. Index map of area covered by this paper.

The area of this paper is within the High Plains physiographic province and has gently rolling topography. Elevations range from less than 2,000 to about 3,500 feet above sea level. The land is predominantly prairie, containing scattered brushy growths of mesquite. Average rainfall is 19 to 20 inches a year. The region has an average population density of about 18.5 persons per square mile, and its principal industries are oil, cotton, and cattle.

PURPOSE AND SCOPE OF THIS PAPER

In 1949, the U. S. Geological Survey, in cooperation with the Bureau of Economic Geology of The University of Texas, began an investigation of reeflike carbonate rocks of Pennsylvanian and Permian ages in western Texas. The purpose of this investigation, which has been concerned mainly with the Horseshoe atoll, was to assemble all available information from cores and logs of holes penetrating these carbonate accumulations; to determine the stratigraphic relationships of the reeflike rocks to the underlying, overlying, and flanking rocks; to determine as far as possible the nature, geologic history and genetic significance of these accumulations as an aid in exploration for other similar carbonate reservoirs; and to suggest interpretations of the origin and migration of oil in these rocks that may aid in petroleum recovery.

In 1951, the U. S. Geological Survey and the U. S. Bureau of Mines were asked by the Petroleum Administration for Defense to make a joint study of the geology and reservoir characteristics of the part of the Horseshoe atoll that underlies Scurry County, Texas, which is called the Scurry oil field and includes producing areas that have been or are known as the Diamond-M, Kelly, North Snyder, Kelly-Snyder, and Sharon Ridge Canyon oil fields. This investigation was completed in 1952, and the results of the geologic study have been reported by Rothrock et al. (1953) and Bergenback and Terriere (1953).

The present paper incorporates all the data obtained during the special study of the Scurry oil field, as well as a large amount of additional data on the entire Horseshoe atoll and adjacent areas compiled in the cooperative study of Pennsylvanian and Permian reeflike carbonate accumulations in Texas. It includes all data available prior to March 1, 1954. Inasmuch as the area is one of active exploration, data obtained by drilling after that date may necessitate considerable modification of the maps accompanying this paper.

For this paper Stafford studied the area consisting of Crosby, Dickens, Garza, Kent, Lubbock, Mitchell, and Scurry counties; and Burnside studied Andrews, Borden, Dawson, Gaines, Howard, Lynn, Martin, and Terry counties (fig. 1). Myers conducted the paleontological work for the entire area.

Although this paper is a cooperative product of the U. S. Geological Survey and the Bureau of Economic Geology of The University of Texas, the classification and nomenclature of the rock units accord, for the most part, with that of the two organizations but differ somewhat from that of the U. S. Geological Survey.

Previous Investigations and Reports

Before 1949 little subsurface information was published on the older rocks in the area underlain by the Horseshoe atoll inasmuch as relatively few tests for oil had extended into rocks older than Leonard (Permian). Early workers were mainly concerned with regional geology and surface stratigraphy. After 1949, more detailed subsurface work was published, but most of the studies were limited to relatively small areas such as those covered by a single oil field, although a few writers (Adams et al., 1951, and Jones, 1949 and 1953) have discussed regional aspects of the subsurface stratigraphy of the Midland basin.

Stewart (1950) and Van Siclen (1950) reported on some aspects of the Horseshoe atoll in Scurry County; Heck, Yenne, and Henbest (1952a) discussed the presence of *Schwagerina* in the reef and its implication regarding the Pennsylvanian-Permian boundary; Anderson (1953) reported on the Wellman oil field in Terry County; and Bergenback and Terriere (1953) described the petrography of the limestone in the Scurry reef. Rothrock et al. (1953) published a map showing the general configuration of the Scurry County part of the atoll and arrived at some preliminary conclusions regarding the genesis of the atoll. Burnside (in press) studied the southern part of the Horseshoe atoll in Borden and Howard counties and presented a cyclic theory of reef growth. Stafford (in press (a)) extended the area covered by Rothrock et al. (1953) and presented considerable new data on the porosity zonation of the atoll in that area.

ACKNOWLEDGMENTS

Several geologists and paleontologists have been associated with this investigation. From 1949 to 1953, D. Hoye Eargle was in charge of the studies made in cooperation with the Bureau of Economic Geology, and in 1951–1952, Howard E. Rothrock was in charge of the study of the Scurry field. Richard E. Bergenback, William A. Heck, Elmer D. Patterson, Robert T. Terriere, and Keith A. Yenne were also associated with the authors and made important contributions to this study of the Horseshoe atoll.

This paper would not have been possible without the valuable subsurface information and the large number of cores generously provided by many individuals and organizations in the oil industry, including the following: Amerada Oil Company, L. H. Armer, Chapman and McFarlin Producing Company, Cities Service Oil Company, Core Laboratories, Inc., General Crude Oil Company, Hiawatha Oil Company, Humble Oil & Refining Company, Lone Star Producing Company, Magnolia Petroleum Company, Montex Drilling Company, Ohio Oil Company, Pan-American Producing Company, Permian Basin Sample Laboratory, Phillips Petroleum Company, Rotary Engineers, Inc., Seaboard Oil Company, Skelly Oil Company, Slick-Moorman Oil Company, Standard Oil Company of Texas, Stanolind Oil & Gas Company, Sun Oil Company, Sunray Oil Company, Texas Gulf Producing Company, Tidewater Oil Company, and Wilshire Oil Company. Walter R. Berger, consulting geologist of Fort Worth, Texas, was especially instrumental in bringing to the attention of the Bureau of Economic Geology and the U. S. Geological Survey the possibilities for research in reef-type structures to be found in the cores being taken in western Texas. R. V. Hollingsworth of Paleontological Laboratories, Midland, Texas, made available fusulinid determinations and other data from wells in this area from which cores were not available. Without these data, many of the details of stratigraphy and geologic history could not have been solved.

This work has been greatly aided by the facilities and services afforded by the Bureau of Economic Geology and by the interest and cooperation of the Director of that organization, Dr. John T. Lonsdale.

METHODS OF STUDY

Initial studies of the Horseshoe atoll made use of standard techniques and methods of subsurface investigation. Approximately 5,000 conventional electrical and radioactivity logs were studied and correlated, representing more than 99 percent of the wells drilled in the area. (For a discussion of the electrical log, see Stratton and Ford, 1950; for a discussion of the radioactivity log, see Mercier, 1950.) Rocks from cores were studied both megascopically and with the petrographic microscope. Fusulinids were collected from the cores and age determinations were made. The data obtained from these studies were compiled and analyzed to discover how the reef grew and why it contains oil. This work failed to reveal diagnostic lithologic or stratigraphic features that could be either correlated over large parts of the atoll or used to reconstruct the geologic history.

The microlog, which is a resistivity curve developed primarily to determine relative permeabilities of beds, was studied to determine if it could be used to show zonation of porosity or permeability. (For a discussion of the microlog, see Doll, 1950.) An evaluation of the micrologs was made by comparing them with quantitative analyses of corresponding cores for permeability and effective porosity. These analyses, available for cores from 53 wells in Scurry County, confirmed the usefulness of the interpretations of the micrologs and furnished semiquantitative values for the microlog permeability classifications. The core analyses for permeability and porosity were compared with permeability classifications for corresponding intervals designated on the micrologs by the categories "good," "fair," and "broken" permeability and impervious. The comparisons were tabulated according to both millidarcys of permeability and percentages of effective porosity. Cumulative curves were prepared to show the range in value of the permeability and porosity for each of the microlog classifications (figs. 2 and 3).

Comparison of the microlog permeability classifications with laboratory analyses of the effective porosity of corresponding cores showed that although each microlog classification includes a wide range of actual porosity values, most of the comparisons give actual values consistent with the terminology of the microlog categories. Thus, 89 percent of the reef limestone classed as "good" on the micrologs showed effective porosity of 4 to 30 percent; whereas only 11 percent showed effective porosity of less than 4 percent. The average effective porosity of all rock classed as "good" was 10.5 percent. In contrast to these values, 86 percent of the "fair" and 70 percent of the "broken" categories showed effective porosities ranging from 0 to 4 percent. The average effective porosities for these categories

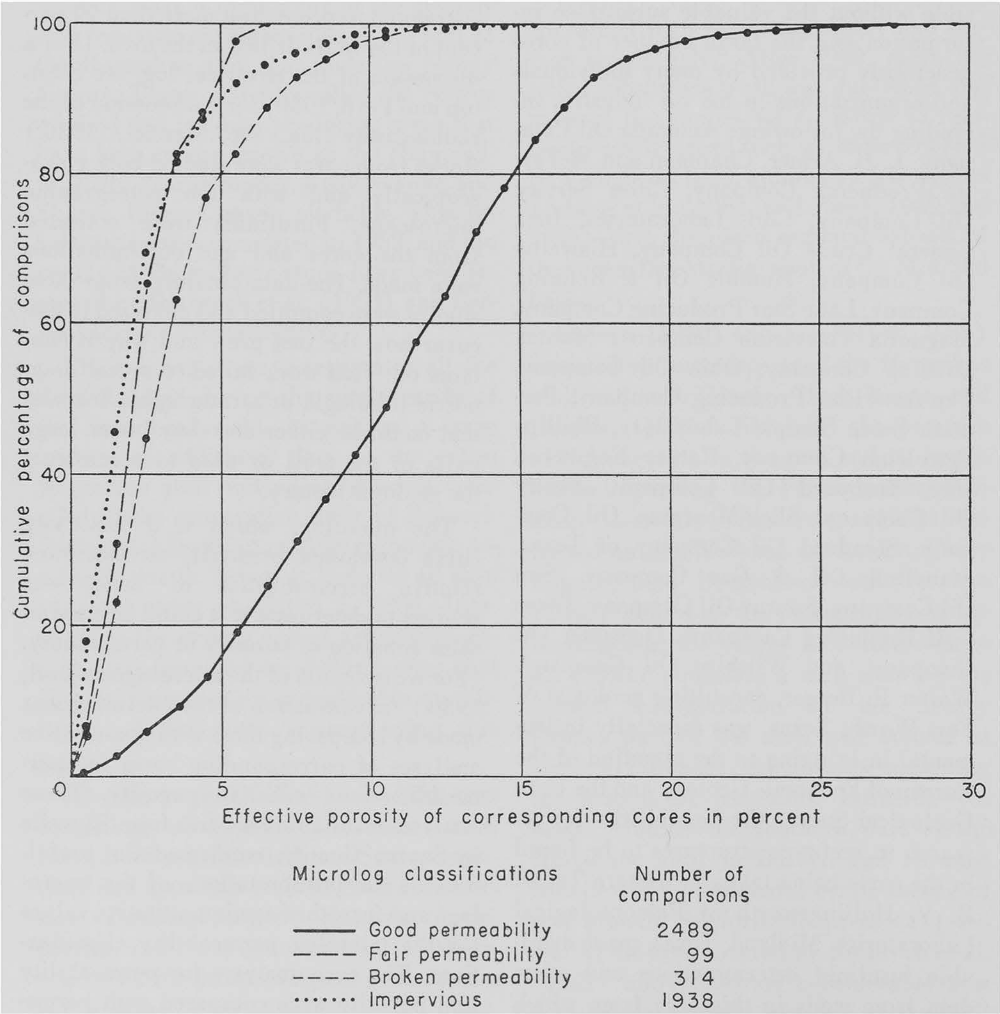


FIG. 2. Quantitative evaluation of microlog classifications in terms of effective porosities.

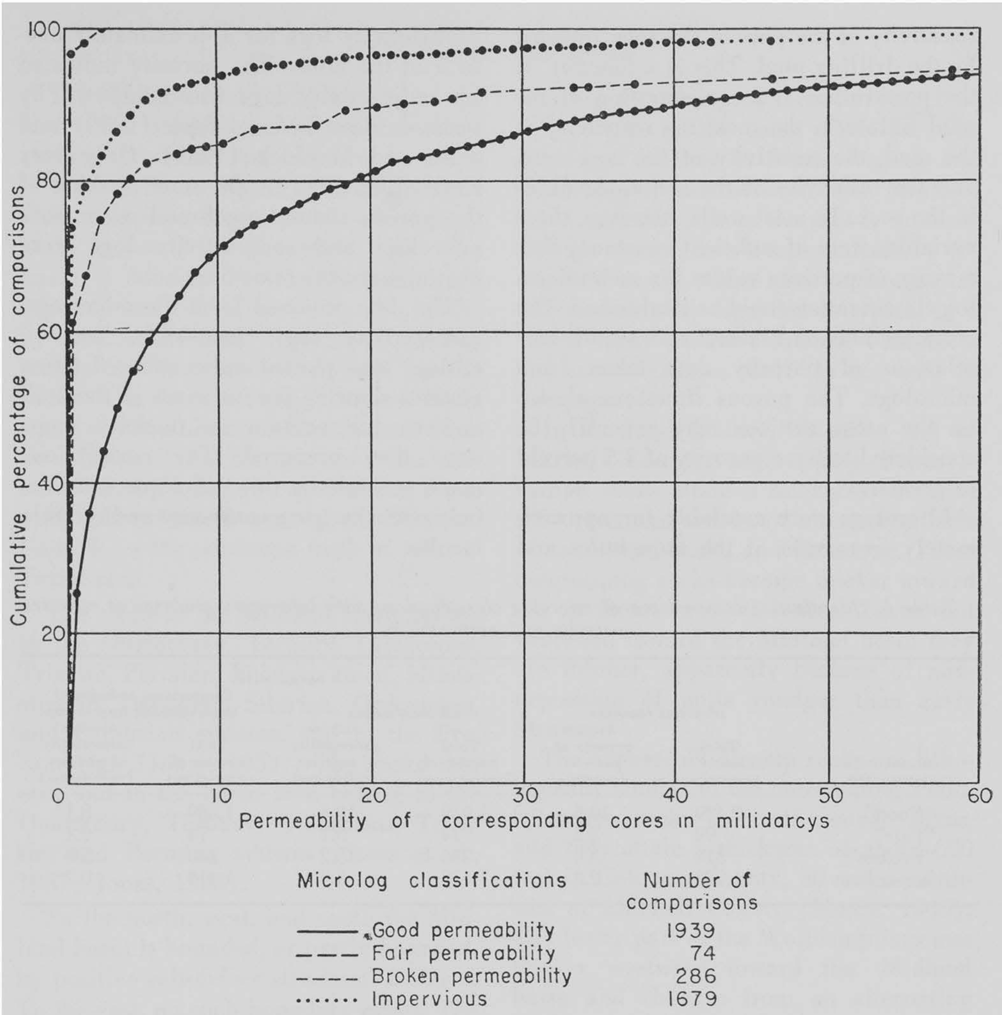


FIG. 3. Quantitative evaluation of microlog classifications in terms of permeabilities.

were 3.2 and 3.8 percent, respectively. In the impervious category, 84 percent of the comparisons showed effective porosities ranging from 0 to 4 percent, and the remaining 16 percent of the comparisons ranged from 4 to 17 percent.

Comparison of the microlog categories with analyses of permeability indicates similar but less definitive results. The cumulative curves in figure 3 show that 70 percent of the rock having microlog classification of "good" has greater than 1 millidarcy of permeability, whereas only 2 percent of the rock classed as "fair," 35 percent classed as "broken," and 23 percent classed as impervious have greater than 1 millidarcy. The difference is more marked when the high permeabilities known to be the result of cracks and fractures are eliminated (Table 1).

These comparative studies indicate that the microlog permeability classifications of the reef limestone can usually be considered to have semiquantitative porosity values, as shown by the averages in Table 1 and the curves in figure 2. Some overlap of porosity values, however, is inherent in comparative studies of the microlog and core analyses. The microlog does not measure actual porosity; it measures the resistivity of the part of the rock invaded by the drilling mud. This is a function of the penetration and concentration of the mud filtrate in the rock, the resistivity of the mud, the resistivity of the host rock, and the resistivity of the contained fluids in the rock. In most wells, however, these variables were of sufficient constancy that a range of porosity values for each microlog classification could be established. The cross sections on Plates 2 and 3 show correlations of porosity data taken from micrologs. The porous limestone shown on the cross sections may generally be considered to have porosity of 4.5 percent or greater.

Micrologs were available for approximately five-sixths of the bore holes and radioactivity logs for approximately one-fifth of the holes. The porosity indicated by radioactivity logs was computed by methods described by Bush (1950) and Bush and Mardock (1951). Only very slight differences in the exact position of the porous zones were found when both micrologs and radioactivity logs were available for the same bore hole.

The data obtained from the micrologs, radioactivity logs, fusulinids, and lithology were plotted and correlated. Cross sections showing porous zones in the atoll and structure contour and thickness maps were then prepared. The correlations made possible by this technique were the only ones that gave consistent and reliable results.

Table 1. Quantitative comparisons of microlog classifications with laboratory analyses of effective porosity and permeability.

	Effective porosity		Permeability: All comparisons		Permeability: Comparisons exclusive of those resulting from cracks	
Microlog classification	Total number of comparisons	Average porosity of analyses (percent)	Total number of comparisons	Average permeability of analyses (millidarcys)	Total number of comparisons	Average permeability of analyses (millidarcys)
"Good"	2,489	10.5	1,939	19.5	1,689	8.1
"Fair"	99	3.2	74	0.1	74	0.1
"Broken"	314	3.8	286	15.2	240	2.0
Impervious	1,938	2.8	1,679	3.9	1,414	0.7

REGIONAL GEOLOGY

The Midland basin, which contains the Horseshoe atoll, is an asymmetric, subsurface structural and sedimentary basin in western Texas (fig. 1). The thickest and most complete sequence of sedimentary rocks is found on its western side. The basin is bounded by the Matador arch (faulted and folded zone) on the north; by the Central Basin Platform on the west; and by the Ozona structural "high" on the south. The form of the Midland basin seems to have been inherited in part from an older structural feature, which has been described by Adams (1954) as the Texas arch. The northern part of the Midland basin is on the southwest flank of Adams' Texas arch.

The rocks in the Midland basin belong to the Quaternary, Tertiary, Cretaceous, Triassic, Permian, Pennsylvanian, Mississippian, Devonian, Silurian, Ordovician, and Cambrian systems, and to the Precambrian (Jones, 1953). The rocks that crop out in the basin area belong to the Quaternary, Tertiary, Cretaceous, Triassic, and Permian systems (Stose et al., 1937; Jones, 1953).

To the north, west, and south the Midland basin is bounded, or partly bounded, by positive subsurface structural features. To the east, no such boundary exists. The name "Eastern shelf" has been applied by some geologists to the area in west-central Texas east of the Midland basin, to indicate that the rocks in this area seem to record a shallower and less uniform depositional environment than equivalent rocks in the Midland basin. This apparent "shelf" is recorded by a facies change in the upper part of the Pennsylvanian system and lower part of the Permian system, from cyclical deposits of carbonate and noncarbonate rocks east of the Midland basin to noncyclical deposits containing little carbonate material within the basin. It is also recorded by abrupt thinning of the Pennsylvanian rocks in passing westward into the Midland basin and a complementary thickening of the overlying Permian rocks in the same direction. The lithologic contrast in Pennsylvanian and Wolfcamp rocks between the Midland basin and the area to the east is not uniformly abrupt, however, particularly toward the north, where environmental conditions generally regarded as typical of a "shelf" may not have existed. Therefore, the name "Eastern shelf" is not used in this paper.

In Eastland County, 95 miles east of Mitchell County, outcropping Pennsylvanian rocks attain a thickness of about 2,500 feet and consist of alternating beds of sandstone, shale, and limestone. These outcropping rocks become thicker toward the northeast in north-central Texas, but westward toward the Midland basin they are thinner, apparently because of nondeposition of units younger than early Strawn.

The exposed Wolfcamp rocks are lithologically similar to the outcropping Pennsylvanian rocks in north-central Texas, and they attain a thickness of about 600 feet in Coleman County, 80 miles southeast of Mitchell County (Moore, 1949). The lower part of the Wolfcamp becomes thicker westward toward the Midland basin and changes from an alternating sandstone, shale, and limestone sequence to a dark, bituminous shale and sandstone sequence. Thickening of the part of the Wolfcamp series that lies between the base of a limestone, approximately equivalent to the Coleman Junction limestone member of the Putnam formation, and the top of the Pennsylvanian rocks, complements the regional thinning of the Pennsylvanian rocks in the Midland basin and eastward.

The Matador arch and the Central Basin Platform, which border the northern part of the Midland basin, seem to have been sources of clastic sediments deposited nearby during the late Pennsylvanian. These uplifts received little or no sediments from late Strawn through early Wolfcamp time.

CHARACTERISTICS OF THE REEF ROCKS

The petrographic study of rocks from the Horseshoe atoll has been confined mainly to the limestone of Canyon, Cisco, and Wolfcamp age and associated shale lentils. Inasmuch as the limestone and shale that constitute the atoll are lithologically similar regardless of stratigraphic position, these rocks will be described by type without regard to age. Most of the petrographic data that follow were incorporated from unpublished work by Bergenback and Terriere and from their published report (1953) on the part of the atoll that underlies Scurry County. The information was derived from the study of more than 300 petrographic thin sections of rocks from the atoll in Scurry County and from the detailed megascopic examination of cores from about 130 wells in all parts of the atoll.

Reef Limestone

Characteristics and classification.—The limestone in the Horseshoe atoll is composed predominantly of clastic calcium carbonate debris of organic origin. It is bonded by calcite cement and by lithified calcium carbonate mud. The organic debris consists of the hard parts of marine organisms, most of which have been comminuted to fragments ranging in size from a few millimeters to particles too small to be resolved under the microscope. Fragments of crinoid columnals, bryozoan fronds, and brachipod shells constitute a large part of the identifiable debris.

For purposes of description, the reef limestone may be classed as "calcilutite," "calcarenite," and "calcirudite," following Grabau's classification of limestones, outlined by Pettijohn (1949, pp. 300, 307) and defined as follows:

> *Calcarenite* is a general term to describe those detrital carbonate rocks of sand-grain size (1/16 to 2 mm in diameter) that are with or without calcite cement and that are composed mainly (over 50 percent) of carbonate detritus. If the fragments are over 2 mm in diameter, the term *calcirudite* may be applied to the rock. . . . By decrease in grain size the calcarenites grade into the *calcilutites.*

The term "bioclastic calcirudite" is here used to represent a special type of rock composed of the hard parts of organisms embedded in a matrix of calcarenite or calcilutite. This usage does not follow Pettijohn (1949, p. 183), who states, "The *bioclastic* rocks, the fragmentation of which is due to organisms, form a small but interesting group. Artificial rocks, such as concrete, may be classed here."

Calcilutite.—The calcilutite of the Horseshoe atoll, although composed mainly of particles too fine to be distinguished megascopically, commonly contains unsorted calcareous organic debris coarser than 1/16 mm. Plate 10, A-D, illustrates specimens of calcilutite from the atoll.

Microscopic examination failed to reveal the origin of most of the particles of the calcilutite. It is possible, however, to distinguish a few of the particles and these are interpreted to be comminuted fossil debris. It is suggested that the comminution of some of the fine-grained material may have been accomplished by passage through the digestive tracts of scavenging organisms. Twenhofel (1939, pp. 179–180) wrote, quoting J. W. Buchanan, "The principal agent in the comminution of the mineral matter found at the bottom of both the deep and shallow seas and oceans is the ground fauna of the sea, which depends for its subsistence on the organic matter which it can extract from the mud. . . . The matter forming the bottom of the sea is being continually passed and repassed through the bodies of the numerous tribes of animals which demonstrably subsist on the mud and its contents." Some calcilutite may be chemically precipitated ooze. The precipitation may have been related to organic agents such as bacteria, but no evidence for bacterial action was found.

The calcilutite contains scattered patches of anhedral calcite. This crystalline material probably was formed by reorganization or replacement of calcium carbonate mud, but it may also have been partly formed as primary cement.

Most fragments coarser than 1/16 mm in the calcilutite are crinoid columnals, bryozoan fronds, shell fragments, and tests of Foraminifera. Other fragments coarser than 1/16 mm are aggregates of clear calcite crystals. Some of the mosaics have outlines closely resembling organic debris and are interpreted to be shell fragments that have been reorganized or recrystallized.

Calcarenite.—The calcarenite of the Horseshoe atoll (Pl. 11, A-D) is composed mainly of unsorted to well-sorted, sharply-angular to well-rounded, organic fragments. Poorly sorted calcarenite containing angular fragments predominates. Oolites and reef-rock fragments, some coarser than 2 mm, are present in small amounts. In some samples the interstitial matrix of the calcarenite is mostly calcium carbonate mud (Pl. 11, B); in others it is crystalline calcite (Pl. 11, C). A special variety of calcarenite or calcirudite (Pl. 12, C), termed "encrinite" by Pettijohn (1949, p. 301), consists almost entirely of crinoid columnal fragments. This type of rock is termed a bioclastic calcarenite (or calcirudite) in this paper.

The clastic organic fragments are mostly chips of crinoid columnals, bryozoan fronds, and shells and tests of Foraminifera. Carbonate fragments composed of anhedral calcite, like those in the calcilutite, are also present.

The lithified carbonate-mud matrix of the calcarenite is identical with the material composing the calcilutite. As the amount of matrix increases, calcarenite grades into calcilutite. The dividing line between the two is a composition of 50 percent of particles coarser than 1/16 mm. The crystalline calcite cement of the calcarenite might be interpreted either as primary chemical cement or as reorganized lime mud. The authors believe that the calcite cement is of primary origin for the following reasons:

1. In most calcarenite that contains considerable cement, the grain boundaries are coated with a fine drusy fringe of calcite. This suggests filling.
2. Prominent crystalline calcite overgrowths on crinoid columnals are in optical continuity. This is a characteristic of primary cement, according to Pettijohn (1949, p. 305).
3. Some calcite-filled fusulinid tests are cut by fractures that do not continue into the surrounding matrix. The fractures are filled with relatively coarsely crystalline calcite, but the matrix is unaltered. Inasmuch as the matrix is unaffected, the calcite within the fracture must be primary.
4. Some fusulinid tests have been ruptured by expansion of their coarse-textured calcite filling (Pl. 18,E). The fragments of the shattered tests are not scattered, indicating that breakage occurred after burial.

These observations indicate that an important factor in the lithification of calcarenite was cementation by precipitated calcite. In some samples the grains and oolites cemented by crystalline calcite do not touch, possibly because the force of crystallization of the cement pushed the loose grains apart, or because the grains were deposited in a matrix of lime mud.

Illing (1954, pp. 91–92) in his discussion of the Bahaman calcareous sands arrived at the conclusion that the nonoolitic, nonskeletal sand grains of calcium carbonate were authigenic. The calcarenite grains illustrated by Illing are morphologically and structurally different from the Horseshoe atoll calcarenite, which appears to be of clastic origin.

Oolites are abundant in some well-sorted calcarenite but are rare in unsorted calcarenite of the Horseshoe atoll. They are spherical or ellipsoidal and range from 0.2 to 2.5 mm in diameter. Only a few oolites are more than 2 mm in diameter. Their nuclei consist of organic fragments, fragments of pre-existing reef limestone, and carbonate fragments of doubtful origin. Most of the oolites show concentric bands or layers, composed of lime mud with a dusty appearance or finely crystalline calcite (Pl. 11,D). Oolites with radial structure were not observed.

The oolites may have been formed by the accumulation of carbonate-mud layers around nuclei as they were rolled about in the mud. The crystalline calcite in the oolites may be the result of reorganization of unstable constituents. Oolites that have relict concentric layers of carbonate mud in the crystalline calcite are evidence of reorganization.

Calcirudite.—Calcirudite is composed of angular to subrounded granule- to boulder-sized fragments in a matrix of carbonate sand or carbonate mud (Pl. 12,A-E). The matrix commonly contains some admixed argillaceous material and, in some places, is composed of shale.

Fragments in the calcirudite that are coarser than 2 mm are of two types: (1) organic fragments consisting chiefly of crinoid columnals and the sturdier parts of shells; and (2) fragments of pre-existing reef limestone and shale. In the finer grained (bioclastic) calcirudite, organic fragments are most common, whereas in the coarser grained calcirudite (reef breccia) fragments of pre-existing rock are most abundant. The largest measured fragment of pre-existing reef limestone was 1.6 feet in diameter. Fragments of calcilutite, calcarenite, and shale were mixed indiscriminately at the time of deposition in a matrix of either carbonate sand or carbonate mud.

The fragments of older reef limestone in most reef breccia are angular and were apparently lithified before breakage and redeposition. The contacts between adjoining fragments commonly are stylolitic, but the stylolites do not appear to continue into the matrix (Pl. 12, A; Pl. 14, C). This suggests that the solution which caused the stylolites between the breccia fragments probably took place before the matrix had lithified.

SHALE

The shale within the Horseshoe atoll is dark gray to black because of its high percentage of bituminous material. Under the petrographic microscope, the shale appears as a black to brownish mass containing a large percentage of clastic limestone particles similar to those in the reef limestone. Secondary chert forms irregular microscopic masses in the shale. Pyrite, very minute particles of quartz and feldspar, and small flakes of detrital muscovite are present in small amounts. The pyrite is present as (1) pyritized spicules of unknown origin that average 1 mm in diameter and are as much as 5 cm long; (2) nodules, sometimes as large as 2 cm in diameter; and (3) pyritized plant fragments and brachiopods. The amount of pyrite in the shale is very small.

The shale in the atoll is present (1) as tongues that project into the reef limestone from the shale surrounding the atoll; (2) as thin lenses and beds which can commonly be traced over widespread areas within the body of the atoll but which are not contemporaneous with the enclosing shale; and (3) as stringers a few millimeters to a few centimeters thick which cannot be traced from well to well (Pl. 13,A-E). The position of the shale units was determined chiefly by electrical and radioactivity logs. A sufficient amount of shale was present in cores, however, to establish correlation with the logs.

The tongues of shale that project into the atoll and the thin lenses and beds of shale within the body of the atoll are of considerable importance in determining stratigraphic relationships and in establishing the geologic history during the time of reef growth. The stratigraphic relationships of the shale to the reef rocks are discussed in the section on stratigraphy, and the importance of the shale units in establishing the sequence of geologic events is discussed in the section on geologic history.

The shale stringers generally form thin bands having uneven surfaces, but in some places they branch into several smaller stringers that in cross section look like the ravelings of a rope end (Pl. 13,B). Some stringers merge into stylolites containing bituminous layers as thick as 3 mm. The dip of the stringers ranges from horizontal to as much as 30°. The highest dips probably reflect preconsolidation slumping. The composition of many of the stringers is in doubt. Clay-sized particles found in insoluble residues from the limestones and in paper-thin laminations of shale indicate that the stringers are chiefly claystone. Most of the stringers contain abundant bituminous material; in some stringers, bitumen is the chief constituent. (See Table 3, p. 17).

Distribution and Abundance of Rock Types

Calcarenite is the most abundant of the textural varieties found in the cores. Calcilutite and calcirudite are next in order of abundance. Total footage and relative abundance of each textural variety from the Scurry County portion of the atoll is given in Table 2. In general, the different limestone textural types are complexly interlensed and do not form distinct lithologic units that are traceable from well to well.

Table 2. Distribution of rock types found in cores from the Horseshoe atoll.

Textural type	Total thickness (*feet*)	Relative abundance (*percent*)	Average thickness (*feet*)	Range in thickness Maximum (*feet*)	Minimum (*feet*)
Calcarenite	3,736	46.3	6.7	79.5	0.3
Calcilutite	2,840	35.2	6.1	41.0	0.2
Calcirudite	1,283	15.9	4.7	26.0	0.3
Shale	211	2.6	2.8	8.5	0.2
Total	8,070				

An exception to the generally random distribution of rock types in the atoll is a tendency toward concentration of oolitic zones along the seaward margins of the atoll. In the Scurry County portion of the atoll, oolitic zones are present at levels ranging from 4,243 feet below sea level to 4,458 feet below sea level. The eastern marginal area of the atoll appears to have the highest concentration of the oolitic zones (fig. 4).

Secondary Mineralization

Silicification.—Secondary chert is present in small amounts in the cores from the Horseshoe atoll. Chert was megascopically observed as gray to white bands from 4 to 9 inches thick (Pl. 14, A) and as nodules and irregular patches as much as 2 inches in diameter. The boundaries of some chert masses are stylolites having a maximum amplitude of 1 cm (Pl. 14,B). On one side of each of these stylolites is dense, white chert and on the other side is dense limestone. This association suggests that the chert was formed after the stylolites, because the pressure-solution phenomenon by which the stylolites were probably formed would probably not have produced so serrated a contact between rocks of such dissimilar hardness and solubility as chert and limestone.

Microcrystalline-granular chert was observed under the microscope as very small, generally irregular patches which replace interstitial filling in places. Such chert is most common within fragments of crinoid stems. Secondary silica is also present in the reef limestone as drusy quartz and, uncommonly, as microcrystalline fibrous chert within vugs.

Dolomitization. — Dolomite was observed megascopically as drusy rhombohedrons lining vugs and as scattered rhombohedrons in the limestone. Microscopic examination revealed that dolomite is much commoner than had previously been suspected. Well-formed rhombohedrons of dolomite, many of which are slightly brownish, are scattered through the calcilutite and the matrix of some calcarenite. Dolomite crystals are not common, however, in the clastic organic fragments examined in cores from the Scurry field.

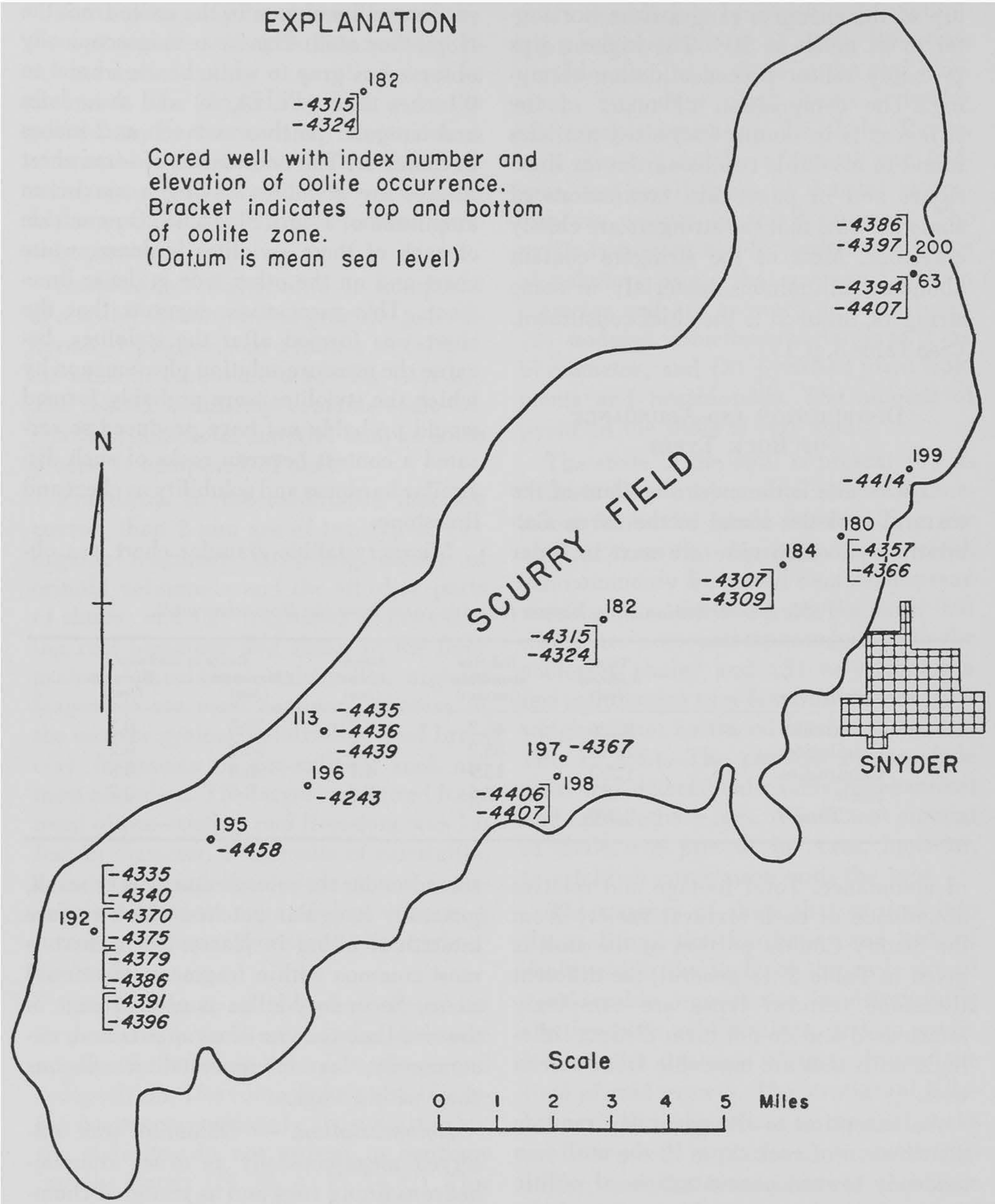


FIG. 4. Map showing the distribution of oolites in cores from wells in the Scurry oil field, Scurry County, Texas.

P. D. Krynine, who studied some of the cores, noted (personal communication) the presence of dolomite also as a poorly defined, finely crystalline mosaic in the carbonate matrix of several thin sections. He believes that primary porosity is very important in the control of dolomitization and that much of the dolomite replacement occurred very shortly after deposition of the rock.

Calcitization.—Calcitization appears to be a process that was initiated early in the atoll's history and that continued, probably with interruptions, into later stages.

The formation of the primary crystalline calcite cement and the mosaics of calcite has been discussed previously. Scalenohedrons and rhombohedrons of drusy calcite are common in vugs, open joints, and open irregular fractures. Crystalline calcite has completely filled many of the openings, especially the fractures. Under the petrographic microscope, the drusy calcite appears as clear to dusty, relatively coarse crystals. Some vugs containing a secondary lining of this calcite have quartz in the center.

Chemical Composition

Chemical analyses of representative cores from the Horseshoe atoll show that except in certain well-defined zones, the reef limestone usually contains more than 97 percent calcium carbonate (Pl. 1). Spectrographic analyses (Newell et al., 1953, p. 110) from the Capitan reef show that the limestone in that reef also contains more than 97 percent calcium carbonate. Most of the remaining non-terrigenous material in the reef rocks of the atoll is magnesium carbonate and magnesium oxide; some compounds of aluminum and iron are present.

The spectrographic analyses of reef rock from two wells (Jessen and Miller, 1955) indicate the presence of several other elements—arsenic, barium, beryllium, bismuth, boron, chromium, cobalt, columbium, copper, gallium, germanium, lead, nickel, potassium, silicon, silver, sodium, strontium, titanium, vanadium, zinc, and zirconium.

The average insoluble residue recorded in 321 analyses of cores from 4 wells in the atoll amounts to an average of 1.4 percent of the total rock by weight. An average of considerably less than 1 percent of insoluble residue, however, is present in the more porous zones of the reef; analyses showing more than 2 percent are mostly from the less porous zones.

Mr. John C. Miller made semiquantitative spectrographic analyses of selected samples from the cores from General Crude Petroleum Company's No. 193–2 Coleman well (Pl. 9, well 169) in the Salt Creek oil field and Chapman and McFarlin Producing Company's No. 25 Cogdell well (Pl. 9, well 173) in the Cogdell oil field (Jessen and Miller, 1955). Some of the results are shown and correlated in figure 5. The correlations of the two wells from spectrographic analyses agree with those correlations made by fusulinids and physical properties.

Chemical analyses of bituminous material from a claystone stringer and the concentrate along a stylolite were made by the U. S. Geological Survey from two wells in the Scurry field. The results of these analyses are shown in Table 3.

Table 3. Chemical analyses of bituminous material from reef limestone from wells drilled in the Scurry oil field, Scurry County, Texas.
(Determinations by U.S. Geological Survey)

Constituents and physical properties	Stylolite filling from General Crude Petroleum Company's No. 3 Land well (well 183, Pl. 9)	Claystone stringer from Hiawatha Oil Company's No. 1 Carden well (well 179, Pl. 9)
SiO_2	8.6	4.2
Al_2O_3	4.6	1.8
Total Fe as Fe_2O_3	2.6	2.6
MgO	3.9	2.1
CaO	21.2	16.7
Na_2O	0.42	0.21
K_2O	0.93	0.52
TiO_2	0.42	0.37
P_2O_5	0.44	0.29
MnO	0.00	0.00
Ignition loss	55.3	70.8
S	1.2	1.9
Solubility in CS_2	nil	nil
Fusibility	infusible	infusible
Color	black	black
Streak	brownish-black	brownish-black
Identification of sample	pyrobituminous shale	pyrobituminous shale

It is interesting to note that about 55 percent of the stylolite filling and about 70 percent of the claystone stringer, probably representing the bitumen in these materials, were lost on ignition. It is difficult to conceive of porosity in these clay materials sufficient to admit such large amounts of bituminous matter during or after the accumulation of the oil. More likely, bitumen was an original constituent of the clay material. In the stylolite the clay material was probably concentrated by solution of the limestone. That in the claystone stringer was probably carried by marine currents into the atoll area from areas of euxinic environment believed to have been present on the floor of the Midland basin during the time of atoll growth and deposition.

Porosity and Permeability

The effective porosity of the limestone in the atoll, determined by core analyses, generally ranges from almost nothing to 30 percent with an average of about 6 percent (fig. 2 and Table 1). When the limestone is observed in thin sections the porosity, other than that resulting from fractures, appears to be developed as irregularly spaced interconnected lenses. When observed megascopically, openings appear to range from pinpoint size to vugs 5 cm in diameter. Most openings are smaller than 3 mm in diameter.

Most porosity appears to be secondary; the only primary porosity found was that in the hollow interiors of some shells. It is best developed in the calcilutite and calcarenite and is independent of grain size. Originally, the limestone in the atoll was probably very porous. Most of the primary interstitial pore space was subsequently filled with calcium carbonate. Eventually, leaching formed secondary porosity in the limestone. The secondary porosity was then reduced by the filling of some pores and the partial filling of others with drusy calcite and, in some places, quartz.

In a zone confined to the top of the atoll, some of the pores have been filled by dark-gray to black clay and, in a few places, by pyrite. The clay may have been squeezed into the pores from the overlying shale. The pyrite was probably precipitated from water entering the reef rocks from the overlying dark, pyrite-bearing shale after the atoll was covered by the shale. Precipitation of iron sulfide in the reef rocks was possibly related to changes in the high hydrogen sulfide and iron sulfide concentrations present in the connate water of the overlying dark shale.

Porosity stratification, as indicated by two distinct types of zones, is an important physical characteristic of the atoll. One type of porosity zone has relatively low porosity, is in general more argillaceous than the other type, and contains thin shale beds and abundant calcirudite composed of fragments of pre-existing reef rock. The other type of porosity zone has relatively high porosity, generally has less than a percent insoluble residue, and contains neither shale nor calcirudite composed of pre-existing reef fragments. These zones appear to have time-stratigraphic significance and are discussed in the section on stratigraphy of rocks in the atoll.

A study of the relationship of insoluble residue to effective porosity indicates that the upper limit of effective porosity resulting from leaching is controlled in large part by the insoluble residue (fig. 5). Leaching of limestone containing a high percentage of insoluble residue produces little effective porosity.

Two explanations are possible of the cause of low porosity in the zones having a high percentage of insoluble residue. The most feasible explanation is early plugging of the pores by insoluble residue, inasmuch as limestone containing low initial insoluble residue can be extensively leached before the insoluble residue concentrations become large enough to plug the pores and thereby slow or stop the pore development. An alternative explanation is that admixed argillaceous material physically impeded solution. It is probable that both processes deterred the leaching of limestone containing relatively high initial insoluble residues.

Insoluble materials are deposited in greater or lesser amounts with carbonate sediments during given intervals of geologic time. The varying rate of deposition results in stratification of the insoluble material. Figure 5 shows that the percent porosity that can be developed by leaching during a given interval of time is con-

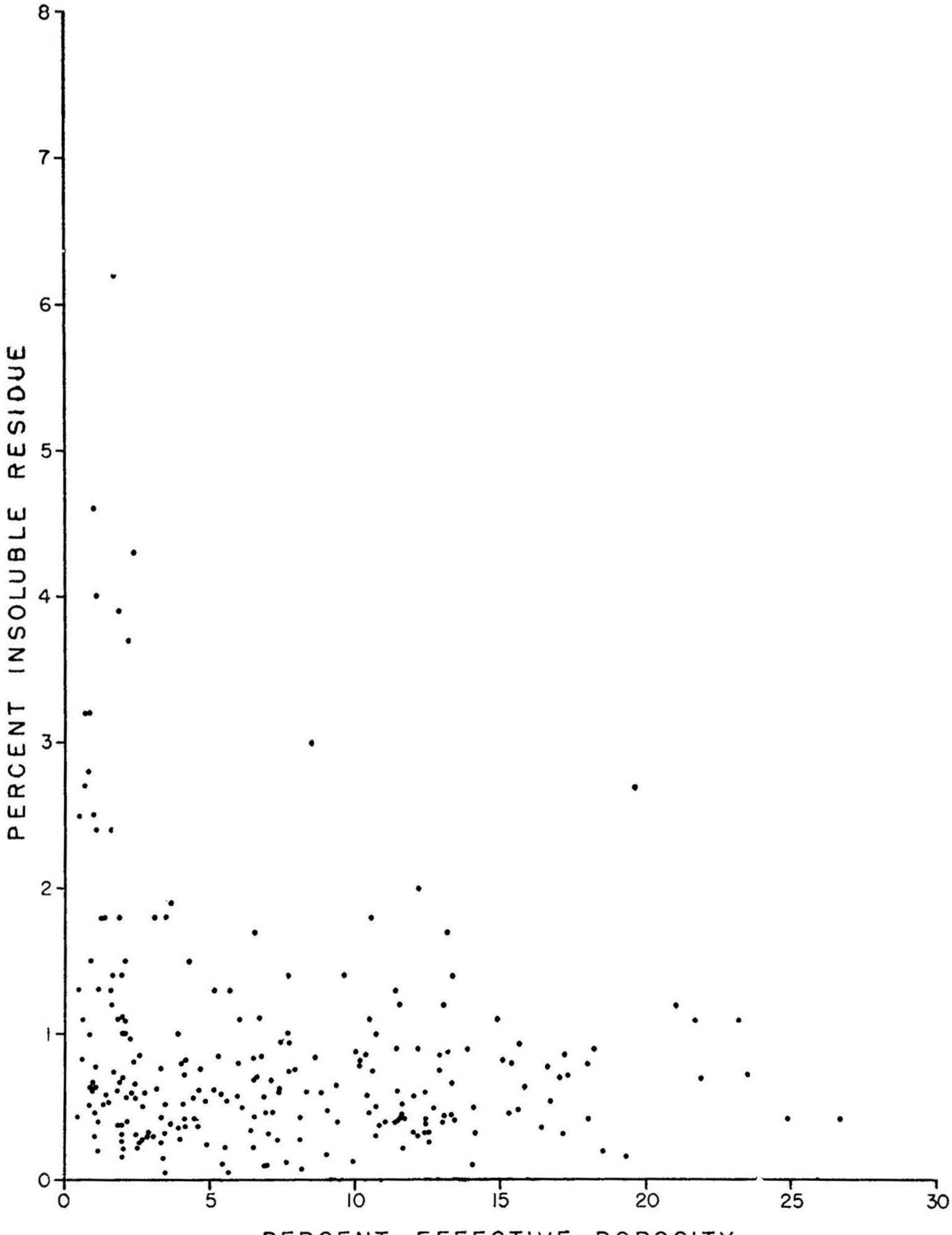


FIG. 5. Diagram showing relationship of insoluble residue to effective porosity in core samples from the Horseshoe atoll.

trolled in large part by the amount of insoluble residue initially present. Stratification of the porosity is therefore related to the stratification of the insoluble residue, which is in turn related to time. Whether figure 5 could be applied to limestones other than those in the Horseshoe atoll is highly speculative, but where insoluble residues are nearly all clay minerals, it is a distinct possibility. The general distribution and stratification of porosity are further discussed in the section on stratigraphy of the rocks in the atoll.

The permeability of the limestone in the atoll generally ranges from a few hundredths of a millidarcy to 85 millidarcys and averages about 4.5 millidarcys (measured horizontally by air). Permeability measured vertically to air has a range of values which is considerably less. This average and range of values do not include those relatively high permeabilities (as much as 2,500 millidarcys) which are known to have been caused by open cracks, fractures, and joints in cores from the atoll. (See fig. 3 and Table 1 for the general range of permeability values.)

STRATIGRAPHY

Stratigraphy of the Rocks Beneath the Atoll

Sedimentary rocks underlying the Horseshoe atoll have been assigned to the Cambrian, Ordovician, Silurian, Devonian, Mississippian, and Pennsylvanian systems by geologists of the petroleum industry. A general review of the stratigraphy of the Midland basin was recently made by Jones (1953). The following discussion is limited to the Mississippian and younger rocks. The general stratigraphic relationships of rocks assigned to the Missisipian(?) and Pennsylvanian systems and lower part of the Permian system in the northern part of the Midland basin are shown in Table 4.

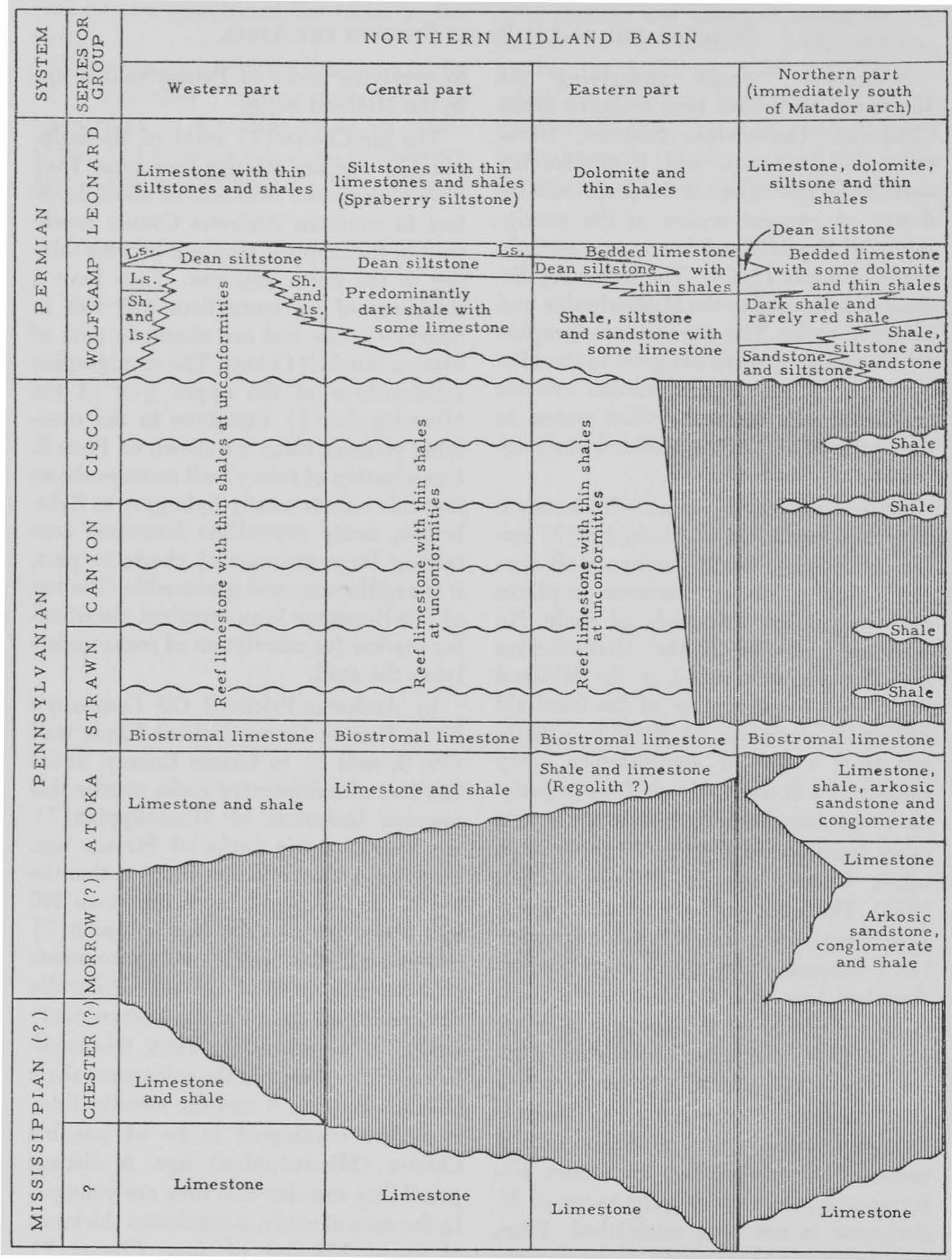
Mississippian(?) system.—Rocks tentatively assigned to the Mississippian(?) system underlying the Horseshoe atoll consist mainly of cherty limestone in places enclosing a few thin beds of shale. No diagnostic fossils of the Mississippian period have been found in the Midland basin with the exception of the fusulinid *Millerella designata* of possible Chester age from a well in southwestern Terry County (Pl. 9, well 165). *Millerella designata* has been reported from only one other locality—in the Clore limestone of upper Chester age in Illinois (Zeller, 1953). The limestone from which *M. designata* is reported from Terry County underlies a limestone that can be correlated by electrical logs with a limestone that contains fusulinids of Atoka age in many places. If *M. designata* is restricted stratigraphically to rocks of Chester age, then an unconformity covering all of Morrow time and possibly part of Atoka time is present between these two limestones. Unfortunately, the stratigraphic range of *M. designata* is not well established. Thus, correlation of these rocks is necessarily made by their general lithologic similarity to rocks of Mississippian age outside this basin and by their stratigraphic relations to underlying rocks of Devonian age and to overlying rocks of Pennsylvanian age in the Midland basin.

The pre-Chester(?) rocks of Mississippian(?) age are massive limestone. They have a maximum thickness of about 1,000 feet in southern Andrews County southwest of the mapped area and become thinner to the north and east. They have a thickness of no more than 225 feet in Scurry County and are absent in part of eastern Mitchell County. The stratigraphic relationships of the upper part of the Mississippian(?) limestone to the overlying younger rocks are shown on Plate 5. Examination of rotary well cuttings shows that this rock is mostly light-gray to light-brown, finely crystalline limestone containing large amounts of chert; in part, it is argillaceous and glauconitic. The top of this limestone is an excellent electrical-log marker for correlation of rocks underlying the atoll.

In Anderson-Prichard Oil Company's No. 2 Parmer County School Lands well (Pl. 9, well 1) in Gaines County, about 925 feet of sedimentary rocks overlie this massive limestone of Mississippian(?) age and underlie rocks of Strawn age. Electrical log correlations indicate that the top of the first argillaceous limestone 240 feet above the massive Mississippian(?) limestone in this well is the approximate stratigraphic position of the *Millerella designata* zone found in the Terry County well (Pl. 9, well 165). Thus, this argillaceous limestone and the calcareous shale that lies between it and the massive limestone are considered to be of possible Chester (Mississippian) age. A distinct possibility remains that they are younger. In the area of study, a maximum thickness of about 265 feet of these Chester(?) rocks was found in east-central Andrews County.

Pennsylvanian system. — The stratigraphy of the rocks of Pennsylvanian age

Table 4. Correlation chart showing general stratigraphic relationships of rocks belonging to the Mississippian(?) and Pennsylvanian systems and lower part of the Permian system in the northern part of the Midland basin.



below the atoll is complicated by the difficulty of separating rocks of Morrow age from rocks of Chester and Atoka ages. At present, recognition of rocks of Morrow age depends upon the presence of *Millerella* and the absence of more advanced genera of fusulinids. Unfortunately, *Millerella* first appears in the Chester and is known from rocks as young as upper Pennsylvanian. The recognition of rocks of Morrow age within this wide stratigraphic range depends upon the absence of diagnostic fossils. This negative type of biostratigraphy is unsatisfactory where sampling of the fossil population is inadequate, as it is in much subsurface study. The possibility remains that conspecific determinations within the genus *Millerella* might be used to characterize Morrow age. For the purpose of this paper the term Morrow(?) will be used, but the inadequacy of the correlation is recognized.

In Honolulu and Signal Oil & Gas Companies' No. 1–24 Elwood well (Pl. 9, well 163) in Hockley County (West Texas Geological Society, 1953) and other wells paralleling the southern side of the Matador arch, arkosic sandstone and conglomerate directly underlie the limestone of Atoka age, which overlies the limestone in Terry County containing *M. designata.* This limestone becomes thinner and is overlapped to the north and east by the limestone of Atoka age. These relationships suggest that the arkosic sandstone and conglomerate may be either Morrow, Atoka, or Chester in age. On the basis of stratigraphic position and regional tectonic history, these coarse clastics underlying the limestone of Atoka age are assigned to the Morrow(?).

The rocks of Morrow(?) age are confined to the northern part of the Midland basin. They are everywhere overlain by rocks of Atoka age, which become markedly thinner as they approach the crest of the old Texas arch.

Rocks of early Pennsylvanian age (Morrow (?) and Atoka) on the western side of the northern part of the Midland basin consist of alternating limestone and shale having a maximum thickness of about 750 feet. They become thinner to the north and east of the deeper parts of the basin. Most of the lithologic units in the lower part of the Pennsylvanian system are overlapped by younger units in the same directions. In Kent, Scurry, and parts of Mitchell, Borden, Howard, Garza, and Dickens counties, only thin (ordinarily 30 feet or less) beds of shale and limestone of Atoka age are present between the massive limestone of Mississippian(?) age and the biostromal limestone of Strawn age.

A thin bed of shale at the top of the Atoka is frequently referred to as the "detrital" zone, and it is possible that it represents a regolith. No cores from this zone were available for examination. Fusulinids from rotary drilling samples from this "detrital" zone are sometimes reported to be of Strawn age. On the other hand, they are also commonly reported to be of Atoka age. Considering the proximity of the overlying limestone of Strawn age and the nature of rotary samples, the writers have interpreted the zone to be of Atoka age. If the zone is a true regolith, however, fusulinids of both ages might be present, in which case it would necessarily be of Strawn age. In northeastern Borden County and northwestern Scurry County a weathered calcareous chert underlies this "detrital" zone and overlies the limestone of Mississippian(?) age. This chert may be a local facies of the regolith(?). In part of eastern Mitchell County this thin shale zone lies upon the Ellenburger group of Early Ordovician age. Elsewhere in the northern part of the Midland basin it overlies rocks of Mississippian(?) or Atoka age. Thus, this thin bed of shale marks a regional unconformity whose magnitude increases to the east. In a few bore holes in Scurry and Kent counties this unit appears to be absent, and overlying rocks of Strawn age lie on limestone of Mississippian(?) age.

A biostromal[2] limestone in the lower part of the sequence of rocks equivalent in age to the Strawn group commonly overlies the thin shale or regolith. This limestone is referred to as the Caddo of local usage. It directly underlies the Horseshoe atoll limestone mass and at

[2] The biostromal limestone is that limestone which everywhere underlies the reef-complex but is not usually separable from it with electrical and radioactivity logs. The term is here used to distinguish this limestone from the fore-reef and back-reef facies of the reef-complex which are also bedded.

most places cannot be distinguished from the limestone in the atoll. The biostromal limestone is present throughout the Midland basin as well as on the Central Basin Platform. On the Central Basin Platform, however, this limestone was involved in folding, and its distribution is more or less restricted to the synclines of that structural unit. The minimum thickness is about 45 feet in eastern Mitchell County, and its maximum thickness is unknown because of the difficulty of distinguishing it in much of the atoll area.

Stratigraphy of the Rocks in the Atoll

Characteristics, age, and zonation.—The rocks that form the body of the Horseshoe atoll belong to the Pennsylvanian and Permian systems. They have a maximum thickness of 3,000 feet, and most are nonbedded. Most of the atoll consists of limestone, but a few thin beds of shale are present and the entire limestone-shale mass may be referred to as the reef-complex.[3]

The rocks of the atoll are considered to be equivalent in age to the Strawn, Canyon, and Cisco groups and the Wolfcamp series (fig. 6). Ages of different parts of the reef-complex have been determined by study of the Fusulinidae, but the age relationships are complex and the rocks are difficult to correlate because faunas from older parts of the reef-complex have been reworked and incorporated into younger parts of the atoll. For example, fragments of reef limestone that contain fusulinids typical of rocks assigned to the Canyon group are commonly found in carbonate matrices that contain fusulinids typical of the Cisco group. Detailed study of several cores of calcirudite considered to be of Cisco age shows that fusulinids typical of the Canyon group are present only in the fragments, whereas fusulinids typical of the Cisco group are found only in the matrix.

Debris eroded from higher and older parts of the atoll has accumulated on both flanks of this structure and has been scattered laterally for many miles, resulting in masses of calcirudite and calcarenite that flank the atoll and (in rocks of Wolfcamp age) interfinger with shale adjacent to the atoll.

Rothrock et al. (1953) in a discussion of the zonal arrangement of the reef-complex in Scurry County presented a map showing contours on the top and the base of the "intermediate zone." This "intermediate zone" was based on differences in lithology and effective porosity of the reef limestone. The zonation as presented in that publication was correct on the basis of the data which were then available and the criteria which were used. Additional data and detailed study have indicated, however, that as many as three distinct zones of low porosity were included as part of the "intermediate zone," and that its relationships to the standard time units were not entirely correct. Therefore, in the following discussion it is necessary to make some revision of the porosity zonation of the reef-complex.

Two distinct types of porosity zones appear to be present in the reef-complex: (1) zones consisting of relatively large amounts of low porosity (hereinafter referred to as "Type A" zones); and (2) zones consisting of relatively large amounts of high porosity (hereinafter referred to as "Type B" zones). (See Pl. 1.) Both types of zones, as shown in cross sections C-C′ through J-J′ (Pls. 2 and 3), are based on porosity determinations from micrologs and neutron curves, the stratigraphic distribution of shale and calcirudites (composed of pre-existing reef fragments), and age determinations. (The utility of the microlog as an indicator of semiquantitative porosity values of the reef limestone is discussed in the preceding section on methods of study.)

Type A zones consist mainly of reef limestone of relatively low effective porosity (less than 4.5 percent). Study of cores and insoluble residues indicates that zones

[3] The term "reef-complex" (Henson, 1950, pp. 215-216; Newell et al., 1953, p. 48; Stafford, in press (a)) is used in this paper to refer to the entire atoll and genetically related rocks. The term does not refer to the bedded limestone and shale of Atoka and early Strawn ages underlying the atoll.

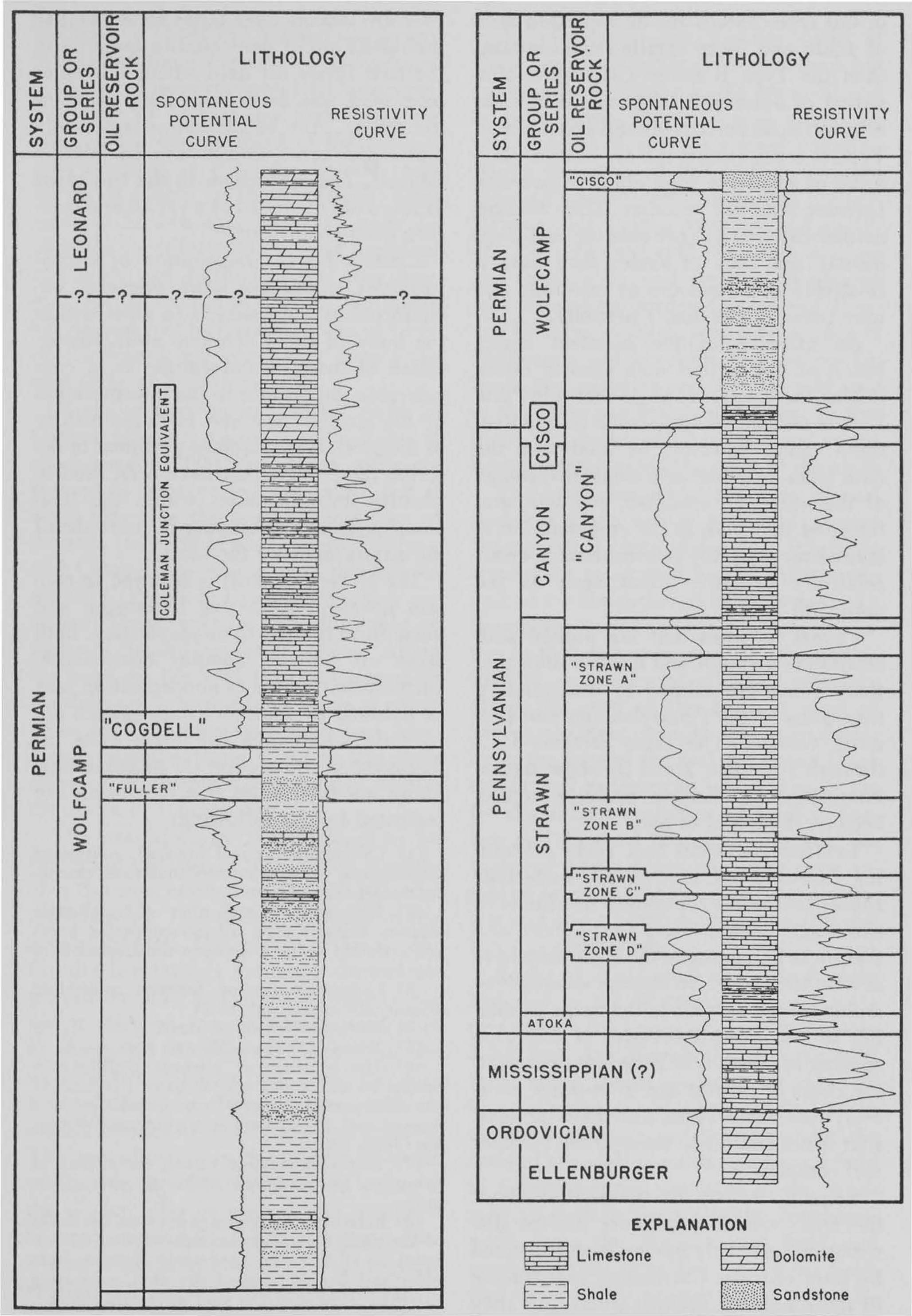


FIG. 6. Composite electrical and lithologic log from Scurry and Kent counties, Texas, showing stratigraphic units and oil reservoirs.

of this type contain one or more thin beds of shale and more argillaceous material than the Type B zones. Calcirudite consisting of older reef fragments comprises as much as 60 percent of the Type A zones. Type B zones consist mainly of reef limestone of relatively high effective porosity (greater than 4.5 percent). They contain neither calcirudite (pre-existing reef fragments) nor beds of shale; they have a relatively small amount of insoluble residue (usually less than 1 percent).

An example of the excellent correlation of the various data used in establishing these major zones is shown in Plate 1 It is difficult or impossible to establish these zones, however, by analyzing the data from only one or a small percentage of the wells. To establish, evaluate, and interpret the zones in the reef-complex, it is necessary to study in considerable detail relatively extensive areas such as the major oil fields.

Faunal horizons that are plotted with relation to Types A and B zones show that these zones are related to the standard time units of the Pennsylvanian and Permian systems. The cross sections C-C′ through J-J′ (Pls. 2 and 3) show the relationships of effective porosity to thin beds of shale and to age.

Evidence indicates that rocks containing fusulinids of Canyon age have four zones; that rocks containing fusulinids of Cisco age likewise have four zones; and that rocks belonging to the Wolfcamp have at least two zones. No attempt was made to define zones in detail in the rocks belonging to the Strawn because of the wide spacing of most of the bore holes penetrating rocks of Strawn age. It appears, however, that these rocks also have at least four zones similar to those in the younger reef-complex.

Some zones can be traced throughout the area; others have more limited distribution, probably having been truncated by later erosion. Correlation and tracing of these zones is difficult where (1) they are thin; (2) two or more zones of the same type coalesce; (3) paleontological data are lacking over large areas; or (4) micrologs are of poor quality (such as in the Salt Creek oil field where salt-water base mud was used in drilling many of the wells). Any of the above factors obscures the zones and makes correlation difficult. The differences in the two types of zones are the result of a varied and complex geologic history.

Criteria for the recognition of unconformities within the atoll.—Several unconformities are believed to exist within the body of the Horseshoe atoll. Recognition of these unconformities is of considerable importance to the interpretation of the stratigraphy and geologic history of the atoll. It is therefore pertinent to describe the criteria that have been used to identify unconformities within the reef-complex before discussing in more detail the stratigraphy of the atoll.

The Horseshoe atoll is believed to contain unconformities due to erosion and unconformities due to nondeposition. Both types are without angular discordance. Unconformities due to nondeposition may be detected by faunal changes within apparently continuous lithologic units, as discussed in the section on paleontology. Those unconformities due to erosion are indicated by the following:

(1) Calcirudite (or reef breccia), containing fragments of pre-existing reef limestone, extending across the atoll.

(2) Widespread distribution of small-scale solution features such as interconnected pores and stylolitic contacts between the fragments of reef breccia.

(3) Large-scale erosion features resembling stream valleys and sink holes.

(4) Widespread beds of shale.

(5) Mixed faunas of different ages.

(6) The presence of younger reeflike carbonate accumulations too far down the flank of the older part of the atoll to be within the biotic zone of reef poential. (For a discussion of this, see Cloud, 1952.)

(7) Lateral truncation (along the strike) of recognized porosity zones within the core of the atoll.

(8) Relatively low angles of slope on the flanks of the atoll, and large amounts of detrital material on the flanks apparently derived from older and higher parts of the atoll, suggesting extensive erosion of the atoll at certain times.

Rocks of Strawn age.—Rocks of Strawn age in the reef-complex have a maximum thickness of about 750 feet and are present throughout the entire atoll. The combined thickness of these rocks and the biostromal limestone of Strawn age underlying the atoll in the eastern third of the mapped area is shown in Plate 4. The reef rocks lie at all places on the biostromal limestone of Strawn age. They are generally overlain unconformably by reef limestone of Canyon age. In the fore-reef area, however, reef limestone of Cisco or Wolfcamp age or post-reef terrigenous rocks of Cisco or Wolfcamp age commonly overlie the reef rocks of Strawn age.

Rocks of Canyon age.—Reef rocks of Canyon age have a maximum thickness of approximately 800 feet. These rocks are present in most parts of the atoll, but at some places in the northernmost part of the area (in parts of Kent, Garza, Dickens, and Crosby counties) and in the Tahoka oil field (Pl. 9) in Lynn County they are absent. These rocks lie unconformably on rocks of Strawn age at all places. Along the crest of the reef they are generally overlain unconformably by rocks of either Cisco or Wolfcamp age. Elsewhere, however, terrigenous shale, siltstone, and sandstone of Wolfcamp age generally overlie the rocks of Canyon age.

The unconformity that appears to be present at the base of the Canyon is probably the most easily recognized within the reef-complex. It is present throughout the area of the atoll. The surface of this unconformity is relatively flat along the eastern part of the atoll and in the lagoonal area, but it steepens toward the seaward side as shown by contours on Plate 4. In the western two-thirds of the area, the surface of the unconformity was not contoured because of insufficient well control. The unconformity in the middle of rocks of Canyon age has been traced only in the higher hills in central and northern Scurry County and in Kent County; elsewhere, it has been removed by subsequent erosion. To the west, this part of the reef-complex is seldom penetrated by drilling.

Rocks of Cisco age.—Rocks of Cisco age in the atoll lie unconformably on reef rocks of Canyon age. Locally rocks of Cisco age are as much as 600 feet thick but are commonly absent in the lagoonal and seaward areas and in places along the reef crest in Scurry and Kent counties. Along the crest of the atoll in western Howard County, western Borden County, Dawson and Gaines counties, and southern Terry County, reef rocks of Cisco age are overlain by reef rocks of Wolfcamp age. In eastern Borden County and Howard County, however, the reef-complex of Wolfcamp age occupies the valleys between the oil fields and the fore-reef area at the same and lower elevations. In this area, reef rocks of Cisco age are everywhere present along the crest of the atoll.

The unconformity at the base of reef rocks of Cisco age is probably present throughout the area of the atoll. It is more commonly penetrated by the drill northeast of the Reinecke oil field because (1) the upper part of the Cisco becomes thinner in that direction, and (2) the unconformity is above the oil-water interface along the crest of the atoll in most of Scurry and Kent counties. The unconformity at the base of the rocks of upper Cisco age is well represented in the area of the Good and East Vealmoor oil fields in Borden and Howard counties. However, the rocks of upper Cisco age have been removed in much of Scurry and Kent counties and this unconformity is usually difficult to distinguish.

Rocks of Wolfcamp age.—Reef rocks assigned to the Wolfcamp series have a maximum thickness of approximately 1,000 feet. At different places in the atoll these rocks are in contact with rocks of Cisco, Canyon, or Strawn age. Reef rocks of Wolfcamp age are present along the crest of the atoll from the Scurry oil field in Scurry County westward to the Wellman oil field in Terry County. Northeastward from the Wellman oil field and northwestward from the Scurry oil field, reef rocks of this age are not known to be present. From the physiographically high part of the atoll along the Gaines-Dawson County line, eastward and northward along the crest of the atoll, the amount of reef rocks of this age progressively lessens. The relatively small amounts of reef rock of Wolfcamp age east and north of the East Vealmoor oil field are especially notable. The most northeasterly reef rock of this age is in northern Scurry County (Pl. 9, well 177), where calcirudite (composed of pre-existing reef fragments) contains fusulinids of Wolfcamp age.

Rocks in reservoirs entirely of Wolfcamp age (such as in the Adair (Wolfcamp) reservoir) were not studied in sufficient detail to determine the presence of unconformities within this part of the reef-complex. An unconformity is known to be present at the base.

Limestone of Wolfcamp age is believed to have been deposited on the crest of the Horseshoe atoll and also on the flanks of the atoll. In the western part of the atoll, limestone of Wolfcamp age that contains almost no clastic material derived from other parts of the atoll was deposited on the tops of hills that now form the East Vealmoor, Vealmoor, Good, Spraberry West, Mungerville, Northwest Mungerville, Adair (Wolfcamp), and Wellman oil fields (Pl. 9) in Borden, Howard, Dawson, Gaines, and Terry counties. Farther east, limestone of Cisco age is present on the tops of hills along the crest of the atoll, but limestone of Wolfcamp age has been found low on the flanks of these hills as far northeast as the northern part of the Scurry oil field (Pl. 9, well 177).

The limestone of Wolfcamp age low on the flanks of the hills in the eastern part of the atoll is either (1) detritus derived from erosion of rocks higher on the atoll, (2) a fringing reef developed by the growth of organisms on the flanks of the atoll, or (3) both detrital and fringing-reef limestone. Study of cores from Wilshire Oil Company's No. 8 Lunsford, Pan-American Producing Company's No. 1 Glass, and Sun Oil Company's No. 1 Brice (Pl. 9, wells 90, 190, and 177, respectively) reveals that this limestone is at least in part composed of fragments of older reef limestone. Fusulinids of Pennsylvanian age are associated with fusulinids of Wolfcamp age in this limestone, indicating that it was derived at least in part from erosion of Pennsylvanian rocks higher on the atoll. Cross section E-E′ on Plate 2 shows the stratigraphic relationships of this Wolfcamp limestone.

Some of the limestone of Wolfcamp age flanking the Horseshoe atoll is extremely low with reference to the crest of the atoll. For example, the base of limestone of Wolfcamp age in Brinkerhoff Drilling Company's No. 1 Jones well (Pl. 9, well 191), southwest of the Vealmoor field in Howard County is approximately 1,800 feet lower than the top of the Cisco rocks along the crest of the atoll to the northeast. In this well fossils were reported to be of Wolfcamp age, and it may be that this limestone was derived from Wolfcamp rocks higher on the atoll and carried down the flanks by submarine slides in the manner postulated by Newell et al. (1953, pp. 69–77) for origin of tongues of limestone apparently derived from the Capitan reef.

Tongues of limestone of Wolfcamp age, along the upper part of the atoll, extend into the shale adjacent to the atoll at many places and contain mixed and reworked fusulinids of Canyon, Cisco, and Wolfcamp ages. It is inferred that the limestone was derived by erosion from rocks along the crest of the atoll—in a manner similar to the limestone along the flanks described above—and was deposited contemporaneously with the shale. Cross section A-A′ (Pl. 5) shows diagrammatically the relationships of such limestone tongues. Presence of fossils of Wolfcamp age in many of the tongues indicates that much of the shale enclosing the tongues and bordering the atoll is also of Wolfcamp age.

Stratigraphy of the Rocks Overlying the Atoll

General characteristics and relation to rocks in the atoll.—Most of the rocks immediately adjacent to and overlying the reef-complex belong to the Wolfcamp series. In eastern Kent County, central Dickens County, and central Crosby County, however, a few hundred feet of shale, siltstone, and sandstone (the "black shale" of most subsurface workers) may belong to the Pennsylvanian system (Pl. 5). Elsewhere nonreef rocks of Pennsylvanian age are much thinner. The stratigraphic relationships of rocks of the reef-complex to the surrounding "black shale" has been controversial since the first reef oil field discovery. Nearly everywhere, the Pennsylvanian reef rocks and the "black shale" are not contemporaneous. Stratigraphic relationships indicate that the interfingering of reef limestone and shale adjacent to the atoll (by which some workers have established contemporaneity) exists only in rocks of Wolfcamp age, and that such interfingering is not generally present between reef rock of Pennsylvanian age and the adjacent shale.

The rocks belonging to the Wolfcamp series overlying the atoll reach a maximum thickness of more than 3,500 feet. The stratigraphy of these rocks is very complex; in general, however, there is a lower unit of 2,000 feet or less, which consists of gray to black shale, siltstone, sandstone, and a relatively small amount of limestone ("black shale," Pl. 5); and an upper unit, which consists largely of limestone and shale and some siltstone. Few lithologic units in the entire Wolfcamp series are persistent and none can be traced throughout the entire mapped area.

The lower "black shale" unit is not of the same age at every place. It transgresses time lines to the south and west. General lithologic characteristics, apparent primary structures, and general stratigraphic relationships indicate this "black shale" unit was probably deposited as deltaic sediment.

The upper limestone-shale-siltstone unit is also stratigraphically complex. It transgresses time lines to the south and west. In large part, this unit is represented by (1) a large mass of carbonate rock resembling a barrier reef, which more or less rims what was formerly considered to be the eastern margin of the Midland basin, (2) shale, siltstone, and limestone which were deposited in the basin on the west side of this carbonate mass, and (3) relatively thinner beds of limestone and shale to the east of this reeflike mass. The siltstone unit that was deposited in the basin westward from this carbonate barrier is commonly called the Dean sandstone by petroleum geologists. A similar facies distribution appears to be present in the Leonard part of the sequence in the Midland basin, wherein the Spraberry siltstone occupies a position analogous to the Dean siltstone.

Relationships in the eastern part of the area.—In general, the lower "black shale" unit, including several limestone lenses, consists of rocks that appear to have been deposited as a part of a transgressing delta. The Dean siltstone (Table 4 and Pl. 5) in most places immediately overlies the lower shale unit; however, it is not present in most of Kent, Lubbock, Crosby, Scurry, Mitchell, Hockley, and Andrews counties, western Gaines County, and southern Howard County (Pl. 6).

The upper unit of limestone and shale becomes thicker in the area east and northeast of where the Dean siltstone is present. As shown in Table 4 and Plate 5, near the Scurry-Borden County line the Dean siltstone becomes thinner and very calcareous. It laps onto the older shale unit. These stratigraphic relationships hold true at all places where the Dean changes to a carbonate rock. Lithologically the Dean is more closely related to the Spraberry siltstone of Leonard age than to any unit within the Wolfcamp. The Dean and Spraberry to the west were deposited contemporaneously with thicker limestone and dolomite to the east of the Borden-Scurry County line and in southern Howard County.

Relationships in the western part of the area.—In Gaines County, southern Terry County, and western Dawson County the lower "black shale" unit and the upper limestone and shale unit fail to cross the atoll and are overlapped by the Dean siltstone. The Dean siltstone rests directly on reef limestone in these areas. In one well in the Mungerville oil field (Pl. 9, well 175), the Dean is apparently absent. No satisfactory explanation has been offered to account for its absence in this well. To the southeast, in eastern Andrews County and northwestward through Gaines County, the Dean siltstone becomes thinner and calcareous, finally disappearing into a limestone mass. The line along which it disappears roughly parallels a carbonate mass resembling a barrier reef on the western side of the Midland basin, which in turn parallels the eastern side of the Central Basin Platform. This siltstone-carbonate change of facies resembles the one described to the east.

Relationships in the northern part of the area.—The stratigraphic relationships of the nonreef rocks of Wolfcamp age in the eastern half of Crosby County and in Dickens County are similar to those in Scurry and Kent counties. The lower "black shale" and upper limestone and shale units are illustrated on Plate 5. In Lubbock and western Crosby counties, the "black shale" sequence becomes considerably thinner, and as a result the entire sequence of rocks of Wolfcamp age also becomes thinner. Throughout the atoll area, a general coarsening of the grain size of the "black shale" rocks is noticeable in a northeasterly direction.

PALEONTOLOGY

The following discussion of faunal associations is based on fossils studied during the detailed examination of cores from 130 wells in the Horseshoe atoll. Megafossils from areas outside the Scurry County portion of the atoll were given no more than a cursory examination. In the section dealing with the Fusulinidae, all available information from all parts of the Horseshoe atoll has been utilized.

Ages of the different rocks in the Horseshoe atoll were determined by study of fusulinids found in cores and data supplied by the Paleontological Laboratory, Midland, Texas. Fossils other than fusulinids were not studied in detail because of their scarcity or because of limited knowledge of their application in these subsurface problems.

Inasmuch as fusulinids were used to the exclusion of other groups of fossils in making age determinations, the following limitations must be borne in mind. A single group of organisms when used for stratigraphic purposes, may give a distorted picture of time relationships. Greater precision in correlation would be obtained by the use of an entire fauna, as the distorting elements in each group of organisms would tend to cancel one another. However, when dealing with subsurface problems, where paleontologic studies are confined to samples from cores or well cuttings, the percentage of the total fauna in any given sample must necessarily be small. This is especially true when dealing with groups of large fossils such as the brachiopods and mollusks. The smaller fossils such as the fusulinids are often represented by a very great number of individuals and thus are more useful for subsurface correlation purposes.

Faunal Associations

The major faunal groups of the Horseshoe atoll include echinoderms, fusulinids and other foraminifers, brachiopods, bryozoans, coelenterates, and mollusks. The relative abundance of the major groups of fossils, as determined from the megascopic core descriptions, is shown in figure 7. For the purposes of this illustration, the carbonate rocks of the atoll were treated as a unit. No attempt was made to associate relative abundance of organisms with lithic types of limestone.

The percentages in the common and abundant categories shown in figure 7 are probably high for the larger sized organisms, such as the brachiopods. When several brachiopods were noted in a small sample of a core, the occurrence would be listed as common or abundant. If the same number of fusulinids were observed in a similar volume of core, the occurrence would be listed in a lower unit of relative abundance.

Relative abundance of the various groups of fossils was determined at the time the cores were being described. The thickness of the unit containing the various categories of relative abundance was noted for each major group of fossils. The distribution figure was then computed using the total amount of available core as 100 percent. Within the limitations described above the percentage numbers represent the gross over-all distribution of the major groups of fossils throughout the body of the reef. No separation was made on the basis of age or stratigraphy. Figure 7 demonstrates the numerical importance of the various kinds of shell-bearing organisms that inhabited the reef during its time of existence. All comminuted fossil debris that could be seen megascopically but could not be identified was lumped under "indeterminate fragments."

Echinoderm remains were found in about 81 percent of the core samples. Echinoderm parts are more abundant than the remains of any other group of metazoan fossils and it is suspected that they are present in all parts of the reef. They are represented by innumerable

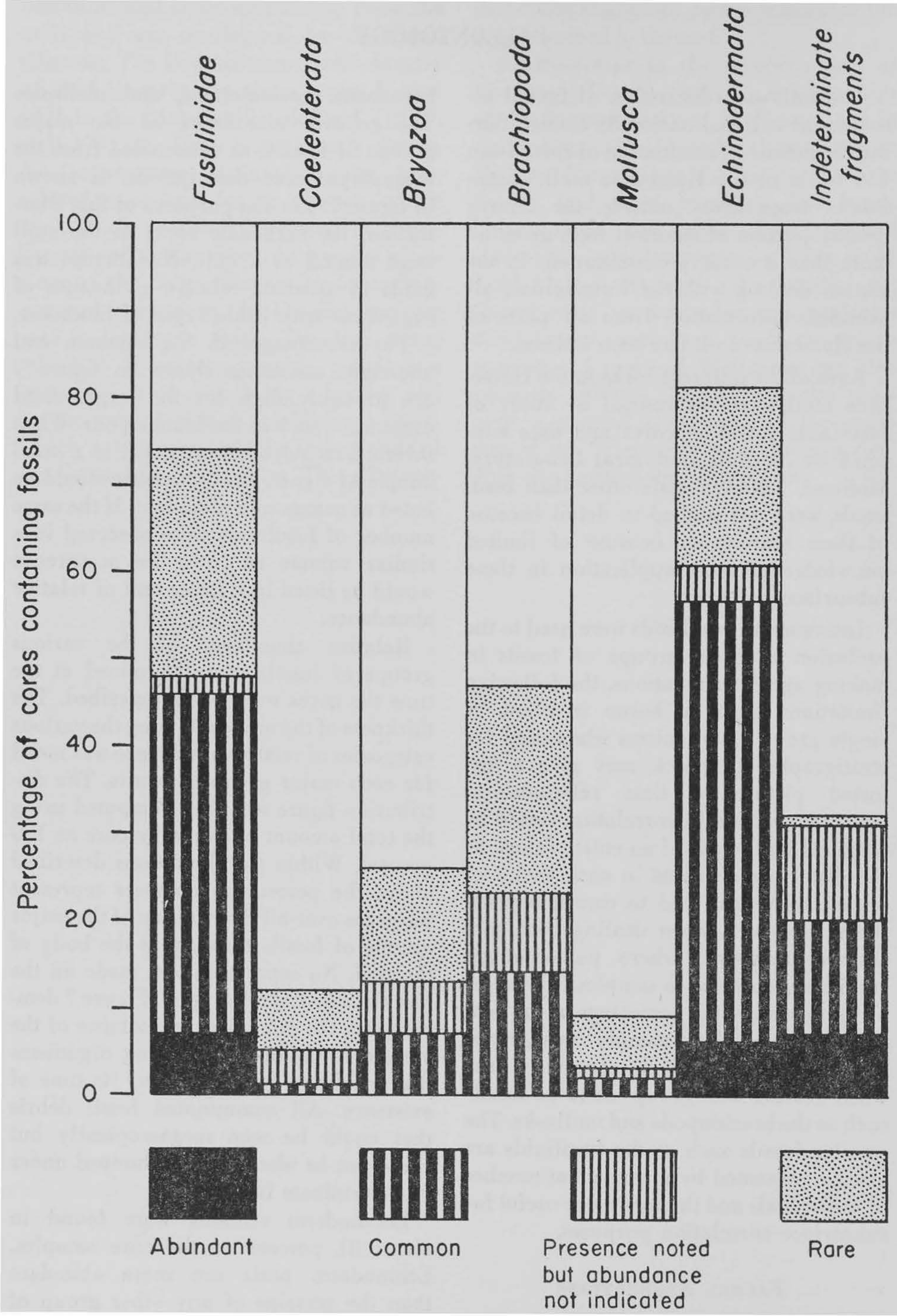


FIG. 7. Distribution of megascopic fossils in cores from 48 wells in the Scurry County part of the Horseshoe atoll.

crinoid columnals, widely scattered calyx plates and cirri, and by echinoid spines. The columnals are mostly dissociated, but segments of stems several inches long have been noted, and segments as much as an inch long are common. Spines have been noted in some hand samples, but are more conspicuous in petrographic thin sections. Crinoids are much more abundant in the darker, slightly more argillaceous (low porosity) zones in the reef limestone than in the less argillaceous (high porosity) zones.

Fusulinids have been observed in about 74 percent of the core samples. The fusulinid tests are generally well preserved and show little evidence of abrasion. Most of them are filled with lithified lime mud, aggregates of anhedral calcite grains, or with a combination of drusy calcite lining the walls and anhedral calcite filling the remainder of the test. In a very few specimens the cavity is incompletely filled. Preservation is generally best in calcilutite and in the relatively low-porosity, argillaceous zones in calcarenite. In the high-porosity zones, many fusulinids are so extensively leached that identification is impossible. Fusulinids in the reef breccias commonly are broken or have lost their outer whorls by abrasion. In many parts of the atoll, assemblages have been found containing species of fusulinids typical of rocks of both Canyon and Cisco ages. Such occurrences indicate reworking of the fauna, a factor that was considered when making faunal determinations. The fusulinids embedded in the shale are commonly crushed, probably because of prelithification compaction.

Brachiopods were noted in about 47 percent of the core samples. Several groups of brachiopods are represented in the fossil record. Productids, the Athyridae, represented by *Composita* sp., and the Rhynchospirinidae, represented by *Hustedia* sp., are the most numerous. Discinid brachiopods are fairly common in shale but have not been noted elsewhere. Other groups of brachiopods are less common. Preservation of the brachiopods is generally good. Many productids are preserved with the spines intact. This is thought to indicate that they lived, died, and were entombed in relatively quiet waters; otherwise, the delicate spines would not have been preserved intact and attached to the shell.

Bryozoa are fairly common, as indicated by their presence in about 26 percent of the core samples. The large amount of bryozoan debris in thin sections suggests that these animals are more numerous than megascopic observations indicate. Wherever fenestellid bryozoans are present, they are the most conspicuous of the class. Many large fragments of fenestellid bryozoans have been found, and inasmuch as they are very fragile, it is unlikely that they have been transported far from the locality in which the organisms died. Encrusting Bryozoa were observed which had grown around segments of crinoid columnals or brachiopod shells. Ramose Bryozoa also were noted.

Coelenterates were found in about 12 percent of the core. They consist of tetracorals resembling *Lophophyllidium* as well as colonial corals resembling *Chaetetes. Chaetetes* has been found only in those portions of the reef known to be of Strawn age. The corals, however, are of minor importance in the reef.

The Mollusca are sparsely distributed in about 9 percent of the core. Gastropods are the most common and have random distribution. Ammonoids are present in both the shale and the limestone of the atoll but are commoner in the former. A small lot of about 15 ammonoids from a granular, porous gray limestone in General Crude Oil Company's No. 193–2 Coleman well in the Salt Creek field, Kent County (Pl. 9, well 169), at 4,365 feet below sea level was submitted to Mackenzie Gordon, Jr., of the Geological Survey, who identified these ammonoids as Pronoritid? sp. indet., and *Peritrochia (Subkargalites) parkeri* (Heilprin). Concerning these ammonoids, he says (personal communication):

The first ammonoid, represented by a single young specimen has not yet developed its mature septum and shape, and therefore cannot be identified even as to genus. It may be a young *Uddenites,* but judging largely from the shape, *Pronorites* or *Neopronorites* is more likely. The second, represented by all the rest of the specimens, has the sort of suture that has been described for three known species all of them upper Carboniferous in age: *Ammonites parkeri* Heilprin, 1884, described first from an incomplete specimen from Wise County, Texas, and said by Plummer and Scott to be common in the Graford formation at Bridgeport, Wise County; *Marathonites? hargisi* Böse, 1917, described from a single specimen from the Hargis Ranch in Brewster County, Texas, and common in the Gaptank formation at several localities in Brewster County; and *Kargalites (Subkargalites) neoparkeri* Ruzhencev, 1950, from Zianchurian "horizon" of the Jigulevian stage in the Ural Mountains of Russia, which Ruzhencev correlates in part with the Missouri series in America (as defined by Moore *et al.*, 1944), and believes is older than the Virgil series. In citing the three species above, I have used the original name as proposed by the author of the species. According to current American usage, all three belong in the genus *Peritrochia* Girty, 1908. *Subkargalites* Ruzhencev may be useful as a subgenus as it was proposed for *P. hargisi.* Some authors believe *hargisi* to be a synonym of *P. parkeri.*

At any rate, this type of peritrochid suture is found in forms that appear to be limited to the upper half of the Pennsylvanian in Texas and roughly equivalent beds in Russia.

The presence of "*Wedekindellina*" *ultimata* in this well at a depth of 6,508 feet below the surface not only supports the ammonite evidence of Canyon age but further suggests early Canyon age. The rocks at this depth fall within the Type A zone at the base of the Canyon.

Pelecypods, represented by the Pectinacea, are commonly present in the shale beds in the reef-complex. Arthropods were observed in less than 1 percent of the core samples. The arthropods recognized in this study consist of ostracods and rare fragments of trilobites. Ostracods are probably more numerous than indicated because they are easily overlooked in the method of study followed in this paper. Fish scales were noted, usually in the shale.

An assemblage of conodonts was found by W. H. Hass, of the Geological Survey, in the Wilshire Oil Company's No. 8 Lunsford well (Pl. 9, well 90), from the Scurry County part of the atoll. These conodonts were in the "black shale" parts of the core. Mr. Hass reports (personal communication):

The conodonts present in the black shale at a depth of 6,741 to 6,979 feet in the Wilshire Oil Company's Lunsford No. 8 well, Scurry County, Texas, do not permit an age determination more precise than late early Pennsylvanian to middle Permian. The same kinds of conodonts were found to range throughout the entire black shale interval; and the faunal assemblage consists of only a few generic kinds of conodonts. These have been identified as *Hindeodella, Ozarkodina,* and *Streptognathodus.* Of these, *Streptognathodus* is the only genus considered to have stratigraphic significance, and the aforementioned age determination is based entirely on the presence of this genus in the collecton.

Except that they suggest a marine environment, the presence of conodonts in the black shale of the Wilshire core has no real paleoecological significance. It is the writer's opinon that the anmal that bore conodonts was a part of the nektonic biota. This view is held because the same conodont genera and species are known to be present in all kinds of marine sedimentary rocks.

Algae, although probably present in the Horseshoe atoll, were not recognized in abundance by the writers. It is believed that they may have played an important part in the formation of the atoll, but that diagnostic algal structures were not widely preserved in the rock. Structures of possible algal origin were found in the Humble No. 2 McLaury well (Pl. 9, well 171) at 4,921 feet below sea level (Pl. 14,D). Elliott and Kim (1952) reported algae from Honolulu Oil Company's No. 1 McGowan well in Terry County, Texas (Pl. 9, well 164). They examined a suite of 84 core samples from depths of 9,941 feet to 10,082 feet below sea level and prepared thin sections of 25 samples taken at about 5-foot intervals. They reported calcareous algae from all thin sections. In many sections, only small amounts of algal material could be definitely identified; however, an algal origin was suggested for much more material by general outline and "ghost" [sic] structure. The best preserved algal remains were fragments or grains in which the internal structures of the algae remained. Elliott and Kim (1952) identified these fragments as belonging to the family Codiaceae. Most fragments were rounded and apparently had been broken and carried from their place of origin.

Elliott and Kim also noted an abundance of material that appeared as a dense to "finely crystalline" [sic] groundmass containing dark lineations. These lineations were concentric or roughly parallel, suggesting either concentric algal growths as in cryptozoan colonies, or branching tubes typical of the Codiaceae, similar to *Anchicodium*. If this material is of algal origin, as suggested by Elliott and Kim, it is likely that a large part of the rock matrix is of algal origin and that the Horseshoe atoll owes its existence to the framebuilding, sediment-binding, and lime-precipitating capabilities of algae.

FUSULINIDAE

Previous studies of Texas fusulinids.— Published reports on the Fusulinidae of Texas have been concerned mostly with studies of collections from the outcropping rocks. Little information has been published on samples from the subsurface. The most notable study was that of Dunbar and Skinner (1937), in which the Texas Fusulinidae of Permian age were described from outcrops, mainly in western Texas. Earlier workers such as Beede and Kniker (1924) and Roth (1931), have discussed some aspects of the fusulinid faunas. White (1932) made a general survey of some of the fusulinids of the State, and his report includes fusulinids ranging in age from Strawn through Wolfcamp. Henbest (1938) made a study of fusulinids of Cisco and Wolfcamp age from central Texas, and his report includes preliminary notes on the ranges of some of the species. Heck, Yenne, and Henbest (1952a, b), and Dunbar (1930, 1932) have published the only data on fusulinids from the subsurface. In their report, Heck, Yenne, and Henbest noted the presence of *Schwagerina* in the Scurry reef; Dunbar noted the presence of *Triticites ventricosus* in the Big Lake oil field. Thompson (1954) described species and gave data on stratigraphic ranges of fusulinids from outcropping rocks of Wolfcamp age in central Texas.

Commercial workers, such as the Paleontological Laboratory in Midland, Texas, and paleontologists working for various oil companies have done considerable work on the fusulinids from the subsurface. The Paleontological Laboratory has generously allowed free access to unpublished data, and the tracing of many horizons above the atoll was largely dependent upon that information.

Comparison of fusulinids in the Horseshoe atoll and in north-central Texas.— The records of the Pennsylvanian and early Permian fusulinids in west and north-central Texas have been used more than those of any other fossil for interpreting the age and significance of the Horseshoe atoll fossils. Most groups of fusulinids found in the outcropping rocks are also encountered in the atoll, and assignment of fusulinids to their correct stratigraphic position is ultimately dependent upon accurate knowledge of the succession of rocks in type sections, most of which are on the surface.

This preliminary outline of the characteristics and stratigraphic range of the fusulinid zones in north-central and in west Texas was made possible by participation in the detailed study in progress of the Fusulinidae in north-central Texas by L. G. Henbest, D. A. Myers, and R. C. Douglass, and since 1950 by studying and collecting from the Permian in west Texas.

It has been found that the fusulinids from each bed are distinctive, and assemblages of them can be approximately matched over great distances. Thus, for example, the Speck Mountain limestone of the Thrifty formation in the Cisco group in Brown and Coleman counties contains a typical *Triticites-Dunbarinella-Schubertella* fauna that is identical with that of the Blach Ranch limestone to the north in Stephens and Eastland counties, Texas. Likewise, the fusulinid fauna from the Adams Branch limestone member of the Graford formation in the Canyon group characteristically carries a fauna of which *Triticites ohioensis* is the dominant species. This fauna usually is near the top of the bed wherever this member is found.

In central Texas, fusulinids are most abundant in limestone and are also present in smaller amounts in shale and sandstone. However, in a few shale units, such as the Brownwood shale member of the Graford formation, fusulinids are abundant. It is not known to what extent sedimentary environment affects the distribution of the fusulinids. It is suspected that they favored an environment in which carbonate sediments were being deposited. It is suggested that assemblages in highly arenaceous or argillaceous rocks may represent a thanatocoenose—a depositional rather than a life assemblage. Objects having the shape of a fusulinid could readily be rolled in a direction normal to the long axis and deposited in great numbers in an environment other than that in which the organism lived. Assemblages in clastic rocks commonly show evidences of reworking, such as tests that are abraded, have the ends broken, or have the outer whorls missing. The fact that fusulinids from the outcrop can be matched from similar horizons over great distances suggests that broad areas of similar ecologic conditions must have existed during the time in which the individual species lived.

The rapid evolution of the Fusulinidae makes various of its species excellent index fossils. Their evolution was such that one species grades imperceptibly into another. At times the difficulties encountered in separating one species from another are almost insurmountable. Variation within a given species is great but usually follows an orderly evolutionary scheme.

For the purposes of this investigation the fusulinids were divided into groups of similar or closely related species which will be identified in this paper by the most characteristic or the best known species of the group. These species groups, the horizon in which the name-bearing species of the group occurs, and the known stratigraphic range of the group are listed in Table 6. Each group ranges through one or more formations. For example, the group of *Triticites ventricosus* first appears in the upper part of the Canyon group and extends into the upper part of the Wolfcamp series. Evolutionary changes within the species group may be used to determine the stratigraphic position of the individual variants. In the species group of *T. ventricosus*, as in most others, the changes consist mainly of an increase in size and complexity of internal features.

Outline of the stratigraphic ranges and characteristics of fusulinid zones in north-central and west Texas.—In order to acquaint the reader with the fusulinid genera and some of their morphologic characteristics, the following discussion of fusulinids found in the outcropping rocks of north-central and west Texas has been introduced.

Fusulina in central Texas is restricted to rocks belonging to the Strawn group. In the lower part of the Strawn, primitive species of this genus are present with *Wedekindellina*. The most highly developed species of *Fusulina* in central Texas occur in the Capps limestone near the top of the Strawn group.

"*Wedekindellina*" *ultimata* Newell and Keroher is found in the lowermost rocks of the Canyon group. It has a general wedekindelloid appearance without the axial filling typical of that genus. The wall structure is intermediate between that of *Fusulina* and *Triticites*. In the Horseshoe atoll, specimens of the genus *Fusulina* are generally found within 30 to 50 feet below the first occurrence of "*W.*" *ultimata*.

In the Canyon group, species of *Triticites* are generally elongate, thin-walled, weakly fluted forms. *T. irregularis*, which occurs most abundantly in the Brownwood shale member, is a small primitive triticite of variable shape. The most primitive *Triticites* generally have fusulinelloid chomata in the earlier whorls. The wall structure in the earlier whorls often resembles that of *Fusulina* or *Fusulinella*. Some species, such as *T. ohioensis*, are large for the genus, a few individuals attaining a length of 8 mm. In general, the Canyon species of these elongate forms will have tunnel angles ranging from 50° to 70° or higher in the penultimate whorl of adult specimens. The younger Canyon species are mainly developed from the *T. irregularis-T. ohioensis* stock, except for the primitive members of the group *T. ventricosus* which first appear in the Ranger limestone.

The fusulinids of the Cisco group include *Triticites, Dunbarinella, Schubertella,* and *Waeringella.* Of these genera, *Triticites* ranges throughout the entire Cisco; *Dunbarinella* has been found as low in the section as the Gunsight limestone member of the Graham formation; *Schubertella* has been collected from the Speck Mountain limestone member of the Thrifty formation; and the genotype of *Waeringella* is present in the lowermost beds of the Cisco. The genotype of *Waeringella* was described from the Salem School limestone member of the Graham formation, which, at the type locality, immediately overlies the Home Creek limestone member of the Caddo Creek formation, being separated only by thin beds of clastic rocks. When encountered in the subsurface, it makes an excellent guide fossil.

The species of *Triticites* in the Cisco group have many shapes. They may be subcylindrical, ventricose, or subspherical. Complexity of septal fluting ranges from almost plane septa, as in *Triticites cullomensis* and related forms, to strongly but irregularly fluted septa. In general, fluting increases in complexity as the geologic column is ascended. Wall thickness ranges from thin in the lower Cisco species to thick in the upper Cisco species. The size of the proloculus becomes larger in the species found in younger rocks.

Dunbarinella is found in rocks of Cisco and Wolfcamp ages. It first appears in the lower Gunsight limestone member. Species of "*Triticites*" resembling *Dunbarinella* are found in the Bunger limestone member of the Graham formation, but the relationships between the Bunger species and the Gunsight species are not clearly understood. It may be that the Bunger species represents a transitional form between the two genera. The lower Gunsight species is schwagerinid in appearance; however, it possesses the characteristic features of the genus *Dunbarinella.* It is present also in collections from the Ivan and Speck Mountain limestone members. In the Speck Mountain member, the genus is similar in many respects to *Dunbarinella compacta* (White).

Species of *Schubertella* in rocks of the Cisco group (this genus occurs most often in rocks of Permian age) have been found in the Speck Mountain limestone member in the Colorado River drainage area. At certain localities they are abundant. The next higher stratigraphic unit containing this genus is the Waldrip limestones of Permian age.

The older Wolfcamp fusulinids are characterized by advanced species of the genus *Triticites,* primitive *Schwagerina,* and species that are intermediate between *Triticites* and *Schwagerina* in development. The *Triticites* are typically rather large, often ventricose, with a large proloculus. Septal fluting is usually strong for the genus; chomata may be weak to massive; the wall is usually thick and coarsely alveolar. An exception is one species in rocks of Wolfcamp age that looks very much like *Triticites irregularis,* a species which is present in the Brownwood shale member of the lower part of the Canyon group.

Schwagerina found in rocks belonging to the lower part of the Wolfcamp series is typically a slender form with well-developed, somewhat irregular fluting, resembling *S. emaciata* in appearance. Other forms, which resemble *Schwagerina* in appearance, have triticite characteristics as well, such as weakly and unequally developed chomata, which in most cases do not extend to the penultimate whorl. In many specimens, chomata are present only in the first two or three volutions and then on one side only.

The lowest stratigraphic unit containing the genus *Schwagerina* s.s., or species known to be associated with *Schwagerina* at other localities, is taken to indicate the base of the Wolfcamp. Stratigraphic evidence indicates that, of the genera of fusulinids which make their first appearance in the Wolfcamp, *Schwagerina* s.s. is the earliest. In the oldest Wolfcamp rocks, there are species of fusulinids which are transitional between *Triticites* and *Schwagerina*. Other genera such as *Pseudoschwagerina*, which are most diagnostic, are not present as near the base of the Wolfcamp as *Schwagerina*. In this paper, the name *Schwagerina* is employed in the sense outlined by Dunbar and Skinner (1936, pp. 85–88). Their diagnosis has been strictly followed.

Significance and methods of subsurface study of fusulinids.—Fusulinid Foraminifera were used exclusively to establish the age of the atoll. Techniques of preparation for study for this paper were essentially those outlined in Dunbar and Henbest (1942, pp. 65–74). During this study more than 2,700 oriented thin sections were prepared from cores from about 130 wells in the atoll. Material from well cuttings was not used because of the uncertainty of the exact position of the sample. Age determinations were made by means of direct comparisons with suites of material collected from known horizons at the surface in central Texas. Wherever possible, assemblages of fusulinids were used rather than individual specimens.

Cores were sampled for fusulinid-bearing material during the routine process of making core descriptions. Samples were taken from as near to the top and as near to the bottom of the core as possible, and usually at intervals ranging from 5 to 20 feet throughout the core. Some cores were sampled at 1- to 2-foot intervals where long sections of fusulinid-bearing limestones were present. Fusulinids were selected for sectioning by slicing the core into thin discs, usually taken normal to the long axis of the core. These discs were examined with the aid of a binocular microscope and specimens were marked for sectioning. Chips containing the individual fusulinid were cut from the discs with a carborundum cut-off blade. The chips were prepared in the usual manner (Dunbar and Henbest, 1942, pp. 65–74). Critical and typical fusulinids from the atoll were photographed at a standard magnification of x10.

The absolute range of many species is imperfectly known because of incompleteness of the geologic record, or because of incompleteness of the collections. In the Horseshoe atoll, certain parts of the geologic column, discussed elsewhere, have been removed by erosion. Except for these missing intervals, the paleontologic record is more complete in the subsurface Horseshoe atoll than on the surface; hence the succession of fusulinid faunas and the intergradational nature of the various fusulinid species are better demonstrated in the subsurface. However, by comparison with the surface collections, enough key forms can be recognized to correlate the section as a whole. Intervals in the atoll containing numerous well-preserved fusulinids may be represented by sections on the surface containing sandstone and conglomerate having few or no fusulinids. Fusulinids found in these clastic rocks are likely to be so poorly preserved or so obviously redeposited that they have little value in stratigraphic work.

There are several difficulties encountered when working with samples from the subsurface. When samples consist of rotary cuttings, it is usually necessary to use fragmentary specimens. Intact specimens are rare. Another problem is to obtain the true depth from which the sample was taken. Factors involved in sampling are: time lag during which the cuttings are flushed to the surface, and contamination by rock fragments from higher beds. Often the chips can be recognized by differences in lithology; however, in reef-type oil fields, the lithology may be uniform throughout. Often differences in fauna will indicate contamination, but it is possible to work with a contaminated sample without being aware of the fact.

For these reasons, work done on fusulinids in this study has been confined to samples taken from cores. In core samples, the depths are known with reasonable accuracy, and it is usually possible to obtain well-oriented intact specimens. By using samples from cores, it was possible to recognize horizons that contained fusulinid faunas mixed by redeposition—something that would be difficult or impossible when working with cuttings.

Many fusulinids from the subsurface Horseshoe atoll differ from those found on the surface. In the atoll certain sequences of fusulinids represent an almost complete evolutionary series wherein the various species grade imperceptibly into one another. To explain the differences in the fusulinid faunas, the working hypothesis is proposed that sedimentation within the depositional area of the atoll was more continuous, except for brief periods of erosion, than that on the surface in central Texas. The surface section in central Texas contains numerous "channel" sandstones and conglomerates as well as thick sections of shale. In these clastic intervals, fusulinids are rare to absent. Sedimentary rocks in the atoll which occupy a position analagous to that of the clastic sequences on the surface contain a more or less continuous series of fusulinids.

Characteristics and stratigraphic distribution of fusulinids in the Horseshoe atoll.—Fossils representing 11 genera of the family Fusulinidae have been collected from cores from the Horseshoe atoll. These genera with their known stratigraphic ranges in Texas and the Mid-continent region are listed in Table 5.

The reef limestone of the Horseshoe atoll contains the faunal zones of *Fusulina* and *Triticites*, and part of the zones of *Wedekindellina* and *Pseudoschwagerina* (Dunbar and Henbest, 1942, pp. 28–31). The oldest parts of this limestone mass are within the upper part of the zone of *Wedekindellina*, which extends from the base to about the middle of the zone of *Fusulina*. Most of the reef limestone lies within the zone of *Triticites*, and it is within this zone that the greatest number of species are found. The zone of *Pseudoschwagerina* embraces the youngest part of the reef. Fusulinids belonging to this zone are usually found in the topographically higher parts of the reef in the southwestern part of the atoll.

Table 5 includes only those genera that have been collected by the persons associated with this study. *Pseudoschwagerina* has been reported from the southwestern part of the atoll by other workers.

As stated in the discussion of fusulinids from rocks exposed in north-central Texas, the species of *Triticites* are divided into species group units rather than species. Table 6 shows the various species groups of *Triticites* that have been found in the atoll along with the typical species and

Table 5. Known ranges of some fusulinid genera in the Mid-Continent region and north-central Texas.

FUSULINID	CENTRAL MID-CONTINENT* (series)	NORTH-CENTRAL TEXAS (groups or series)
Fusulinella	Atoka (very rare above)	"Atoka"
Wedekindellina	Lower Des Moines	Lower Strawn group
Fusulina	Des Moines	Strawn group
"Wedekindellina" ultimata	Missouri	Basal Canyon group
Triticites	Missouri-Wolfcamp	Canyon group—Wolfcamp series
Waeringella	?	Basal Cisco group—Wolfcamp series
Dunbarinella	?	Cisco group—Wolfcamp series
Schubertella	?	Cisco group—Leonard series
Schwagerina	Wolfcamp-Leonard	Wolfcamp series—Leonard series
Paraschwagerina	Wolfcamp	Wolfcamp series
Pseudofusulina	?	Wolfcamp series—Leonard(?) series

* Series names as used by the State Geological Survey of Kansas.

their known stratigraphic ranges, using the central Texas section as a standard. (For ranges of the genera of fusulinids, see Thompson, 1948, p. 22).

Redeposited faunas in the reef are perhaps the greatest single cause of mistaken correlations. Erosion of pre-existing rocks can release many intact tests. The shape of the fusulinid test is such that it can be readily transported by currents and deposited in another environment. Another source of redeposited faunas is in the calcirudite. Most, if not all, of the nonbioclastic calcirudite is composed of fragments of pre-existing reef limestone. These fragments can be carried for great distances by means of submarine slides (Newell et al., 1953, pp. 69–77). Hence, fusulinids of quite different ages can be mixed in a single piece of core. For example, in Humble Oil & Refining Company's No. 1 L. R. Spires at 4,461 feet below sea level, the core contains species of both *Fusulina* and *Triticites*. (See Pl. 9, well 172.) The species of *Fusulina* is very similar to a form in the Capps limestone; that of *Triticites* resembles the forms in the Palo Pinto limestone. Plate 15, D through H, illustrates specimens of the two genera from this core. In other cores, where the genera are the same, and the species are closely related, the mixing of faunas may not be as apparent.

Separation of the atoll fusulinids from the zone of *Fusulina* into species groups was not made because of insufficient comparative material from outcrops of rocks belonging to the Strawn group in north-central Texas. *Wedekindellina* (Pl. 15,A) has been found in rocks of early Strawn age. The most highly developed species of *Fusulina* (Pl. 15, B–C) collected from reef cores resemble those from the Capps limestone at the top of the Strawn group in central Texas.

The base of the Canyon group coincides in the atoll with the base of the zone of *Triticites*. Inasmuch as the zone of *Fusulina* and the zone of *Triticites* do not overlap, the base of the Canyon in the subsurface is taken at a convenient position between the lowest occurrence of *Triticites* and the highest occurrence of *Fusulina*. "*Wedekindellina*" *ultimata* (Pl. 15, I) is commonly associated with primitive species of *Triticites* and is not known to be associated with *Fusulina*. Hence, this species is regarded as an early Canyon form. The lowest occurrence in the reef is usually no more than 75 feet above the highest occurrence of *Fusulina*.

Fusulinids from the lower part of the Canyon group belong to the groups of *Triticites irregularis* and *T. ohioensis*. Typical fusulinids of this group are illustrated on Plate 16, A–D. In the upper part of the Canyon, the triticite fauna begins to show resemblances to the groups of *T. secalicus* and *T. ventricosus*, as illustrated on Plate 16, E. Surface collections indicate that this form first appears in the Ranger or Home Creek limestone.

In the Horseshoe atoll, fusulinids in rocks of Cisco age differ from those of

Table 6. Species groups of Triticites found in the Horseshoe atoll.

Fusulinid group	Typical species and stratigraphic position	Stratigraphic range: Formation	Stratigraphic range: Member or bed
Triticites irregularis	T. irregularis s.s. (Brownwood)	Whitt Graford	Brownwood (Palo Pinto) Home Creek
Triticites ohioensis	T. ohioensis s.s. (Adams Branch)	Graford Brad	Adams Branch Placid shale
Triticites secalicus	T. secalicus s.s. (Graham)	Caddo Creek Graham	Home Creek Gunsight
Triticites ventricosus	T. ventricosus s.s. (Saddle Creek)	Caddo Creek Harpersville	Home Creek Saddle Creek
Triticites plummeri	T. plummeri s.s. (Breckenridge)	Graham Thrifty	Wayland Breckenridge

Canyon age in several respects. In rocks of Cisco age, the ventricose fusulinids become more prominent than in the earlier rocks of Canyon age. Also, the *secalicus*-like forms (which are essentially a very generalized triticite) become prominent, especially in the lower part of the Cisco. In general, the fusulinids of the Cisco exhibit an increase in size, wall thickness, diameter of initial chamber (the proloculus), and degree and complexity of septal fluting. As a general rule, the more highly fluted species of *Triticites* are younger than the less highly fluted species. The converse is not necessarily true. A notable exception is *T. osagensis,* in the middle part of the Canyon group. The fluting in this species is quite highly developed, although it is somewhat irregular. Weakly fluted species of *Triticites,* of which *T. cullomensis* Dunbar and Condra is a good example, are common in the lower part of the Cisco group.

The lowermost rocks of Cisco age in the atoll are identifiable by the presence of *Waeringella spiveyi.* In north-central Texas this species is known only from the basal part of the Cisco. Associated with *W. spiveyi* in the Horseshoe atoll are early Cisco species of *Triticites.* Unfortunately, *Waeringella* is present in only a few of of the wells that penetrate rocks of Cisco age. A typical specimen of *Waeringella spiveyi* Thompson from the atoll is illustrated on Plate 16, F, and an eccentric section of *Triticites* sp., that was associated with this specimen, is shown on Plate 16, G. Typical fusulinids of lower Cisco age are illustrated on Plate 16, H–J. These specimens resemble species of *Triticites* that have been found in the Bunger limestone. The group of *Triticites secalicus* is represented by specimens similar to those figured on Plate 17, A and B.

The group of *T. ventricosus* in rocks of the lower part of the Cisco group resembles the specimens figured on Plate 17, C–F. These specimens resemble those found in rocks from the Gunsight limestone and the Wayland shale, which crop out in central Texas.

The interval between rocks equivalent to the Wayland shale and rocks equivalent to the Chaffin limestone in the Horseshoe atoll contains few fusulinids. Whether this is due to an unfavorable environment or is a measure of the length of time of the middle Cisco unconformity is unknown.

Plate 17, G, illustrates a characteristic species from the atoll that is related to *Triticites pinguis* Dunbar and Skinner. Associated with this specimen was a single specimen of *Dunbarinella* (Pl. 17, H). *Triticites beedei* Dunbar and Condra also is present in this part of the section (Pl. 17, I). In north-central Texas, similar larger, ventricose species of *Triticites* are found in the Chaffin limestone member of the Thrifty formation.

The Wolfcamp species of *Triticites* (Pl. 18) are mostly ventricose forms that differ from their predecessors mainly in being larger, having thicker walls, possessing larger proloculi, and in having a more coarsely alveolar wall. The degree of septal fluting does not change appreciably from the forms in the rocks of Cisco age. It is in the lower Wolfcamp that the true *Triticites ventricosus* (Meek and Hayden) is found. Other species of *Triticites* present in rocks of Wolfcamp age in the atoll and elsewhere possess characteristics that suggest *Schwagerina,* and it may be that some of these species represent transitional forms between *Triticites* and *Schwagerina.* Two specimens approaching the true *Triticites ventricosus* are illustrated on Plate 18, A and B. Plate 18, C, illustrates a specimen of *Pseudofusulina,* a typically Wolfcamp genus, which superficially resembles *Schwagerina.* The chomata are weakly and unevenly developed beyond the third whorl. This type of chomata is suggestive of *Schwagerina.* However, true *Schwagerina,* as defined by Dunbar and Skinner (1937, pp. 624–627), does not possess chomata beyond the initial volutions. The septal fluting in the illustrated specimen is of a type commonly found in primitive species of *Schwagerina.* Plate 18, D, represents a triticite, although the fluting—especially in the earlier stages—is schwagerinid. Another triticite that exhibits schwagerinid characteristics is *Triticites koschmanni* Skinner. This species was reported by Heck, Yenne, and Henbest (1952a) from the Scurry County part of the Horseshoe atoll.

Heck, Yenne, and Henbest (1952a, Pl. 1, 1–11) illustrated a number of fusulinids of Wolfcamp age from the Scurry reef. The fauna reported from the Wilshire Oil Company's No. 8 Lunsford well is listed below with the depths from which the specimens were obtained:

	Feet
"Schwagerina" compacta Triticites koschmanni	6,804
Schwagerina ? sp. Triticites pinguis ?	6,813
Triticites pinguis ? Schwagerina longissimoidea Schwagerina sp. Triticites ventricosus Triticites sp.	6,817
Triticites pinguis ?	6,826
Triticites pinguis ?	6,830
Triticites pinguis ? Triticites aff. T. ventricosus	6,834– 6,875
Triticites sp. (Canyon form)	6,877

The *Triticites* sp. Canyon forms reported by Heck, Yenne, and Henbest (1952a, fig. 5), in apparent association with Cisco fusulinids, represent a redeposited fauna. Ventricose *Triticites* of Cisco age have been found in underlying samples of this core. The authors state (p. 10):

> Later work by geologists of the U. S. Geological Survey on other cores of the Scurry reef indicates that reef rock of Cisco age is widespread and relatively thick. These Cisco rocks are commonly calcirudites containing much Canyon debris with abundant fusulinids. Also scattered throughout are the rarer, more ventricose fusulinids of Cisco age. Because of their abundance fusulinids of Canyon age are more commonly recovered from these rocks than those of Cisco age, and consequently these rocks were at first believed to be of Canyon age. This situation may apply to the section below 6,875 feet in the No. 8 Lunsford well. The fusulinids immediately below 6,875 feet are of Canyon age but at 6,916 feet are ventricose forms that may be of Cisco age. Accordingly, although it was originally thought that rocks of Cisco age were absent or very thin in the No. 8 Lunsford well, on the basis of more detailed work on these cores, it is more probable that these rocks are of considerable thickness and contain abundant debris of Canyon age. In any case, at least part of the reef is of Wolfcamp age, and all the overlying black shales must be Wolfcamp. Because interfingering organic limestones and shales are relatively rare along the fringes of the reef, it is probable that the shales of Wolfcamp age extend a considerable distance down the flanks of the reef.

Masses of reef-type limestone in the southwestern part of the atoll contain specimens of *Paraschwagerina* sp. (Pl. 18, E–G), which resemble a form found in the Coleman Junction limestone.

Ecology

Some information concerning the ecologic conditions that existed during the time of formation of the reef is obtainable from the fauna. The entire assemblage indicates that the waters were marine and were probably of normal or near normal salinity. Apparently, there was little turbidity during periods of maximum reef development. Attached forms, such as bryozoans, and bottom-dwelling forms, such as the productids, apparently require clear waters in order to thrive. Appreciable amounts of silt in the water would inhibit living processes and kill these organisms. The absence of such forms in the claystone corroborates this interpretation. Preservation of fragile forms, such as fenestellid Bryozoa and productid brachiopods with their attached spines, indicates either periods of quiescence or protected areas.

The environment of shale deposition appears to have been toxic to most forms. The fauna is limited to scattered crinoid columnals, discinid brachiopods, rare ammonoids, fish scales, and, in the thin shale partings, fusulinids. Preservation of the fusulinids in the shale partings is generally poor. They are usually crushed together and walls are broken. In most specimens the outer whorls have been eroded apparently by solution. It is believed that fusulinids when found in the shale in appreciable numbers represent a post-mortem assemblage or thanatocoenose (Krumbein and Sloss, 1953, p. 228).

Broken and abraded specimens of megafossils are commonly associated with the calcirudites. This type of preservation is due to formation of breccias under turbulent conditions of sedimentation. The reef breccias were probably formed under one or more of the following three conditions: subaerial erosion, submarine slides, or submarine erosion by wave action and currents. Any of these three conditions could easily produce broken and abraded specimens. The presence of reworked faunas, which is discussed in greater detail in the section on Fusulinidae, may also be attributed to these conditions.

The shale lenses (which mark unconformities) associated with many of the reef breccias represent encroachments of mud which repeatedly killed off many of the reef organisms.

Newell et al. (1953, pp. 12–14) have pointed out the many instances of reef growth in areas which had poorly circulating sea water and suggested that upwelling of these nutrient-rich waters in the reef area contributed food to the organisms that grew on the reef. The Horseshoe atoll apparently had a similar environment as shown by the black shales at its base. If this is a prerequisite of reef growth, then the structural control of the semiclosed basin is important to the growth of the reef.

STRUCTURAL GEOLOGY

Interpretations of the geologic structures in the northern part of the Midland basin are complicated by the presence of the Horseshoe atoll and other reeflike masses of carbonate rocks of post-Strawn age. Some of these carbonate masses have hundreds to thousands of feet of relief resulting from nontectonic processes; consequently contours drawn on the Pennsylvanian or Permian rocks containing these masses reveal little about the structure of the rocks that results solely from tectonic movements. Many structures in the younger rocks are a result of differential compaction of the sediments overlying the reeflike masses; consequently, contours drawn on these rocks do not clearly reveal the structure resulting only from tectonism. Contours drawn on older rocks, such as those on top of the rocks of Atoka age (Pl. 7), are generally difficult to interpret owing to the paucity of bore holes penetrating these rocks. These factors make it possible to describe and interpret only the larger regional structures in the area of the Horseshoe atoll.

Structure of Pennsylvanian and Wolfcamp Rocks

Structure of rocks of Atoka age.—Because of their great depth, rocks of Atoka age or older are not commonly penetrated by the drill in the northern part of the Midland basin and therefore control is usually inadequate for satisfactory contouring. For this reason the contours shown on Plate 7 are limited to the eastern half of the atoll area, which contains the most control. Several contour interpretations are possible in this mapped area. With the limitations of the control in mind, the most generalized interpretation was selected.

The contours on top of the rocks of Atoka age on Plate 7 reveal a regional dip to the west in northern Garza County and southern Crosby County; this regional dip swings to the southwest through Borden and Howard counties. In western Garza County the dip to the west is about 20 feet to the mile, whereas in northwestern Borden County the southwestern dip is as great as 200 feet to the mile.

Studies of rocks of Atoka age in the northern part of the Midland basin indicate that in addition to the regional dip to the west and southwest two major regional structural features are present. One is a doubly plunging syncline curving around the western and southern sides of the atoll. The other is a plunging anticline trending northeast. Superimposed on these broader regional structures are minor folds and plications whose structural relief progressively increases westward toward the Central Basin Platform. These smaller structures have a regional "grain" trending northeast, which contrasts with the northwest trend of most of the structural features of western Texas but which is accordant with the trend of the folds in the Marathon region to the south of the Midland basin.

The older (pre-Pennsylvanian) rocks appear to be folded though very moderately so. The younger (Pennsylvanian and Wolfcamp) rocks appear to be folded also, but the magnitude of the folds apparently decreases upward.

Structure of rocks of post-Atoka age.—Southwestward tilting during the growth of the Horseshoe atoll is suggested by a general thickening of the sequence of reef and associated rocks in that direction. Evidence is lacking for tectonic structure within the reef rocks of the Horseshoe atoll.

The structure contours on the base of the Dean siltstone (Pl. 6) overlying the Horseshoe atoll appear to reflect differential compaction over the atoll and other reeflike masses, plus regional tilting that occurred after the Dean siltstone was deposited. The relatively steep dips shown at the margin of the siltstone are largely due to the abrupt thickening of limestone of Wolfcamp age, which immediately underlies the Dean in most of the area. This limestone apparently passes from a biostromal phase to a biohermal phase at the margins of the Dean siltstone.

The structure contours on the top of the Coleman Junction limestone (Pl. 6) show the effects of differential compaction and regional tilting in the easternmost part of the mapped area. The effects of differential compaction appear to be more subdued on the top of the Coleman Junction than on the base of the Dean siltstone, even though the latter is a stratigraphically higher horizon. This is primarily due to the westward thinning of the Wolfcamp "black shale" unit. In southwestern Scurry County, the Coleman Junction dips relatively steeply in a westerly direction, and there the effects of compaction are subordinated to the effects of initial dip and westward tilting.

Structural Control of the Horseshoe Atoll

The most prominent structural feature which may have influenced the position of the Horseshoe atoll is the curvilinear doubly plunging syncline in the platform on which the atoll accumulated. This structural feature may have determined the position of the southwestern and western sides of the atoll. The atoll nowhere crosses this syncline but stays high on its northern and eastern flanks as far east as the Central Vealmoor oil field. Northeastward, the atoll crosses obliquely the plunging anticline that lies within the arc of the syncline but is so broad that it resembles a tilted structural plateau. Location of the eastern part of the atoll was not controlled by an obvious structural feature in the platform underlying the atoll.

ORIGIN OF THE HORSESHOE ATOLL

Applicability of Reef Definition to the Horseshoe Atoll

The relationships of the different types of rocks in the Horseshoe atoll are unlike those of any reef described in the literature. In areas that would commonly be considered to be reef core, calcirudite is found. In the near back-reef area, the only distinguishing characteristic of the reef rocks seems to be that the crinoid columnals are smaller than those in the reef core. The slopes on the flanks of the Horseshoe atoll are generally low compared to such reefs as the Capitan reef of Texas and New Mexico or the Quaternary reefs in the Pacific. Dips on the reef flank are ordinarily of the magnitude of 4° to 6°, although in one area in Scurry County a dip of at least 33° is known. These low slopes and the presence of calcirudite in what would normally be considered reef core, as well as the absence of conclusive evidence that frame-building organisms formed an important part of the biota, give rise to the question of whether this structure can be termed an organic reef or an organic bank.

Lowenstam (1950, p. 433) defines a reef as follows: ". . . a reef, in terms of ecologic principles, is the product of the actively building and sediment-binding biotic constituents which, because of their potential wave resistance, have the ability to erect rigid, wave-resistant topographic structures."

The same factors necessary for a reef are also necessary for a reef-complex such as the Horseshoe atoll. The sediment-retention and binding constituents and frame-building organisms of the biota may have been algae. As discussed in the section on paleontology, few recognizable traces of algae were found in the Horseshoe atoll. The lack of widespread evidence of algae, however, may be only a result of their poor preservation in the reef rocks.

The contour maps (Pls. 4 and 8) show that the Horseshoe atoll was a prominent topographic structure, its crest at times being as much as 2,000 feet above the surrounding sea floor.

Thick masses of calcirudite on the seaward or convex side of the atoll (as found in wells 105, 180, 185, 186, 187, and 188, Pl. 9), composed of fragments of preexisting rock, indicate that the reef-complex was subjected to fragmentation by a violent erosional agent. Inasmuch as the atoll accumulated in a marine environment, it seems most logical to attribute this fragmentation to the action of strong waves, and it seems probable, therefore, that the atoll was a wave-resistant structure.

MacNeil (1954a, p. 389) has defined an organic reef as:

> . . . a rigid structure—composed of the calcareous skeletons of: (1) colonial and commensal animals or plants, whether algae, corals, stromatoporids, mollusks, bryozoa, or others, interlocked or cemented together by growth; (2) all detrital materials derived from the breaking up of the colonial organisms (which might be unconsolidated when deposited but which may become indurated later); and (3) the remains of organisms which normally live in, on, or near the organic lattice, such as foraminifers, crabs, echinoids, and other forms, which are added either to it or to the detrital deposits—which grows independently of and builds up at a rate greater than all surrounding types of sediments (except where becoming part of the reef body), and maintains its upper growing or depositional surface at or near the level of the sea (some parts of which may be exposed at low tide). During periods of emergence the upper surface of a reef may become a surface of planation due to solution and erosion. A surface of planation may result without emergence where storm-cast detritus has become cemented to the reef and has been eroded subsequently. An organic reef may thus consist of a bioherm alone, or of a bioherm and detrital materials derived from it and other organic remains normally brought to it, which together, by growth and accumulation, and without other outside assistance, maintain a prominence close to sea level. A living reef may, therefore, extend upwards far above the level of contemporaneous surrounding sediments, and a

reef in the geologic column may have great vertical dimensions compared with surrounding sediments and be separated from them by nearly vertical or greater than vertical boundaries. Detrital materials derived from the biotic community, which do not contribute to the building of the near sea level component, such as those settling in the lagoon or on the steep submarine slope, though not reef in the navigator's sense, are nevertheless an important part of the reef structure, and in a buried reef would be more related in composition, texture, porosity, and genesis to the reef than to any surrounding rock.

Stafford (in press (a)), following MacNeil's definition, argues that the Horseshoe atoll was most likely a reef. As evidence, he cites the large masses of calcirudite (reef breccia) on the flanks of the atoll, attributing them to wave action and pointing out that the atoll must have possessed a rigid framework or it could not have been broken into the rock fragments that are included in the calcirudite. He notes that the Horseshoe atoll conforms to MacNeil's definition of an organic reef in containing the remains of commensal animals and plants—crinoids, bryozoans, corals, brachiopods, mollusks, and possibly algae, although none of these remains were observed interlocked and cemented together in a growth lattice. Another constituent of an organic reef, as defined by MacNeil, is detrital material derived from organisms; as noted previously, fragments of the hard parts of organisms comprise most of the limestones of the atoll. A third constituent of an organic reef according to MacNeil, the remains of organisms which normally live in, on, or near the organic lattice, is represented in the atoll by fusulinids and other Foraminifera.

Stafford notes that evidence for a lattice or rigid framework is lacking in the Horseshoe atoll. However, citing MacNeil (1954a), Ladd (1950), and Fairbridge (1950), he has arrived at the conclusion that although a rigid framework is essential around the periphery of a reef, quantitatively it may be unimportant. He concludes that an organic lattice was probably present and that it may have been destroyed by repeated changes of sea level accompanied by wave attack on successive levels of the atoll. He discounts the theory that the Horseshoe atoll was an organic bank because numerous changes of sea level, postulated in his own and Burnside's reports (in press), would repeatedly destroy the living structure, leaving only a fossil structure having little or no organic lattice.

Burnside (in press) is uncertain whether the Horseshoe atoll is a true reef or a "shell bank." He notes the lack of organisms which seem capable of erecting a framework or binding sediment. He believes, however, that algae may have played an important role in sediment retention. He notes that backreef-type sediments, such as those found in the Horseshoe atoll, are considered by MacNeil (1954a) to indicate the former existence of reef core. He believes, however, that other ecologic conditions may produce backreef-type sedimentation. He prefers to consider the possibility that the atoll represents an extremely large "shell bank."

There are several anomalous relationships in the Horseshoe atoll that must be considered in classifying the feature as a reef or bank and in a discussion of its geologic history. These are listed below.

1. Apparently autochthonous reef limestone deposited at elevations too low (with reference to topographically higher and older reef rocks) to be within the biotic zone of reef growth.
2. An extraordinarily high percentage of clastic limestone.
3. Facies distribution involving calcirudite of detrital origin in positions which would normally be considered to be within the reef core.
4. Calcirudite in which the contacts between fragments show solution to have been active after deposition.
5. Dips on the flanks of the atoll which are much lower than the normal steep dips found on both recent and fossil reefs.
6. Reef-top hills, which resemble youthful limestone islands, having hundreds of feet of relief.
7. Limestone debris, apparently derived from the atoll, spread laterally for tens of miles from the crest of the reef.
8. Mixed fusulinid faunas which indicate reworking of the sediments.

Environmental Influences on the Growth of the Atoll

Platform underlying the atoll.—The term "platform" is a misnomer when applied to the base on which the atoll rests. It is firmly entrenched in reef literature, however, and as used in this paper refers to the lower biostromal limestone of Strawn age and included shales.

The biostromal limestone is present throughout most of the Midland basin and the area eastward to the Pennsylvanian outcrop in north-central Texas. Every reef and reeflike mass of limestone of Strawn age in this area has its base on the biostromal limestone. These reefs, including the Horseshoe atoll, grade downward from a biohermal facies into the biostromal limestone.

The Horseshoe atoll grew in a subsiding basin and on a platform that was being very moderately flexed and folded. During subsidence, which did not proceed at a uniform rate throughout the basin, parts of the atoll were being locally uplifted over rising anticlines. The rise of these anticlines was nowhere greater than the general subsidence rate. This produced a net thickening of the reef throughout the atoll area.

Cloud (1952) believes that the calcareous algae as reef builders are indicative of shallow water. He comments (p. 2134) that, ". . . they strongly indicate depths of less than 50 fathoms, very probably less than 25 fathoms, and ordinarily less than 15 fathoms." Reefs whose framework builders are solely algae probably indicate depths somewhat less than Cloud's minimum figure. Considering these figures and the wide distribution of reefs in the Midland basin which had their inception during early Strawn time, if it is assumed that algae may have been important in the growth of these reefs, it would seem that the topography of the sea bottom in the Midland basin at the time of the inception of reef growth was nearly flat. The regional slope was probably toward the southwest.

Remnants of the biostromal limestone are reported to be present in the synclines of the Central Basin Platform. This probably indicates that this platform had not become strongly positive until after the deposition of the biostromal limestone.

Relation of the atoll to regional sedimentation.—The Plainview basin, the Delaware basin, and an unnamed basin immediately east of the Midland basin appear to have been between the Midland basin (fig. 1) and the major source areas of clastics during middle and late Pennsylvanian time. Structural "highs" such as the Matador arch and Central Basin Platform, as well as the reeflike carbonate barrier along the eastern side of the Midland basin, may have acted as partial barriers to the influx of sediments into the Midland basin from surrounding source areas. A small amount of clastic sediment was probably derived directly from these barriers, but large quantities of clastics seem to have been kept out of the Midland basin during Pennsylvanian time while the Horseshoe atoll grew.

The cyclical deposition characteristic of the Pennsylvanian and early Permian east of the Cordilleran geosyncline has been described by many writers. Wanless (1950) and others (Wanless and Shepard, 1936; Wanless and Patterson, 1951) have interpreted these cycles as being due to eustatic changes of sea level. Rocks of Pennsylvanian and Wolfcamp ages in north-central Texas exhibit cyclic deposition (Lee, Nickell, Williams, and Henbest, 1938). However, these workers state (p. 86) that the orderly sequence of beds in cyclothems of the interior basins was not recognized in north-central Texas. They believe the fluctuations of sea level to have been too violent and too frequent and sedimentation too erratic to leave a record of rhythmic deposition.

It seems very likely that any cyclical changes in depositional environment that affected the Midcontinent region generally would also affect the growth of the Horseshoe atoll in the Midland basin. If these cyclical changes were related to changes in sea level, as some have suggested, then the growth of the atoll was governed by the principle that a well-developed and actively growing reef in a subsiding basin will maintain its top at or very near sea level (Cloud, 1952). If these cyclical changes, however, were related to periodic regional changes in climate or in relations of depositional areas and sediment source areas, then the growth of the atoll may have been governed by the turbidity of the water and fluctuations in current trends or velocities.

Correlation may be possible between the thin shales which mark the erosion intervals in the atoll and the major channel-filling deposits in the outcrop section in north-central Texas. However, any such correlation must wait until more detailed work has been done in both the subsurface and on the surface.

Environments in the atoll area.—The shape of atolls seems to be directly related to the direction of the prevailing winds and currents. Closed atolls are found in areas which have variable wind and current directions over a part of the year; e.g., atolls in the Central Pacific. Horseshoe-shaped atolls are found in areas where wind and current have a fairly constant direction over the whole year (Kuenen, 1950, p. 440). Krempf (1927, 1930) has also drawn attention to double, opposed horseshoe shapes that exist off Indo-China, where there is a 6-month northeast monsoon and a 6-month southwest monsoon. This relationship of shape to prevailing winds and currents strongly suggests that the most common direction of winds and currents in the Horseshoe atoll area may have been from the south or possibly slightly west of south.

The small amount of shale which seems to be contemporaneous with the growth of the Horseshoe atoll is bituminous, dark-gray to black clay shale. Rocks of this type are usually formed in euxine basins which have poorly circulating waters. The presence of reef rocks in a basin of this type indicates that the environment of carbonate accumulation and the euxine environment were closely associated but sharply separated.

Similar relationships of reef growth associated with euxine environments are known from several areas. Newell et al. (1953, p. 12–14) give an excellent discussion of these relationships from the Upper Triassic of the Tyrol, the Permian of East Greenland, the Mississippian of northern England, and the Guadalupian of the Delaware basin in western Texas. They suggest that the unventilated bottoms of these areas provided "an unusually rich source of upwelling nutrient salts for lime-secreting reef plants." The reefs of Pennsylvanian and Wolfcamp age in the Midland basin and the carbonate reeflike accumulations of late Wolfcamp and Leonard age in the same area appear to be examples of similar relationships.

The apparent primary structures in the shales and sandstones which are older than the Dean siltstone and younger than the atoll resemble marine top-set and fore-set beds in the eastern half of the area. These dark marine shales and sandstones grade, in part, into red shales in Dickens and Motley counties to the northeast. Contemporaneous red shales are also found in the outcrop area in north-central Texas. A southwestward-transgressing delta deposited in a euxine environment is a logical interpretation for these sedimentary rocks. This interpretation is corroborated by (1) the thickening of rocks to the northeast and east, (2) the lateral gradation into small amounts of red shales, (3) the increase in the amount and coarseness of sandstone, and (4) the presence of a conglomerate in Dickens County which may have been deposited in a channel. It appears that these deltalike deposits progressively smothered reef growth toward the west and southwest during Wolfcamp time.

Theories of Atoll Origin and Their Application to the Horseshoe Atoll

The problem of the origin of atolls has been one of investigation and speculation for more than 100 years. The literature pertaining to the subject is voluminous. Space will allow only a short resumé of the more generally accepted theories and a comparison of the Horseshoe atoll with criteria suggested by these theories.

Darwin's Subsidence theory.—Charles Darwin (1837, 1840) classified reefs into three types—fringing reefs, barrier reefs, and atolls. He considered the three types intergradational and believed that fringing reefs became barrier reefs by the subsidence of the adjacent land area and by the upward growth of the reef itself, more or less *in situ*, keeping pace with subsidence. Where the land mass was an island, subsidence might continue until the original island had disappeared beneath the sea and the engirdling reef remained as an atoll.

J. D. Dana (1949, pp. 379–392) added an important corollary to Darwin's theory when he noted that many "almost-atolls"[4] were embayed and these embayments resembled drowned stream valleys.

Darwin's theory would require that the lagoonal area of the Horseshoe atoll be a land mass at the inception of reef growth and gradually sink beneath the sea with the general subsidence of the Midland basin. If this were true, the biostromal ("Caddo") limestone should have undergone considerably more erosion in the lagoonal area than elsewhere, and either a large dome in the lagoonal area or a north-trending nose plunging to the south should have been present. Neither of these relationships has been observed. The biostromal limestone is everywhere present and of normal thickness. A regional nose is present which probably controlled the position of the western and southern sides of the atoll, but the eastern side of the atoll lies across the trend and plunge of the nose. There is no evidence that the nose was subjected to erosion in the lagoon. It could not, therefore, have been a land mass. Subsidence certainly occurred during the growth of the Horseshoe atoll, but there does not seem to be any evidence of progressive growth from fringing reef, to barrier reef, to atoll.

The Solution theory.—Rein (1870), Semper (1863), and Murray (1880) believed that lagoons are excavated by solution of the limestone in sea water. Most geologists now agree that lagoons are actually the sites of deposition. Though some solution certainly occurred during the intervals of lowered sea level, the writers can find no evidence that the magnitude of this solution was sufficiently great to have dissolved the great mass of limestone which would have occupied the entire lagoon area.

Recently, F. Stearns MacNeil (1954b) revived the Solution theory and combined it with Daly's Glacial Control theory. MacNeil postulated that the platforms on which atolls now grow owe their shapes to solution of the central lagoon during the glacial maxia (low sea level) of the Pleistocene. The solution was accomplished by meteoric water rather than by sea water. The objections to MacNeil's Solution theory are the same as those to the older Solution theory insofar as the Horseshoe atoll is concerned.

The Glacial Control theory.—R. A. Daly (1910, 1915, 1934), in his Glacial Control theory, took cognizance of the vast amounts of water in the continental ice sheets of the Pleistocene epoch. He felt that the water which was withdrawn from the oceans would cause sea level to be lowered 30 or 40 fathoms, and that this change of sea level would have drastic effects on the platforms upon which the atolls grew. Daly postulated that there were no atolls prior to the initial lowering of sea level. He considered that the lowering of sea level was accompanied by a chilling of the tropic seas. Reefs that were present were killed by chilling and by increased turbidity in the seas due to the vast amount of mud churned up by the waves. This mud was formerly beneath wave base.

Daly further postulated that during the interval in which the sea was at its lower level, platforms which had formerly been islands or seamounts were attacked by

[4] A reef with the configuration of an atoll but containing a relatively small island of nonreef origin in its lagoon.

waves, beveled to a uniform level, and "cleansed" in preparation for the return of the original sea level. The returning organisms, according to Daly, found conditions most hospitable at the peripheries of the platforms and accumulated there to their present elevation. Daly studied many charts of the world's atolls and found that there was a remarkable uniformity of depth of the lagoons, normally varying between 30 and 40 fathoms in their deepest parts. More recent and more accurate bathymetric charts indicate little such uniformity of depth is actually present. He considered this uniformity of depth to be evidence of the uniform planation of the platforms.

Daly's Glacial Control theory is certainly appealing when the postulated eustatic shifts of sea level are considered, but this theory deals primarily with the bases on which atolls grow; more especially the Pacific atolls. Moreover, Daly did not consider subsidence to have been important in the growth of atolls, attributing their thickness to the difference between low and high sea levels.

Inasmuch as there does not appear to have been any prereef beveling, the Glacial Control theory does not appear to apply to the Horseshoe atoll. It is worth remarking, however, that if the Pennsylvanian and early Permian were times of eustatic shifts of sea level, the development of the Horseshoe atoll paralleled the development of atolls during the changes of sea level in Pleistocene time.

Davis' Torrid Belt theory.—W. M. Davis (1928), after extensive studies of the reefs and geomorphology of the islands of the Pacific, reemphasized Dana's observation that the encircled islands of the "almost-atoll" and barrier reefs in an equatorial belt are deeply embayed and that these embayments resemble drowned stream valleys. He also pointed out that they do not possess the steep sea cliffs which Daly's Glacial Control theory would imply. On the other hand, belts of similar islands, both north and south of the central "torrid belt," possess steeply plunging sea cliffs. Davis supported Darwin's Subsidence theory and restricted Daly's chilling effect of the Pleistocene glaciers to the marginal belts of islands possessing steep sea cliffs. He denied the existence of uniformity in lagoon depth, pointing out several lagoons at variance with the limits set by Daly. In general, Davis granted glacial control for the marginal belts but not for the inner belt.

Davis' contribution concerning the climatology and consequent restriction of reefs to a central torrid belt during the Pleistocene may possibly have application to the Horseshoe atoll.

The Rising Foundation theory.—Semper (1863) and Guppy (1884) have proposed that atolls instead of growing on subsiding foundations actually grew on rising ones. They pointed out several elevated atolls and reefs as evidence. The Rising Foundation theory, however, has not been generally accepted. Unless one considers that the eustatic shifts of sea level were actually effects of local tectonism, it does not seem to apply here.

The Antecedent-Platform theory.—Vaughan (1916) and Hoffmeister and Ladd (1935 and 1944) supported an Antecedent-Platform theory. They postulated that atolls grew atop tectonically stationary platforms that were formerly flat. Their theory requires no particular method (erosion or deposition would serve) to achieve the flatness. It was considered that any platform in less than 30 fathoms of water would serve as a foundation on which the reefs could grow. Hoffmeister and Ladd (1944) believed that an ecologic explanation would be necessary to account for the annular shape of the atolls. Ladd (Ladd et al., 1953), after examining the cores from Eniwetok atoll bore holes, agreed that great subsidence must have taken place.

The Antecedent-Platform theory probably best describes the foundation on which the Horseshoe atoll grew, but the insistence that no subsidence could take place during the growth of the reef makes it inapplicable to the Horseshoe atoll. Hoffmeister and Ladd's (1944) observation that the annular shape of atolls is probably due to an ecologic explanation seems to best fit the relationships found in this study of the Horseshoe atoll.

The Winds and Currents theory.—Fairbridge (1950, pp. 356–361) discussed a Winds and Currents theory to account for the shape of the atolls. He considered that reefs which initially grew transverse to the prevailing winds and currents would develop "horns" of detrital calcarenite at each end which would point leeward. When cause the current to be refracted inward upon the leeward area in the same manner that the waves are refracted. This current refraction brings fresh sea water and food to the sessile reef organisms. Without this refraction the water in the lee of the patch reef would be relatively stationary and the food supply much diminished. This would most likely produce an environment much like that of a lagoon where reefs are somewhat suppressed. Current refraction is therefore necessary for strong reef growth in those areas not directly in the path of the current.

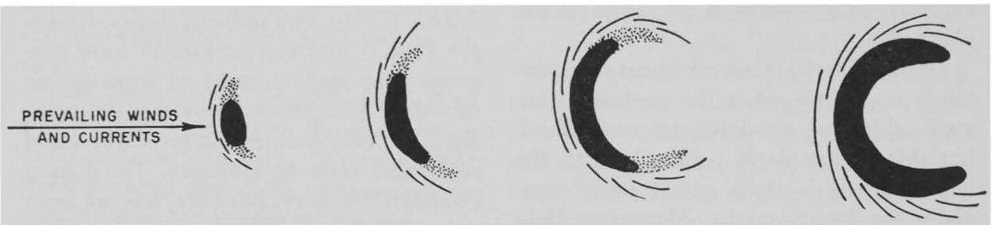


FIG. 8. Successive stages of atoll development according to the Winds and Currents theory of Fairbridge.

enough calcarenite had accumulated to make the water sufficiently shallow, reef organisms would colonize the seaward side. This process would be repeated again and again until a horseshoe shape is achieved (fig. 8). Several living reefs were illustrated by Fairbridge (1950, p. 358) as examples of various stages of development of this process.

Fairbridge's Winds and Currents theory partly explains the shape of the reefs outside the oceanic areas and may explain the shape of the Horseshoe atoll. The Pacific atolls may inherit part of their shape from the platforms or guyots(?) (Emery, 1948; Ladd et al., 1950) upon which they grew, but in areas such as the continental shelf of Australia and the Midland basin the pre-existing shape of the foundation does not seem to be related to the configuration of the atolls.

An additional observation may be added to Fairbridge's theory. It is that the parasitic drag on the current caused by the initial patch reef and later reef stages will

It is considered that the shape of the Horseshoe atoll resulted from conditions similar to those prescribed by the Winds and Currents theory. The Horseshoe atoll was maintained over a relatively long interval of geologic time by subsidence in a stable environment. There were, however, several interruptions which may have been due to eustatic changes of sea level.

HYPOTHESES OF GROWTH OF THE HORSESHOE ATOLL

The primary problems of reef growth in the Horseshoe atoll are related to unconformities within the body of the reef. These unconformities have several hundred feet of relief. The physical evidence presented by the rocks suggests that subaerial erosion and solution may account for the relief.

Inasmuch as living reefs maintain their tops near sea level, two possibilities are suggested to account for lowering of the sea with reference to the reef top. The first is tectonic uplift; the second is eustatic lowering of sea level.

The first possibility would require an uplift of several hundred feet at each of the unconformities. It would require subsequent subsidence until several hundred feet of reef rock had accumulated. There seems to be no direct way of showing that this first possibility is less likely than the second.

The second possibility is that the reef grew in a subsiding basin. Eustatic shifts of sea level are called upon to produce the unconformities found in the rocks of the atoll.

Lowering of sea level in a reef area would produce islands. The area and relief of these islands would be proportional to the original area of the reef, the amount caused by the two types of reef planation. If sea level were restored before planation was complete, such fringing reefs as may have been growing during the time of lowered sea level would advance up the flanks of the islands with the rise of sea level and eventually become the new reef.

During the time of lowering of sea level and the time during which the sea level is at the lower level (and also during the rise of sea level), large amounts of clastic material derived from erosion of the reef would be deposited on wave-cut benches and on the flanks of the reef. The resulting complex facies distribution would be preserved when the sea level rose again, permitting the younger reef to cover the older detritus. The abnormal abundance of detritus would reduce the normally

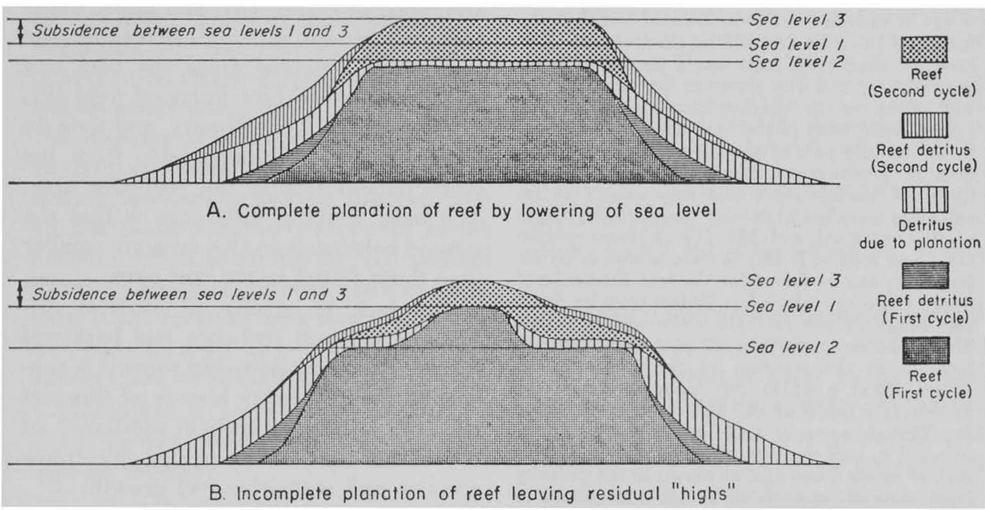


FIG. 9. Diagrammatic cross sections illustrating complex facies distribution and stratigraphic relationships due to the lowering of sea level.

that sea level is lowered, and the relief of the reef above the bottom. During the time of lowered sea level the islands would be attacked by the waves; wave-cut benches and many surface features such as stream valleys and sink holes resulting from subaerial erosion would be formed. If sea level is not restored, the agencies of erosion would eventually plane the islands to wave-base level. Figure 9 illustrates the complex stratigraphic relationships steep reef slopes to gentler slopes like those found on the flanks of the Horseshoe atoll. This detritus would contain a fauna older than the sea in which it was deposited, with consequent mixing of faunas of two different ages.

Two hypotheses may be advanced to relate the growth of the Horseshoe atoll to the probable changes in sea level in the Midland basin. The first hypothesis postulates normal reef growth with several lowerings of sea level to account for the reworked faunas and abundance of clastic limestone. This hypothesis requires that sea level be lowered only after sufficiently rapid subsidence of the basin to cause the reef to restrict itself to small areas of growth (the hills in the Good, East Vealmoor, and Reinecke fields). These areas were then exposed to erosion for a very short interval prior to the return of the sea. Reef growth over the old "highs" recommenced. This process was repeated several times, with the intervals of erosion being marked by the thin beds of shale. Thus the reef hills are considered to be a natural reef configuration caused by rapid subsidence slightly modified by erosion.

Several serious objections can be raised to this theory:

(1) If the sea level were lowered less than the height of the hills (caused by the restricted reef growth), then these hills would be truncated or partially so, and the wave-cut bench would be well above the surrounding (but topographically lower) main body of the reef. The unconformity in the middle part of the Cisco in the Good oil field in southwestern Borden County seems to have the configuration one may expect to result from a sea level lowering less than the height of the restricted reef hill (Pl. 3, cross section G-G′ and H-H′). If this is true, however, no explanation can be found for the reef limestone of upper Cisco age which lies 90 feet or more down the flanks of the reef from the unconformity. This is below a reef's biotic potential when sea level is at the position of the unconformity (Cloud, 1952, p. 2134). Similar relationships are known over much of the atoll area (Pls. 2 and 3). Though some of this limestone can be attributed to reef detritus, the distribution of reef rock of upper Cisco age, as shown in the porosity cross sections, appears to be too widespread to attribute it all to scree.

2. In the writers' opinion, the extraordinarily high percentage of clastic limestone would not be explained by this hypothesis. Admittedly, the percentage of clastic limestone would be increased more than the amounts usually associated with reefs. It is believed, however, that these amounts would not represent as high a percentage as is found in the Horseshoe atoll.

3. The rapid subsidence which caused the restriction of reef growth to scattered hills on the crest of the reef must have been stopped at precisely the right time. If sea level were to rise before subsidence of the reef slowed or stopped, the reef would be drowned. The top of the reef would be below the zone of biotic potential.

The above theory is therefore rejected in favor of a new hypothesis which postulates that the internal reef "highs" are erosional remnants of an older, thicker, and broader reef, rather than configurations of restricted reef growth resulting from rapid subsidence. These "highs" certainly influenced later reef growth to a considerable extent, but prior to the "highs," the crests of the atolls are considered to have been as continuous and as smooth as the tops of the Pacific atolls.

The concept of fore-reef, reef-core, and back-reef facies that has been established by other reef investigators can probably be applied to this reef only after its history has been taken into consideration. Few cores have been obtained from either the fore-reef area or the back-reef area. Fore-reef facies are present in wells on the eastern (seaward) side of the Scurry County portion of the reef (Pl. 9, wells 105, 180, 185, 186, 187, and 188). These cores are almost entirely calcirudite. The only cores obtained from the back-reef area are from the East Polar oil field (Pl. 9) in southern Kent County, and they do not differ much lithologically from the cores obtained from the reef-core area. The most striking difference is that the crinoid columnals in this area are smaller than those found in the reef core.

The lack of strong lithological differences between reef-core and back-reef facies is not too surprising when it is considered that the entire history of this reef seems to be one of vertical movement of the strand line accompanied by transgressive and regressive reef growth.

It has been noted in the borings of the Cenozoic reefs in the Pacific (Fairbridge, 1950; Ladd et al., 1953) that, except for their surfaces, these reefs are generally not well cemented. In those areas which are alternately wetted and dried, cementation is so rapid that cans and bottles have been incorporated into the so-called "beach rock." The same process of cementation by wetting and drying may have operated in the Horseshoe atoll. As sea level was lowered, each part that came into the tidal range became cemented Thus, by the time a particular part of the reef was undergoing subaerial erosion it was already a well-cemented rock because of the previous wetting and drying (with consequent loss of carbon dioxide and precipitation of calcium carbonate inherent in any such lowering of sea level). If, however, the reef was largely algal, the limestone deposit could have been fairly hard from the start. In that case, the wetting and drying process described above would have had little effect upon the lithification of the rock.

The secondary porosity may have been caused by leaching of the exposed reef by meteoric water after the cementation had taken place. The leaching may have been facilitated by the presence of humic acids, if the exposed reef developed a heavy cover of vegetation.

Burnside believes that the "*Calamites*" found in the shales of the atoll are significant in that they represent the remains of vegetation which developed on exposed islands and that this vegetation would provide a source of humic acid to assist in the leaching processes. He feels that this contention is strengthened by the fact that all the plant material was found at the unconformities predicted by his Cyclical theory. The other authors maintain that these plant remains were most likely carried into the atoll by prevailing currents during times of increased turbidity.

The sequence of reef growth and cementation in each reef cycle seems to have been as follows:

1. Normal reef growth commenced and continued, with subsidence of the basin amounting to several hundred feet.

2. Sea level (which probably was never completely stationary) was lowered, and the upper part of the reef-complex became emergent and was subjected to subaerial erosion.

3. The islands (emergent reef) were subjected to wave action and subaerial erosion. Wave-cut benches and a topography of hills and valleys were formed. Leaching of the older rocks by circulating meteoric waters caused secondary porosity and other solution features in the islands. Streams on the surface left their imprint in the form of deep gullies. Relatively greater amounts of terrigenous particles of clay size entered the basin as a result of the much closer shore lines. At the same time new sources of material for erosion were made available by the lowering of sea level. Breccias were deposited on the wave-cut benches and other surface features. Normal reef growth was limited to the flanks of the islands as fringing reefs. Figure 10 illustrates the topography that may have been developed by a combination of subaerial and wave erosion modified by sporadic deposition of breccias and local reef growth.

4. Sea level rose covering most or all emergent parts of the reef-complex. As the water level rose, terrigenous particles of clay size and reef breccia continued to be deposited in lessening amounts on the wave-cut benches and platforms behind the rising fringing reefs and outside the zone of wave activity. When most or all islands were below sea level, normal reef growth continued throughout the area. The most pronounced growth was on the old hills where as much as several hundred feet of reef accumulated.

The writers believe the foregoing hypothesis explains the anomalous relationships pointed out at the beginning of this section.

In general the concepts of regressive and transgressive reef growth as outlined by Link (1950) seem to apply to the Horseshoe atoll. The eustatic changes of sea level may be thought of as transgressions and regressions of the sea; reef growth was upward over the older reef with each transgression and downward over the old flanks with each regression.

FIG. 10. Interpreted topography of the eastern part of the atoll during early Wolfcamp time. (This pattern is modified from the true pattern by local reef growth and southwest tilting.)

GEOLOGIC HISTORY

Developments During Mississippian(?) and Early Pennsylvanian Time

For an unknown length of time, possibly during most of the Mississippian period, carbonate sediments were deposited throughout the mapped area (Pl. 5). During Chester(?) time, subsequent to the deposition of the limestone of Mississippian(?) age, large quantities of clay- and silt-sized particles of terrigenous material and small amounts of carbonate particles were deposited in the Midland basin (Pl. 5).

Beginning in Morrow(?) time, positive structural movements occurred in the Matador arch area, and the structurally high parts underwent considerable erosion. Deposition of the products of this erosion, however, was confined to the area adjacent to these structural "highs." These sediments were arkosic sands and gravels and a little mud. If the Central Basin Platform at this time contributed any sediments to this area, they were clay- and silt-sized clastic particles.

During Atoka time as much as 1,000 feet of carbonate and terrigenous material of clay size and small amounts of silt were deposited in the western part of the Midland basin. In areas adjacent to the Matador arch, arkosic sands and gravels were still being deposited. Toward the end of Atoka time, possibly as late as very early Strawn time, the region, at least in the eastern part, emerged. Erosion at this time truncated rocks of Atoka and Mississippian(?) age. In parts of Mitchell County the limestone of Mississippian(?) age was completely removed. Westward thickening of the rocks of Atoka age may indicate that deposition rather than erosion was taking place in the western part of the basin. Until more cores are available from this part of the section, the relationships in the younger rocks of Atoka age will be difficult to understand.

In early Strawn time a limestone containing some thin beds of shale was deposited over the entire area including the Central Basin Platform. This limestone is the "biostromal limestone."

Growth of the Horseshoe Atoll During Pennsylvanian Time

Rocks of Strawn age are present throughout the area covered by the atoll. The lowest 45 to 250 feet of this rock are biostromal limestone that can be traced in the subsurface far from the atoll. It is not considered to be a reef rock. From this foundation reef growth began and continued cyclically throughout the remainder of the Pennsylvanian period. About 750 feet of reef rock of Strawn age accumulated above the earlier "biostromal limestone" (Pl. 4). Evidence indicates that cyclic reef growth took place throughout the time of accumulation of reef rocks with the possible exception of Wolfcamp time. This is indicated by the Type A and B porosity zones, which are believed to be the result of eustatic changes of sea level.

At least two cycles are indicated by rocks of Strawn age, two by rocks of Canyon age, two by rocks of Cisco age, and one by rocks of Wolfcamp age. Sufficient data are not available for a detailed description of events during Strawn time. Correlation of shale beds, calcirudite, and porosity zones with fusulinid data, however, indicates that a sequence of events took place during Strawn time similar to that which occurred during later Pennsylvanian and earliest Wolfcamp time.

Evidence indicates that sea level was lowered in early Canyon time and that the atoll emerged to an unknown height. The emergent atoll was subjected to extensive wave action and subaerial erosion which beveled the rocks of Strawn age to a relatively flat surface (Pl. 4). Large quantities of detrital limestone were removed from the crest and deposited in both the fore-reef and lagoonal areas, spreading for tens of miles over the sea floor. Terrigenous clay-sized material began entering the area, probably because the lowered sea level brought the continental land areas nearer to the atoll. Growth in the atoll was restricted to fringing reefs at this time. The exposed rocks immediately underlying the eroded surface were leached possibly by circulating meteoric water which contained carbonic and humic acids derived from plant life on the emergent portions of the atoll.

The tremendous quantities of limestone removed by this truncation indicate that this period of erosion lasted longer and contributed more clastic limestone to the areas surrounding the atoll than any previous or later interval of erosion. During early Canyon time sea level rose, and the crest of the atoll was submerged beneath the effective action of the waves. Terrigenous material of clay size entered the basin in lessening amounts, and the thin beds of shale which covered the upper Strawn reef were deposited. Reef growth over this horizon was renewed during Canyon time.

Similar cycles of reef development—growth during high sea level combined with basin subsidence and later erosion during low sea level—were repeated once more during Canyon time, twice during Cisco time, and once during Wolfcamp time. The atoll, however, was never again so completely truncated as at the beginning of Canyon time.

Developments During Wolfcamp Time

In early Wolfcamp time large amounts of clay and silt particles were deposited in the Midland basin. Sedimentary structures and thickening of these deposits to the north and east indicate that the source of these terrigenous sediments lay to the north and east of the atoll area. The Wichita-Arbuckle complex of mountains in Oklahoma was being uplifted at this time and may have been an important contributor of sediments to the atoll area. The turbidity of the water in the eastern part of the atoll probably killed the fringing reefs. The eastern and northern parts of the basin were rapidly filled with terrigenous muds which at times became very calcareous. In the early stages of the basin-filling, some of the calcium carbonate in the predominately terrigenous section was probably contributed by the erosion of the topographically high parts of the atoll and other reefs.

Reef growth continued in the southwestern part of the atoll during the time in which the northern and eastern parts were being covered with mud. The slightly more argillaceous character of the reef of Wolfcamp age indicates the increased turbidity of the sea in the entire area. Slowly the muds encroached on the southwestern part of the atoll smothering the reef organisms. Intertonguing of the shale and reef limestone took place in the southwestern part of the atoll during Wolfcamp time. Reef growth in this area was restricted by the increasingly turbid waters. By late Wolfcamp time (but preceding deposition of the Dean siltstone) the muds had been deposited across the entire atoll area except in southeastern Terry, northeastern Gaines, and northwestern Dawson counties. Deposition of the Dean siltstone finally covered the remaining part of the reef-complex, and the atoll was completely buried. Including the part of the reef of Wolfcamp age, a maximum of nearly 3,000 feet of limestone had accumulated.

The top of the Wolfcamp series cannot be placed precisely but is known to be within an argillaceous limestone interval between the Dean siltstone and the Spraberry siltstone. Fusulinids of Wolfcamp age have been found in the lower part of this limestone and fusulinids of Leonard age in the upper part (Pl. 5). There is no apparent lithologic change within this limestone to suggest the contact between these series.

The argillaceous limestone immediately beneath the Dean siltstone over most of the area thickens and becomes fairly pure limestone along the Borden-Scurry County line. The Dean siltstone becomes thinner, very calcareous, and laps up onto the thickening limestone beneath it. These relationships suggest the existence of a barrier reef which grew during late Wolfcamp time at the margins of the area in which the Dean was deposited (Pl. 6). Similar relationships are found between the Spraberry siltstone and a dolomite of equivalent age slightly east of the area in which the Dean merges into limestone. This dolomite directly overlies the reef of late Wolfcamp age in Scurry County.

OIL AND GAS

History of Development

The first hole drilled into the Horseshoe atoll was Gulf Oil Corporation's No. 1-B E. P. Swenson Cattle Company well in Garza County (Pl. 9, well 166). This hole was completed as a producing oil well from reef rocks of Strawn age on November 11, 1938. No other holes were drilled to this reservoir at this time, and the well was abandoned in April 1939, after producing 504 barrels of oil.

From 1939 to 1948, few holes were drilled to rocks of Wolfcamp age or older in the area of the Horseshoe atoll. In January 1948, however, the Seaboard Oil Company discovered the Vealmoor oil field (Pl. 9) in the southern part of the atoll. In July 1948, the one-well Schattel oil field was discovered in Scurry County, and by the end of that year three widely separated oil discoveries were made in the reef limestone in Scurry County. Eventually these three wells became a part of one large reservoir (Diamond-M, Sharon Ridge, and Kelly-Snyder fields) which in this paper is referred to as the Scurry field. Numerous other oil discoveries in the reef rock were made in 1949 and subsequent years. Exploitation of the fields producing from reef rocks in the eastern part of the atoll continued at a rapidly increasing pace through 1950. From 1950 to 1953, the number of holes drilled in Scurry and Kent counties each year has decreased, but exploration remained at a high level in the eastern part of the atoll and continued unabated in the southern and western parts of the atoll.

Oil was first produced from nonreef rocks of Wolfcamp age in 1950 from the Cogdell (4,900 feet) reservoir (Table 9) in the Cogdell field (Pl. 9). Most oil discoveries in nonreef rocks of Wolfcamp age have resulted from studies of subsurface data obtained during development of the fields producing from the reef rocks.

On March 1, 1954, 36 fields were producing oil from reef rocks of the Horseshoe atoll; six additional fields had been abandoned. These fields, their location by county, year of discovery, age of rock producing oil, and cumulative production are shown in Table 8 (p. 61).

Total annual production of oil from all reservoirs in the Horseshoe atoll is tabulated in Table 7.

Table 7. Total production of oil from the Horseshoe atoll.

(Data for 1948 through 1953 obtained from the Railroad Commission of Texas)

YEAR	YEARLY PRODUCTION (barrels)	CUMULATIVE PRODUCTION (barrels)
1939	504	504
1940–1947	0	504
1948	179,249	179,753
1949	4,888,321	5,068,074
1950	43,163,219	48,231,293
1951	65,318,409	113,549,702
1952	66,542,782	180,092,484
1953	63,974,510	244,066,994

On March 1, 1954, four fields were producing oil from rocks of the Wolfcamp series overlying the Horseshoe atoll. (Within the mapped area, two additional fields produced from rocks of this age. These are excluded, however, from the above number and not included on Plate 9 or in Tables 9 and 10. Only those reser-

FOOTNOTES FOR TABLE 8—

[1] Data obtained from the Railroad Commission of Texas.

[2] "Canyon" reservoir of Cogdell field only.

[3] Lower Strawn reservoirs of Cogdell field only (consist of Cogdell (Strawn), Cogdell, West (Strawn), and Fuller (Strawn "B") of the Railroad Commission of Texas).

[4] Includes Good and Good, Northeast (Canyon reef) fields.

[5] Includes Salt Creek, South (Lower Penn.) and Salt Creek (Strawn) fields.

[6] "Canyon" reservoirs of Scurry field only (consist of Diamond-M, Kelly, Kelly-Snyder, North Snyder, and Sharon Ridge Canyon fields as now or formerly recognized by the Railroad Commission of Texas).

[7] "Strawn Zones B, C, and D" reservoirs of Scurry field only (consist of Collins, Kelly-Snyder (Caddo), North Snyder (Strawn), North Snyder (Zone "B"), and North Snyder (Zone "C") as now or formerly used by the Railroad Commission of Texas).

[8] "Strawn Zone A" reservoir (known as North Snyder (Strawn "A" Zone) used by the Railroad Commission of Texas).

[9] Includes Vincent (lower Canyon) and Vincent (upper Canyon) fields.

[10] Abandoned oil field.

Table 8. Oil production from fields in the reef rocks of the Horseshoe atoll.

(Names of fields are those officially used by the Railroad Commission of Texas unless otherwise noted)

FIELD (See Pl. 9 for location)	LOCATION (County)	YEAR OF DISCOVERY	AGE OF ROCK PRODUCING OIL	CUMULATIVE PRODUCTION TO JAN. 1, 1954[1] (BARRELS)
Adair (Wolfcamp)	Terry and Gaines	1950	Wolfcamp	4,679,856
Allen-Holiday (Penn.)	Scurry	1952	Cisco	16,293
Bond (Canyon)	Howard	1950	Canyon	65,305
Brownfield, So. (Canyon)	Terry	1950	Cisco and Canyon?	1,121,719
Clairemont (Lower Penn.)	Kent	1950	Cisco and Canyon	863,453
Cogdell[2]	Kent and Scurry	1949	Cisco, Canyon, and upper Strawn	25,857,756
Cogdell[3]	Kent and Scurry	1951	Lower Strawn	104,686
Dunn[10]	Mitchell	1949	Canyon	4,962
Early (Strawn)	Scurry	1949	Lower Strawn	79,124
Fuller, Southeast (7100 feet Strawn)	Scurry	1952	Canyon	11,244
Fullerville (Strawn)	Kent and Scurry	1952	Lower Strawn	48,138
Good[4]	Borden	1949	Wolfcamp and Cisco	7,210,054
Hobo (Penn.)	Borden	1951	Cisco	1,888,574
Luther, North (Canyon reef)	Howard	1952	Wolfcamp	134,416
Mound Lake[10]	Terry	1948	?	58,553
Mungerville (Penn.)	Dawson	1951	Wolfcamp	582,728
Mungerville, Northwest (Penn.)	Dawson	1953	Wolfcamp	6,183
Myrtle (Penn.)	Borden	1951	Canyon	37,799
Oceanic (Penn.)	Howard	1953	Wolfcamp	92,788
O'Daniel (Canyon)	Howard	1950	Canyon	35,410
Polar, East (Penn.)	Kent	1950	Canyon and lower Strawn	402,906
Reinecke	Borden	1950	Cisco	9,920,695
Salt Creek	Kent	1950	Cisco, Canyon, and upper Strawn	8,841,534
Salt Creek, South[5]	Kent	1952	Canyon	100,174
Schattel	Scurry	1948	Cisco	35,657
Scurry[6]	Scurry	1948	Wolfcamp, Cisco, and Canyon	153,102,340
Scurry[7]	Scurry	1949	Lower Strawn	2,964,979
Scurry[8]	Scurry	1953	Upper Strawn	9,876
S M S (Canyon reef)	Kent	1953	Canyon	4,630
Sparenburg (Penn.)[10]	Dawson	1951	Cisco	15,719
Spires	Kent	1950	Canyon and upper Strawn	64,622
Spraberry West (Penn.)	Dawson	1953	Wolfcamp	34,856
Spur (Canyon)[10]	Garza	1951	Canyon	3,271
Statex (Cisco reef)	Terry	1952	Cisco	379,383
Swenson[10]	Garza	1938	Lower Strawn	504
Tahoka (Penn.-Strawn lime)	Lynn	1953	Strawn	106,344
Tobe (Strawn)	Garza	1951	Canyon and upper Strawn	144,876
Vealmoor	Borden and Howard	1948	Wolfcamp and Cisco?	7,447,432
Vealmoor, Central (Canyon reef)	Howard	1953	?	3,708
Vealmoor, East	Borden and Howard	1950	Wolfcamp? and Cisco	8,587,612
Vealmoor, North[10]	Borden	1950	Wolfcamp	43,981
Vernon, Cox (Canyon reef)	Kent and Scurry	1951	Canyon	24,699
Vincent[9]	Howard	1950	Canyon	60,413
Von Roeder	Borden	1949	Cisco	3,956,056
Wellman	Terry	1950	Wolfcamp	4,905,686

FOOTNOTES ON OPPOSITE PAGE.

voirs are shown whose traps were primarily the result of compaction of sediments over the atoll.)

The fields, petroleum reservoirs, reservoir rocks, and cumulative production from rocks of the Wolfcamp series overlying the atoll are tabulated in Table 9.

Production of oil from the postreef rocks of Wolfcamp age overlying the atoll is tabulated in Table 10.

Free gas caps do not exist in any of the reservoirs in the atoll or in the postreef rocks of Wolfcamp age. The only gas production has been solution gas incidental to oil production, and estimates of the quantities produced are not available. Oil is also produced in this area from rocks of the Ordovician, Silurian, Devonian, and Mississippian systems and from those of the Leonard and Guadalupe series of the Permian system; discussion of the fields and reservoirs in these rocks is beyond the scope of this paper. For a more comprehensive summary of the distribution and production of oil in the area, see Stafford (in press (b)).

Table 10. Production of oil from reservoirs in postreef rocks of Wolfcamp age.
(Data obtained from Railroad Commission of Texas)

YEAR	YEARLY PRODUCTION (*barrels*)	CUMULATIVE PRODUCTION (*barrels*)
1950	74,247	74,247
1951	509,835	584,082
1952	2,103,810	2,687,892
1953	2,005,285	4,693,177

Table 9. Oil production from fields in nonreef rocks of Wolfcamp age.
(Names of fields are those officially used by the Railroad Commission of Texas)

FIELD (See Pl. 9 for location)	LOCATION (County)	YEAR OF DISCOVERY	OIL RESERVOIR ROCK (See fig. 6)	CUMULATIVE PRODUCTION TO JAN. 1, 1954[1] (*barrels*)
Canning (Wolfcamp)	Borden	1950	bedded limestone	104,739
Cogdell, East (Cogdell sand)	Kent	1952	"Fuller" sandstone	102,955
Cogdell (Fuller sand)[2]	Kent	1950	"Fuller" sandstone	342,731
Cogdell (4,900 feet)[2]	Kent	1950	"Cogdell" limestone	279,857
Diamond-M (Wolfcamp)[3]	Scurry	1952	bedded limestone	155,407
Fuller[2]	Scurry	1951	"Fuller" sandstone	548,676
Kelly-Snyder (Cisco)[4]	Scurry	1951	"Cisco" sandstone	3,142,123
Vealmoor, East (Wolfcamp)	Borden	1950	bedded limestone	2,085
Vealmoor (Cisco)	Borden	1952	bedded limestone	14,604

[1] Data obtained from the Railroad Commission of Texas.
[2] Reservoir in Cogdell field.
[3] Reservoir in Scurry field.
[4] Three reservoirs in Scurry field.

Reservoirs

Reservoirs in the Horseshoe atoll.—Oil is produced from five stratigraphic positions within the Horseshoe atoll. These are commonly called the "Wolfcamp," "Canyon," and "Strawn Zones A, B, C, and D" reef reservoir rocks (fig. 6). Production is from reef limestone of Strawn, Canyon, Cisco, and Wolfcamp age in the "Wolfcamp" and "Canyon" reef reservoirs; from reef limestone of late Strawn age in the "Strawn Zone A" reef reservoir rocks; and from reef limestone of early Strawn age in the "Strawn Zones B, C, and D" reservoirs. The oil in the "Wolfcamp" and "Canyon" reef reservoirs is trapped in the structurally higher parts of the atoll, which are overlain by impervious shale. The ages of the rocks in which the oil is found differ considerably from place to place in the atoll (Table 7), but in general the oil-water interface is in progressively younger rocks to the south and as far west as the West Spraberry, Mungerville, and Adair (Wolfcamp) oil fields in Dawson, Gaines, and Terry counties. Toward the northeast the oil-water interface is in successively older rocks, and in the extreme northeast the Tahoka oil field in Lynn County produces entirely from rocks of Strawn age.

The reasons for most of the traps forming the "Strawn Zones A, B, C, and D" reservoirs on the eastern side of the atoll have not been determined. Inasmuch as all oil accumulations in the atoll are in porous zones overlain by younger rocks, an updip decrease in porosity and permeability is the factor controlling the accumulations at some places; other traps may be a combination of porosity changes and anticlinal structures involving zones of porous and relatively nonporous reef rock.

Reservoirs above the Horseshoe atoll.—Oil is produced from five stratigraphic positions from nonreef rocks of Wolfcamp age overlying the Horseshoe atoll. These are commonly called "Cisco," "Canyon," "Fuller," "Cogdell," and "Wolfcamp" reservoir rocks (fig.6).

The reasons for the traps forming the "Cisco" sandstone, "Canyon" sandstone, "Cogdell" limestone, "Fuller" sandstone, and "Wolfcamp" limestone reservoir rocks in the Wolfcamp series overlying the atoll are the flexures resulting from differential compaction of the terrigenous deposits over the Horseshoe atoll. In the "Cisco" sandstone, however, some accumulation of oil was caused by the lenticular nature of some of the porous sandstones within the body of the bituminous shales of Wolfcamp age. The oil in the other bedded limestone and sandstone reservoirs of Wolfcamp age accumulated in much the same manner as in the reef. These traps are caused primarily by differential compaction but in some places by loss of updip permeability.

Source of the Oil

The source of oil in the reef reservoirs is a matter of much importance in the search for petroleum. The oil could not have originated within the atoll inasmuch as the porosity of the reef limestone is almost entirely secondary (Bergenback and Terriere, 1953, p. 1023; Stafford, in press (a); and Burnside, in press). The oil must, therefore, have migrated into the atoll from an external source, probably from the enclosing bituminous shale of Wolfcamp age.

According to Grout (1932, p. 337), if shale has an initial porosity of 50 percent in the first 100 feet, an overburden of 1,000 feet would reduce that porosity to about 30 percent; 2,000 feet to about 23 percent; 3,000 feet to about 18 percent; and 8,000 feet to about 8 percent. The decrease in porosity and volume represents fluids squeezed out of the shale. The bituminous shale which encloses the reef-complex is considered to be the source of the oil in the reef rocks. The migration of the fluids from source rock to reservoir rock was accomplished by the compaction of the source rocks with the inherent loss of fluids in the process of compaction. It is probable that both water and oil were squeezed out of the compacted shales. These fluids then migrated into the porous parts of the leached reef rocks. This process probably began during Wolfcamp time before the southwestern part of the reef was completely covered with terrigenous rocks. Differential separation of the oil and water in the reef rocks probably occurred as soon as a reservoir was effectively sealed by the covering shales.

The source of the oil in the postreef reservoirs of Wolfcamp age is probably also the shale that encloses both the reef reservoir rocks and those postreef rocks of Wolfcamp age.

Economic Aspects of Porosity Zonation

The main source of reservoir energy in the reef rock is the expansion of gas from solution. In most reservoirs little water drive or encroachment of water is evident. The oil reservoirs and fields of the atoll are interconnected by the lower porous parts of the reef and are also connected with the structurally high, water-saturated, barren reef hills (such as at the

Gaines-Dawson County line and in northeastern Garza and northwestern Kent counties). A large hydrostatic head, therefore, must be present in the oil reservoirs. If the reef were homogenous and uniformly porous, a natural water drive would be effective, but the zonation of porosity (Pls. 2 and 3) indicates that this is not true. A natural water drive will be effective only in zones that have good porosity and permeability and are in direct contact with the oil-water interface.

It is not known to what extent the zones of low porosity act as barriers to the vertical circulation of fluids. That some of these zones are definitely impermeable is indicated by the presence of large amounts of perched water above the main oil-water interface in the south-central edge of the largest "Canyon" reservoir in Scurry County (Rothrock et al., 1953). This water is perched above the impervious zone at the base of reef rock of Cisco age. Relatively few vertical or nearly vertical open joints were observed in the cores from wells in the Horseshoe atoll; however, calcite-filled fractures are fairly common. It is therefore probable that insufficient open joints and fractures are present to allow appreciable vertical circulation of fluids.

The importance of a better understanding of the development and distribution of porous and permeable zones in carbonate reservoirs has been stressed by Imbt (1950, pp. 616–617), as follows:

> The industry has developed techniques of increasing porosity and permeability; however, only a relatively small amount of fundamental research has been undertaken in the mechanics and development of naturally occurring porosity and permeability. The need for systematic research in carbonate porosity becomes more urgent when it is realized that over half of the world's presently known petroleum reserves are contained in carbonate rocks. . . .
>
> Why, then, have not more attempts been made to repressure the carbonate class of reservoirs? The answer to this question is manifold and complicated, and there is lack of general agreement among geologists and engineers regarding the difficulties of secondary projects in carbonate reservoirs. Basically, most of the difficulty results from a lack of fundamental data pertaining to the formation of carbonate porosity and the character of the resulting rock. . . .

Imbt (1950, p. 620) writes further:

> The apparent lack of active interest in repressuring carbonate reservoirs undoubtedly may be attributed to the lack of success attained in those projects already undertaken. Figures are not available from which the total number of failures can be counted. Assumptions are dangerous, but in this instance it is safe to assume that the majority of attempts have ended in failure or have achieved only moderate success. Such a record certainly does not encourage continued attempts at carbonate reservoir repressuring.
>
> Most of the difficulty experienced is thought to be due to a lack of fundamental data bearing on the nature of the porosity and the manner in which it was formed.

It is believed that the technique developed in correlating the zones of different porosity within the Horseshoe atoll will aid in the understanding of the porosity relationships in the atoll and in secondary recovery efforts. It is possible that the use of this technique in studying other carbonate reservoirs will be helpful in determining porosity distribution for guidance of petroleum recovery operations.

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APPENDIX

Description of Cores Taken from the Horseshoe Atoll

The following descriptions of cores from 23 wells are included in order that the reader might better visualize the lithologic components of the rocks that constitute the Horseshoe atoll. The descriptions represent typical cores from the atoll. The rocks from the cores represent different ages: Wolfcamp, Cisco, Canyon, and Strawn. It is apparent from these descriptions that there are few lithologic differences within the body of the reef. Much of the limestone is considered to be clastic and is classified according to the size of its constituent grains into three categories defined as follows:

Calcilutite—Limestone composed mostly of fragments too small to be distinguished megascopically.
Calcarenite—Limestone composed mostly of fragments large enough to be distinguished but smaller than 2 mm in diameter.
Calcirudite—Limestone composed mostly of fragments larger than 2 mm in diameter.

The specific meanings that have been applied to some other terms are given below:

Phenoclast—Any clastic fragment larger than 2 mm in diameter.
Fissures—Short, irregular fractures (in contrast to joints which are straighter and more extensive).
Pinpoint porosity—Containing megascopically visible pore spaces smaller than 1 mm in diameter.
Vug—A pore larger than 1 mm in diameter.
Crinoid—Crinoidal debris consisting entirely of columnal segments except for a very few tiny circular segments that may have come from the arms or pinnules of the crinoid.

Measurements are given in both the English and metric systems. The English system of feet and inches is used for depths and bed thicknesses; the metric system for the size of grains, phenoclasts, and vugs.

The initials "K. B." after the surface elevation indicates that datum is the top of the Kelly Bushing that generally is about 2 feet higher than the derrick floor.

Cities Service Oil Company No. 4 Austin

(Pl. 9, well 104)

Location: 467 feet from south and east lines of lot 31, sec. 39, Kirkland and Fields survey, Scurry County.
Elevation: 2407 feet K. B.
Cored interval: 6697.0 to 6804.0 feet subsurface.
Top of reef: 6681 feet subsurface.
Fusulinid data indicate the rocks in this core to be of Cisco age.

CORE DESCRIPTION

Depths (*feet*) From	To	Available core (*percent*)	Description
6697.0	6710.0	85	Calcirudite, bioclastic, contains claystone fragments; vugs and pinpoint porosity common, incipient stylolites; crinoids, fusulinids, and brachiopods common, bryozoans rare.
6710.0	6753.0	68	Calcarenite, fine-grained, bioclastic; contains claystone stringers in top portion, claystone fragments in lower half; vertical joints: crinoids and unidentified shell fragments common.
6753.0	6763.0	70	Calcirudite; stylolites; vugs and pinpoint porosity abundant; unidentified shell fragments abundant; crinoids, fusulinids, and bryozoans common.
6763.0	6796.5	80	Calcarenite, very fine grained, and calcilutite; open joints at 6787–6793; drusy vugs and pinpoint porosity abundant, especially in lower part; crinoids common, brachiopods rare.
6796.5	6804.0	80	Calcarenite, oolitic in part; open vertical joints in top 2 feet, vugs and pinpoint porosity abundant and horizontally banded; crinoids, fusulinids, and other Foraminifera common.

CITIES SERVICE OIL COMPANY NO. H-2 JOHNSON
(Pl. 9, well 113)

Location: 850 feet from north line, 330 feet from east line of sec. 200, blk. 97, Houston and Texas Central survey, Scurry County.
Elevation: 2432 feet K. B.
Cored interval: 6737.0 to 6933.0 feet subsurface.
Top of reef: 6724 feet subsurface.
Fusulinids of Canyon age were found in the rocks from depths 6819 to 6901 feet subsurface.

CORE DESCRIPTION

Depths (*feet*) From	To	Available core (*percent*)	Description
6737.0	6755.0	78	Calcarenite; vertical joints well developed, stylolites; crinoids and unidentified shell fragments common, fusulinids rare.
6755.0	6760.0	92	Calcarenite and calcilutite interbedded; well-developed stylolites, incipient vertical joints, vugs rare; unidentified shell fragments and crinoids common, brachiopods rare.
6760.0	6778.0	73	Calcarenite; contains scattered calcilutite masses as much as 2 cm in diameter and very thin claystone stringers; vertical joints in lower part, stylolites; crinoids and unidentified shell fragments common, bryozoans and brachiopods rare.
6778.0	6787.5	88	Calcarenite, intercalated calcilutite; stylolites, occasional vugs, pinpoint porosity; unidentified shell fragments abundant, crinoids, bryozoans, and brachiopods common, gastropods rare.
6787.5	6812.0	71	Calcilutite; stylolites, vertical joints; vugs common in upper 5 feet; unidentified shell fragments, crinoids, bryozoans, and brachiopods common.
6812.0	6836.0	60	Calcarenite; stylolites, vertical joints; fissures in upper half; crinoids, fusulinids, unidentified shell fragments, brachiopods, and bryozoans common, corals rare.
6836.0	6840.0	78	Calcirudite, composed of subangular to subrounded calcilutite phenoclasts as much as 4 cm in diameter in calcilutite matrix; contains claystone fragments as much as 1 cm long; stylolites, vertical and oblique calcite veins; fusulinids and crinoids common, brachiopods rare.
6840.0	6846.0	74	Calcarenite, interbedded with calcilutite; calcite-lined vertical and oblique joints; stylolites; occasional vugs in lower part; fusulinids and crinoids common, brachiopods rare.
6846.0	6863.0	85	Calcarenite; vertical joints, some open; stylolites in lower part; vugs common; some vugs and open joints are drusy; fusulinids, crinoids, and unidentified shell fragments common.
6863.0	6871.0	87	Calcarenite, very fine grained; vertical joints, some open; stylolites, vugs, and pinpoint porosity abundant; fusulinids, brachiopods, and crinoids common, corals rare.
6871.0	6890.5	78	Calcilutite; vertical joints; vugs and pinpoint porosity abundant except in bottom 5 feet; fusulinids abundant, crinoids and Foraminifera other than fusulinids common.
6890.5	6895.5	00	
6895.5	6910.0	75	Calcilutite to very fine-grained calcarenite; vertical and oblique joints, some open; calcite-filled fissures; vugs and pinpoint porosity common, abundant in middle 5 feet; fusulinids, crinoids, and unidentified shell fragments common, brachiopods rare.
6910.0	6926.0	00	
6926.0	6933.0	54	Calcilutite; contains claystone stringers as much as 7 mm thick and lenticular calcilutite masses as much as 3 x 5 mm in cross section; stylolites; fusulinids and crinoids common.

Cities Service Oil Company No. 6 Patterson
(Pl. 9, well 110)

Location: 1200 feet from west line, 330 feet from south line of sec. 215, blk. 97, Houston and Texas Central survey, Scurry County.
Elevation: 2465 feet K. B.
Cored interval: 6863.5 to 6962.0 feet subsurface.
Top of reef: 6868 feet subsurface.
Fusulinids of Cisco age were found from 6870 to 6918 feet subsurface.

CORE DESCRIPTION

Depths (feet) From	To	Available core (percent)	Description
6863.5	6868.0	?	Claystone, fissile, occasional calcilutite beds as much as 3 cm thick, claystone contains disseminated pyrite crystals, tar is present along cleavage planes; fish scales and discinid brachiopods common in the claystone; in the calcilutite crinoids and brachiopods common and fusulinids rare.
6868.0	6890.0	?	Calcirudite, composed of calcilutite and large fossil fragments in bioclastic calcarenite matrix, fragments have maximum diameter of 4 cm; stylolites, vertical and oblique joints; crinoids and unidentified fossil fragments abundant, fusulinids common, brachiopods rare.
6890.0	6891.0	?	Calcarenite, very fine grained, and calcilutite, contains one oblique 2-inch claystone bed; well-developed vertical joints.
6891.0	6905.0	?	Calcirudite, consists of calcilutite and calcarenite fragments as much as 16 cm in diameter in calcareous claystone matrix; occasional pyrite crystals, scattered claystone fragments, stylolites, vertical joints; crinoids, fusulinids, and bryozoans common, brachiopods rare.
6905.0	6906.0	?	Claystone, contains disseminated pyrite crystals and fragmental layers as much as 1-inch thick; crinoids abundant.
6906.0	6908.0	?	Calcarenite, near base subrounded calcilutite fragments are rare; crinoids rare.
6908.0	6909.5	?	Claystone, fissile, calcareous; contains disseminated pyrite crystals; pyritized pelecypods common, brachiopods rare.
6909.5	6912.5	?	Calcilutite, argillaceous and calcareous claystone; vertical joints; brachiopods *("Chonetes")* common, ammonoids rare.
6912.5	6925.5	?	Calcarenite, contains occasional pyritic claystone fragments; stylolites; horizontal, oblique and vertical joints; calcite-filled cavities in top portion; crinoids, fusulinids and other Foraminifera common.
6925.5	6962.0	?	Calcilutite; occasional horizontal claystone partings, well-developed oblique joints; stylolites, calcite-filled fissures; crinoids, fusulinids, Foraminifera other than fusulinids, and brachiopods rare.

General Crude Oil Company No. 193–2 Coleman
(Pl. 9, well 169)

Location: 560 feet from south line and 3494 feet from east line of sec. 193, blk. G, WACO and NW survey, 7 miles west of Clairemont, in Kent County, Texas.
Elevation: 2157 feet K. B.
Cored interval: 6223 feet to 6546 feet subsurface.
Top of reef: 6200 feet subsurface.
Fusulinids of Cisco age were found between depths 6258 and 6290 feet subsurface. Fusulinids of Canyon age were found between depths 6311 and 6508 feet subsurface.

CORE DESCRIPTION

Depths (feet) From	To	Available core (percent)	Description
6223.0	6231.0	88	Calcilutite; stylolites, calcite-filled joints; vugs; fusulinids rare, bryozoans common, corals rare, crinoids common, unidentified shell fragments common.
6231.0	6235.3	?	Calcarenite, calcilutite groundmass; filled joints; oolites in upper 6 inches; fusulinids and crinoids rare to common, brachiopods, bryozoans rare, unidentified shell fragments common.

6235.3	6246.0	?	Claystone, calcareous, with interbedded argillaceous limestone to 12 inches thick, becomes more calcareous in lower 2 feet, basal 3 inches contains well-sorted fossil debris; comminuted fossil debris scattered throughout.
6246.0	6258.0	?	Calcarenite with calcilutite groundmass; interbedded claystone to 3 inches thick; pyrite cubes common; crinoids very common to abundant, fusulinids occasional.
6258.0	6265.0	47	Calcirudite; boundaries of phenoclasts indistinct, phenoclasts calcarenite and calcilutite; vugs; fusulinids common, Foraminifera other than fusulinids rare, unidentified shell debris very common.
6265.0	6311.0	91	Calcirudite, with calcarenite and calcilutite beds to 8 feet thick; vugs and small vertical joints, usually filled; becoming stylolitic in lower 33 feet; crinoids and fusulinids common, bryozoans, brachiopods, Foraminifera other than fusulinids rare, unidentified shell debris common.
6311.0	6317.5	92	Calcarenite, bioclastic; horizontal claystone bands; fusulinids common, crinoids rare, unidentified shell debris common.
6317.5	6329.0	71	Calcarenite, oolitic; vugs common, some filled with calcite; crinoids and fusulinids common, fusulinids hollow.
6329.0	6334.0	100	Calcilutite, bioclastic, occasional oolites; drusy vugs; fusulinids common, unidentified shell fragments common.
6334.0	6385.0	84	Calcilutite, bioclastic; stylolitic, drusy vugs rare, filled joints rare; lower 3 feet contains fragments calcilutite and calcarenite as much as 2 inches in diameter; fusulinids and crinoids common; Foraminifera other than fusulinids rare, bryozoans, brachiopods, corals rare.
6385.0	6390.0	100	Calcirudite, fragments oolitic or calcarenitic, 13 inches calcarenite at top; vertical joints; fusulinids rare, crinoids very common.
6390.0	6399.0	87	Calcarenite, oolitic; occasional open joints, vugs; no identifiable fossil debris.
6399.0	6424.0	81	Calcarenite, oolitic; occasional stylolite, vertical joints; fusulinids and crinoids common.
6424.0	6429.0	90	Calcarenite, bioclastic; stylolites, filled vertical joints; fusulinids and crinoids common, Foraminifera other than fusulinids rare.
6429.0	6441.0	79	Calcilutite, bioclastic; stylolitic, vertical fractures mostly filled but a few open, occasional, small vugs; fusulinids, crinoids, bryozoans, and Foraminifera other than fusulinids common.
6441.0	6452.0	97	Calcarenite; vertical joints, small vugs; fusulinids and crinoids rare, unidentified shell fragments common.
6452.0	6458.0	75	Calcilutite containing scattered fragments of calcarenite and bioclastic calcilutite as much as 3 inches in diameter; stylolites, crinoids, and fusulinids rare to common, bryozoans common, unidentified shell fragments common.
6458.0	6473.0	80	Calcarenite, composed of rounded unidentified pellets; small vugs rare; crinoids rare.
6473.0	6475.0	100	Calcilutite, bioclastic; stylolites; crinoids and fusulinids rare, unidentified shell fragments.
6475.0	6490.0	95	Calcarenite, oolitic, calcilutite groundmass; drusy vugs; unidentified shell fragments.
6490.0	6495.0	92	Calcirudite, fragments of calcarenite and calcirudite in groundmass of calcarenite; stylolites; crinoids common, comminuted fossil debris common.
6495.0	6510.0	82	Calcilutite, bioclastic, 1 foot of calcirudite at base; stylolites, small vugs; crinoids, fusulinids, bryozoans common, Foraminifera other than fusulinids rare, unidentified shell fragments common.
6510.0	6512.0	00	
6512.0	6523.0	83	Calcarenite, bioclastic; vugs; crinoids common, fusulinids and other Foraminifera rare, gastropods and brachiopods rare. Lowermost 6 inches contains a rich fauna of ammonoids.
6523.0	6530.0	87	Calcarenite, bioclastic, scattered oolites; drusy vugs; crinoids common, ammonoids rare, unidentified shell fragments.
6530.0	6546.0	71	Calcilutite, bioclastic; stylolites; crinoids very common, becomes an encrinite in lower 5 feet; unidentifiable shell fragments common.

GENERAL CRUDE OIL COMPANY NO. 3 LAND
(Pl. 9, well 183)

Location: 467 feet from the south and east lines of sec. 247, blk. 97, Houston and Texas Central survey, Scurry County.
Elevation: 2460 feet K. B.
Cored interval: 6766.0 to 6874.0 feet subsurface.
Top of reef: 6755 feet subsurface.
Fusulinids of lower Canyon age were found from 6766 to 6870 feet subsurface.

CORE DESCRIPTION

Depths (feet) From	To	Available core (percent)	Description
6766.0	6773.5	?	Calcarenite, contains three beds of calcilutite 1 to 1½ feet thick and at the top a claystone bed 2 inches thick; stylolites; calcite-filled vugs rare; crinoids rare to common, brachiopods, bryozoans, and gastropods rare.
6773.5	6780.0	?	Calcilutite; stylolites, vertical joints, vugs rare; crinoids common, brachiopods and corals rare.
6780.0	6786.0	?	Calcarenite, contains a calcilutite bed 2½ feet thick in middle; stylolites, crystalline calcite masses as much as 2 mm in diameter; fusulinids and crinoids common, bryozoans and brachiopods rare.
6786.0	6788.0	?	Calcilutite; stylolites, vertical joints, vugs in uppermost part (mostly leached fossils); fusulinids common, crinoids, bryozoans, and Foraminifera other than fusulinids rare.
6788.0	6802.5	?	Calcarenite contains very small amounts of disseminated carbonaceous material; stylolites, vertical and oblique joints; fusulinids and crinoids common, brachiopods *(Linoproductus?)*, unidentified spines, and bryozoans rare.
6802.5	6805.0	00	
6805.0	6809.0	?	Calcarenite, bioclastic; stylolites, joints; fusulinids and unidentified shell fragments common, brachiopods, crinoids, and corals rare.
6809.0	6810.0	?	Calcilutite; calcite-filled fissures and vugs common, drusy vugs rare; fusulinids, unidentified shell fragments, other Foraminifera, and brachiopods common.
6810.0	6812.5	?	Calcarenite; stylolites, calcite-filled vugs; crinoids and fusulinids common, bryozoans rare.
6812.5	6824.5	?	Calcilutite; stylolites, calcite-filled fissures and vugs; crinoids common, brachiopods (productid), unidentified fragments, and bryozoans rare.
6824.5	6840.5	?	Calcarenite, bioclastic, contains two 1-foot calcilutite beds; stylolites, calcite-filled vugs; fusulinids and crinoids common, bryozoans rare.
6840.5	6848.0	?	Calcilutite, contains minor thin calcarenite zones; stylolites rare, calcite-filled fissures and vugs; fusulinids and crinoids common, other Foraminifera rare.
6848.0	6851.5	?	Calcarenite, bioclastic, stylolites; crinoids and fusulinids common, brachiopods rare.
6851.5	6856.0	?	Calcarenite and calcilutite intercalated; stylolites, vertical joints; fusulinids and crinoids common, bryozoans rare.
6856.0	6856.5	?	Calcarenite, bioclastic, contains limestone and claystone fragments; unidentified shell fragments and fusulinids common.
6856.5	6859.5	?	Claystone, massive, contains disseminated pyrite crystals; unfossiliferous.
6859.5	6860.0	?	Calcarenite and claystone intercalated. Calcarenite bioclastic, contains fissures. Claystone contains disseminated pyrite. Fusulinids rare to common.
6860.0	6865.0	?	Calcarenite, bioclastic, vugs and pinpoint porosity common; fusulinids and crinoids common, bryozoans rare.
6865.0	6874.0	?	Calcilutite; stylolites; vugs common in upper half where porous zones alternate with nonporous zones; lower half is dense. Unidentified shell fragments common, fusulinids, bryozoans, and crinoids rare.

HIAWATHA OIL AND GAS COMPANY NO. 1 CARDEN
(Pl. 9, well 179)

Location: 1953.4 feet from east line, 1995.6 feet from south line of sec. 293, blk. 97, Houston and Texas Central survey, Scurry County.

Elevations: 2452 feet K. B.

Cored interval: 6640.0 to 6728.5 feet subsurface.

Top of reef: 6637 feet subsurface.

Fusulinids from rocks between 6642 and 6672 feet subsurface are of lower Cisco age; fusulinids from rocks between 6682 and 6710 feet subsurface are of Canyon age.

CORE DESCRIPTION

Depths (*feet*) From	To	Available core (*percent*)	Description
6640.0	6648.0	100	Calcarenite, fine to very fine grained; stylolites common in upper 2 feet; vertical joints rare; fusulinids and bryozoans rare.
6648.0	6650.5	84	Calcilutite, contains a very fine-grained calcarenite bed 1 foot thick; unfossiliferous except for rare fusulinids in basal 1½ feet.
6650.5	6655.0	100	Calcarenite, very fine to fine grained, argillaceous in top and basal portions; basal 1 foot contains disseminated pyrite crystals; fusulinids and bryozoans common, Foraminifera other than fusulinids, crinoids, brachiopods, and gastropods rare.
6655.0	6656.5	27	Claystone, calcareous, fissile; contains fusain and disseminated pyrite crystals, basal portion contains limestone stringers. Fish plates and brachiopods common, fusulinids, gastropods, corals, and plant remains (*Calamites(?)* stem) rare.
6656.5	6659.0	80	Claystone interbedded with very fine-grained calcarenite; claystone is fissile and contains calcareous fossils; calcarenite contains calcite-filled vugs and fissures; fusulinids generally common, but are abundant in basal portion, brachiopods common, bryozoans, corals, and other Foraminifera rare.
6659.0	6667.0	60	Calcarenite; fine to very fine grained; contains minor thin claystone stringers in top portion; occasional well-developed stylolites and calcite-filled fractures; fusulinids common, brachiopods, bryozoans, and other Foraminifera rare.
6667.0	6673.0	73	Calcarenite, very fine grained; contains a calcilutite bed 1½ feet thick near top; pinpoint porosity common 6670–6671; fusulinids and bryozoans rare to common, unidentified shell fragments rare.
6673.0	6678.0	60	Calcarenite, medium to very fine grained; stylolites; pinpoint porosity common, developed mostly by leaching of fossils; fusulinids common, unidentified shell fragments, bryozoans, crinoids, and other Foraminifera rare.
6678.0	6681.5	69	Calcarenite, very fine to fine grained; small crystalline calcite masses, vertical joints; pinpoint porosity common; fusulinids rare.
6681.5	6686.0	93	Calcarenite, fine to very fine grained, vertical joints common; pinpoint porosity common; fusulinids and unidentified shell fragments, bryozoans, and crinoids rare.
6686.0	6690.5	71	Calcarenite, fine to very fine grained, contains a calcilutite zone 1 foot thick in center; pinpoint porosity common, leached stylolites; drusy vugs rare in upper foot; fusulinids common.
6690.5	6693.5	50	Calcarenite, fine grained, to calcilutite; stylolites, joints, and calcite-filled fissures common; pinpoint porosity common; fusulinids common, bryozoans rare.
6693.5	6699.5	85	Calcarenite, very fine grained, stylolites, vertical joints, pinpoint porosity, and vugs common; fusulinids common to abundant, brachiopods, and bryozoans rare.
6699.5	6701.0	53	Calcarenite, very fine grained grading into calcilutite; stylolites common; calcite-filled vugs and fissures; pinpoint porosity common; fusulinids common.
6701.0	6704.0	?	Calcilutite, grading into very fine-grained calcarenite in topmost portion; incipient vertical joints; stylolites rare; fusulinids common, crinoids rare.

6704.0	6710.0	87	Calcarenite, fine to very fine grained; incipient vertical joints; stylolites very common. Fusulinids common, bryozoans and crinoids rare.
6710.0	6711.0	100	Calcarenite, very fine grained; stylolites abundant, fusulinids abundant.
6711.0	6713.0	100	Calcilutite, stylolites common; incipient vertical joints; calcite-filled vugs; fusulinids common, crinoids rare.
6713.0	6718.0	54	Calcilutite; stylolites; calcite-filled vugs and fissures common; fusulinids, crinoids, and fenestellid bryozoans rare.
6718.0	6725.0	72	Calcilutite; stylolites common, filled with considerable black clay, containing pyrite crystals; pinpoint porosity rare to common; brachiopods, corals, fusulinids, and crinoids rare. (Fusulinids and crinoids are common along stylolites.)
6725.0	6726.0	100	Calcarenite, argillaceous; incipient stylolites abundant; crinoids abundant.
6726.0	6728.5	?	Calcilutite in top 6 inches contains calcirudite composed of crinoid debris and calcarenite fragments in calcilutite matrix. Calcite-filled vugs and fissures common; incipient stylolites; crinoids common, brachiopods and bryozoans rare.

HONOLULU OIL CORPORATION AND CASCADE PETROLEUM COMPANY NO. Y-2 CANNING
(Pl. 9, well 192)

Location: 2200 feet from north line, 650 feet from east line of sec. 125, blk. 25, Houston and Texas Central survey, Scurry County.
Elevation: 2324 feet K. B.
Cored interval: 6653.0 to 6720.0 feet subsurface.
Top of reef: 6645 feet subsurface.

CORE DESCRIPTION

Depths (feet) From	To	Available core (percent)	Description
6653.0	6655.0	?	Calcarenite; incipient oblique joints and incipient stylolites common; pinpoint porosity and small vugs common; crinoids common.
6655.0	6657.5	?	Calcarenite, contains occasional fragments of calcilutite; incipient stylolites rare; pinpoint porosity and vugs common; crinoids common, fusulinids rare.
6657.5	6659.0	?	Calcarenite; pinpoint porosity and vugs common; crinoids common, fusulinids rare.
6659.0	6661.0	?	Calcarenite, fine grained, oolitic; contains oblique joints, stylolites and thin claystone stringers; unfossiliferous.
6661.0	6663.0	00	
6663.0	6664.5	?	Calcilutite to very fine grained calcarenite; slightly oolitic in part; incipient vertical joints and claystone stringers common; crinoids and Foraminifera other than fusulinids common.
6664.5	6669.0	?	Calcarenite, very fine grained, oolitic; incipient stylolites rare; crinoids common, Foraminifera other than fusulinids rare.
6669.0	6675.0	?	Calcarenite, very fine grained, oolitic; incipient vertical joints common; pinpoint porosity abundant, developed largely in fossils; crinoids and unidentified shell fragments common; fusulinids rare.
6675.0	6676.0	?	Calcarenite, very fine grained, to calcilutite; incipient vertical joints; Foraminifera other than fusulinids common, crinoids rare.
6676.0	6681.5	00	
6681.5	6683.0	?	Calcarenite, very fine grained and calcilutite; pinpoint porosity and drusy vugs common in thin zones; crinoids rare.
6683.0	6687.5	?	Calcilutite and very fine grained oolitic calcarenite; pinpoint porosity and drusy vugs abundant and largely associated with vertical fractures and fossil material; unidentified shell fragments common.
6687.5	6689.0	?	Calcilutite; incipient vertical joints; pinpoint porosity abundant in certain horizontal zones; unfossiliferous.
6689.0	6694.0	00	
6694.0	6697.0	?	Calcarenite, fine to very fine grained, oolitic; incipient vertical joints. Pinpoint porosity abundant, drusy vugs common; crinoids and Foraminifera other than fusulinids common.

6697.0	6701.0	?	Calcilutite and very fine grained calcarenite; pinpoint porosity and drusy vugs abundant, frequently representing leached fossil material; vugs commonly contain pyrite crystals; crinoids are rare, unidentified leached shell fragments common.
6701.0	6703.0	00	
6703.0	6710.5	?	Calcarenite, very fine grained, oolitic; stylolites end in thin claystone stringers; crinoids and Foraminifera other than fusulinids common, unidentified shell fragments rare.
6710.5	6711.5	21	Calcilutite and very fine grained calcarenite; stylolites with much clay along them; claystone galls common; fusulinids, other Foraminifera, and ostracods rare.
6711.5	6713.5	00	
6713.5	6715.0	?	Calcarenite, very fine grained; pinpoint porosity and drusy vugs abundant; fusulinids and other Foraminifera common, crinoids rare.
6715.0	6720.0	?	Calcilutite and very fine grained oolitic calcarenite; pinpoint porosity; fusulinids and other Foraminifera rare.

Lion Oil Company No. 45 McLaughlin
(Pl. 9, well 193)

Location: 1808 feet from west line, 1976 feet from north line of sec. 197, blk. 97, Houston and Texas Central survey, Scurry County.
Elevation: 2373 feet K. B.
Cored interval: 7316.5 to 7360.0 feet subsurface.
Top of reef: 6607 feet subsurface.
Fusulinid data indicate the following horizon is represented in this core: Strawn—7,326 to 7,336 feet subsurface.

CORE DESCRIPTION

Depths *(feet)* From	To	Available core *(percent)*	Description
7316.5	7317.5	33	Calcilutite, bioclastic; stylolites; fusulinids.
7317.5	7319.0	00	
7319.0	7328.2	92	Calcarenite, very fine grained, calcilutite lenses; stylolites; fusulinids.
7328.2	7329.4	100	Calcilutite, stylolites; fusulinids.
7329.4	7334.0	100	Calcarenite, very fine grained, occasional calcilutite lenses, claystone stringers; stylolites; fusulinids, crinoids, brachiopods.
7334.0	7335.3	00	
7335.3	7340.1	83	
7340.1	7347.8	84	Calcilutite, chert nodules containing fusulinids; stylolites; fusulinids.
7347.8	7360.0	100	Calcarenite, very fine grained, calcilutite lenses, bioclastic, leached; stylolites, vertical joints, some joints are open; vugular pinpoint porosity; fusulinids, crinoids, and bryozoans.

Montex Drilling Company No. 3 Country Club
(Pl. 9, well 180)

Location: 3151 feet from west line and 2946 feet from south line of sec. 178, blk. 3, Houston and Great Northern survey, Scurry County.
Elevation: 2377 feet K. B.
Cored interval: 6685.0 to 6785.0 feet subsurface.
Top of reef: 6675 feet subsurface.
Fusulinids of Cisco age were found in rocks above 6740 feet subsurface; fusulinids of Canyon age were found in rocks below 6751 feet subsurface.

CORE DESCRIPTION

Depths *(feet)* From	To	Available core *(percent)*	Description
6685.0	6689.0	78	Calcarenite, with calcilutite, calcarenite and claystone fragments and claystone stringers; stylolites, vertical and oblique joints; fusulinids and crinoids common.
6689.5	6690.1	83	Calcirudite with calcarenite phenoclasts as much as 4 cm in diameter and claystone fragments; vertical joints; fusulinids and crinoids common.

6690.1	6693.9	89	Calcarenite, coarse grained, with phenoclasts of very fine grained calcarenite and calcilutite as much as 15 mm in diameter, claystone fragments as much as 25 mm in diameter, claystone stringers; stylolites and vertical joints; fusulinids and crinoids common.
6693.9	6702.2	81	Calcirudite, with calcilutite and calcarenite phenoclasts as much as 65 mm in diameter; stylolites; vugular porosity, drusy calcite in vugs; fusulinids and crinoids common, corals rare.
6702.2	6703.8	69	Calcarenite, very fine grained; stylolites; pinpoint and vugular porosity, calcite-filled vugs; fusulinids common.
6703.8	6718.8	90	Calcirudite, claystone fragments, calcilutite and very fine grained calcarenite phenoclasts and large crinoid fragments in a very fine-grained groundmass, phenoclasts as much as 11 cm in diameter; claystone-coated stylolites; crinoids and fusulinids common.
6718.8	6726.4	00	
6726.4	6729.2	36	Calcarenite, very fine grained, with calcilutite lenses as much as 12.5 cm, leached, vugular porosity, some vugs contain drusy calcite, others are calcite-filled; fusulinids, bryozoans, and crinoids common.
6729.2	6732.8	44	Calcirudite, phenoclasts of calcilutite and very fine-grained calcarenite as much as 10 cm in diameter; oolite and pisolite fragments which are leached and filled with calcite.
6732.8	6750.9	88	Calcarenite, oolites and pisolites dispersed in calcilutite groundmass, oolites and pisolites are leached but occasionally only groundmass is leached; claystone-coated stylolites, vertical fractures, vugular porosity, fusulinids and crinoids common.
6750.9	6754.7	100	Calcirudite, phenoclasts of calcarenite as much as 26 mm in diameter, random leaching; stylolites, vertical fractures; vugular porosity; fusulinids and crinoids common.
6754.7	6785.0	80	Calcarenite, fine grained, leached; occasional oolites, stylolites, vertical fractures; vugular porosity, vugs as much as 12 mm in diameter, vugs contain drusy dolomite; crinoids and fusulinids common.

Montex Drilling Company No. 2 Harrell
(Pl. 9, well 106)

Location: 467 feet from north and east lines of sec. 15, blk. 1, J. P. Smith survey, Scurry County.
Elevation: 2395 feet K. B.
Cored interval: 6802.0 to 6828.0 feet subsurface.
Top of reef: 6727 feet subsurface.

CORE DESCRIPTION

Depths (feet) From	To	Available core (percent)	Description
6802.0	6804.7	60	Calcarenite, coarse grained; stylolites, incipient vertical joints; crinoids and fusulinids common.
6804.7	6805.7	100	Calcirudite; composed of calcilutite phenoclasts as much as 4 cm in diameter in calcarenite matrix; stylolites common especially around phenoclast boundaries and have bituminous claystone concentrated along them; claystone stringers nearly horizontal; calcite-filled fractures in phenoclasts end abruptly at contact of phenoclast and matrix; crinoids abundant, fusulinids common, brachiopods rare.
6805.7	6807.0	00	
6807.0	6808.6	22	
6808.6	6809.6	00	
6809.6	6814.0	57	
6814.0	6817.0	00	
6817.0	6822.8	60	
6822.8	6824.5	00	
6824.5	6828.0	86	

MONTEX DRILLING COMPANY NO. 4 HARRELL
(Pl. 9, well 188)

Location: 467 feet from south and west lines of sec. 15, blk. 1, J. P. Smith survey, Scurry County.
Elevation: 2401 feet K. B.
Cored interval: 6738.0 to 6825.0 feet subsurface.
Top of reef: 6722 feet subsurface.
Fusulinid data indicate the following horizons are represented in this core: Cisco—6744 to 6767 feet subsurface; Canyon—6776 to 6824 feet subsurface.

CORE DESCRIPTION

Depths (*feet*) From	To	Available core (*percent*)	Description
6738.0	6750.0	100	Calcirudite, composed of calcilutite phenoclasts as much as 5 cm in diameter in calcilutite matrix; stylolites, thin claystone stringers, and lenses; crinoids and fusulinids common, bryozoans and pelecypods rare.
6750.0	6752.5	100	Calcirudite, composed of calcilutite, calcarenite, and scattered claystone phenoclasts as much as 4 cm in diameter in calcilutite matrix; stylolites, thin claystone stringers, pinpoint porosity; fusulinids and crinoids common.
6752.5	6758.5	100	Calcirudite, composed of calcilutite and calcarenite phenoclasts in calcarenite matrix; stylolites; pinpoint porosity; fusulinids and crinoids common, bryozoans, brachiopods, corals, and gastropods rare.
6758.5	6761.0	100	Calcarenite, containing a very few calcilutite phenoclasts as much as 1.5 cm in diameter; stylolites; fusulinids and crinoids common, corals rare.
6761.0	6767.0	100	Calcarenite, containing calcarenite phenoclasts as much as 2 cm in diameter and occasional claystone and calcilutite phenoclasts. In a few places phenoclasts are abundant enough to make the rock calcirudite. Claystone stringers, incipient stylolites, vertical joints; pinpoint porosity; fusulinids and brachiopods common, crinoids, bryozoans and gastropods rare.
6767.0	6770.5	83	Calcirudite, composed of calcarenite and calcilutite phenoclasts as much as 3 cm in diameter in calcarenite matrix; stylolites, claystone stringers; crinoids and fusulinids common, brachiopods rare.
6770.5	6772.0	100	Calcarenite, containing occasional calcilutite and calcarenite phenoclasts as much as 4 cm in diameter; stylolites, claystone stringers; pinpoint porosity; crinoids and fusulinids common to abundant.
6772.0	6785.2	96	Calcirudite, composed of calcarenite matrix, calcite-filled fractures in phenoclasts only; claystone stringers, stylolites; pinpoint porosity; crinoids and fusulinids are common, brachiopods, bryozoans, and Foraminifera rare.
6785.2	6786.6	100	Calcarenite, fine grained; fossils leached; unidentified shell fragments abundant, fusulinids common, brachiopods rare.
6786.6 6797.5 6788.6	6797.5 6788.6 6821.1	91 00 87	Calcirudite, composed of calcilutite and calcarenite phenoclasts in calcarenite matrix; maximum size of phenoclasts varies from 2.5 cm at the top to 46 cm at the base; stylolites, claystone stringers; crinoids and fusulinids common.
6821.1	6825.0	85	Calcarenite, fine to medium grained, oolitic; stylolities; considerably leached; fusulinids abundant, unidentified shell fragments and Foraminifera common, crinoids and bryozoans rare.

MONTEX DRILLING COMPANY NO. 4 JOYCE
(Pl. 9, well 185)

Location: 467 feet from north line, 702 feet from east line of sec. 15, blk. 1, J. P. Smith survey, Scurry County.
Elevation: 2352 feet K. B.
Cored interval: 6731.0 to 6766.5 feet subsurface.
Top of reef: 6730 feet subsurface.
Rocks between 6735 and 6765 feet subsurface contain fusulinids of Canyon age.

CORE DESCRIPTION

Depths (feet) From	To	Available core (percent)	Description
6731.0	6733.0	?	Calcarenite; incipient vertical joints; small drusy vugs; crinoids and gastropods rare.
6733.0	6748.0	?	Calcirudite, composed of calcilutite and calcarenite in fine-grained calcarenite matrix; phenoclasts are as large as 6 cm in diameter; stylolites, claystone stringers, vugs; fusulinids, crinoids and unidentified shell fragments common, bryozoans and brachiopods rare.
6748.0	6759.0	00	
6759.0	6766.5	?	Calcirudite, composed of calcilutite and calcarenite phenoclasts as large as 4 cm in diameter in calcarenite matrix; stylolites, claystone stringers; vugs in basal 1 foot only; crinoids and fusulinids common.

MONTEX DRILLING COMPANY NO. 5 JOYCE
(Pl. 9, well 107)

Location: 467 feet from south and west lines of sec. 15, blk. 1, J. P. Smith survey, Scurry County.
Elevation: 2384 feet K. B.
Cored interval: 6743.0 to 6819.0 feet subsurface.
Top of reef: 6734 feet subsurface.

CORE DESCRIPTION

Depths (feet) From	To	Available core (percent)	Description
6743.0	6746.2	66	Calcarenite, coarse grained; sand-sized fragments of calcilutite and fine-grained calcarenite, claystone stringers; stylolites; fusulinids common, crinoids and bryozoans rare.
6746.2	6771.7	89	Calcirudite, calcilutite and calcarenite phenoclasts as much as 75 mm in diameter, claystone stringers; stylolites; fusulinids and crinoids common, brachiopods, bryozoans, ostracods, and corals rare.
6771.7	6781.0	93	Calcarenite, fine grained, with scattered calcilutite lenses and claystone stringers; stylolites; fusulinids and crinoids common, bryozoans, brachiopods, ostracods noted.
6781.0	6785.0	100	Calcirudite, with phenoclasts of calcilutite and calcarenite as large as 35 mm in diameter; some calcarenite phenoclasts are oolitic; stylolites, vertical fractures, some are open; open-fissure porosity; fusulinids, crinoids, brachiopods, bryozoans, corals, and ostracods rare.
6785.0	6792.5	40	Calcarenite; vertical fractures; fusulinids and bryozoans rare, crinoids common.
6792.5	6793.5	60	Calcirudite, with phenoclasts of calcilutite and calcarenite as much as 9 cm in diameter; stylolites with claystone coating; vertical fractures; fusulinids rare, crinoids and bryozoans occasional.
6793.5	6802.0	00	
6802.0	6803.0	?	Calcilutite, leached; oblique fractures; vugular porosity, some vugs as much as 12 mm in diameter, some vugs contain drusy calcite; bryozoans rare.
6803.0	6812.6	84	Calcarenite, fine to medium grained, claystone stringers, leached; stylolites; vugular porosity, some vugs have drusy lining; crinoids and bryozoans rare.
6812.6	6819.0	63	Calcilutite, fine-grained calcarenite lenses, leached; stylolites; vugular porosity; crinoids and bryozoans rare.

MONTEX DRILLING COMPANY NO. 1 PAYNE
(Pl. 9, well 187)

Location: 467 feet from west line, 2026.2 feet from south line of sec. 179, blk. 3, Houston and Great Northern survey, Scurry County.
Elevation: 2352 feet K. B.
Cored interval: 6755.0 to 6766.5 feet subsurface.
Top of reef: 6746 feet subsurface.
Fusulinids of Cisco age were found in rocks from 6756 to 6771 feet subsurface.

CORE DESCRIPTION

Depths (feet) From	To	Available core (percent)	Description
6755.0	6762.0	?	Calcirudite, composed of calcilutite and calcarenite phenoclasts as large as 2 cm in diameter in calcarenite matrix; leached fossils and vugs.
6762.0	6762.5	00	
6762.5	6766.5	?	Calcirudite, composed of calcarenite and calcilutite fragments as large as 2.5 cm in diameter in calcarenite matrix; stylolites, thin claystone stringers, claystone concentrations around phenoclast boundaries; fusulinids and crinoids, unidentified shell fragments, bryozoans, brachiopods, corals, and Foraminifera other than fusulinids rare.

MONTEX DRILLING COMPANY NO. 2 PAYNE
(Pl. 9, well 186)

Location: 2651 feet from south line, 467 feet from west line of sec. 179, blk. 3, Houston and Great Northern survey, Scurry County.
Elevation: 2352 feet K. B.
Cored interval: 6744.0 to 6773.3 feet subsurface.
Top of reef: 6744 feet subsurface.
Fusulinids of Cisco age were found in rocks from 6745 to 6773 feet subsurface.

CORE DESCRIPTION

Depths (feet) From	To	Available core (percent)	Description
6744.0	6746.0	?	Claystone, containing irregular subordinate lenses of calcarenite; amount of calcarenite increases downward, crinoids common, fusulinids and fish scales rare.
6746.0	6747.0	?	Calcarenite, containing irregular subordinate claystone lenses; oblique bedding; fusulinids and crinoids common.
6747.0	6748.5	?	Calcarenite, containing scattered phenoclasts of calcilutite as large as 5 mm in diameter and of claystone as large as 3 cm vertical joints; fusulinids and crinoids common.
6748.5	6762.2	?	Calcirudite, composed of phenoclasts of calcilutite and calcarenite, as large as 5 cm in diameter but averaging 5 mm, in calcarenite matrix; horizontal claystone stringers; vugs in lower portion; fusulinids and crinoids common.
6762.2	6762.4	?	Claystone, nonfissile.
6762.4	6762.7	100	Calcirudite, composed of calcarenite and calcilutite fragments in dark-gray, argillaceous, very fine-grained calcarenite matrix.
6762.7	6773.3	86	Calcirudite, composed of calcarenite and calcilutite phenoclasts as large as 5 cm in diameter in calcarenite matrix. In a few thin zones phenoclasts are much less abundant than elsewhere and the rock becomes calcarenite with only scattered phenoclasts. Stylolites; occasional claystone stringers; crinoids and fusulinids common, brachiopods and Foraminifera other than fusulinids rare.

OHIO OIL COMPANY NO. 2 HAYS
(Pl. 9, well 96)

Location: 467 feet from north and east lines of the NW¼ sec. 249, blk. 97, Houston and Texas Central survey, Scurry County.
Elevation: 2458 feet K. B.
Cored interval; 6631.0 to 6832.9 feet subsurface.
Top of reef: 6595 feet subsurface.
Fusulinids of Cisco age were found in rocks between 6332 and 6755 feet subsurface. Fusulinids of Canyon age were found in rocks between 6810 and 6826 feet subsurface.

CORE DESCRIPTION

Depths (feet) From	To	Available core (percent)	Description
6631.0	6631.6	100	Calcirudite containing calcilutite phenoclasts as much as 4 cm in diameter in calcarenite matrix; stylolites with black claystone coating, small vertical fractures; vugular porosity; fusulinids and crinoids rare.
6631.6	6633.6	100	Calcilutite with calcarenite lenses; stylolites with black claystone coating, vertical fractures filled or partially filled with crystalline calcite; vugular porosity; fusulinids, crinoids, brachiopods, and corals rare.
6633.6	6634.0	55	Calcirudite, calcilutite phenoclasts as much as 15 mm long in a matrix of calcarenite; stylolites with black claystone coating; corals common, crinoids rare.
6634.0	6635.0	100	Calcarenite, vertical fractures partially filled with black claystone or bituminous material and crystalline calcite; Foraminifera other than fusulinids common, crinoids, corals, and brachiopods rare.
6635.0	6635.6	100	Calcirudite, calcilutite phenoclasts as much as 4 cm long, largest fragment is oolitic; stylolites, vertical, horizontal, and oblique fractures; some black claystone or bituminous material in fractures; vugular porosity; crinoids, Foraminifera other than fusulinids, fusulinids, bryozoans, brachiopods, and corals rare.
6635.6	6642.5	58	Calcilutite, with megascopic shell fragments which are embedded in translucent calcite from 6637.5–6642.5 feet; stylolites, vertical and oblique fractures, some partially and others completely filled with crystalline calcite; vugular and open-fissure porosity; crinoids common, corals, fusulinids, bryozoans, and brachiopods rare.
6642.5	6644.5	100	Calcirudite, phenoclasts of calcilutite, oolites, and calcarenite as much as 8 cm in diameter; stylolites, vertical and oblique fractures, some are calcite-filled, others are open; vugular and open-fracture porosity; crinoids rare to common, fusulinids, corals, brachiopods, gastropods, and Foraminifera other than fusulinids rare.
6644.5	6645.0	100	Calcarenite, contains patches of crystalline calcite; irregular fractures; vugular porosity; Foraminifera, crinoids, and corals rare.
6645.0	6645.5	100	Calcilutite, small patch of calcarenite; stylolites, vertical fractures, open-fracture porosity; crinoids, corals, gastropods, and fusulinids rare.
6645.5	6646.0	100	Calcirudite with calcilutite phenoclasts; stylolites between phenoclasts, vertical fractures, some contain black claystone; fusulinids common, Foraminifera other than fusulinids, crinoids, and corals rare.
6646.0	6647.7	58	Calcarenite, stylolites, vertical fractures; vugular and open-fracture porosity; corals, crinoids, ostracods, and Foraminifera rare.
6647.7	6648.2	100	Calcilutite, stylolites, vertical fractures, some contain brown clayey material, vugular and open-fracture porosity; corals, Foraminifera, crinoids rare.
6648.2	6649.5	77	Calcirudite with calcilutite phenoclasts as much as 8 cm long; stylolites, vertical fractures; vugular and open-fracture porosity; crinoids, corals, ostracods, fusulinids, and Foraminifera other than fusulinids rare.
6649.5	6650.3	100	Calcilutite, patches of clear crystalline calcite; open oblique fractures, vertical fractures filled with calcite; Foraminifera, corals, and crinoids rare.

6650.3	6650.8	100	Calcirudite, calcilutite phenoclasts as much as 8 cm long; stylolites containing pyrite; fractures with no general orientation; crinoids, bryozoans, and Foraminifera rare.
6650.8	6653.4	100	Calcilutite, cement from 6652.6–6653.4 feet is crystalline calcite; stylolites contain pyrite, vertical, oblique, and horizontal fractures, some are open, others are calcite-filled; crinoids, Foraminifera other than fusulinids common, brachiopods, fusulinids, bryozoans, and corals rare.
6653.4	6657.4	100	Calcarenite, medium to coarse grained with occasional phenoclasts of calcilutite as much as 3 cm long; stylolites; horizontal, oblique, and vertical fractures; some vertical fractures are filled with crystalline calcite; crinoids common, ostracods and bryozoans rare.
6657.4	6659.1	?	Encrinite.
6659.1	6659.8	100	Calcirudite, phenoclasts of calcilutite, top half is calcarenite as above; stylolites; horizontal and vertical fractures, vertical fractures are calcite-filled; crinoids common, fusulinids and other Foraminifera rare.
6659.8	6661.5	100	Calcarenite, coarse grained with scattered calcilutite phenoclasts, 40 percent of the phenoclasts are 72 mm; large crinoid fragments common; stylolites; horizontal, oblique, and vertical fractures, oblique fractures filled with calcite; crinoids common, bryozoans, brachiopods, and corals rare.
6661.5	6661.8	100	Calcirudite; calcilutite phenoclasts as much as 4 cm long; stylolites; horizontal and vertical fractures, some of which are filled with calcite; crinoids common, brachiopods rare.
6661.8	6662.0	100	Calcilutite; stylolites; horizontal and vertical fractures; crinoids common, brachiopods rare.
6662.0	6667.1	?	Calcarenite, coarse grained with lime mud matrix, 10 to 30 percent consists of phenoclasts coarser than 2 mm some of which are as much as 6 cm long; stylolites; horizontal, oblique, and vertical fractures, vugular porosity, some vugs have drusy calcite lining; crinoids common, brachiopods, corals, bryozoans, and fusulinids rare.
6667.1	6670.0	93	Calcirudite; calcarenite and calcilutite phenoclasts as much as 8 cm long in a lime mud matrix; stylolites; oblique and vertical fractures, some are open; vugular and open-fracture porosity; crinoids common, brachiopods, fusulinids, corals, and bryozoans rare.
6670.0	6670.5	100	Calcarenite, coarse grained, occasional phenoclasts; horizontal fractures; crinoids common, fusulinids and corals rare.
6670.5	6671.5	73	Calcirudite with calcarenite and calcilutite phenoclasts as much as 5 cm long in a calcilutite matrix; stylolites; vertical, oblique, and horizontal fractures; vugular porosity; crinoids common, ostracods, corals, fusulinids, and Foraminifera other than fusulinids rare.
6671.5	6675.4	100	Calcarenite, coarse to fine grained and calcirudite with phenoclasts of fine-grained calcarenite as much as 5 cm long; stylolites; horizontal and vertical fractures; vugular porosity, some vugs contain drusy calcite; crinoids common, Foraminifera other than fusulinids rare.
6675.4	6675.8	100	Calcirudite with calcilutite and calcarenite phenoclasts as much as 6 mm long in a fine-grained calcarenite matrix; stylolites; vugular porosity; brachiopods common, crinoids, fusulinids, Foraminifera other than fusulinids, and corals rare.
6675.8	6676.2	100	Calcarenite, coarse grained to fine grained; stylolites; crinoids common, fusulinids and brachiopods rare.
6676.2	6678.5	100	Calcirudite with calcarenite and calcilutite phenoclasts as much as 6 cm long; stylolites with black claystone coating, stylolites along fragment boundaries, vertical fractures; vugular porosity; crinoids, corals, ostracods, fusulinids, and Foraminifera other than fusulinids rare.
6678.5	6679.1	100	Calcarenite, coarse grained, and calcirudite composed of phenoclasts as much as 6 mm in diameter; vertical fractures; vugular porosity; crinoids, fusulinids, corals, and Foraminifera other than fusulinids rare.
6679.1	6681.7	100	Calcilutite with calcarenite lenses which constitute about 45 percent of core; stylolites, vertical fractures, some are open; vugular and open-fracture porosity; corals, fusulinids, and crinoids rare.

6681.7	6684.0	00	
6684.0	6684.8	100	Calcirudite with phenoclasts of calcilutite and fine-grained calcarenite as much as 5 cm long; stylolites; vugular porosity; crinoids, brachiopods, Foraminifera rare.
6684.8	6685.2	100	Calcarenite, very fine grained; stylolites, vertical fractures; vugular porosity; crinoids, fusulinids, corals, and bryozoans rare.
6685.2	6688.0	71	Calcirudite with phenoclasts of calcilutite and calcarenite (some with crystalline calcite cement) as much as 8 cm long; stylolites, vugs, vertical and horizontal fractures, vertical fractures open; fusulinids and crinoids rare.
6688.0	6688.5	100	Calcarenite, very fine to fine grained, 35 percent of grains coarser than 2 mm, phenoclasts of calcilutite as much as 12 mm in diameter; stylolites, fissures, horizontal fractures; vugular porosity.
6688.5	6688.9	100	Calcirudite, phenoclasts as much as 3 cm long in matrix of fine-grained calcarenite; stylolites, vertical fractures; vugular porosity; fusulinids and crinoids rare.
6688.9	6718.0	82	Calcarenite, fine to coarse grained, occasional phenoclasts as much as 5 cm in diameter; stylolites; vertical, oblique, and horizontal fractures, some open, some calcite-filled; vugular and open-fracture porosity, some vugs are calcite-filled; crinoids occasional to common, fusulinids, Foraminifera other than fusulinids, corals, ostracods, bryozoans, and brachiopods rare to occasional.
6718.0	6718.5	100	Calcirudite, calcarenite phenoclasts as much as 8 cm long; stylolites; crinoids very common, fusulinids rare.
6718.5	6718.8	100	Calcarenite, fine grained; stylolites; calcite-filled vugs, crinoids, fusulinids, and brachiopods rare.
6718.8	6727.0	?	Calcilutite with phenoclasts at 6719.4–6719.7 feet; phenoclasts of calcilutite as much as 6 cm in diameter at 6719.3–6719.7 feet; stylolites coated with reddish-brown claystone, vertical, horizontal, and oblique joints and irregular fractures, some fractures are open, some are calcite-filled; crinoids, ostracods, bryozoans, corals, Foraminifera other than fusulinids, and brachiopods rare.
6727.4	6734.0	100	Calcilutite, approaching very fine-grained calcarenite, with thin calcarenite lenses; stylolites with coating of black claystone, irregular fractures; some calcite-filled; fractures and vugs; crinoids, Foraminifera other than fusulinids, corals, brachiopods, ostracods, and fusulinids rare.
6734.0	6753.0	66	Calcarenite generally very fine to fine grained but with occasional coarse material and oolites; stylolites coated with black claystone, irregular fractures and vertical joints, some open, some filled with calcite; others have drusy lining; open-fissure and vugular porosity; crinoids, fusulinids, corals, brachiopods rare.
6753.0	6754.8	100	Calcilutite, approaches a very fine-grained calcarenite, stylolites coated with black claystone; vertical, horizontal, and irregular fractures, fissures; calcite-filled fractures and fissures; fusulinids and brachiopods common, crinoids, ostracods, and corals rare.
6754.8	6756.9	100	Calcarenite, very fine to fine grained, grayish-white chert layer at 6756.5 feet, bluish-white bands of chert containing small pyrite particles at 6756.7 feet; stylolites with black claystone coating, chert bounded by stylolite, vertical and horizontal fractures; crinoids, fusulinids, and brachiopods rare.
6756.9	6757.3	100	Chert with calcilutite as a minor constituent; numerous fractures and fissures; fusulinids and crinoids rare.
6757.3	6758.0	100	Calcarenite, very fine grained, bluish-white chert layer 12 mm thick at base of core; stylolite with black claystone coating, small amount of bluish-white chert around stylolite; brachiopods and fusulinids common, crinoids rare.
6758.0	6759.0	100	Calcilutite, chert band 25 mm wide near top of zone, stylolites with claystone coating; fusulinids common, crinoids rare.
6759.0	6759.6	100	Calcirudite with calcilutite matrix, partly silicified; stylolites; fusulinids rare.
6759.6	6760.0	100	Calcirudite, band of chert 12 mm thick; stylolites; fusulinids and crinoids rare.

6760.0	6764.0	100	Calcarenite, very fine grained; stylolites, conchoidal fracture; fusulinids and crinoids common, bryozoans rare.
6764.0	6766.0	00	
6766.0	6769.4	88	Calcarenite, coarse grained, crinoidal; stylolites, vertical fractures.
6769.4	6773.0	83	Calcarenite, medium to coarse grained; stylolites; fusulinids common, crinoids rare.
6773.0	6782.7	00	
6782.7	6785.7	100	Calcarenite, fine to medium grained; stylolites; pinpoint and vugular porosity; crinoids, fusulinids, and corals rare.
6785.7	6786.1	100	Calcirudite, fossil fragments in a groundmass of fine- to medium-grained calcarenite; stylolites; pinpoint porosity; fusulinids common, crinoids and bryozoans rare.
6786.1	6788.5	100	Calcarenite, coarse grained; stylolites; pinpoint porosity; fusulinids and crinoids common, bryozoans and brachiopods rare.
6788.5	6789.3	74	Calcirudite to medium-grained calcarenite; branching stylolites; crinoids abundant.
6789.3	6796.0	33	Calcarenite, fine to coarse grained; stylolites, vugs filled with crystalline calcite; crinoids common.
6796.0	6812.9	91	Calcarenite, medium grained, a band of chert 18 mm thick at 6798.5 feet; stylolites, some have claystone coating which rarely contains pyrite, chert along stylolite at 6803.0 feet; incipient vertical fractures; crinoids and fusulinids common, ostracods, bryozoans rare.
6812.9	6821.2	80	Calcarenite, fine grained, patches of chert as much as 1.2 cm in diameter at 6815.5, 6817.0, and 6821.2 feet; stylolites; fusulinids and Foraminifera other than fusulinids rare.
6821.2	6831.2	97	Calcarenite, medium grained, large patches of chert as much as 5 cm long at 6821.2 feet; stylolites, incipient vertical fractures; crinoids and fusulinids rare.
6831.2	6832.9	100	Calcirudite, large crinoid fragments are phenoclasts in a medium-grained calcarenite groundmass; stylolites; crinoids, fusulinids, and Foraminifera other than fusulinids common.

Pan-American Producing Company No. 2 Davis
(Pl. 9, well 98)

Location: 467 feet from the north and east lines of sec. 249, blk. 97, Houston and Texas Central survey, Scurry County.
Elevation: 2446 feet K. B.
Cored interval: 6584.0 to 6808.0 feet subsurface.
Top of reef: 6562 feet subsurface.
Fusulinids of Wolfcamp age were found in rocks between 6609 and 6785 feet subsurface. Fusulinids of Cisco age were found at 6808 feet subsurface.

CORE DESCRIPTION

Depths (feet) From	To	Available core (percent)	Description
6584.0	6585.4	57	Calcirudite, composed of calcilutite phenoclasts as much as 2 cm in diameter in a matrix of calcarenite, claystone stringers, leached; vertical joints with claystone filling; vugular porosity, vugs as much as 5 mm in diameter.
6585.4	6614.0	58	Calcilutite, calcarenite zones, leached, occasional angular calcarenite phenoclasts as much as 3 cm in diameter, claystone bands 5 mm thick; stylolites, vertical joints, some joints open; vugular and open-joint porosity, many vugs contain drusy calcite and bituminous claystone filling, vugs as much as 6 cm in diameter; crinoids and brachiopods rare to abundant, corals, gastropods, and bryozoans rare.
6614.0	6615.6	95	Calcarenite, leached; bryozoans common.
6615.6	6616.0	100	Calcilutite, calcarenite-claystone zones as much as 3 mm thick, leached; stylolites, calcite-filled, oblique and vertical joints; drusy calcite in vugs, vugs as much as 4 mm in diameter.
6616.0	6621.0	00	
6621.0	6624.6	70	
6624.6	6627.0	00	
6627.0	6630.7	57	
6630.7	6632.0	85	Calcarenite, leached, contains calcilutite lenses; stylolites, vertical joints filled with calcite and bituminous material; vugular porosity, drusy calcite in vugs; crinoids common, brachiopods rare.

6632.0	6634.0	60	Calcilutite with calcarenite lenses; stylolites, vertical joints; crinoids very common, brachiopods common.
6634.0	6671.0	00	
6671.0	6676.5	85	Calcarenite, very fine grained with calcilutite lenses, leached; stylolites, oblique joints; vugs with drusy calcite; crinoids common, fusulinids and brachiopods rare.
6676.5	6680.0	91	Calcilutite, leached; vertical joints, some calcite-filled; vugular porosity, drusy calcite in vugs.
6680.0	6683.6	81	Calcarenite, containing calcilutite lenses as much as 1 foot thick, leached, clay-coated stylolites, oblique and vertical joints; vugular porosity, some vugs contain drusy calcite; crinoids common to very common.
6683.6	6686.0	00	
6686.0	6694.6	81	
6694.6	6696.0	100	Calcilutite, vertical joints; vugular porosity, some vugs contain drusy calcite; crinoids and brachiopods common, corals and bryozoans rare.
6696.0	6710.0	94	Calcarenite, bioclastic, leached, one greenish-gray claystone phenoclast noted; stylolites, vertical joints; vugs as much as 4 cm in diameter containing drusy calcite and dolomite; crinoids common to very common, brachiopods and bryozoans rare to common, corals, fusulinids, and gastropods rare.
6710.0	6723.0	00	
6723.0	6727.2	74	
6727.2	6728.5	46	Calcirudite, leached, contains phenoclasts as much as 4 cm in diameter, calcite-filled fissure; drusy vugs; crinoids common, fusulinids and bryozoans rare.
6728.5	6734.9	75	Calcarenite, fine to medium grained, bioclastic, with calcilutite lenses as much as 5 inches thick; stylolites, vertical joints; vugs with drusy calcite; crinoids common, bryozoans, brachiopods, and fusulinids rare.
6734.9	6740.0	59	Calcirudite with subangular phenoclasts of calcarenite and calcilutite; stylolites, calcite-filled vertical and oblique joints; vugular porosity; crinoids common, brachiopods rare.
6740.0	6743.0	33	Calcilutite; stylolites, calcite-filled oblique fissures; vugs as much as 1.5 cm in diameter with drusy calcite; crinoids and bryozoans rare.
6743.0	6750.0	00	
6750.0	6756.1	85	
6756.1	6757.2	64	Calcarenite, leached; stylolites, vertical joints; claystone-filled cavities; crinoids and bryozoans common.
6757.2	6758.4	50	Calcilutite, leached; claystone-coated stylolites; crinoids.
6758.4	6759.5	100	Calcirudite, leached; calcilutite phenoclasts as much as 2.5 cm in diameter; stylolites; vugs as much as 2.5 cm in diameter, containing drusy dolomite crystals; brachiopods common.
6759.5	6768.1	76	Calcilutite, rounded to subrounded calcilutite phenoclasts, fine-grained calcarenite lenses, leached; stylolites, vertical joints; vugs with drusy calcite; crinoids common to abundant, bryozoans and brachiopods rare.
6768.1	6770.5	75	Calcirudite, subrounded phenoclasts of calcilutite and calcarenite; stylolites, vertical joints with calcite filling; crinoids common to very common, brachiopods rare.
6770.5	6772.0	60	Calcilutite; calcite-filled vertical and oblique joints; fusulinids, crinoids, and brachiopods rare.
6772.0	6774.0	00	
6774.0	6777.3	94	Calcarenite, coarse grained; stylolites, vertical joints, some joints are calcite-filled, others have a drusy calcite veneer; vugs as much as 3 mm in diameter; crinoids very common, brachiopods and corals rare.
6777.3	6779.9	92	Calcilutite, vertical joints, bituminous claystone (?) filling in joints; vugs as much as 5 cm with drusy calcite and bituminous claystone (?) fillings; crinoids common to very common, fusulinids, brachiopods, bryozoans, and corals rare.
6779.9	6780.9	00	
6780.9	6784.8	90	
6784.8	6804.0	92	Calcarenite, fine to coarse grained, leached, earthy, occasional calcilutite phenoclasts as much as 4 mm in diameter and claystone fragments; pinpoint and vugular porosity; drusy calcite in vugs; crinoids common to very common, fusulinids common, brachiopods rare.
6804.0	6805.0	100	Calcirudite, phenoclasts of coarse crinoidal debris in a very fine-grained calcarenite matrix, leached; pinpoint porosity; fusulinids and crinoids common, bryozoans occasional.
6805.0	6808.0	53	Calcarenite, very fine grained, occasional angular calcilutite phenoclast, leached, earthy; stylolites; pinpoint and vugular porosity; crinoids common to very common, fusulinids common, bryozoans rare.

PHILLIPS PETROLEUM COMPANY No. 4 MEBANE
(Pl. 9, well 194)

Location: 467 feet from north and west lines of sec. 210, blk. 97, Houston and Texas Central survey, Scurry County.
Elevation: 2444 feet K. B.
Cored interval: 6699.0 to 6928.0 feet subsurface.
Top of reef: 6681 feet subsurface.
Fusulinid data indicate the following horizons are represented in this core: Cisco—6713 to 6784 feet subsurface; Canyon—6806 to 6925 feet subsurface.

CORE DESCRIPTION

Depths (feet) From	To	Available core (percent)	Description
6690.0	6699.4	100	Calcarenite, bioclastic; stylolites, fractures; leached along fractures; crinoid fragments.
6699.4	6719.5	99	Calcirudite, calcilutite phenoclasts in calcilutite matrix; leached stylolites, vertical fractures; pinpoint porosity and leaching along fractures; crinoids and fusulinids rare.
6719.5	6721.0	100	Calcilutite, bioclastic; leached stylolites.
6721.0	6722.5	100	Calcarenite, bioclastic; stylolites; crinoids rare.
6722.5	6725.5	100	Calcirudite, phenoclasts of calcarenite and calcilutite, stylolitic contacts between phenoclasts.
6725.5	6736.0	100	Calcarenite, bioclastic, leached; stylolites; vugular and pinpoint porosity; fusulinids abundant in zones, crinoids.
6736.0	6738.0	00	
6738.0	6744.0	100	Calcilutite, bioclastic; stylolites; vugular and pinpoint porosity; fusulinids rare.
6744.0	6753.0	100	Calcarenite, bioclastic, leached; stylolites; pinpoint and vugular porosity; fusulinids.
6753.0	6754.5	100	Calcirudite, stylolitic contacts between phenoclasts.
6754.5	6756.0	100	Calcilutite, bioclastic; lenses of calcarenite, incipient stylolites.
6756.0	6759.0	100	Calcirudite, slightly leached; stylolites; pinpoint porosity.
6759.0	6762.0	100	Calcilutite, bioclastic; stylolites; pinpoint porosity; fusulinids.
6762.0	6763.5	100	Calcirudite, stylolitic contacts between phenoclasts; stylolites.
6763.5	6769.5	100	Calcilutite, bioclastic with interbedded calcarenite; stylolites; fusulinids and crinoids.
6769.5	6771.0	100	Calcirudite, stylolitic contacts between phenoclasts.
6771.0	6784.5	100	Calcilutite, bioclastic; stylolites; pinpoint porosity; fusulinids and crinoids.
6784.5	6793.5	100	Calcarenite, bioclastic; calcilutite lenses; stylolites; pinpoint and vugular porosity; crinoids.
6793.5	6799.5	100	Calcirudite, stylolites, some stylolitic control of leaching; crinoids.
6799.5	6804.0	100	Calcilutite, stylolites, stylolitic control of leaching; pinpoint porosity.
6804.0	6805.5	100	Calcirudite, calcilutite phenoclasts in a calcilutite matrix; stylolites, filled fissures; crinoids, coral and shell fragments.
6805.5	6813.0	100	Calcarenite, very fine grained, bioclastic with calcilutite lenses and occasional calcilutite phenoclasts; stylolites, fissures enlarged by leaching; pinpoint porosity; fusulinids, crinoids, bryozoans, and coral.
6813.0	6816.0	57	Calcilutite, bioclastic; stylolites, vertical joints; fusulinids and crinoids.
6816.0	6823.5	100	Calcirudite, calcilutite phenoclasts as much as 5 cm in diameter in a matrix of very fine-grained calcarenite, stylolitic contacts between phenoclasts, argillaceous zones; stylolites, vertical joints; crinoids, fusulinids, and brachiopods.
6823.5	6827.5	100	Calcarenite, with very fine-grained argillaceous bands; stylolites, vertical joints; fusulinids, other Foraminifera, and shell fragments.
6827.5	6859.0	100	Calcilutite, bioclastic; calcarenite lenses as much as 1.5 inches thick and argillaceous bands; claystone stringers 1 inch thick; stylolites, vertical joints, calcite-filled fissures; fusulinids very common; crinoids, brachiopods, and shell fragments.
6859.0	6867.5	100	Calcarenite, bioclastic, leached; stylolites, vertical joints; pinpoint porosity; fusulinids very common, crinoids and shell fragments common.

6867.5	6891.0	100	Calcirudite, calcilutite phenoclasts in a calcilutite matrix; stylolites, vertical joints, calcite-filled fissures; occasional small open fissures, pinpoint porosity; fusulinids, crinoids, and shell fragments common and brachiopods rare.
6891.0	6901.5	?	Calcilutite, leached, with very fine-grained calcarenite lenses; stylolites, vertical joints, some open fissures, calcite-filled fissures; pinpoint and vugular porosity, vugs as much as 4 mm in diameter; crinoids are common and shell fragments occasional.
6901.5	6910.5	100	Calcarenite, leached; stylolites, vertical joints, some open fissures; pinpoint porosity; fusulinids very common, crinoids and shell fragments common.
6910.5	6918.0	100	Calcilutite, with argillaceous bands, contains a few large calcilutite phenoclasts and claystone stringers; claystone-coated stylolites, vertical joints, open fissures, some enlarged by leaching; fusulinids, shell fragments, and crinoids occasional to common, bryozoans scattered.
6918.0	6919.5	00	
6919.5	6928.0	100	

SUN OIL COMPANY NO. 1 BRICE
(Pl. 9, well 177)

Location: 467 feet from north and west lines of S½ sec. 392, blk. 97, Houston and Texas Central survey, Scurry County.
Elevation: 2439 feet subsurface.
Cored interval: 6586.0 to 6687.0 feet subsurface.
Top of reef: 6558 feet subsurface.
Fusulinids of Wolfcamp age and reworked fusulinids of Canyon age were found throughout this core.

CORE DESCRIPTION

Depths (feet) From	To	Available core (percent)	Description
6586.0	6619.0	79	Calcarenite, fine to medium grained, bioclastic, angular calcilutite, slightly leached phenoclast 4 cm in diameter; clay-coated stylolites, vertical joints; calcite-filled fissures; pinpoint and vugular porosity, some vugs have drusy calcite, vug diameter as much as 2 cm; crinoids common, fusulinids, brachiopods, and bryozoans; trilobites rare.
6619.0	6649.0	76	Calcilutite, claystone stringers 1 mm thick, bioclastic, leached, earthy; stylolites, vertical joints, some joints enlarged by leaching; vugular, pinpoint and open-joint porosity, some vugs are 4 cm in diameter and are lined with drusy calcite; crinoids common and fusulinids and brachiopods rare.
6648.0	6663.0	49	Calcarenite, very fine to medium grained, bioclastic, bioclastic calcilutite zones as much as 1 foot thick, leached, earthy appearance, shaly lime zone 4 cm thick; finely vugular; crinoids very common.
6663.0	6675.0	62	Calcilutite, bioclastic, many branching claystone stringers, very fine-grained calcarenite lenses as thick as half an inch, partly leached, earthy; vertical joints, some enlarged by leaching; vugular and open-joint porosity, vugs as large as 2 cm in diameter; crinoids.
6675.0	6687.0	58	Calcarenite, fine to medium grained, bioclastic, leached, earthy; incipient vertical joints, some enlarged by leaching; vugular and open-joint porosity, vugs as above; crinoids are common.

Sun Oil Company No. 10 Brice
(Pl. 9, well 64)

Location: 2173 feet from north line, 660 feet from east line of sec. 385, blk. 97, Houston and Texas Central survey, Scurry County.
Elevation: 2499 feet K. B.
Cored interval: 6950.0 to 7456.0 feet subsurface.
Top of reef: 6930 feet subsurface.

CORE DESCRIPTION

Depths (*feet*) From	To	Available core (*percent*)	Description
6950.0	6965.0	72	Calcarenite, fine to medium grained, calcilutite lenses less than 3 feet thick, leached; incipient stylolites with bituminous or claystone coating; vugular porosity, some vugs contain drusy calcite; crinoids, bryozoans, brachiopods, and fusulinids very common near base.
6965.0	6968.0	00	
6968.0	6974.0	42	Calcilutite, bioclastic; incipient stylolites with claystone or bituminous coating; vugular and pinpoint porosity, vugs as much as 1 mm in diameter; fusulinids, crinoids, bryozoans, and brachiopods.
6974.0	6976.0	00	
6976.0	6985.0	73	Calcarenite; fine to medium grained, occasional angular phenoclast of calcilutite as much as 2 cm in diameter, shaly limestone zone 0.4 feet thick at 6982 feet, leached, earthy in spots; stylolites; vugular and pinpoint porosity, vugs as much as 1 mm in diameter; crinoids, fusulinids, and brachiopods.
6985.0	7007.0	00	
7007.0	7025.0	62	Calcarenite, very fine to medium grained; stylolites, with claystone or bituminous coating, some leaching along stylolites, vertical joints, open fissures, some fissures have 1–2 mm opening; pinpoint, vugular, and open-fissure porosity, vugs as much as 1 cm in diameter; crinoids and fusulinids.
7025.0	7377.0	00	
7377.0	7386.0	59	Calcarenite, very fine grained, leached, earthy; stylolites, vugular porosity, vugs as much as 2 cm in diameter; crinoids, bryozoans, gastropods, and echinoid spines.
7386.0	7389.0	00	
7389.0	7395.0	55	Calcarenite, as at 7377 to 7386 feet.
7395.0	7423.0	00	
7423.0	7432.0	65	Calcilutite, fragmental material leached, matrix not leached; dark-gray chert lenses, claystone layers, leached, earthy; stylolites; vugular porosity; vugs as much as 2 mm in diameter; crinoids, bryozoans, and brachiopods.
7432.0	7437.0	80	Calcarenite; vertical joints; vugular porosity, vugs as much as 5 mm in diameter; crinoids.
7437.0	7438.0	00	
7438.0	7456.0	52	Calcarenite, contains occasional calcilutite and calcarenite phenoclasts, claystone layers 0.4 feet thick at 7453 feet; stylolites, vertical joints; vugular porosity, vugs as much as 5 mm in diameter; crinoids, brachiopods, and fusulinids.

SUN OIL COMPANY NO. 1 FENTON
(Pl. 9, well 122)

Location: 1998 feet from north line, 660 feet from west line of sec. 194, blk. 97, Houston and Texas Central survey, Scurry County.
Elevation: 2344 feet K. B.
Cored interval: 6612.0 to 6698.0 feet subsurface.
Top of reef: 6593 feet subsurface.
Fusulinids of Canyon age occur between 6625 and 6644 feet subsurface.

CORE DESCRIPTION

Depths (feet) From	To	Available core (percent)	Description
6612.0	6648.0	33	Calcilutite, slightly leached, thin calcarenite layers as much as 1 foot thick, occasional subangular to subrounded calcilutite phenoclasts as much as 2 cm in diameter; occasional ramifying claystone stringers as much as $1\frac{1}{4}$ inch thick; stylolites with claystone coating, well-developed oblique and vertical joints, some joints are open; vugular, pinpoint, and open-joint porosity; fusulinids and crinoids common, brachiopods and bryozoans rare.
6648.0	6666.0	00	
6666.0	6669.0	33	
6669.0	6675.0	00	
6675.0	6687.0	33	
6687.0	6690.0	00	
6690.0	6698.0	33	

SUN OIL COMPANY NO. 1 ROSENBERG
(Pl. 9, well 118)

Location: 660 feet from north line and 330 feet from west line of the N½ sec. 195, blk. 97, Houston and Texas Central survey, Scurry County.
Elevation: 2404 feet K. B.
Cored interval: 6779.0 to 6817.0 feet subsurface.
Top of reef: 6758 feet subsurface.
Fusulinids of early Cisco age were found in rocks from 6782 to 6809 feet subsurface.

CORE DESCRIPTION

Depths (feet) From	To	Available core (percent)	Description
6779.0	6782.0	33	Calcarenite, very fine grained; slightly leached; stylolites; vugular porosity; fusulinids common.
6782.0	6785.0	60	Calcilutite, debris leached; stylolites, vertical joints; pinpoint and vugular porosity; fusulinids.
6785.0	6800.0	66	Calcarenite, fine to medium grained; stylolites, incipient vertical joints; fissures, joints, and fissures enlarged by leaching; vugular, open-joint, and open-fissure porosity; fusulinids common, bryozoans.
6800.0	6803.0	93	Calcilutite and very fine-grained calcarenite; stylolites; fusulinids common.
6803.0	6809.0	00	
6809.0	6817.0	?	Calcilutite, incipient stylolites, incipient vertical joints; fusulinids rare to occasional.

WILSHIRE OIL COMPANY NO. 8 LUNSFORD
(Pl. 9, well 90)

Location: 467 feet from north and west lines, sec. 253, blk. 97, Houston and Texas Central survey, Scurry County.

Elevation: 2451 feet K. B.

Cored interval: 6741 to 6945 feet subsurface.

Top of reef: 6789 feet subsurface.

Fusulinid data indicate the following horizons are represented in this core: Wolfcamp—6740 to 6875 feet subsurface; Cisco or Canyon—below 6875 feet subsurface.

CORE DESCRIPTION

Depths (*feet*) From	To	Available core (*percent*)	Description
6741.0	6762.0	95	Claystone, slightly limy; tough, breaks down readily; pyrite casts of fossils; conodonts, orbiculoids, echinoid spines, fish scales, brachiopods, cephalopods, and pelecypods.
6762.0	6796.0	6	Calcirudite, angular phenoclasts, claystone lenses; crinoids, fusulinids, and brachiopods common.
6796.0	6805.5	100	Calcarenite, medium to coarse grained, coarse crinoid fragments, claystone lenses; fusulinids and corals rare, crinoids and brachiopods common.
6808.5	6811.0	100	Calcirudite, phenoclasts of calcilutite and calcarenite as much as 1½ inches in diameter, claystone stringers ¼ inch thick; fusulinids and crinoids common, corals rare.
6811.0	6815.0	100	Calcarenite, fine to coarse grained, slightly argillaceous, occasional phenoclasts, claystone lenses and stringers, claystone fragments; crinoids, fusulinids, bryozoans, and corals occasional.
6815.0	6816.0	60	Calcirudite, phenoclasts as much as 1 inch in diameter in a calcilutite matrix.
6816.0	6820.4	100	Calcarenite, medium to coarse grained; silica in irregular masses, claystone lenses, occasional phenoclasts; crinoids common.
6820.4	6821.0	100	Calcirudite, as at 6815.0–6816.0 feet.
6821.0	6826.0	94	Claystone with calcarenite lenses; crinoids common, brachiopods and spines occasional.
6826.0	6827.0	100	Calcirudite, phenoclasts as much as 3 inches in diameter; calcarenite lens; fissures filled with calcite; corals, fusulinids, and crinoids occasional.
6827.0	6844.0	?	Calcarenite, medium to coarse grained; stylolites; crinoids common, fusulinids and brachiopods occasional.
6844.0	6875.0	00	
6875.0	6945.5	?	Calcarenite with calcilutite lenses; stylolites, vertical fractures; vugular and pinpoint porosity; crinoids common, fusulinids, bryozoans, brachiopods, and ostracods rare.

Plates 10–18

All figured specimens have been deposited at the United States National Museum, Washington, D.C.

PLATE 10

Calcilutite from the Horseshoe atoll

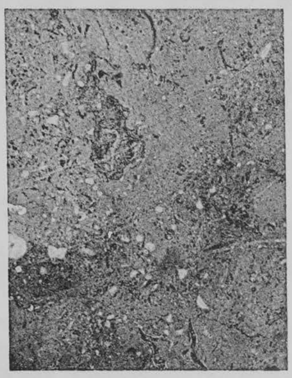
(PAGE 18)

A. Calcilutite containing fusulinids and crinoid stems, x¾. USNM 109199. (Ohio Oil Company No. 2 Hays, Scurry County, Texas, 4,278 feet below sea level.)

B. Calcilutite containing a stylolite and drusy vugs, x¾. USNM 109200. The indistinct mottling may be algal. (Wilshire Oil Company No. 1 Rinehart, Scurry County, Texas, 4,258 feet below sea level.)

C. Photomicrograph of a calcilutite, plane light, x30. USNM 109212. The larger fragments consist of unsorted organic debris. (General Crude Oil Company No. 3 Land, Scurry County, Texas, 4,295.5 feet below sea level.)

D. Photomicrograph of a bioclastic calcilutite, plane light, x10. USNM 109213. Note the fragment of a brachiopod shell near the base of the photograph. (Lion Oil Company No. 24 McLaughlin, Scurry County, Texas, 4,276 feet below sea level.)



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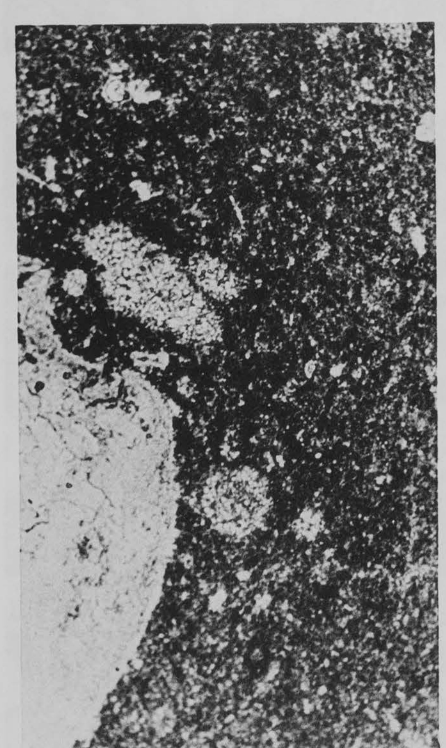

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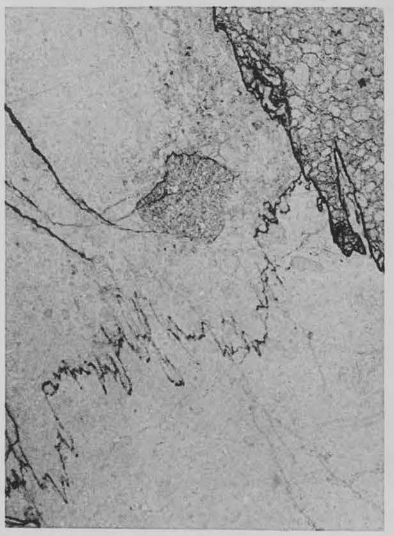

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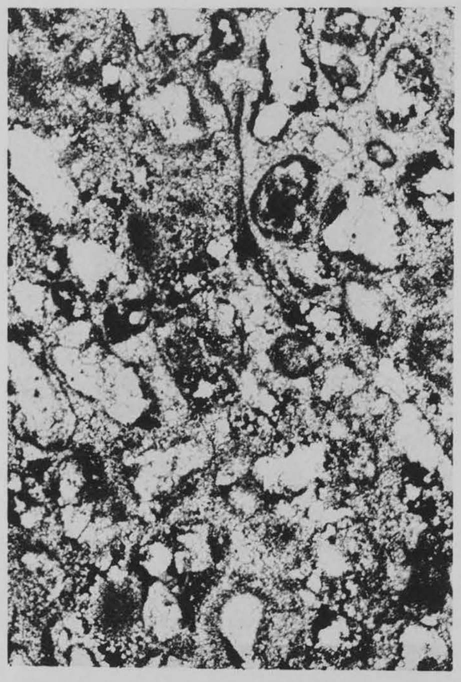

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PLATE 11

Calcarenite from the Horseshoe atoll

(PAGE 19)

A. Stylolitic contact between fragments of calcarenite, x¾. USNM 109211. The lighter colored rock is a fine-grained, somewhat leached calcarenite; the darker portion is a bioclastic calcarenite containing numerous fusulinid tests. Note the time relationships of the two stylolites. This rock may be a calcirudite; however, the fragments are so large that it cannot be determined from examination of the core whether one is fragment and one is matrix or whether both are fragments. (Wilshire Oil Company No. 1 Rinehart, Scurry County, Texas, 4,309 feet below sea level.)

B. Photomicrograph of a poorly sorted calcarenite, plane light, x30. USNM 109214. The interstitial fill in this rock is mostly lime mud. (Sun Oil Company No. 1 Brice, Scurry County, Texas, 4,179.5 feet below sea level.)

C. Photomicrograph of a well-sorted calcarenite, plane light, x30. USNM 109215. The interstitial fill in this rock is mostly crystalline calcite. (General Crude Oil Company No. 3 Land, Scurry County, Texas, 4,406.2 feet below sea level.)

D. Photomicrograph of an oolitic calcarenite, plane light, x30. USNM 109201. The material composing the oolites has been partially reorganized, causing them to have a somewhat indistinct appearance. The large rectangular object near the center of the photograph is a piece of unidentifiable organic debris. (General Crude Oil Company No. 193–4 Coleman, Kent County, Texas, 4,296 feet below sea level.)

PLATE 12

Calcirudite from the Horseshoe atoll

(PAGE 20)

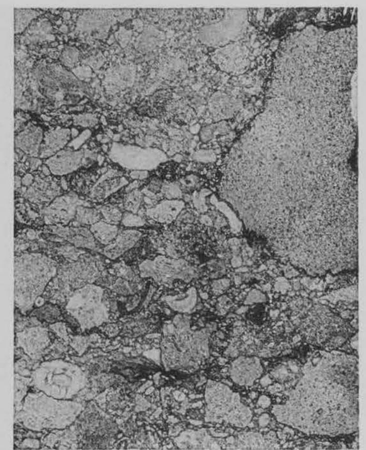
A. Medium-textured calcirudite composed of poorly sorted fragments of calcilutite, calcarenite, and fragments of fossils in a calcarenite matrix, x¾. USNM 109202. Note the stylolitic contacts between pebbles. (Montex Drilling Company No. 3 Country Club, Scurry County, Texas, 4,322 feet below sea level.)

B. Fine-textured calcirudite composed of moderately sorted fragments of calcilutite, calcarenite, shale, and fragments of fossils in a calcarenite matrix, x¾. USNM 109203. (Montex Drilling Company No. 3 Country Club, Scurry County, Texas, 4,318 feet below sea level.)

C. Bioclastic calcirudite (encrinite), x¾. USNM 109204. This rock is composed of crinoid columnals in a matrix of calcilutite. (Chapman & McFarlin Producing Company No. 25 Cogdell, Kent County, Texas, 4,396 feet below sea level.)

D. Photomicrograph of calcirudite, plane light, x10. USNM 109216. This rock is composed of angular to rounded fragments of shells, fusulinids, and pre-existing rocks in a matrix of calcilutite. (Montex Drilling Company No. 5 Joyce, Scurry County, Texas, 4,365 feet below sea level.)

E. Photomicrograph of a bioclastic calcirudite (encrinite), plane light, x10. USNM 109205. This rock is composed largely of crinoidal debris in a matrix of crystalline calcite. The fusulinid is a tangential section of *Paraschwagerina* sp. (Standard Oil Company of Texas No. 1 Pool, Gaines County, Texas, 5,318 feet below sea level.)



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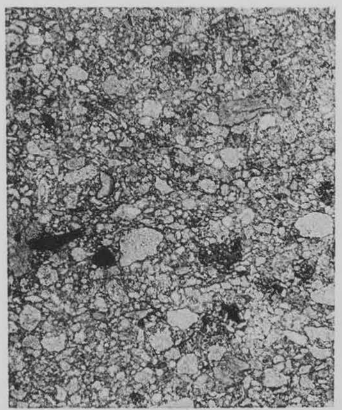

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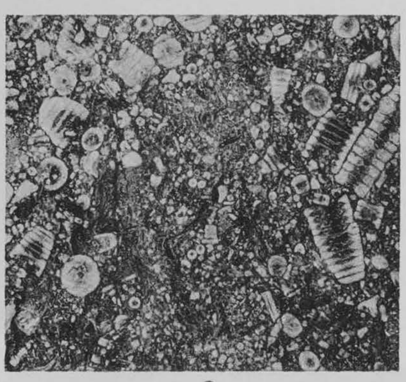

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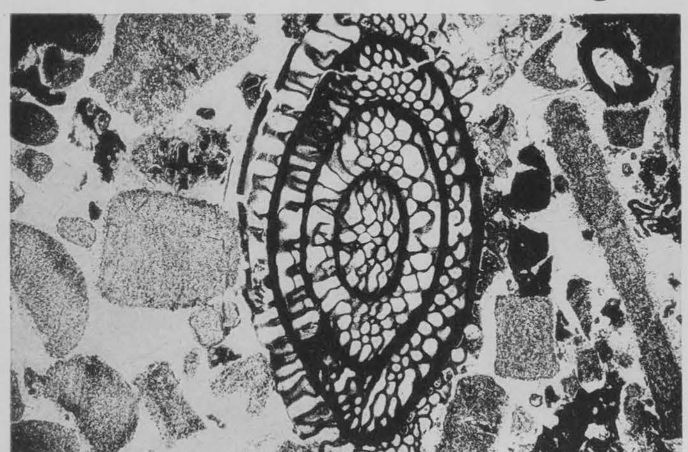

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PLATE 13

Shale in the Horseshoe atoll

(PAGE 20)

A. Shale which overlies the reef, x¾. USNM 109206. The bands of limestone represent debris that has been eroded from the high portions of the reef and mixed in with the shale at the time of deposition. The top of the reef in this well is at 4,252 feet below sea level. (Wilshire Oil Company No. 8 Lunsford, Scurry County, Texas, 4,221 feet below sea level.)

B. Claystone stringers in calcilutite, x¾. USNM 109207. These stringers are in part stylolitic (see vicinity of large crinoid stem near center of photograph). The branching nature of these stringers resembles the unraveled end of a rope. (Chapman & McFarlin Producing Company No. 25 Cogdell, Kent County, Texas, 4,154 feet below sea level.

C. Stylolitic claystone stringers in calcilutite, x¾. These stringers resemble stylolites with low amplitude. Note the fibrous bands of shale associated with the stringer. This mode of occurrence is quite common. (Ohio Oil Company No. 2 Hays, Scurry County, Texas, 4,278 feet below sea level.)

D. Photomicrograph of a calcareous claystone, plane light, x10. USNM 109217. The clear areas are calcite. (Cities Service Oil Company No. 3 Popnoe, Scurry County, Texas, 4,458.5 feet below sea level.)

E. Photomicrograph of a calcarenite containing numerous claystone stringers, plane light, x30. USNM 10218. (Sun Oil Company No. 1 Brice, Scurry County, Texas, 4,226 feet below sea level.)

PLATE 14

Miscellaneous rocks in the Horseshoe atoll

PAGE

A. Contact between chert and calcarenite, x¾. USNM 109208 21
The chert contains several vertical joints which stop at the contact. The clear areas in the chert represent fossils replaced with silica. (Ohio Oil Company No. 2 Hays, Scurry County, Texas, 4,363 feet below sea level.)

B. Stylolitic contact between chert and limestone, x¾. 21
(Sunray Oil Corporation No. 2-A Hardy, Scurry County, Texas, 4,387 feet below sea level.)

C. Stylolites in calcirudite, x¾. USNM 109209 20
(Montex Drilling Company No. 3 Harrell, Scurry County Texas, 4,414 feet below sea level.)

D. Photomicrograph of algal(?) material coating a fragment of pre-existing reef limestone, plane light, x10. USNM 109210 40
The dark material surrounding the lighter colored pebble is probably algal. (Humble Oil & Refining Company No. 2 McLaury, Kent County, Texas, 4,921 feet below sea level.)

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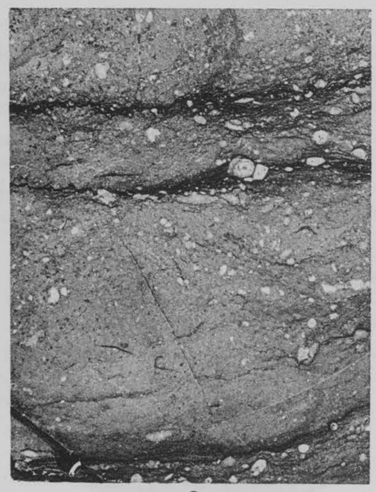

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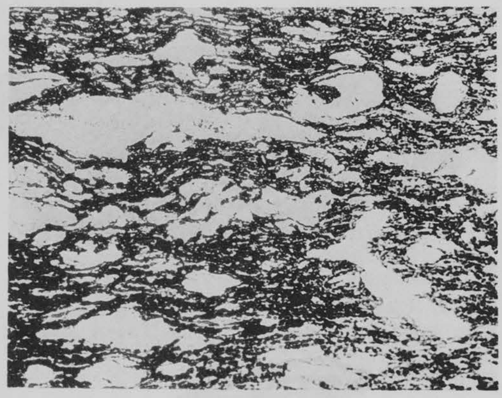

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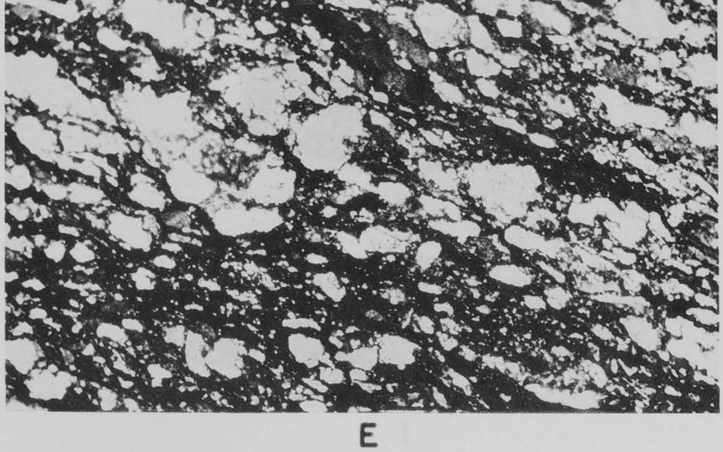

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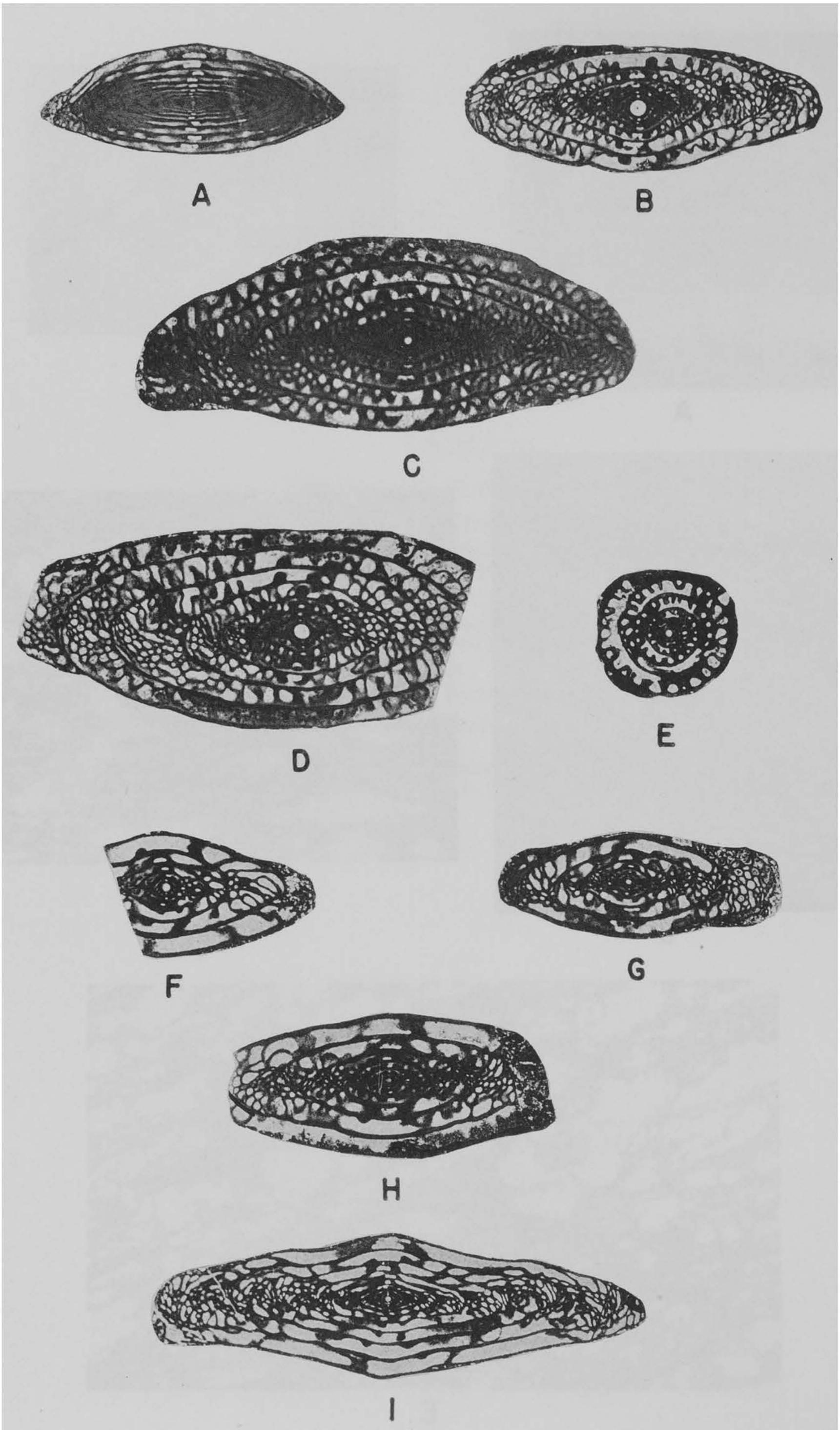
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PLATE 15

Fusulinidae of Strawn and lower Canyon age from the Horseshoe atoll (all x10)

(PAGE 46)

A. *Wedekindellina* sp., lower Strawn. USNM 119431. (Humble Oil & Refining Company No. 2 McLaury, Kent County, Texas, 4,964 feet below sea level.)

B. *Fusulina* sp., Strawn. USNM 119432. (General Crude Oil Company No. 13–6 Jones, Kent County, Texas, 4,229 feet below sea level.)

C. *Fusulina* sp., Strawn. USNM 119433. (Standard Oil Company of Texas No. 2–5 Brown, Scurry County, Texas, 4,718 feet below sea level.)

D-H. These figures illustrate a mixed fauna. All specimens from Humble Oil & Refining Company No. 1 L. R. Spires, Kent County, Texas, 4,672 feet below sea level.
- D. *Fusulina* sp., Strawn. USNM 119434.
- E. *Fusulina* sp., Strawn. USNM 119435.
- F. *Triticites* sp., Canyon. USNM 119436.
- G. *Triticites* sp., Canyon. USNM 119437.
- H. *Triticites* sp., Canyon. USNM 119438.

I. "*Wedekindellina*" aff. "*W.*" *ultimata* Newell and Keroher, basal Canyon. USNM 119439. (General Crude Oil Company No. 28 Hunt Trust-Young, Kent County, Texas, 4,486 feet below sea level.)

PLATE 16

Fusulinidae of Canyon and lower Cisco age from the Horseshoe atoll (all x10)

(PAGES 46–47)

A. *Triticites irregularis* (Staff), Canyon. USNM 119440. (Phillips Petroleum Company No. 4 Mebane, Scurry County, Texas, 4,430 feet below sea level.)

B. *Triticites irregularis* (Staff), Canyon. USNM 119441. (Montex Drilling Company No. 4 Joyce, Scurry County, Texas, 4,413 feet below sea level.)

C. *Triticites* cf. *T. ohioensis* Thompson, Canyon. USNM 119442. (Phillips Petroleum Company No. 4 Mebane, Scurry County, Texas, 4,481 feet below sea level.)

D. *Triticites* cf. *T. ohioensis* Thompson, Canyon. USNM 119443. (Phillips Petroleum Company No. 4 Mebane, Scurry County, Texas, 4,481 feet below sea level.)

E. *Triticites* sp., Home Creek. USNM 119444. This is a very early species of the group of *T. ventricosus*. (Cities Service Oil Company No. 6 Patterson, Scurry County, Texas, 4,304 feet below sea level.

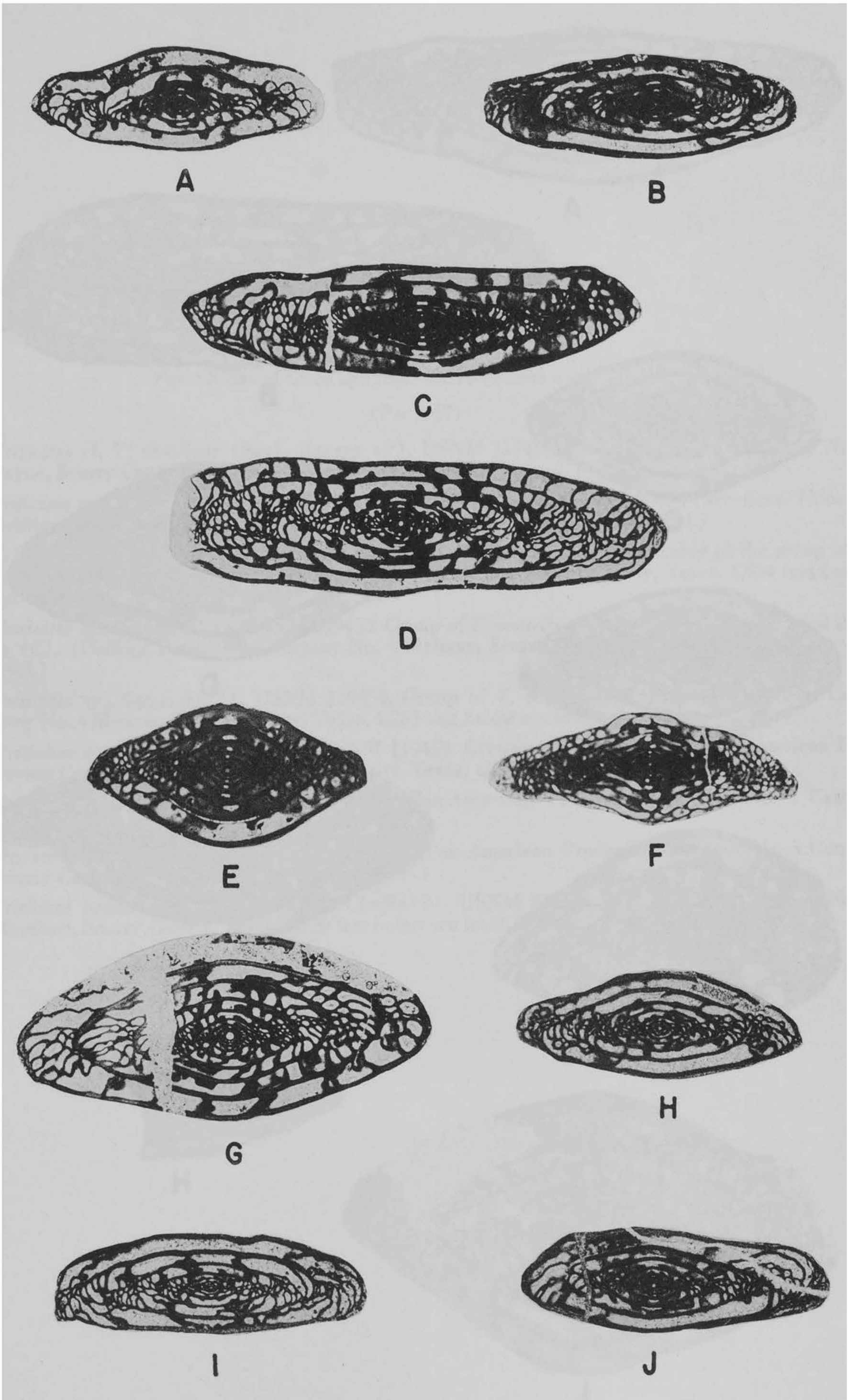
F. *Waeringella* aff. *W. spiveyi* Thompson, basal Cisco. USNM 119445. (Magnolia Petroleum Company No. 3-C Conrad, Scurry County, Texas, 4,446 feet below sea level.

G. *Triticites* sp., found associated with the *Waeringella* figured in (F). USNM 119446. (Magnolia Petroleum Company No. 3-C Conrad, Scurry County, Texas, 4,446 feet below sea level.)

H. *Triticites* sp., Bunger(?). USNM 119447. (General Crude Oil Company No. 193–4 Coleman, Kent County, Texas, 4,312 feet below sea level.)

I. *Triticites* sp., Bunger(?). USNM 119448. (General Crude Oil Company No. 193–4 Coleman, Kent County, Texas, 4,312 feet below sea level.)

J. *Triticites* sp., Bunger(?). USNM 119449. (General Crude Oil Company No. 193–4 Coleman, Kent County, Texas, 4,312 feet below sea level.)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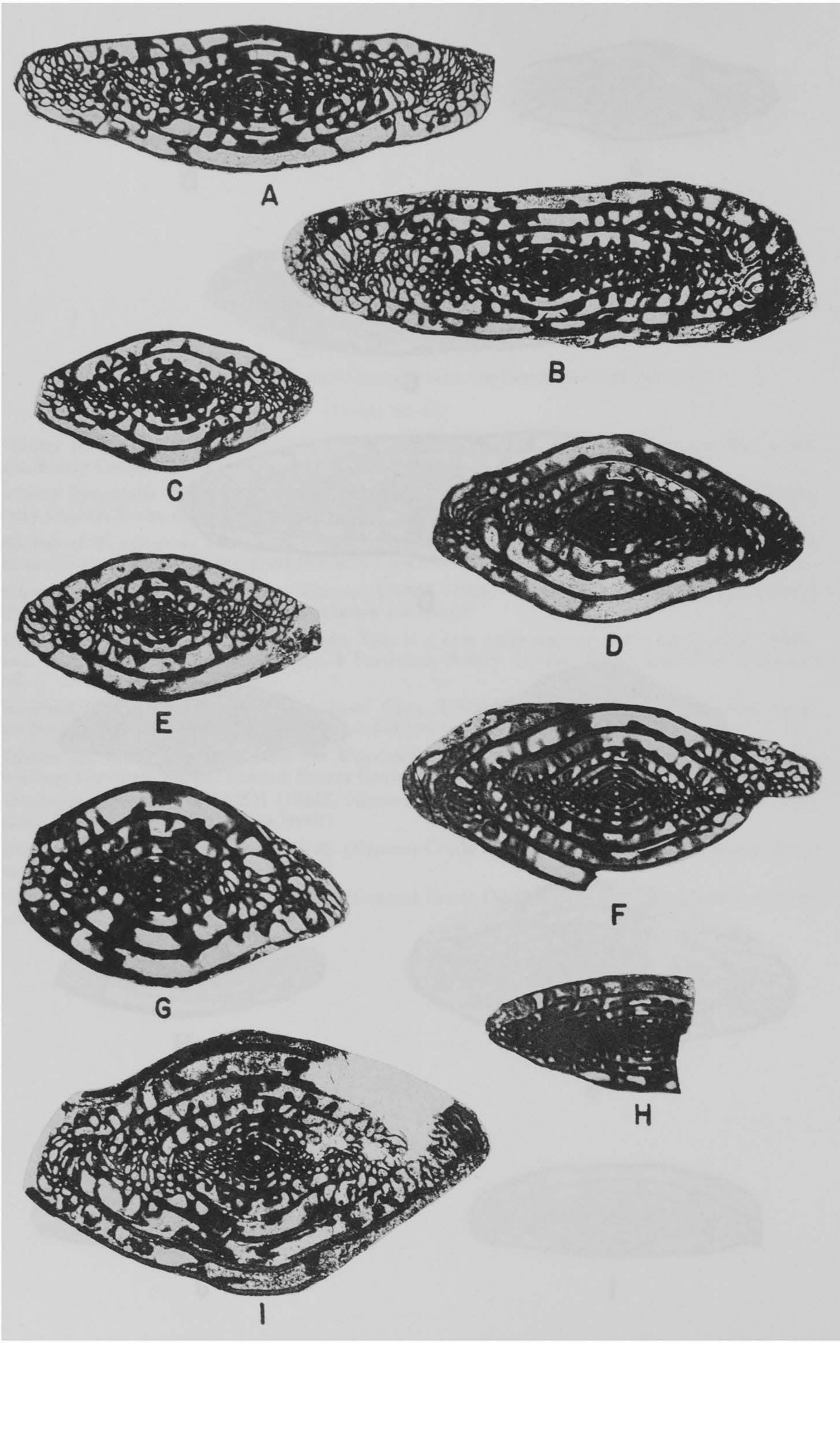


PLATE 17

Fusulinidae of Cisco age from the Horseshoe atoll (all x10)

(Page 47)

A. *Triticites* cf. *T. secalicus* (Say), Bunger (?). USNM 119450. (Montex Drilling Company No. 2 Payne, Scurry County, Texas, 4,417 feet below sea level.)

B. *Triticites* sp., Bunger(?). USNM 119451. This is a member of the group of *T. secalicus.* (Montex Drilling Company No. 2 Payne, Scurry County, Texas, 4,420 feet below sea level.)

C. *Triticites* sp., Gunsight or Wayland. USNM 119452. This is a primitive member of the group of *T. ventricosus.* (Cities Service Oil Company No. 6 Patterson, Scurry County, Texas, 4,434 feet below sea level.)

D. *Triticites* sp., Gunsight(?). USNM 119453. Group of *T. ventricosus,* somewhat more advanced than in (C). (Phillips Petroleum Company No. 4 Mebane, Scurry County, Texas, 4,285 feet below sea level.)

E. *Triticites* sp., Gunsight(?). USNM 119454. Group of *T. ventricosus.* (Phillips Petroleum Company No. 4 Mebane, Scurry County, Texas, 4,285 feet below sea level.)

F. *Triticites* sp., Wayland or younger. USNM 119455. Group of *T. ventricosus.* (Pan-American Producing Company No. 5 Carrell, Scurry County, Texas, 4,363 feet below sea level.)

G. *Triticites* sp., Chaffin(?). USNM 119456. (Pan-American Producing Company No. 5 Carrell, Scurry County, Texas, 4,327 feet below sea level.)

H. *Dunbarinella* sp., Chaffin(?). USNM 119457. (Pan-American Producing Company No. 5 Carrell, Scurry County, Texas, 4,327 feet below sea level.)

I. *Triticites beedei* Dunbar and Condra, Chaffin(?). USNM 119458. (Wilshire Oil Company No. 1 Rinehart, Scurry County, Texas, 4,299 feet below sea level.)

PLATE 18

Fusulinidae of Wolfcamp age from the Horseshoe atoll (all x10)

(PAGE 47)

A. *Triticites ventricosus* (Meek and Hayden), Waldrip(?). USNM 119459. (Sun Oil Company No. 1 Brice, Scurry County, Texas, 4,217 feet below sea level.)

B. *Triticites* cf. *T. ventricosus* (Meek and Hayden), Waldrip(?). USNM 119460. (Sun Oil Company No. 1 Brice, Scurry County, Texas, 4,197 feet below sea level.)

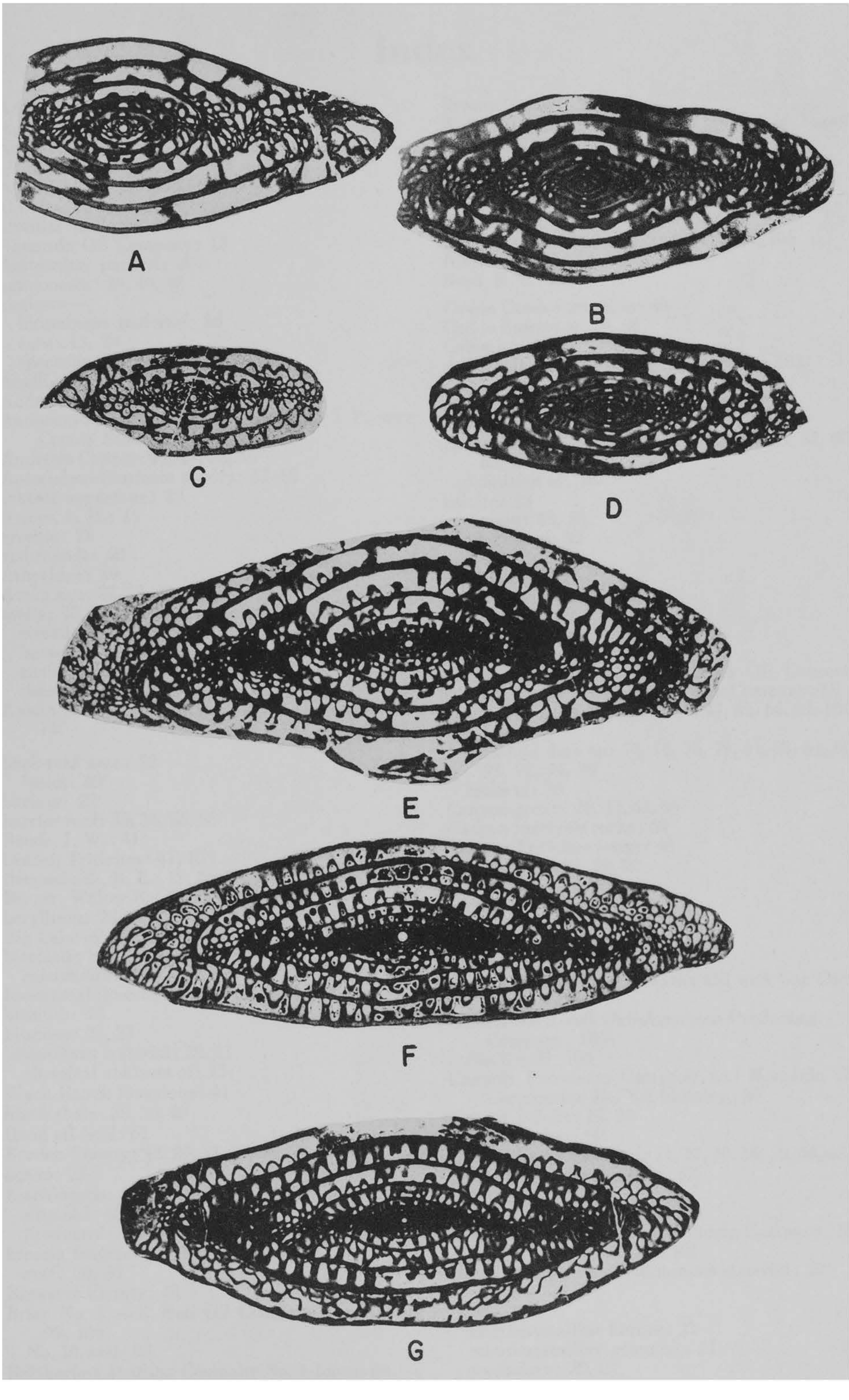
C. *Pseudofusulina* sp., Wolfcamp. USNM 119461. (Pan-American Producing Company No. 5 Carrell, Scurry County, Texas, 4,288 feet below sea level.)

D. *Triticites* sp., Wolfcamp. USNM 119462. (Pan-American Producing Company No. 5 Carrell, Scurry County, Texas, 4,288 feet below sea level.)

E. *Paraschwagerina* sp., upper Wolfcamp (Coleman Junction?). USNM 119463. (Standard Oil Company of Texas No. 2 Pool, Gaines County, Texas, 5,318 feet below sea level.)

F. *Paraschwagerina* sp., upper Wolfcamp (Coleman Junction?). (Standard Oil Company of Texas No. 2 Pool, Gaines County, Texas, 5,326 feet below sea level.)

H. *Paraschwagerina* sp., upper Wolfcamp (Coleman Junction?). USNM 119464. (Standard Oil Company of Texas No. 2 Pool, Gaines County, Texas, 5,339 feet below sea level.)


A
B
C
D
E
F
G

Index

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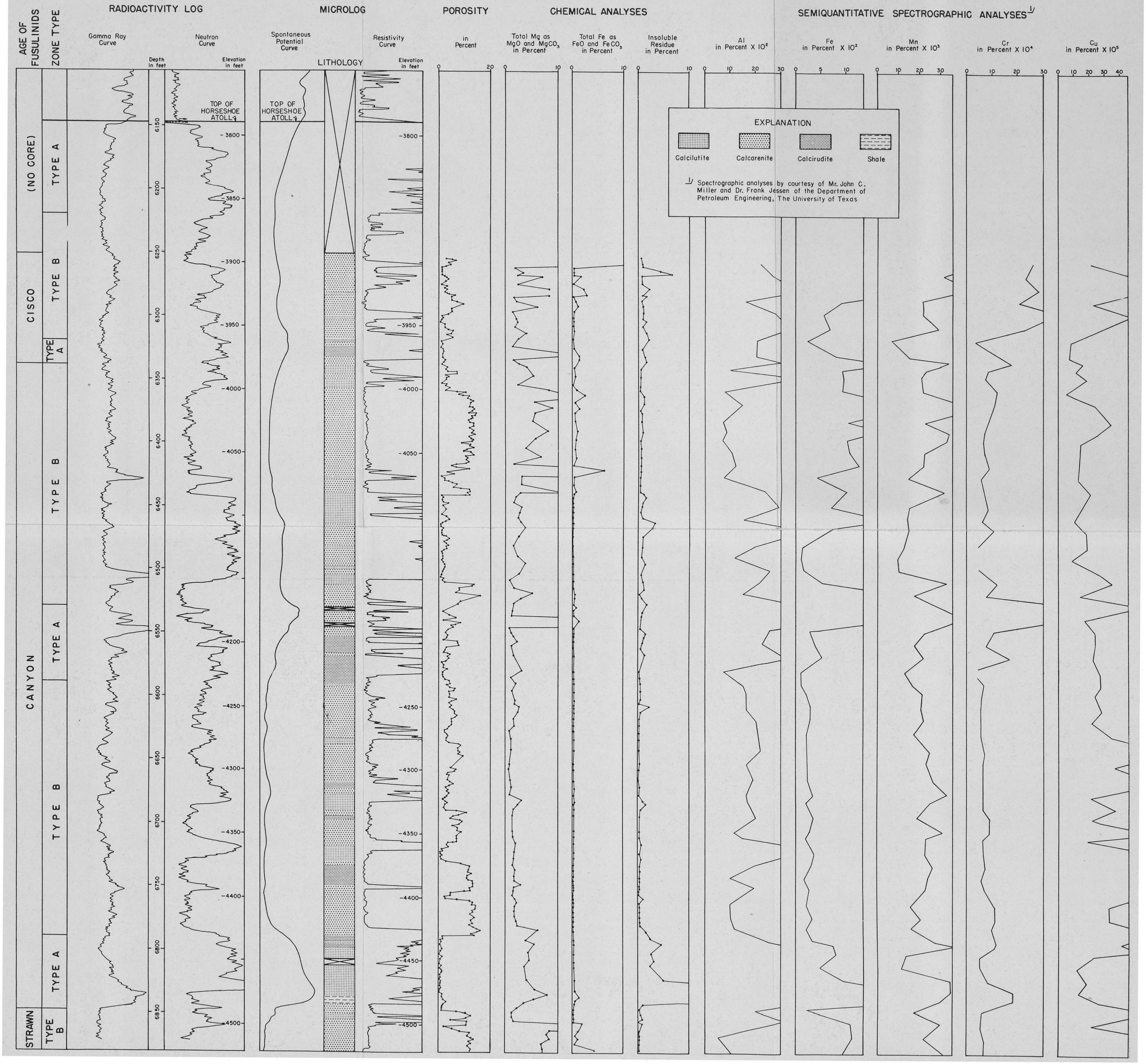
UNITED STATES GEOLOGICAL SURVEY

LATE PALEOZOIC HORSESHOE ATOLL
WEST TEXAS
PLATE I



CORRELATION OF DATA FROM CHAPMAN & MC FARLIN PRODUCING COMPANY'S NO. 25 COGDELL WELL, KENT COUNTY, TEXAS

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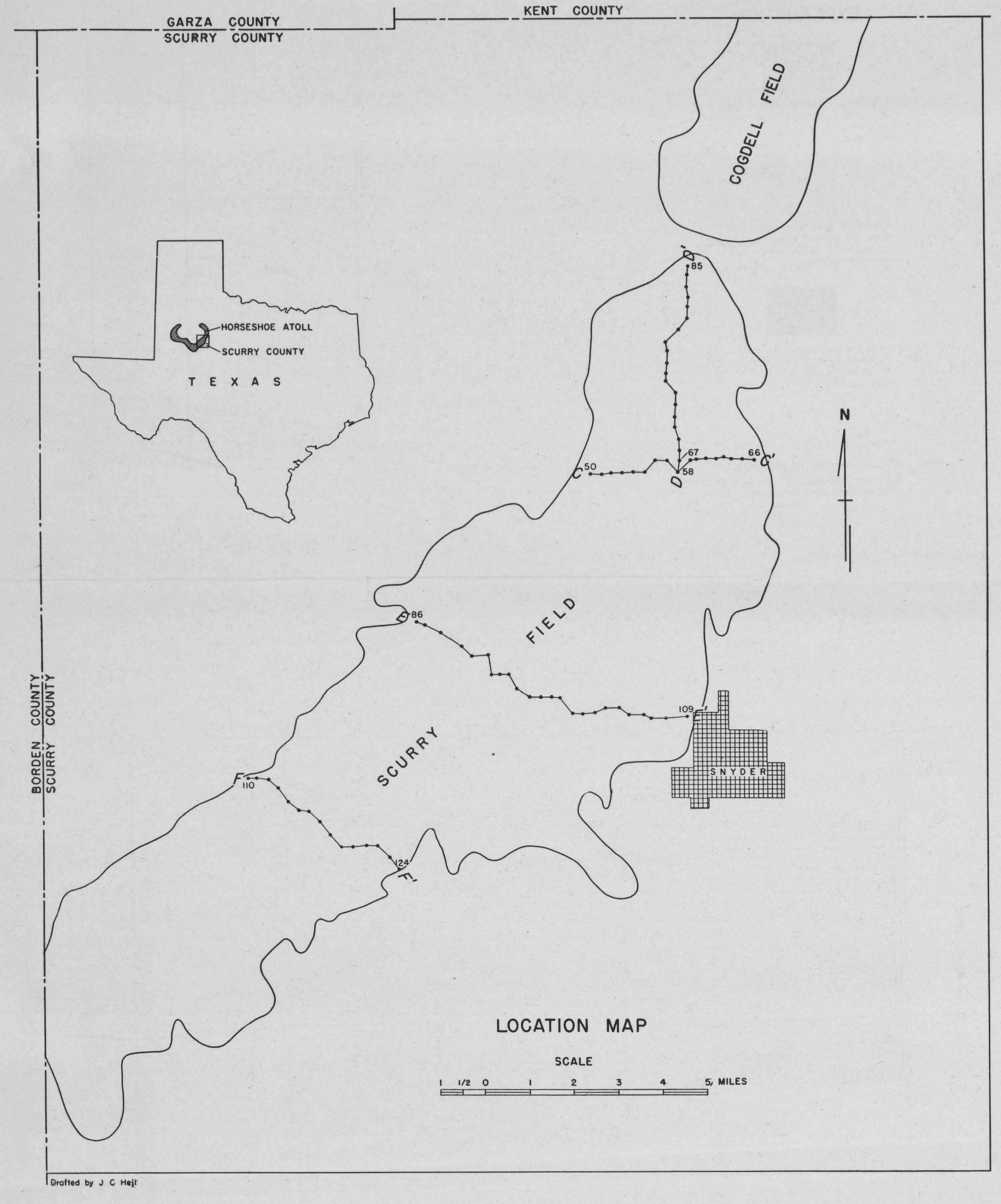
LATE PALEOZOIC HORSESHOE ATOLL
WEST TEXAS
PLATE 2



LOCATION MAP

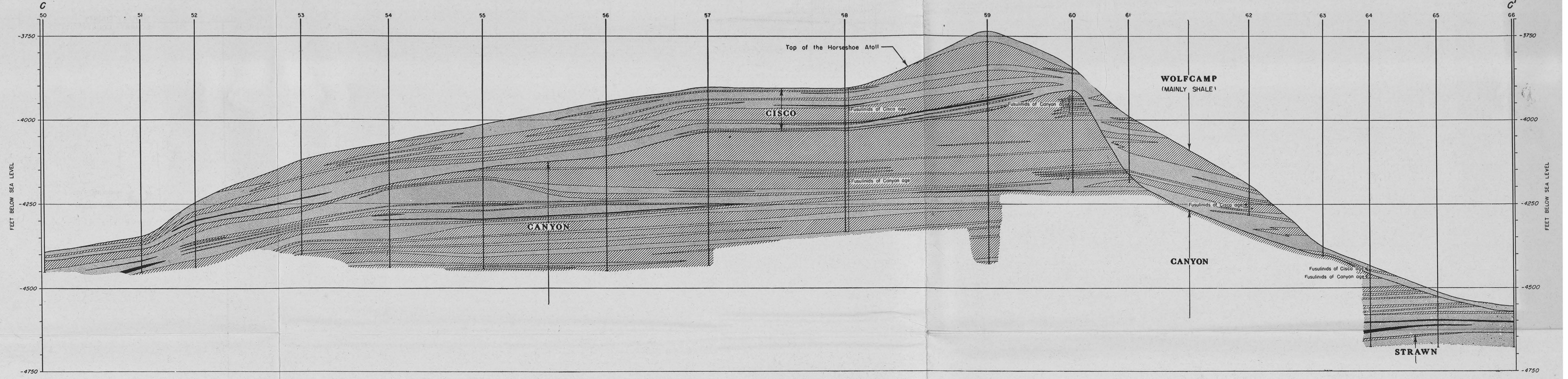
EXPLANATION

Limestone generally having more than 4.5 percent effective porosity as indicated by micrologs and radioactivity logs

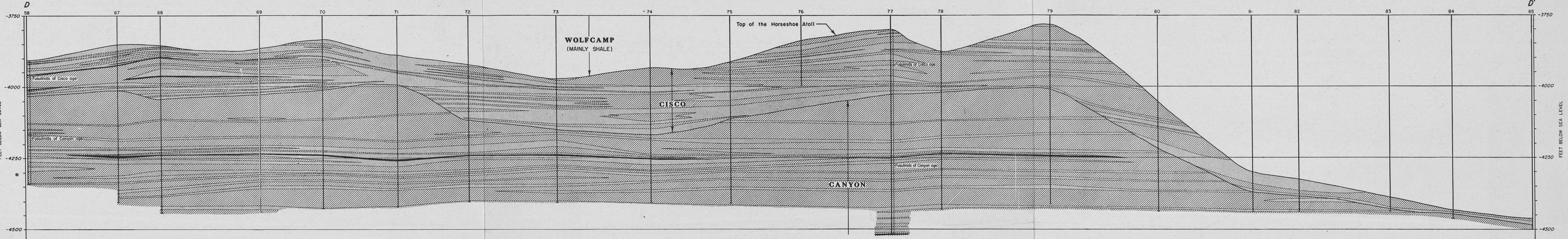
Limestone generally having less than 4.5 percent effective porosity as indicated by micrologs and radioactivity logs

Shale or calcareous shale as indicated by micrologs and radioactivity logs (in some places may be argillaceous limestone)

Note All boundaries are approximate
All fusulinids used for age determination were obtained from cores.



CROSS SECTION C-C'



CROSS SECTION D-D'

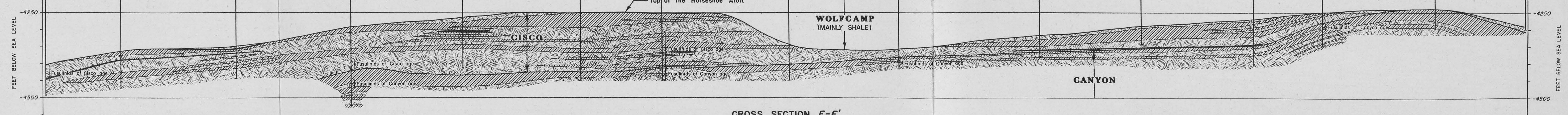
CROSS SECTION E-E'

HORIZONTAL SCALE

1000 0 1000 2000 3000 4000 5000 6000 7000 8000 9000 10000 FEET

VERTICAL EXAGGERATION X 5

DATUM IS MEAN SEA LEVEL



CROSS SECTION F-F'

CROSS SECTIONS SHOWING POROSITY ZONES AND STRATIGRAPHIC RELATIONSHIPS OF THE HORSESHOE ATOLL IN SCURRY COUNTY, TEXAS

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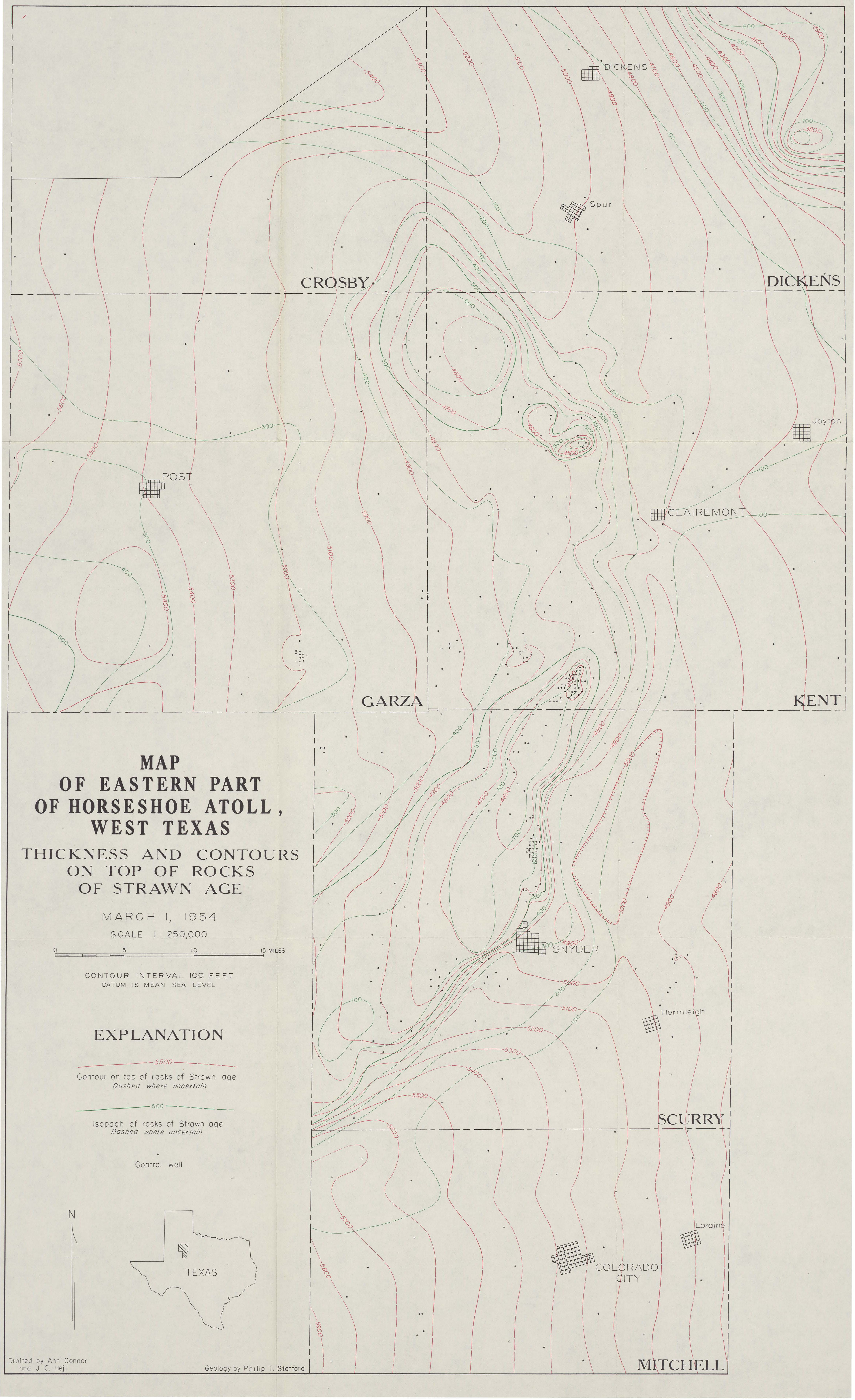
LATE PALEOZOIC HORSESHOE ATOLL
WEST TEXAS
PLATE 3

CROSS SECTIONS SHOWING POROSITY ZONES AND STRATIGRAPHIC RELATIONSHIPS OF THE HORSESHOE ATOLL IN BORDEN AND HOWARD COUNTIES, TEXAS


MAP
OF EASTERN PART
OF HORSESHOE ATOLL,
WEST TEXAS
THICKNESS AND CONTOURS
ON TOP OF ROCKS
OF STRAWN AGE
MARCH 1, 1954
SCALE 1 : 250,000
0
5
10
15 MILES
CONTOUR INTERVAL 100 FEET
DATUM IS MEAN SEA LEVEL
EXPLANATION
-5500
Contour on top of rocks of Strawn age
Dashed where uncertain
500
Isopach of rocks of Strawn age
Dashed where uncertain
Control well
N
TEXAS
Drafted by Ann Connor
and J. C. Hejl
Geology by Philip T. Stafford
CROSBY
DICKENS
GARZA
KENT
SCURRY
MITCHELL
DICKENS
Spur
Jayton
POST
CLAIREMONT
SNYDER
Hermleigh
Loraine
COLORADO
CITY

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LATE PALEOZOIC HORSESHOE ATOLL
WEST TEXAS
PLATE 5

CROSS SECTIONS SHOWING STRATIGRAPHIC RELATIONSHIPS OF ROCKS OF MISSISSIPPIAN (?), PENNSYLVANIAN, AND PERMIAN AGES IN THE NORTHERN PART OF THE MIDLAND BASIN, WEST TEXAS

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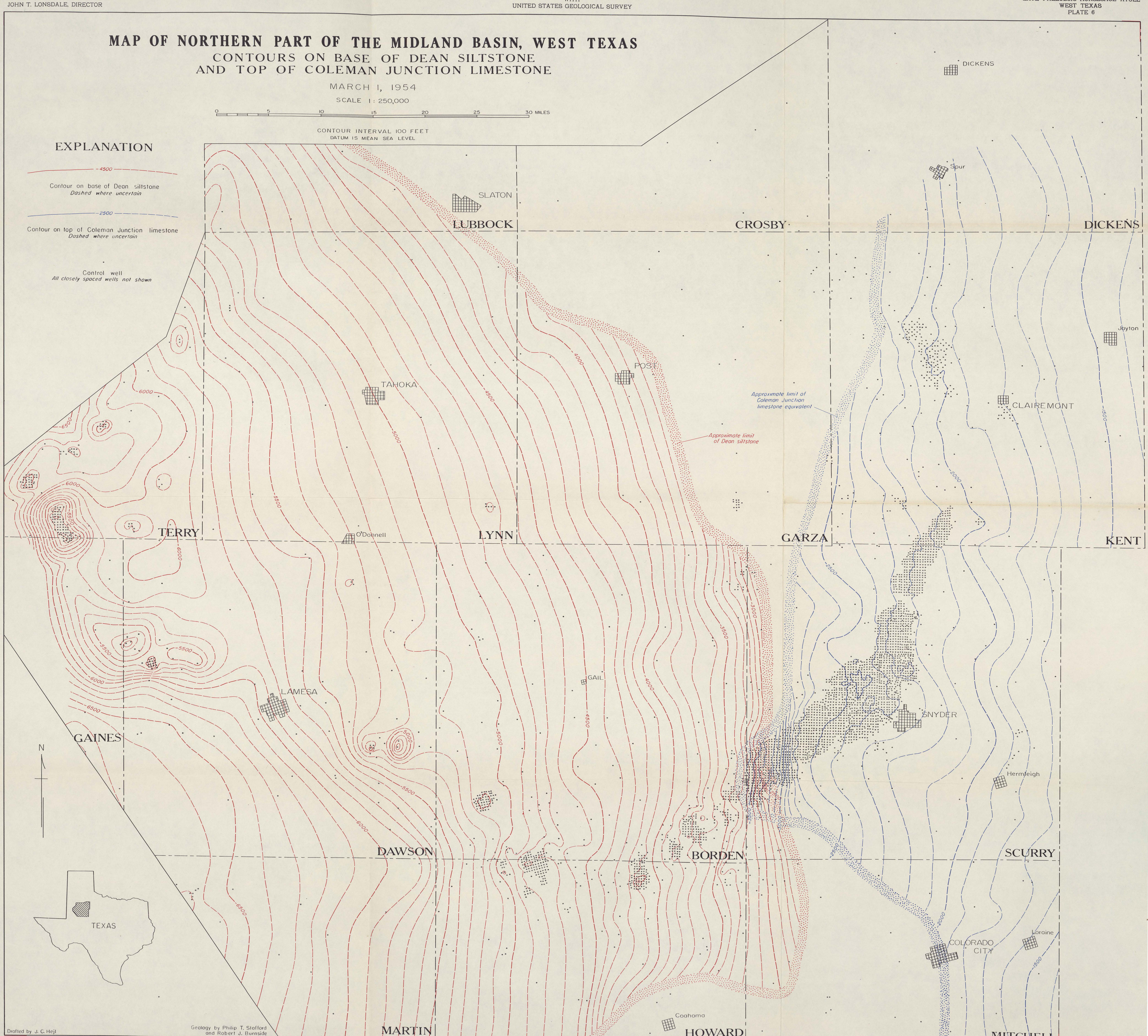

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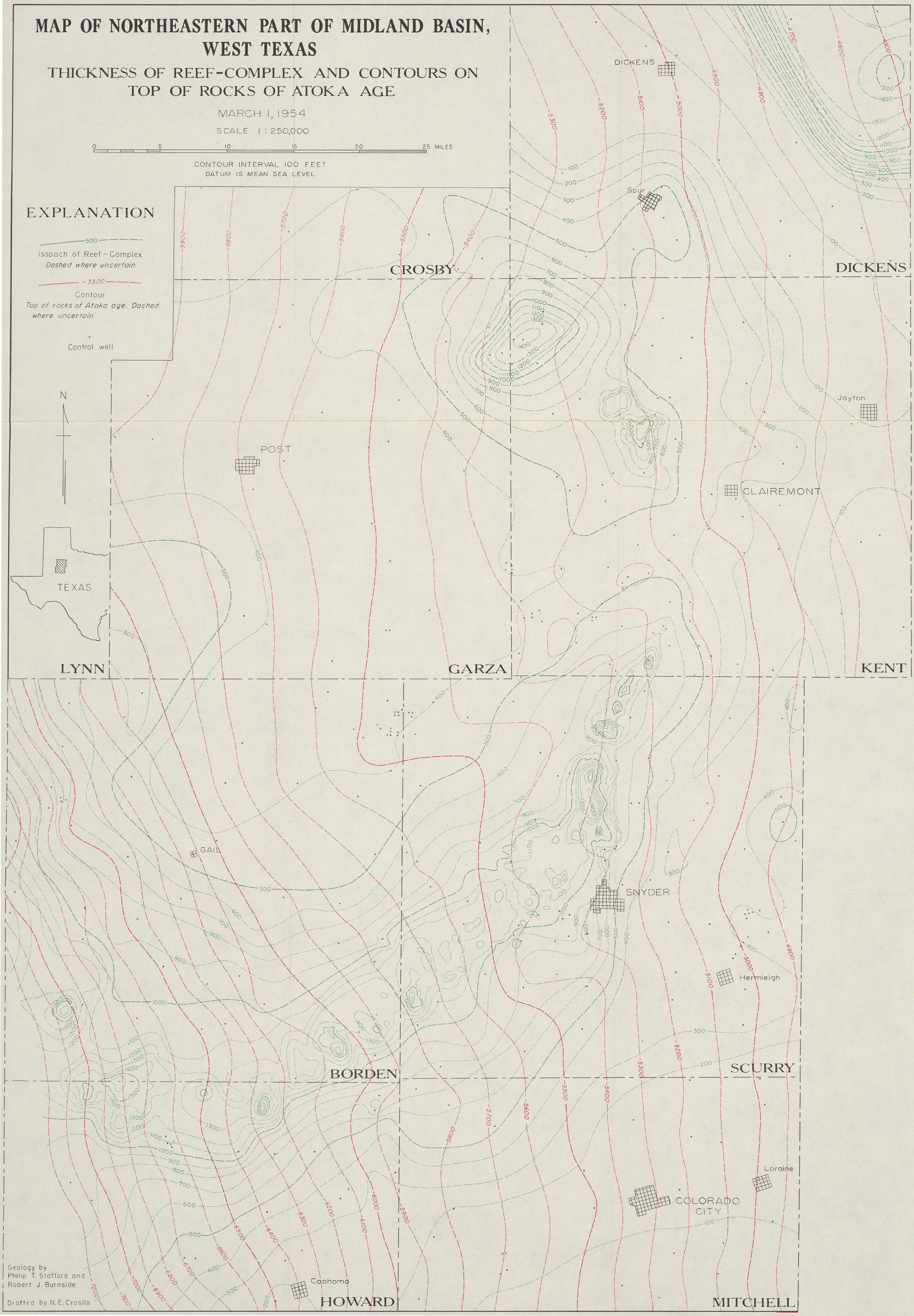
LATE PALEOZOIC HORSESHOE ATOLL
WEST TEXAS
PLATE 7



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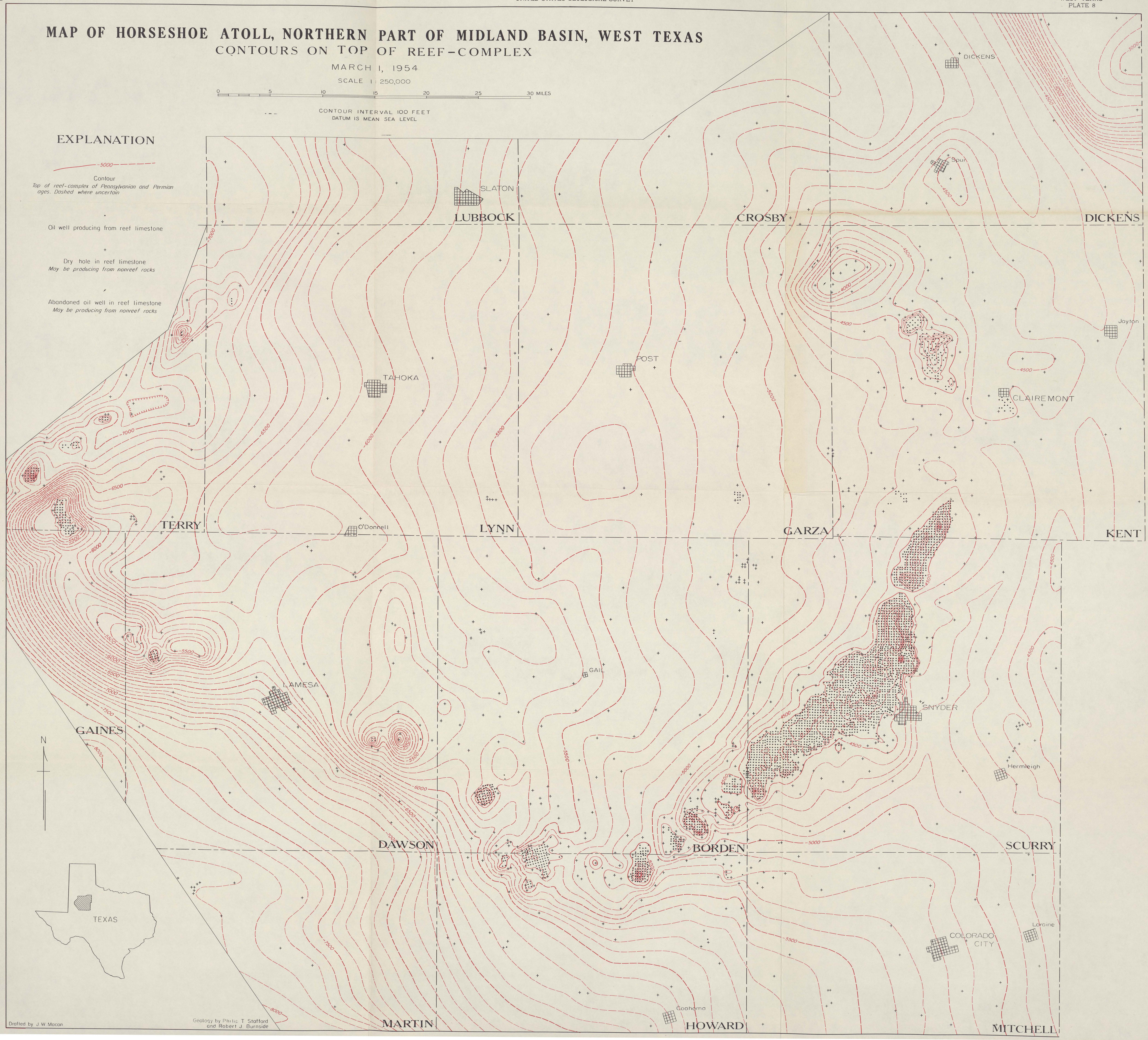

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MAP OF OIL FIELDS IN THE HORSESHOE ATOLL AND OVERLYING WOLFCAMP ROCKS, IN THE NORTHERN PART OF THE MIDLAND BASIN, WEST TEXAS

March 1, 1954

INDEX TO WELL NUMBERS

INDEX NO.	OPERATOR	WELL NO. AND FARM
1	Anderson-Prichard Oil Corporation	2 Parker County School Lands "A"
2	Seaboard Oil Co. of Delaware	1 Doss
3	Sinclair Oil & Gas Cas Company	1 Lee
4	Standard Oil Company of Texas	1 Pool
5	Cities Service Oil Company	14 Dupree
6	Cities Service Oil Company	1 Gregory
7	Humble Oil & Refining Company	1 Thomas
8	Barnsdall Oil Company	1 Williams
9	Phillips Petroleum Company	1-A Bartley
10	J. H. Snowden et al.	1 Williams
11	Jim-Lee Drilling Company	1 Williams
12	Cosden Petroleum Corporation	1 Tipton
13	Union Oil Co. of California and Cities Service Oil Co.	1-A Davis
14	Continental Oil Company	1 Fumagalli
15	Aurora Gasoline Company	1 Swenson
16	Ohio Oil Company	1 Swenson
17	Spartan Drilling Company	1 Emory Trust
18	Novi Equipment Co.	1 Self
19	Big Chief Drilling Company	1 House
20	Union Oil Co. of California	1 Elliot
21	Placid Oil Company	1 Hughes
22	Placid Oil Company	1 Swenson
23	Magnolia Petroleum Company	1 Wiley
24	Humble Oil & Refining Company	2 Matador Land and Cattle Company "F"
25	Ashland Oil & Refining Company	1 Pitchfork "3"
26	Tidewater Associated Oil Company	1 Pitchfork Ranch "D"
27	Anderson-Prichard Oil Corporation	1 White
28	Shell Oil Company	1 Southland Royalty
29	Magnolia Petroleum Company	1 Garza Land & Cattle Company
30	Phillips Petroleum Company	1 Dennis "A"
31	Stanolind Oil & Gas Company	1 Miller
32	Cosden Petroleum Corporation	1 Sealy
33	Crown Central Petroleum Corporation	1 York
34	Delta Gulf Drilling Company and Delta Drilling Company	2 Eiland
35	Delta Gulf Drilling Company and Delta Drilling Company	1 Eiland
36	Spartan Drilling Company	1 Langford
37	Cities Service Oil Company	7 Patterson
38	Pure Oil Company	2 R. W. Boyd
39	Sun Oil Company	4 Boyles
40	Newman Brothers Drilling Co., Alaska Steamship Co., and Calvert Corp.	3 Eiland
41	Sun Oil Company	6 Eiland
42	Sun Oil Company	7 Voss
43	Sun Oil Company	5 Fenton
44	Sun Oil Company	1 Rollins "A"
45	General Crude Oil Company	1 Martin
46	V. A. Brill	1 Winston
47	Honolulu Oil Corporation	1 Brown
48	Ohio Oil Company	1-A Merkett
49	Capital Oil Company	1 Ebie
50	Standard Oil Company of Texas	2 Bell "2"
51	Standard Oil Company of Texas	1 Bell Unit
52	Standard Oil Company of Texas	2 Herod
53	Standard Oil Company of Texas	1 Herod
54	Pure Oil Company	2 Adams
55	Pure Oil Company	1 Adams
56	Tidewater Associated Oil Company	1 Dodson-House
57	Tidewater Associated Oil Company	2 Dodson-House
58	Tidewater Associated Oil Company	3 House
59	Tidewater Associated Oil Company	4 Dodson-House
60	Sun Oil Company	3 Brice
61	Sun Oil Company	5 Brice
62	Sun Oil Company	7 Brice
63	Sun Oil Company	16 Brice
64	Sun Oil Company	10 Brice
65	Standard Oil Company of Texas	5 Martin "2"
66	Standard Oil Company of Texas	8 Martin "2"
67	Tidewater Associated Oil Company	3 Dodson-House
68	Standard Oil Company of Texas	3 Dodson-Terry
69	Standard Oil Company of Texas	7 Terry
70	Standard Oil Company of Texas	6 Beck
71	Standard Oil Company of Texas	3 Beck
72	Cities Production Corporation	6 Jolly
73	Cities Production Corporation	3 Jolly
74	Standard Oil Company of Texas	4 Brown "3"
75	Standard Oil Company of Texas	1 Brown "3"
76	Standard Oil Company of Texas	1 Brown "2"
77	Standard Oil Company of Texas	5 Brown "2"
78	Standard Oil Company of Texas	1 Brown "9"
79	Standard Oil Company of Texas	5 Brown "9"
80	Standard Oil Company of Texas	5 Brown "8"
81	Standard Oil Company of Texas	8 Brown "8"
82	Standard Oil Company of Texas	4 Brown "15"
83	Standard Oil Company of Texas	8 Brown "15"
84	Standard Oil Company of Texas	4 Brown "14"
85	Standard Oil Company of Texas	6 Brown "14"
86	Skelly Oil Company	4 Head "A"
87	Byrd-Frost, Incorporated	4 Arnett
88	Phillips Petroleum Company	4 Caudle
89	Phillips Petroleum Company	1 Pate
90	Wilshire Oil Company	8 Lunsford
91	Lone Star Producing Company	4 Bynum
92	Wilshire Oil Company	4 Lunsford
93	Lone Star Producing Company	2 Davis "A"
94	Lone Star Producing Company	3 Davis "A"
95	Placid Oil Company	1 Fesmire
96	Ohio Oil Company	2 Hays
97	Pan-American Producing Company	2 Woolever
98	Pan-American Producing Company	2 Davis
99	Tidewater Associated Oil Company	3 Johnson
100	Tidewater Associated Oil Company	2 Johnson
101	Magnolia Petroleum Company	2 Lyons
102	Magnolia Petroleum Company	3 Lyons
103	Cities Service Oil Company	3 Austin
104	Cities Service Oil Company	4 Austin
105	Montex Drilling Company	3 Harrell
106	Montex Drilling Company	2 Harrell
107	Montex Drilling Company	5 Joyce
108	Montex Drilling Company	3 Joyce
109	Hiawatha Oil and Gas Company	1 York
110	Cities Service Oil Company	6 Patterson
111	Cities Service Oil Company	4 Patterson
112	Cities Service Oil Company	3 Patterson
113	Cities Service Oil Company	H-2 Johnson
114	Amerada Petroleum Corporation	1 Boyles
115	Lion Oil Company	25 McLaughlin
116	Lion Oil Company	24 McLaughlin
117	Lion Oil Company	28 McLaughlin
118	Sun Oil Company	1 Rosenberg
119	Sun Oil Company	3 Rosenberg
120	Sun Oil Company	4 Rosenberg
121	Sun Oil Company	5 Rosenberg
122	Sun Oil Company	1 Fenton
123	Sun Oil Company	3 Arledge "B'
124	Sun Oil Company	6 Arledge "B"
125	Ada Oil Company	1 Anderson
126	Skelly Oil Company	20 Gunn
127	Skelly Oil Company	14 Gunn
128	Skelly Oil Company	12 Gunn
129	Skelly Oil Company	8 Gunn
130	Skelly Oil Company	2 Gunn
131	Lario Oil & Gas Company	2 Brannon "A"
132	Lario Oil & Gas Company	4 Brannon "A"
133	Norwood Drilling et al.	2 Brannon
134	American Republics Corporation	1 Barber
135	Skelly Oil Company	16 Gunn
136	Skelly Oil Company	13 Gunn
137	Skelly Oil Company	5 Gunn
138	Skelly Oil Company	1 Noll
139	Skelly Oil Company	2 Noll
140	Skelly Oil Company	3 Noll
141	Skelly Oil Company	7 Noll
142	Sunray Oil Corporation	7 Wilson
143	Sunray Oil Corporation	8 Wilson
144	Sunray Oil Corporation	10 Wilson
145	Sunray Oil Corporation	2 Wilson
146	Tidewater Associated Oil Company	2 Coates
147	Seaboard Oil Company of Delaware and Pan-American Producing Company	28 Good
148	Seaboard Oil Company of Delaware and Pan-American Producing Company	11 Good
149	Seaboard Oil Company of Delaware and Pan-American Producing Company	8 Good
150	Seaboard Oil Company of Delaware and Pan-American Producing Company	5 Good
151	Seaboard Oil Company of Delaware and Pan-American Producing Company	3 Good
152	Seaboard Oil Company of Delaware and Pan-American Producing Company	14 Good
153	Seaboard Oil Company of Delaware and Pan-American Producing Company	24 Good
154	Seaboard Oil Company of Delaware and Pan-American Producing Company	1 Clayton
155	Seaboard Oil Company of Delaware and Pan-American Producing Company	3 Clayton
156	Seaboard Oil Company of Delaware and Pan-American Producing Company	26 Good
157	Condor Petroleum Company	4 Good
158	Condor Petroleum Company	3 Good
159	Seaboard Oil Company of Delaware and Pan-American Producing Company	19 Good
160	Seaboard Oil Company of Delaware and Pan-American Producing Company	1 Good
161	Seaboard Oil Company of Delaware and Pan-American Producing Company	7 Good
162	Seaboard Oil Company of Delaware and Pan-American Producing Company	29 Good
163	Honolulu Oil Corporation and Signal Oil and Gas Company	1–24 Elwood
164	Honolulu Oil Corporation	1 McGowan
165	R. H. Fulton et al.	1 Eubanks
166	Gulf Oil Corporation	1-B Swenson Cattle Company
167	General Crude Oil Company	13–6 Jones
168	General Crude Oil Company	193–4 Coleman
169	General Crude Oil Company	193–2 Coleman
170	General Crude Oil Company	28 Hunt Trust-Young
171	Humble Oil & Refining Company	2 McLaury
172	Humble Oil & Refining Company	1 L. R. Spires
173	Chapman and McFarlin Producing Co.	25 Cogdell
174	Standard Oil Company of Texas	2 Pool
175	El Tee Oil Company	2–96 Briley
176	Magnolia Petroleum Company	3 Conrad "C'
177	Sun Oil Company	1 Brice
178	Sunray Oil Corporation	2 Hardy "A"
179	Hiawatha Oil and Gas Company	1 Carden
180	Montex Drilling Company	3 Country Club
181	Wilshire Oil Company	1 Rinehart
182	Pan-American Producing Company	5 Carrell
183	General Crude Oil Company	3 Land
184	Cities Service Oil Company	2 Von Roeder
185	Montex Drilling Company	4 Joyce
186	Montex Drilling Company	2 Payne
187	Montex Drilling Company	1 Payne
188	Montex Drilling Company	4 Harrell
189	Seaboard Oil Company of Delaware	2 Tora Campbell
190	Pan American Producing Company	1 Glass
191	Brinkerhoff Drilling Company	1 Jones
192	Honolulu Oil Corporation and Cascade Petroleum Company	Y-2 Canning
193	Lion Oil Company	45 McLaughlin
194	Phillips Petroleum Company	4 Mebane
195	Lion Oil Company	1 Zelma
196	Lion Oil Company	36 McLaughlin
197	Sun Oil Company	6 Lemons
198	Sun Oil Company	7 Lemons
199	Cities Service Oil Company	3 Poponoe "A"
200	Sun Oil Company	17 Brice