

**KANSAS GEOLOGICAL SURVEY
OPEN-FILE REPORT 1977-16**

Reservoir Geology of the Captain Creek Limestone,
Wilson Creek Oil field,
Ellsworth and Russell Counties, Kansas

by

Robert Thomas Hopkins

Disclaimer

The Kansas Geological Survey does not guarantee this document to be free from errors or inaccuracies and disclaims any responsibility or liability for interpretations based on data used in the production of this document or decisions based thereon. This report is intended to make results of research available at the earliest possible date, but is not intended to constitute final or formal publications.

Kansas Geological Survey
1930 Constant Avenue
University of Kansas
Lawrence, KS 66047-3726

RESERVOIR GEOLOGY OF THE CAPTAIN CREEK
LIMESTONE, WILSON CREEK OIL FIELD, ELLSWORTH AND
RUSSELL COUNTIES, KANSAS

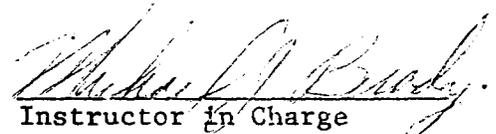
by

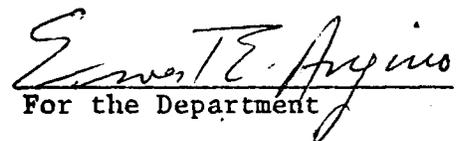
Robert Thomas Hopkins
B.S., University of Kansas, 1975

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

Thesis
1977
H 776
c. 2
Marvin

R00033 68106


Instructor in Charge


For the Department

OCT 1977

385 2076

ABSTRACT

Oil is produced from an upper Pennsylvanian oolitic limestone in the Wilson Creek Field, Ellsworth and Russell Counties, Kansas. This limestone correlates with the Lansing B zone in the subsurface and the Captain Creek Limestone (Stanton Formation, Lansing Group) at the surface in eastern Kansas. In the Wilson Creek Field, the Captain Creek Limestone comprises a prograding marine, shoaling-upward depositional sequence. This sequence is: open-marine (shelf) fossil wackestone, high energy (shoal) ooid grainstone, and restricted-water (lagoonal) pelletoid mudstone, from base to top. The location of the oolite shoal was influenced by a fault in the underlying Arbuckle Group, expressed as a ridge in upper Pennsylvanian time. Avalanche cross-bedding is developed in the thickest, most seaward (southward) part of the oolite. Absence of cross-bedding, abundant lenses of skeletal debris, and micrite indicate that the limestone on the northern side of the field was deposited in a back-shoal environment. Diagenetic features include calcite cement of two ages, oomoldic pores, dolomite spar pore-filling, and stylolites. Good oil production occurs in the main part of the field where cross-bedding and lensing of alternating ooid and oomold layers affords good porosity and permeability. Areas of low permeability within the ooid grainstone occur where the moldic pores are separated by fine carbonate matrix or by cement.

The Wilson Creek Field is located slightly south of an east-west trending structural high. The hydrocarbon trap results from a combination of structural, stratigraphic, and hydrodynamic controls. Areas of low permeability updip from the field combine with water flow downdip through higher permeability areas to cause localization of the oil off

of the highest part of the structure. There is a noticeable southward tilt to the oil-water contact. Vertical fractures are concentrated in long, narrow zones, and these greatly increase the productivity of wells drilled into them.

More than 16 million stock-tank barrels of oil will remain after the primary recovery phase of operation in the Captain Creek Limestone, making it desirable to consider an enhanced oil recovery project. Geological parameters such as structure, thickness, fractures, hydrodynamics, and variability of the reservoir rock are important to the design of a process that will most efficiently recover oil remaining after earlier production.

TABLE OF CONTENTS

	Page
Introduction	1
Purpose of Investigation	1
Interpretations	1
Location and History	3
Previous Investigations	5
Acknowledgements	6
Geology of the Upper Lansing Group in Kansas	8
Stratigraphy	8
Vilas Shale	10
Stanton Limestone	10
Captain Creek Limestone Member	10
Eudora Shale Member	12
Stoner Limestone Member	12
Rock Lake Shale Member	13
South Bend Limestone Member	13
Paleogeography and Tectonic Framework of the Region	14
Geology and Depositional Environments of the Captain Creek	
Limestone in the Wilson Creek Field	18
Geometry	18
Petrography	24
Ooid-oomold Grainstone	24
Fossil Wackestone	31
Lime Mudstone	31

Environments of Deposition	34
Facies of the Captain Creek Limestone	34
Depositional Model	36
Comparison to Modern Oolitic Sediments	41
Comparison to Other Upper Pennsylvanian Oolite Deposits	43
Alternative Interpretations	48
Diagenesis	50
Petroleum Geology of the Wilson Creek Field	53
Structural Attitude and Thickness of the Captain Creek Limestone	53
Petrophysics of the Reservoir Rock	56
Oil Entrapment and Migration	60
Hydrodynamics	60
Other Trapping Mechanisms	69
Oil Migration	70
Enhanced Oil Recovery in the Wilson Creek Field	73
Importance of Enhanced Oil Recovery	73
Reservoir Characteristics in Engineering Design	75
Recommendations	79
Summary	83
References	85
Appendices	90

LIST OF ILLUSTRATIONS

Figure	Page
1 Lansing-Kansas City oil fields in Kansas	2
2 Index map	4
3 Stratigraphic section of the upper Lansing Group and Lower Douglas Group in the Wilson Creek Field	9
4 Comparison of Parkhurst's, Morgan's, and Wilson Creek Field stratigraphic sections	11
5 Subsurface structural provinces in Kansas	15
6 Location of Ellsworth fault in Wilson Creek Field area . . .	17
7 Isopach map of Captain Creek oolite	19
8 Lease map of Wilson Creek Field	20
9 Cross-section location map	21
10 Stratigraphic cross-section A-A'	22
11 Stratigraphic cross-section B-B'	23
12 Photomicrographs of the ooid-oolite grainstone	26
13 Photographs of cores	28
14 Photomicrographs of fossil wackestone and lime mudstone . .	32
15 Structure map - base of Captain Creek oolite	38
16 Idealized diagram of a Bahama Bank oolite shoal	44
17 Stratigraphic section of the Drum Limestone oolite near Independence, Kansas	46
18 Structure map - top of Captain Creek oolite	54
19 Isopach map of porosity thickness of Captain Creek oolite .	55
20 Map of fracture zones in the Wilson Creek Field	59
21 Map of oil-water contact in the Captain Creek oolite	61

22	Structural cross-section C-C'	63
23	Structural cross-section D-D'	64
24	Map of potentiometric surface for the Captain Creek oolite .	65
25	Map of initial shut-in-pressures taken in the Captain Creek oolite	67
26	Map showing low initial shut-in-pressure areas around the Wilson Creek Field	68
27	Directions of migration of hydrocarbons in the Arbuckle Group	71
28	Map showing proposed flood pattern for the Wilson Creek Field	81

INTRODUCTION

Purpose of Investigation

Oil is produced from several formations in an elongate trend in the Wilson Creek Oil Field on the northeastern flank of the Central Kansas Uplift (Fig. 1). The chief producing zone, known locally as the Lansing "B" zone, is an oolitic limestone. The hydrocarbon trap is not a simple structurally high trap. Earliest drilling high on the subsurface structure was not successful; and the reservoir was not easily found. The Lansing and Kansas City Groups are present over the crest and on the flanks of the Central Kansas Uplift, a major oil producing province in Kansas. A greater understanding of the geology of these units might result in discovery of other obscure hydrocarbon traps which are similar to the Wilson Creek Field.

The purposes of this research on the geology of the Wilson Creek Field were to: 1.) describe the stratigraphy and local geology of the upper Lansing Group; 2.) determine the depositional environments of the reservoir rock and associated lithologies; 3.) determine the petroleum geology of the reservoir; 4.) show the applications of geology to planning of processes for enhanced recovery of oil in the "B" zone reservoir.

Interpretations

Important conclusions about the geology of the Lansing "B" zone limestone in the Wilson Creek Oil Field, based on evidence presented in the following sections, are: 1.) The main oil-producing unit is probably equivalent to the Captain Creek Limestone Member of the Stanton Limestone Formation; 2.) The deposition of the oolitic limestone was influenced by a fault in the underlying Arbuckle Group. Uplift of this

UPPER PENNSYLVANIAN

Lansing-Kansas City

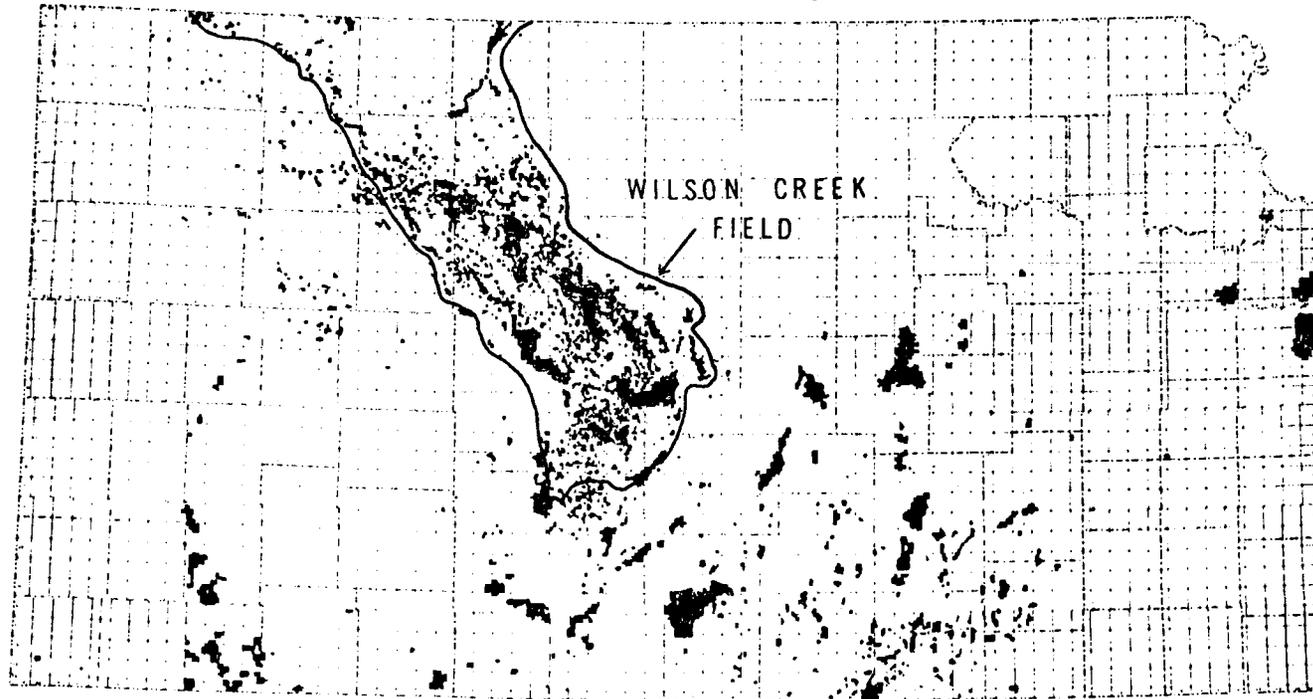


Figure 1.- Location of Wilson Creek Field (arrow) in relation to other areas of oil and gas production from the Lansing and Kansas City Groups in Kansas. The Central Kansas Uplift is outlined. From Ebanks (1974).

structure combined with sedimentation to produce a bathymetric high and a shoaling environment during deposition of the Captain Creek oolite; 3.) The oolitic reservoir limestone, representing shoaling conditions, overlies a normal marine limestone. Overlying the oolite is a pelleted limestone which was deposited in very shallow water; subsequent increase in water depth allowed deposition of a gray shale followed by a marine, fossiliferous limestone; 4.) The reservoir rock is a porous oomoldic limestone which produces oil in an elongate trend; the trap is formed by a combination of lateral change in permeability and a hydrodynamic head within the reservoir formation; 5.) A target for enhanced oil recovery of approximately 16 million barrels of oil indicates the need for a well-designed secondary and tertiary recovery project. Porosity and permeability distributions, geometry and attitude of the unit, and inhomogeneities of the reservoir rock must be considered in designing an effective project.

Location and History

Wilson Creek Oil Field is located in T14S-R10W of northwestern Ellsworth County and T14S-R11W of southeastern Russell County (Fig. 2). It is the most recently discovered large Kansas oil field, having produced 4,537,373 barrels of oil as of January 1, 1977 (anonymous, 1976).

The main producing zone, the "B" zone or Captain Creek of this study, is referred to as the Lansing-Kansas City 30' zone by geologists working in the area. This zone is encountered at a depth of approximately 2800 ft. (853 m.). In addition, minor oil production is obtained from the Lansing-Kansas City 80' and 90' zones encountered 50 to 60 ft. (15 to 18 m.) below the 30' zone, respectively. These are correlative to limestones of the Kansas City Group at the outcrop (Parkhurst, 1959).

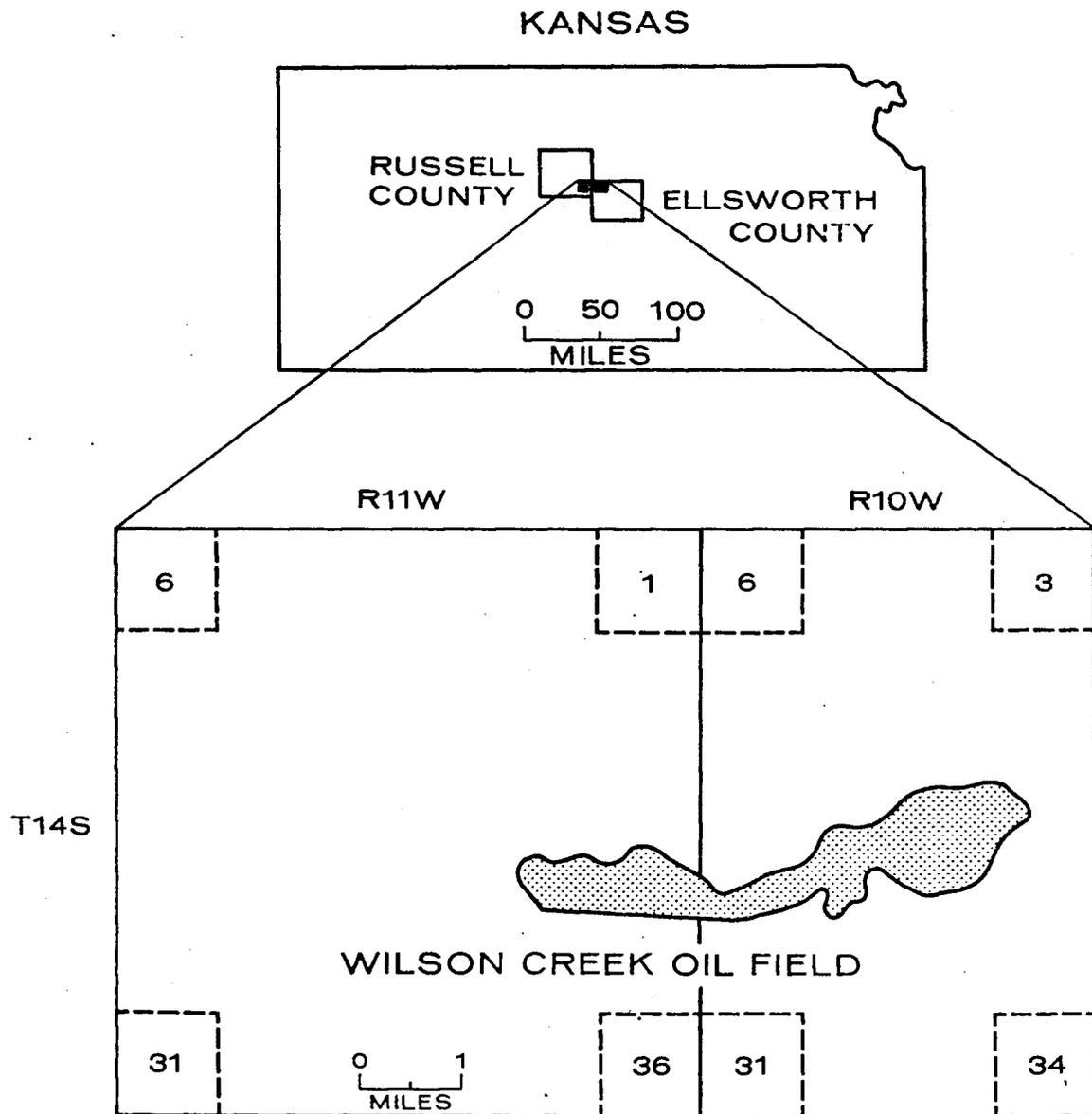


Figure 2.- Index map showing area of study.

Minor amounts of oil are also obtained from the Topeka Limestone (Shawnee Group), located about 350 ft. (106 m.) above the 30' zone, and from the Tarkio Sandstone (Wabaunsee Group) about 350 ft. (106 m.) above the Topeka Limestone. Minor gas production for field operations is also obtained from the Tarkio.

Only the 30' zone (Captain Creek) is productive over much of the field and it contains 85-90% of the estimated 23.4 million stock tank barrels of oil originally-in-place. Produced oil is co-mingled, however, and the proportion of oil actually produced from the 30' zone can only be estimated.

Wilson Creek Field was discovered in January, 1967 with completion of Borell A-1 well (Ash), NW-NE-SE, Sec. 19, T14S-R10W, in the Lansing-Kansas City 30' zone for an initial potential of 33 barrels of oil per day (BOPD), no water. The field was confirmed by the completion of Borell A-2 (Ash) later in 1967. Approximately 120 producing oil wells exist at present, with occasional in-field drilling continuing.

The field is located on the eastern flank of the Central Kansas Uplift, a prolific oil producing area (Fig. 1). Many of the fields in this area are depleted of primary oil, and secondary waterfloods have been in operation for some time. Recent field discoveries off of the highest part of the uplift area indicate the potential for more discoveries such as the Wilson Creek Field along the flanks of the uplift.

Previous Investigations

Surface stratigraphic studies of the Lansing and Kansas City Groups in eastern Kansas have been made by Newell (1933), Wagner and Harris (1953), Wagner (1954), Wilson (1957), Eastwood (1958), and Mossler (1973). Algal bank limestones in the Lansing Group of southeastern

Kansas have been studied by Wilson (1957; 1957b), Heckel and Cocke (1969), Chelikowski and Burgat (1974), and Heckel (1975).

Correlation of surface Lansing and Kansas City Groups to Morgan's (1952) subsurface alphabetic designations was made by Parkhurst (1959). Parkhurst also determined that lateral porosity pinchouts were responsible for some Lansing and Kansas City oil reservoir traps in north central Kansas. Harbaugh and Davie (1964) noted lithologic differences in the Lansing-Kansas City Groups in two wells which are more than 190 mi. (300 km.) apart along the Central Kansas Uplift. The possible importance of underlying structural development in the Arbuckle Group on the location of the reservoir oolite facies in the Wilson Creek Field was noted by Ebanks (1974). Watney (in prep.) has described the importance of reservoir rock facies to oil accumulation in northwestern Kansas.

Acknowledgements

This research project was funded by the Tertiary Oil Recovery Project of the Department of Chemical and Petroleum Engineering of the University of Kansas, Lawrence, and the Kansas Geological Survey. The project was under the direction of Dr. W. J. Ebanks, Jr. of the Kansas Geological Survey; the Survey also provided laboratory and research facilities. The well sample library of the Kansas Geological Survey in Wichita provided well samples in the project area.

I wish to thank Drs. M. J. Brady (chairman), W. J. Ebanks, Jr., and W. R. Van Schmus for serving as master's thesis advisors. I wish also to thank Mr. Larry G. Stephenson of LGS Co., Wichita, Kansas for providing numerous well logs, engineering data, and suggestions for the project. Thanks also must go to Mr. Richard B. Schmidt, geologist in

Topeka, for helpful suggestions and for some well samples. Mr. Toby Elster, and Mr. Glen N. Rupe, both of Wichita, provided logs of several wells in the field. Drs. D. W. Green and G. P. Willhite gave valuable insight into the enhanced oil recovery aspect of the project. The manuscript was typed by Kaye Long and the figures were drafted by Carla Kuhn.

GEOLOGY OF THE UPPER LANSING GROUP IN KANSAS

Stratigraphy

The Lansing Group, as defined by the Kansas Geological Survey (Zeller, 1968), is the highest group of the Missourian Stage, Upper Pennsylvanian Series, Pennsylvanian System. The Lansing Group is typically a regressive-marine sequence of alternating limestone and shales (Heckel, 1977). The Stanton Formation (Fig. 3), including the Wilson Creek Field reservoir limestone, is the upper formation, and it overlies the Vilas Shale. Overlying the Stanton is the Stranger Formation of the Douglas Group, Virgilian Stage. The Lansing Group averages 85 ft. (26 m.) thick in eastern Kansas.

The upper Lansing Group in the outcrop area of eastern and southeastern Kansas has received a great deal of attention. Newell (1933; 1935), Moore (1949), Ball (1959), and Heckel and Cocke (1969) have summarized the distinctive characteristics of the Lansing Group in northeastern Kansas. Heckel (1975) indicates that the Stanton Formation comprises an open marine facies in northeastern Kansas. The Stanton Limestone and Vilas Shale undergo distinct changes southward into the algal-mound facies belt, extending from Anderson to northern Montgomery Counties, Kansas. Farther south, the units change to a terrigenous detrital facies belt of northern Oklahoma (Oakes, 1940). In the subsurface, the Lansing Group and the underlying Kansas City Group are considered together and termed Lansing-Kansas City. Morgan (1952) correlated radioactivity logs of the Lansing-Kansas City in central Kansas and assigned alphabetic designations to the subsurface units in the groups. Parkhurst (1959) correlated members of the surface Lansing and Kansas City Groups to Morgan's alphabetic units. The units in the

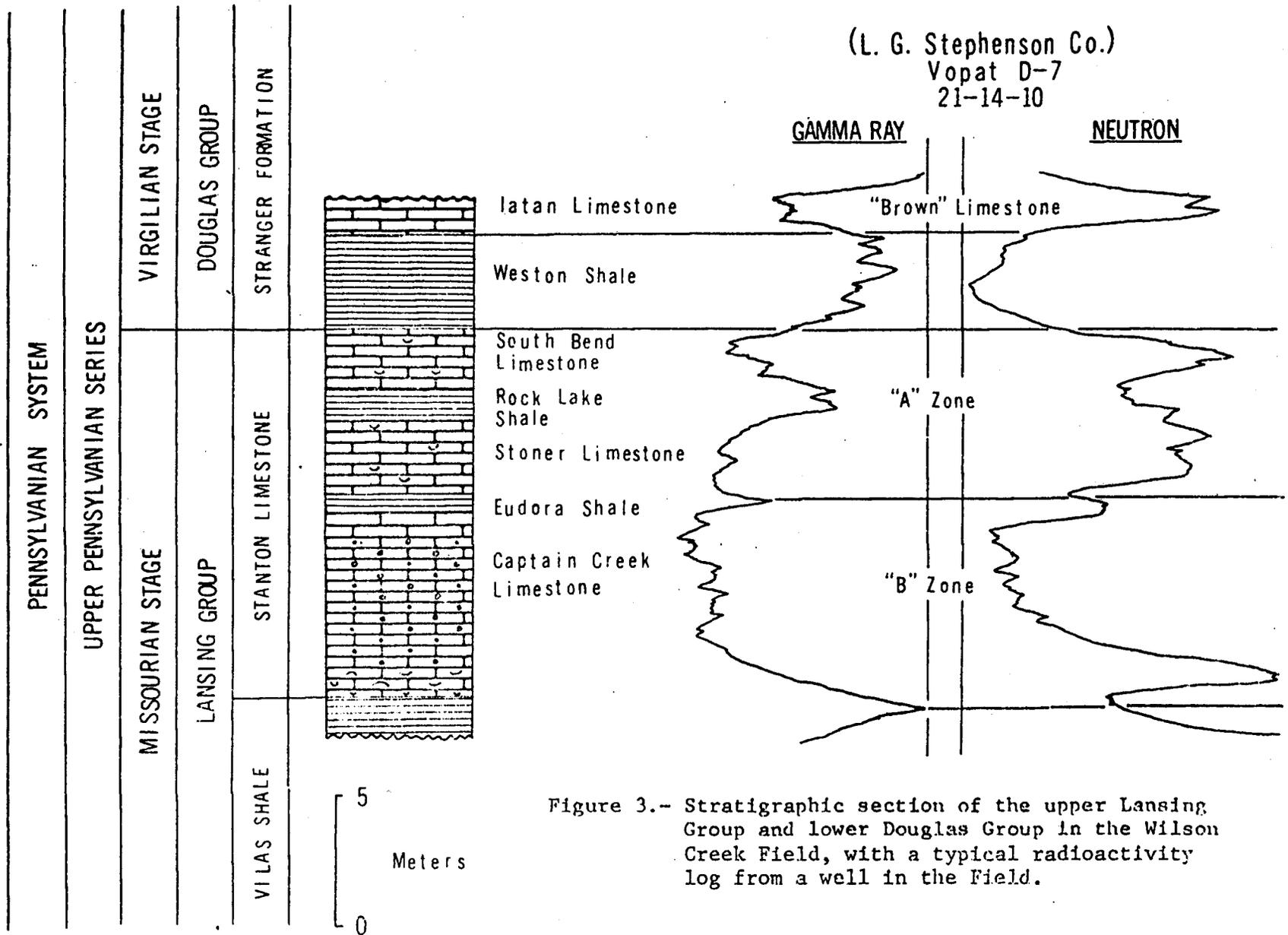


Figure 3.- Stratigraphic section of the upper Lansing Group and lower Douglas Group in the Wilson Creek Field, with a typical radioactivity log from a well in the Field.

Wilson Creek Field may be correlated to Morgan's and Parkhurst's sections (Fig. 4). The Wilson Creek producing zone correlates with the "B" zone (Morgan) and is equivalent to the Captain Creek Limestone of the Stanton Formation (Parkhurst). Parkhurst has not distinguished the uppermost South Bend Limestone and the Rock Lake Shale (Fig. 3) from the Stoner Limestone. The "30' zone" used by geologists in some areas is the productive interval of the "B" zone Limestone. The stratigraphic units in Wilson Creek Field are slightly thicker than equivalent units in Morgan's area of study (Fig. 4) because of slight thinning of the beds on top of the Central Kansas Uplift.

Vilas Shale

The Vilas Shale immediately overlies the Plattsburg Limestone. As described by Moore (1951) and Zeller (1968), the thickness of the Vilas Shale varies from one to more than 100 ft. (.3 to 31 m.) in eastern Kansas. It is commonly a silty, carbonaceous, gray shale, which is fossiliferous in the upper part. This shale has conformable contacts over most of Kansas, as do other formations of the group except the South Bend Limestone. The Vilas Shale is an easily-recognized marker bed in the Wilson Creek area. It ranges from near zero to 10 ft. (0 to 3 m.) thick and is a light to dark gray or green, slightly silty, fissile shale.

Stanton Limestone

Captain Creek Limestone Member.- The Captain Creek Limestone overlies the Vilas Shale and is the basal member of the Stanton Formation (Fig. 3). In eastern Kansas it varies from 4 to 64 ft. (1.5 to 19.5 m.) thick. In northeastern Kansas it is a skeletal limestone with a typical open-marine fauna. The Captain Creek thickens southward and becomes an

Day Petroleum Corporation No.3 Hunter Westgate-Greenland No.1 Simpson

American No.1 Baisel

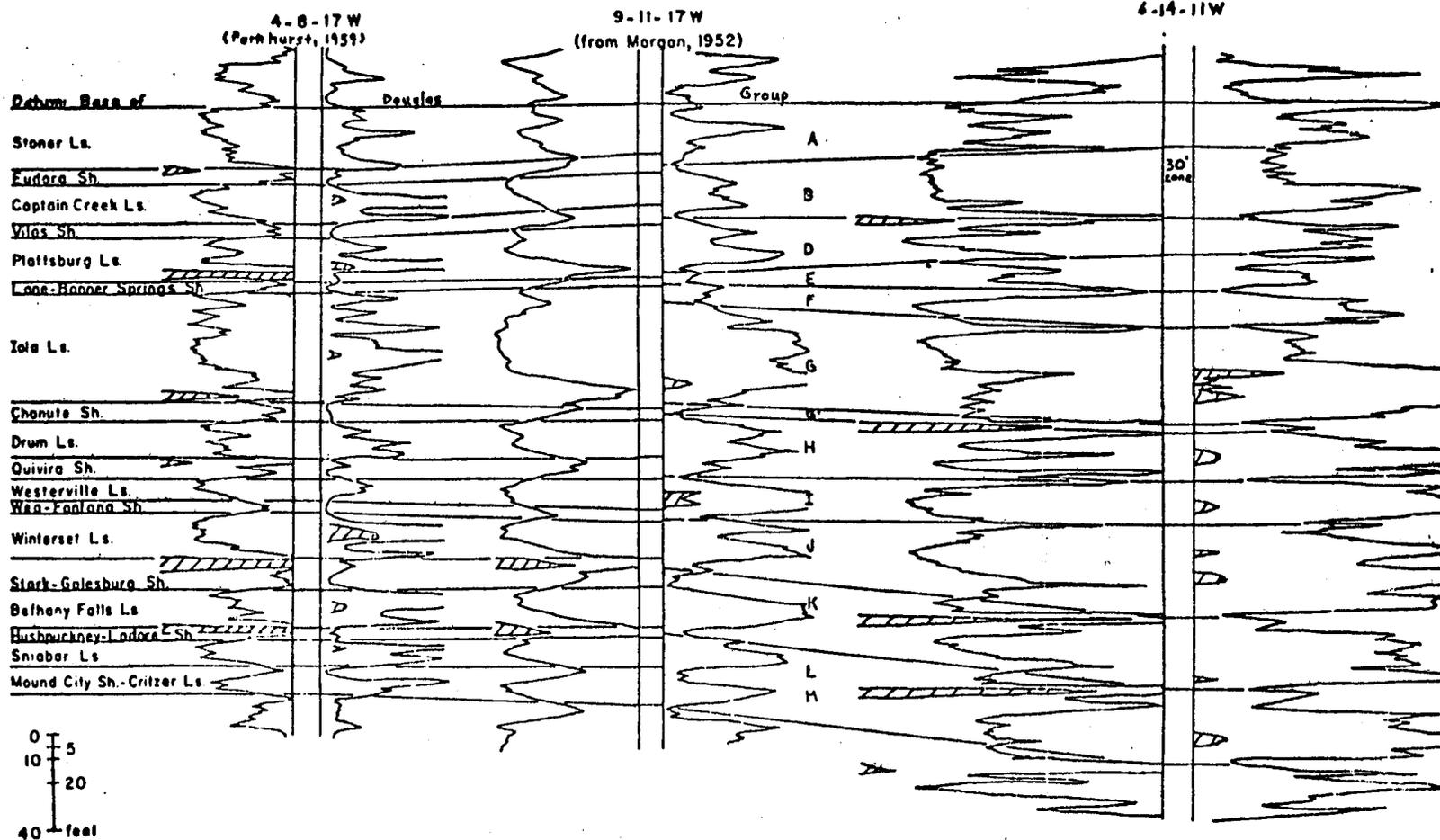


Figure 4.- Stratigraphic section showing relationships between Parkhurst's surface Lansing and Kansas City Groups, Morgan's subsurface alphabetic designations, and a log near the Wilson Creek Field.

algal-mound limestone. The Captain Creek Limestone is equivalent to the "B" zone in the Wilson Creek Field area, ranging in thickness from 6 to 40 ft. (1.5 to 12.5 m.). The Captain Creek is thickest in the field as an oolite facies. This member consists of three distinct limestone lithofacies in the Wilson Creek area: a basal tan to light gray fossiliferous limestone, similar to the Captain Creek in northeastern Kansas; a tan to white oolitic limestone; and a tan lime mudstone at top. This lime mudstone is generally absent over areas of thick oolite.

Eudora Shale Member.- The Eudora Shale overlies the Captain Creek Limestone (Fig. 3). This shale varies from 4 to 11 ft. (1.0 to 3.5 m.) thick in eastern Kansas except in Montgomery County, Kansas, where it is as much as 70 ft. (21.3 m.) thick. It is a black to gray, slightly silty, fissile shale. It contains phosphorite nodules and fossils (Heckel and Cocke, 1969). In the Wilson Creek area, the Eudora Shale comprises zero to 3 ft. (1 m.) of green to gray, fissile shale. It is absent over areas of thickest oolite development in the Captain Creek Limestone and thickens away from these areas.

Stoner Limestone Member.- Overlying the Eudora Shale is the Stoner Limestone (Fig. 3). The Stoner varies from 10 to 50 ft. (3.0 to 15.0 m.) thick in eastern Kansas. It is thickest as an algal limestone in Montgomery County, Kansas, coincident with thick algal Captain Creek Limestone. Elsewhere in eastern Kansas, the Stoner is a light gray, wavy-bedded fossiliferous limestone. In the Wilson Creek Field, the Stoner ranges from 3 to 13 ft. (1 to 4 m.) thick, with no apparent relation of thickness to oolite development in the Captain Creek. It is typically a chalky white to tan limestone, fossiliferous to slightly oolitic. Some wells penetrate a thin shale bed in the Stoner.

Rock Lake Shale Member.- The Rock Lake Shale overlies the Stoner Limestone with a sharp contact (Fig. 3), (Hackel, 1975). It varies from about 1 to 30 ft. (.5 to 9.0 m.) thick in eastern Kansas; it is thickest between the Stoner algal banks in Montgomery County, Kansas. The Rock Lake Shale consists of gray silty to sandy shale and cross-bedded sandstone in eastern Kansas. In the Wilson Creek Field, the Rock Lake Shale is often absent from rotary drilling samples and is poorly shown on well logs. Its thickness varies from zero to 3 ft. (0 to 1 m.), and it is often absent over areas of thickening in the Captain Creek. The Rock Lake is a green to gray, fissile shale. It occasionally consists of two thin shale beds separated by a light gray limestone.

South Bend Limestone Member.- Overlying the Rock Lake Shale is the South Bend Limestone, the uppermost member of the Lansing Group (Fig. 3). The South Bend is 1 to 6 ft. (.5 to 2.0 m.) thick over most of the outcrop belt in eastern Kansas. It consists of a calcareous sandstone to oolitic limestone bed, overlain by a gray fossiliferous limestone in this area. In northern Montgomery County, Kansas, it thickens to more than 27 ft. (8.0 m.) of algal limestone. In the Wilson Creek Field area, the South Bend varies from 5 to 8 ft. (1.5 to 2.5 m.) in thickness and has a sharp contact with the overlying gray shale. The contact with the Rock Lake Shale varies from sharp to gradational and, occasionally, the South Bend directly overlies the Stoner Limestone, with no Rock Lake present. The South Bend is usually a creamy white to light gray dense, slightly fossiliferous limestone. It may be oolitic in part, especially near the base, with minor oomoldic limestone like that in the Captain Creek.

icates that, prior to late Pennsylvanian time, gentle upwarping on the uplift caused erosion of sediments, in some areas, down to the Precambrian. This uplifted area is surrounded by several low-relief basins in Kansas.

Structural features in Kansas reached their maximum differentiation in Mississippian or earliest Pennsylvanian time (Fig. 5). The early Paleozoic Arbuckle Group was deposited on a Precambrian surface of apparent low relief (Merriam and Atkinson, 1955), except locally where Precambrian granite hills were present (Walters, 1946). Major uplift and sediment erosion occurred between Ordovician (Arbuckle) and Pennsylvanian time. Mississippian and some lower Pennsylvanian strata were never deposited on the Central Kansas Uplift because of its positive topographic relief. This accounts for the absence of these units below the Lansing and Kansas City Groups in the Wilson Creek Field. Rascoe (1962) indicates that Paleozoic sediments were deposited in Kansas during a transgression of the sea from the south. By Missourian time, the Central Kansas Uplift area was low enough to be inundated and covered by Kansas City and Lansing strata. Minor regressive phases in the Lansing Group were present during this overall transgression (Heckel, 1972).

The Wilson Creek Field is on the eastern flank of the Central Kansas Uplift, which is bounded by the Salina Basin on the northeast (Fig. 5). Figure 6 shows the approximate location of the Ellsworth anticline, a subordinate structure of the uplift. This is a fault in the Arbuckle and deeper units, part of which extends beneath the Wilson Creek Field. It provided a major tectonic control on sedimentation in the area.

Paleogeography and Tectonic Framework of the Region

In early Paleozoic time, central North America was a stable, structurally positive craton, bounded by active tectonic areas. The craton was dissected intermittently by a transcontinental arch (Eardley, 1951) which extended southward from the Canadian shield. Rascoe (1962) indicates, "the Cambridge Arch-Central Kansas Uplift formed a subordinate structural trend southeastward off this cratonal axis". Weaver (1958) indicates that, prior to late Pennsylvanian time, gentle upwarping on the uplift caused erosion of sediments, in some areas, down to the Precambrian. This uplifted area is surrounded by several low-relief basins in Kansas.

Structural features in Kansas reached their maximum differentiation in Mississippian or earliest Pennsylvanian time (Fig. 5). The early Paleozoic Arbuckle Group was deposited on a Precambrian surface of apparent low relief (Merriam and Atkinson, 1955), except locally where Precambrian granite hills were present (Walters, 1946). Major uplift and sediment erosion occurred between Ordovician (Arbuckle) and Pennsylvanian time. Mississippian and some lower Pennsylvanian strata were never deposited on the Central Kansas Uplift because of its positive topographic relief. This accounts for the absence of these units below the Lansing and Kansas City Groups in the Wilson Creek Field. Rascoe (1962) indicates that Paleozoic sediments were deposited in Kansas during a transgression of the sea from the south. By Missourian time, the Central Kansas Uplift area was low enough to be inundated and covered by Kansas City and Lansing strata. Minor regressive phases in the Lansing Group were present during this overall transgression (Hec- kel, 1972).

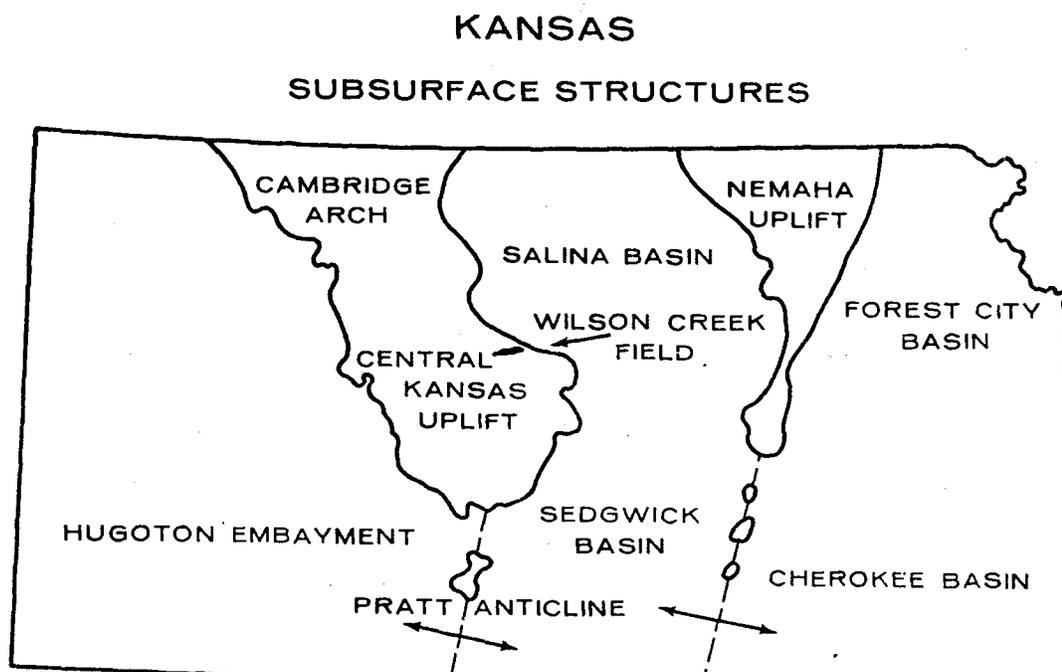


Figure 5.- Regional subsurface structural provinces in Kansas.
Adapted from Merriam (1963), Fig. 112.

The Wilson Creek Field is on the eastern flank of the Central Kansas Uplift, which is bounded by the Salina Basin on the northeast (Fig. 5). Figure 6 shows the approximate location of the Ellsworth Anticline, a subordinate structure of the uplift. This is a fault in the Arbuckle and deeper units, part of which extends beneath the Wilson Creek Field. It provided a major tectonic control on sedimentation in the area.

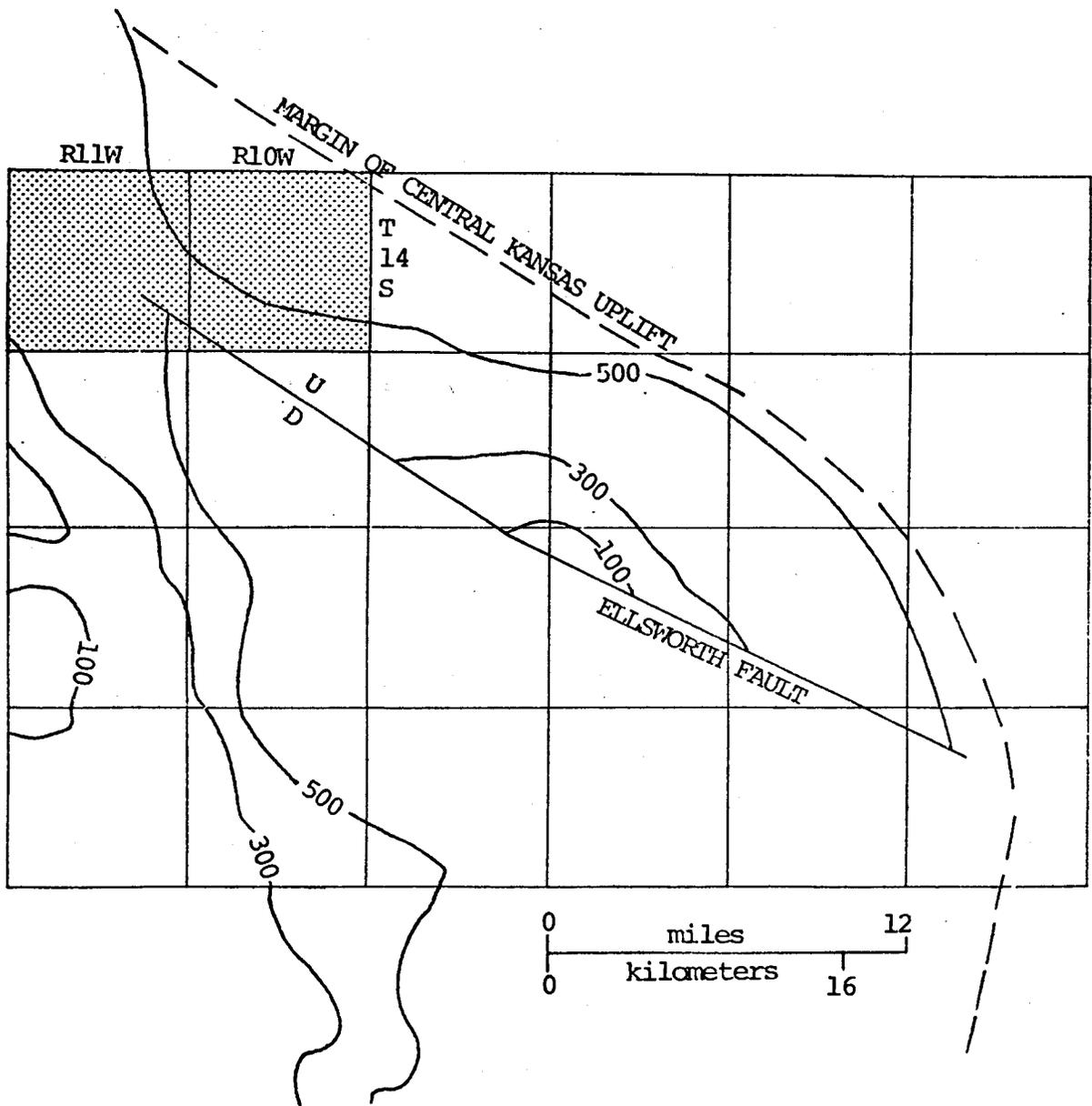


Figure 6.- Location of Ellsworth fault in Ellsworth and Russell Counties, Kansas. Contours indicate thickness of Arbuckle Group in feet. T14S-R10W and R11W of Wilson Creek Field area shown. Adapted from Cole (1975), Plate 1. (Stippled townships indicate study area).

GEOLOGY AND DEPOSITIONAL ENVIRONMENTS OF THE CAPTAIN CREEK
LIMESTONE IN THE WILSON CREEK FIELD

Geometry

The Captain Creek Limestone, which is the main oil reservoir in the Wilson Creek Field comprises an elongate, generally west to east trending, porous, oolitic limestone and associated facies. The entire extent of the oolite is not known because of incomplete well control, but it extends at least from T14S-R12W in Russell County, to T16S-R7W in Ellsworth County. Upper Lansing oolitic limestones have been recognized in other parts of western Kansas (Schmidt, personal communication), but these probably occur as similar facies of separate limestone formations.

The Wilson Creek Field is on the south flank of an elongate, lens-shaped oolite, as shown on the isopach map (Fig. 7). As the contours show, the oolite continues west of Sec. 23-T14S-R11W, and southeast of Sec. 27-T14S-R10W. The isopach map also shows several areas where the oolitic zone is absent, that is, parts of Secs. 16, 17, 29, and 30 of T14S-R10W; and Secs. 25 and 26 of T14S-R11W. The oolite extends somewhat beyond the area shown by the map of Figure 7. The oolite is thickest at the south end of the Wilson Creek Field and thins gradually to the north. In sections through the field (Figs. 10, 11), the thinning or absence of the dense limestone and Eudora Shale above the thickest parts of the oolite are apparent. The dense zone in the center of the porous interval is fairly persistent and may be continuous across most of the field. Laterally, the oolite thins and grades into nonporous dense limestones.

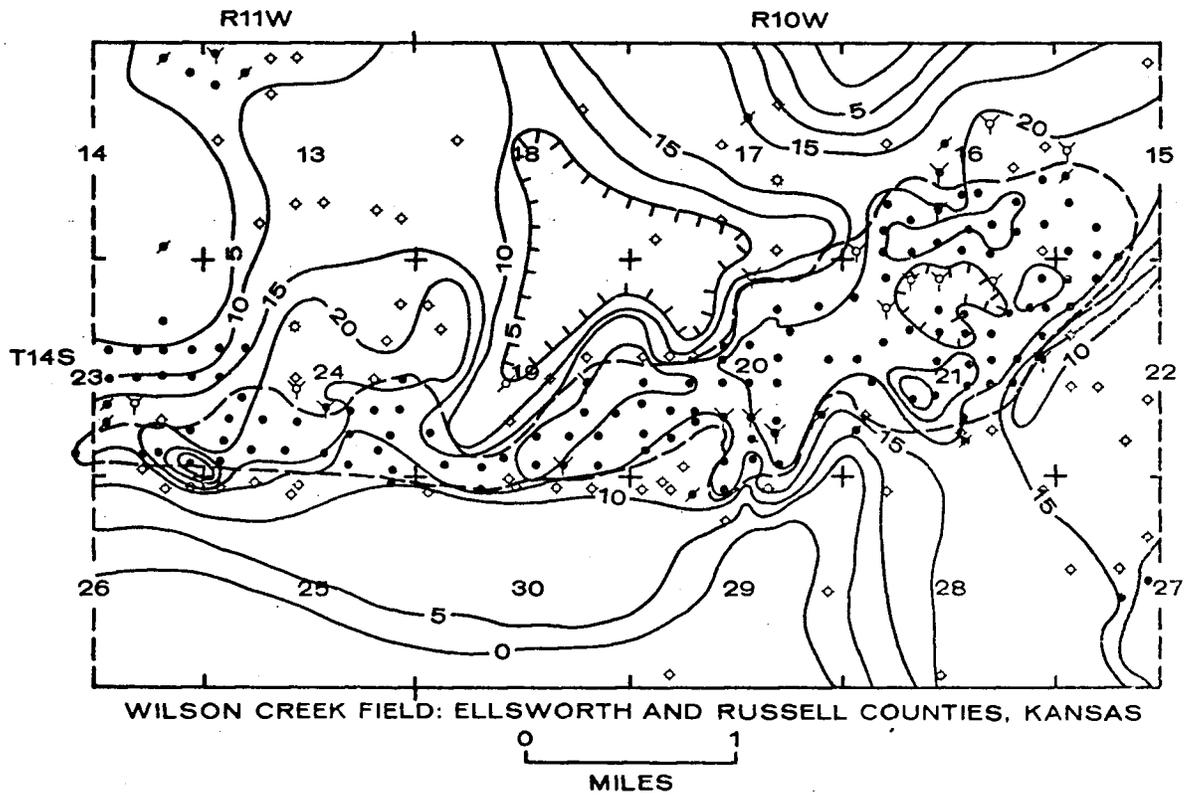


Figure 7.- Isopach map of the Captain Creek oolite in the Wilson Creek Field area. Contour interval is 5 ft. Dashed line represents limits of oil production from this oolite. See Fig. 8 for symbol designations.

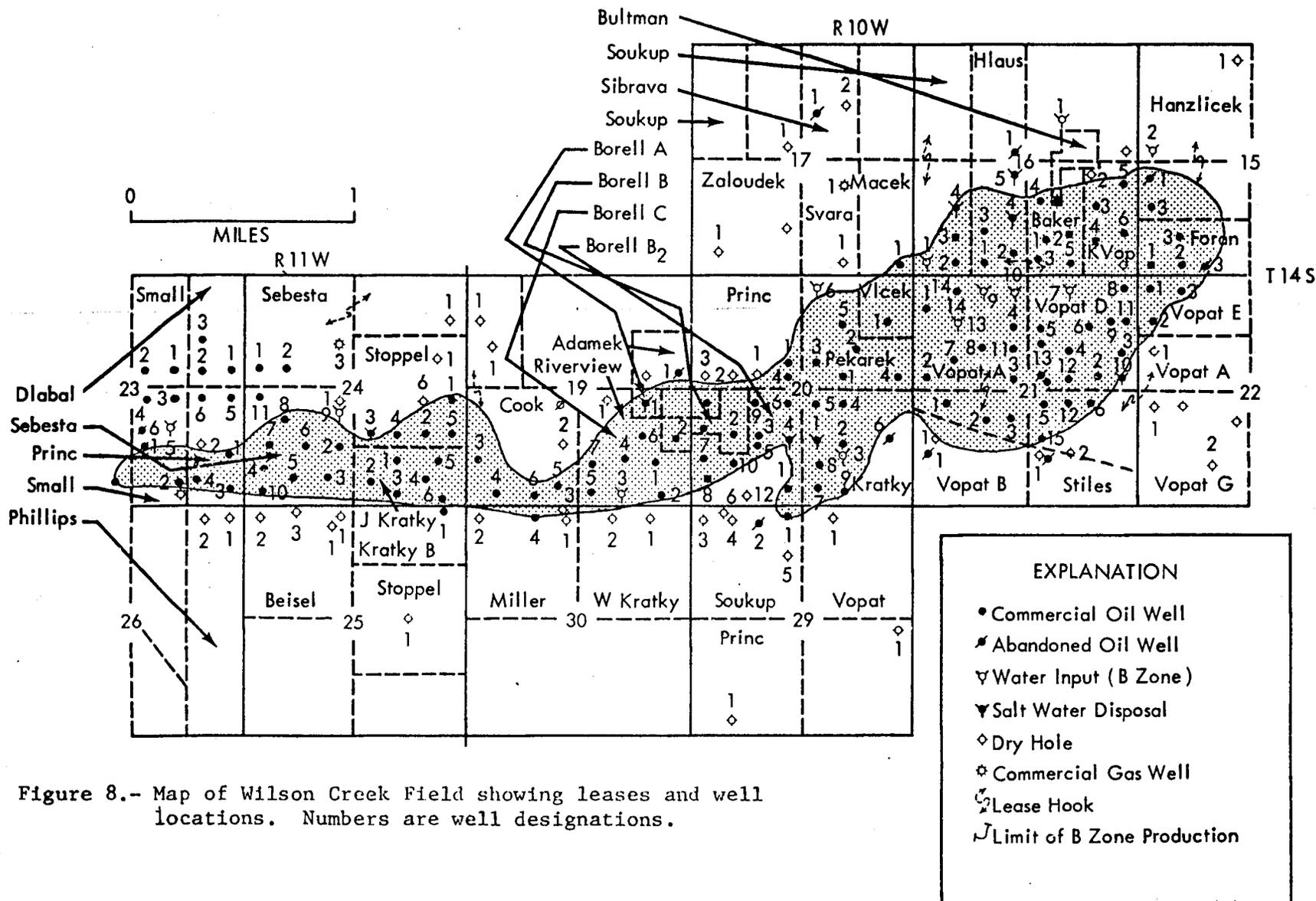


Figure 8.- Map of Wilson Creek Field showing leases and well locations. Numbers are well designations.

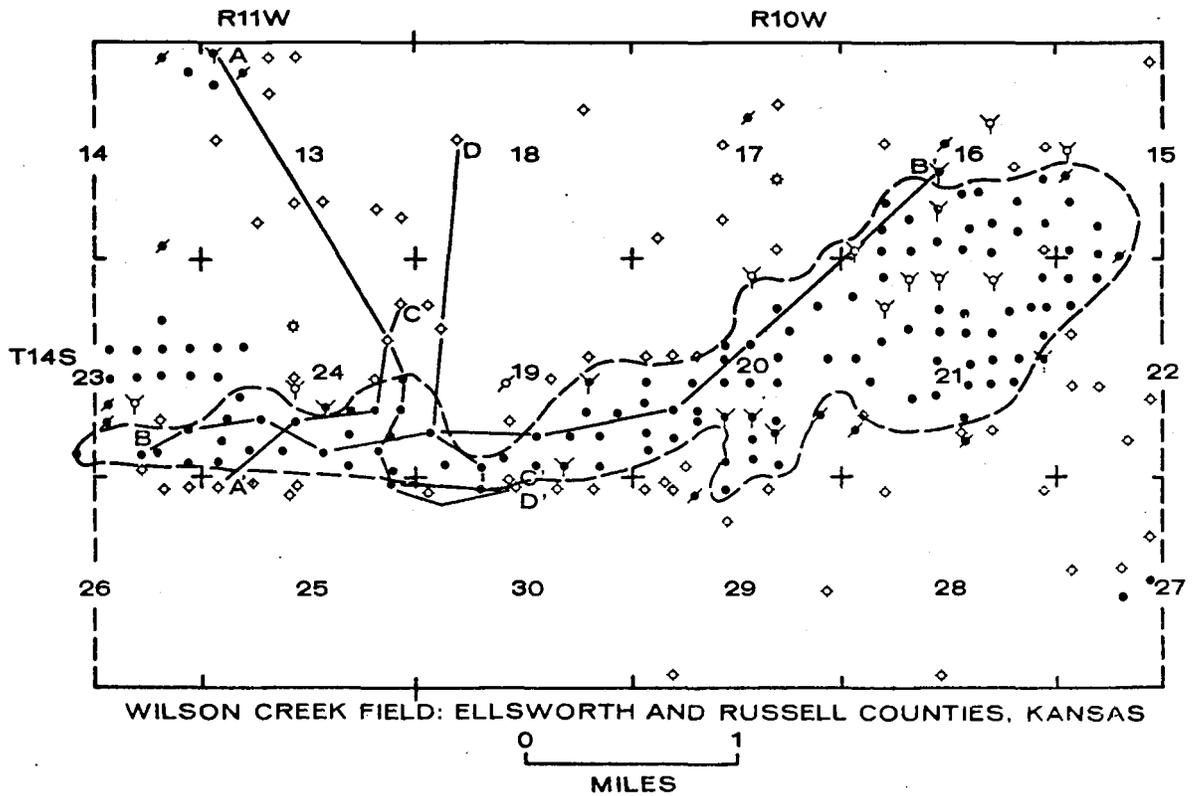


Figure 9.- Locations of cross-sections through Wilson Creek Field.
See Figs. 10, 11, 22, 23.

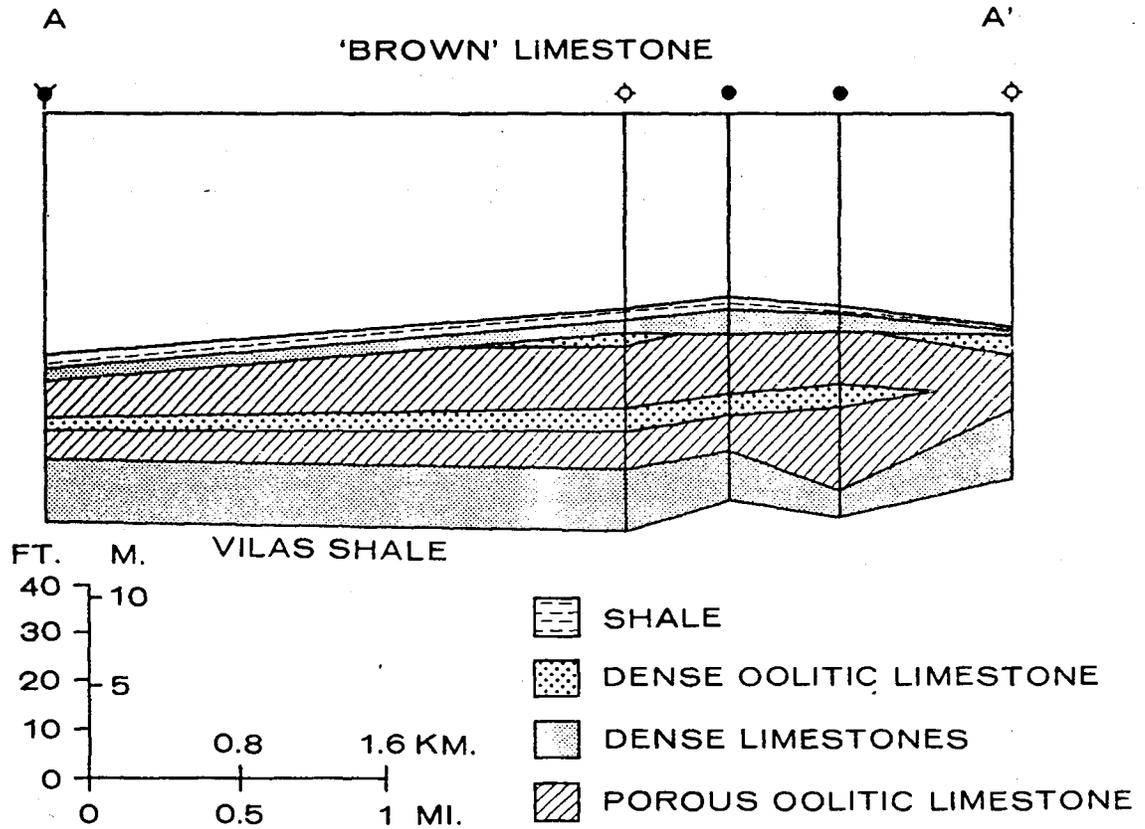


Figure 10.- Stratigraphic cross-section across Wilson Creek Field, with porous interval of Captain Creek Limestone shown. Datum is, base of "Brown" Limestone. See Figure 9 for location of section.

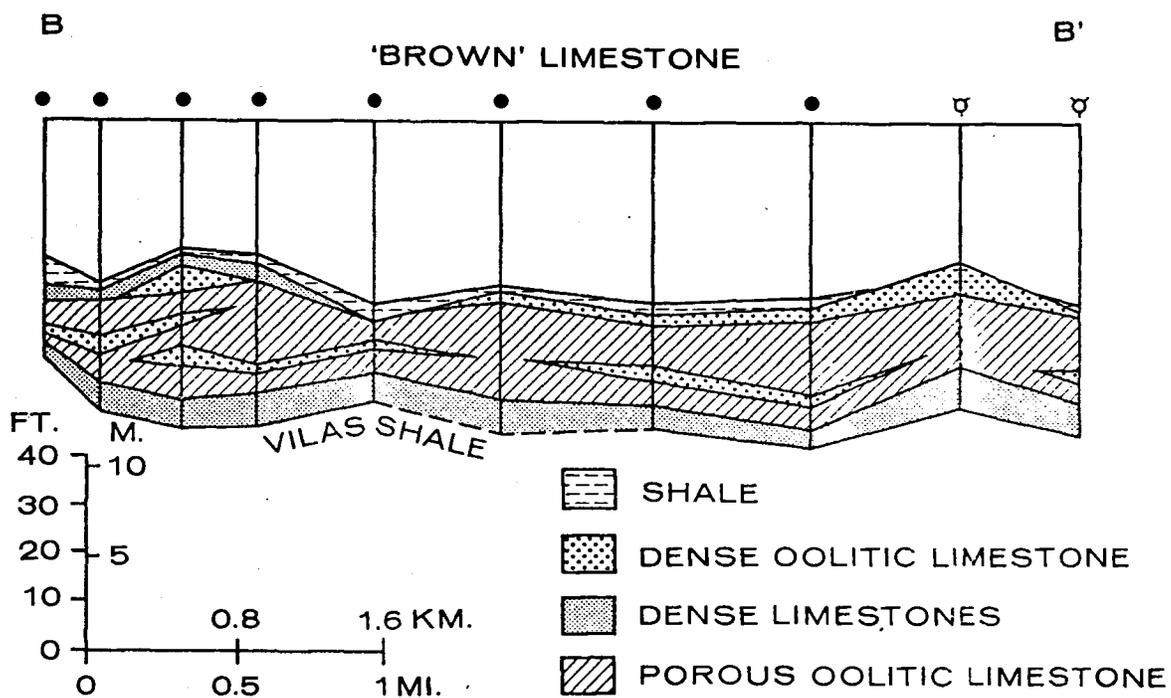


Figure 11.- Stratigraphic cross-section along the length of Wilson Creek Field, with porous interval of Captain Creek Limestone shown. Datum is base of "Brown" Limestone. See Figure 9 for location of section.

Petrography

Ooid-Oomold Grainstone

The porous reservoir rock of the Wilson Creek Field is ooid-oomold grainstone (Dunham, 1962). Descriptions of one complete core of the producing zone and two cores of part of the zone are included as Appendix I. The constituent composition based on visual estimates of core thin sections is 80-95% ooids (including subequal amounts of whole ooids and oomolds), and 5-20% fossil fragments (chiefly fragments of echinoderms, brachiopods, foraminifers, and algal blades). A typical estimate is from a slide of the Vopat A-3 (Rupe) core (C E2 NE SW, 21-14-10), taken at 2825 ft. (861.1 m.): 93% ooids, 4% echinoderms (chiefly crinoid columnals and plates), 2% brachiopod fragments, and 1% fragments of algal blades.

The rock fabric is entirely grain supported. Two types of alternating layers are observed in this lithology: ooid grainstone with a few molds, and oomold grainstone with a few ooids. Point counts of seven thin sections indicate a greater percentage of grains in the ooid layers than in the oomold layers. Boundaries between layers were chosen where one grain type is overwhelmingly abundant. The ooid layers contained 53-63% grains (the remainder is cement); the oomold layers contained 39-52% grains (as molds). Although not great, the difference indicates slightly closer packing in the ooid layers. Point counts were also made of the average sizes of these grains in the ooid and oomold layers of four of these thin sections. The ooid layers include grains whose average size ranges from 0.301 to 0.332 mm., and the oomold layers include moldic pores whose average size ranges from 0.353 to 0.422 mm. The smaller sizes of grains in the ooid layers may account for closer

packing (greater % of grains) than in the mold layers. Some enlargement of molds by dissolution undoubtedly caused an increase in the size of the molds measured.

A minor amount of micrite is present as matrix in this lithology, especially near the top (Fig. 12-3) in the F. Princ 1 (Texaco) core (SW SE NW, 20-14-10). The rock is an ooid packstone since it is grain-supported and lacks oomolds where micrite is present. Elsewhere, space between grains is entirely filled by calcite spar cement, with no intergranular porosity. The matrix and grains have been diagenetically altered. Grains vary from whole ooids to partially dissolved ooids to oomolds. The original tangential aragonite ooid lamellae (Illing, 1954) have been replaced by a medium-crystalline equant calcite spar. Molds often contain a coarse blocky dolomite spar (Fig. 12-4). This is ferroan dolomite, which stained blue in Alizarin Red S and potassium ferricyanide stain (see Appendix II). Two intergranular cements are present. A scalenohedral (calcite) cement evenly coating grains is present and is partly recrystallized to more equant spar. Medium to coarsely crystalline calcite spar cement fills the remaining voids between grains.

Other diagenetic features are a result of compaction and pressure solution. Stylolites are abundant (Fig. 13-3) and often include concentrations of resistant grains (like echinoderm fragments). Near these are small, crushed oomolds, which appear as ovals. Areas of densely-packed ooids (overly-close packing) are associated with some stylolites. Small vertical fractures are present and are filled with coarse dolomite spar in one place.

An important sedimentary structure is the cross-bedding observed in the Vopat A-3 core. This consists of layers dipping less than 25° com-

Figure 12.- Photomicrographs of the oolitic limestone.

- 1.- Boundary between ooid layer (top) and oomold layer. From Vopat A-3 core (21-14-10) at 2829 ft. (862 m.) (x-nicols; 40x); scale = 0.5 mm.

- 2.- Ooid-skeletal lens, showing foraminifer (top), echinoderm plate and spine (lower left and center), and brachiopod fragment (bottom). From F. Princ 1 core (20-14-10) at 2796 ft. (852 m.) (x-nicols; 40x); scale = 0.5 mm.

- 3.- Ooid packstone at top of oolitic zone. Dark patches between ooids are micrite. From F. Princ 1 core at 2795 ft. (852 m.) (x-nicols; 40x); scale = 0.5 mm.

- 4.- Dolomite spar (d) filling molds (outlined with dots). From F. Princ 1 core at 2807 ft. (856 m.) (x-nicols; 40x); scale = 0.5 mm.

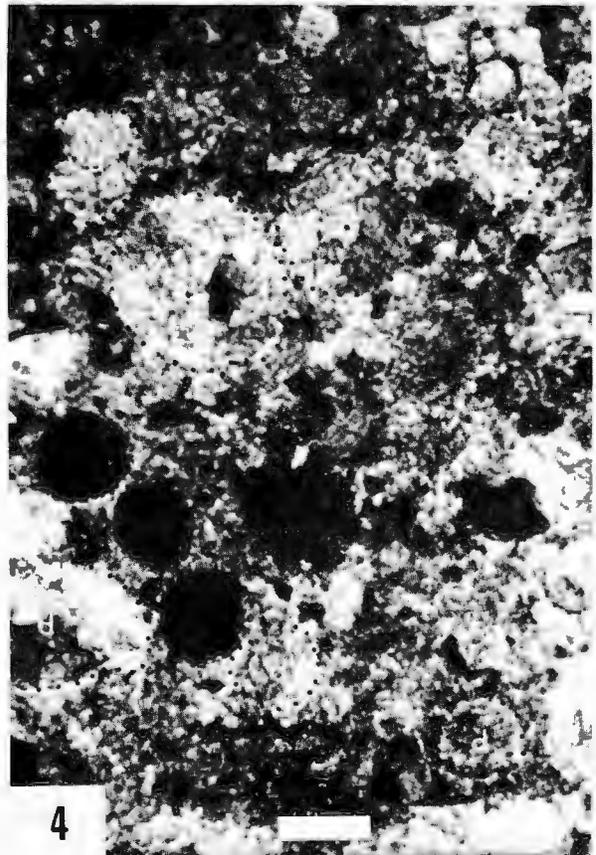
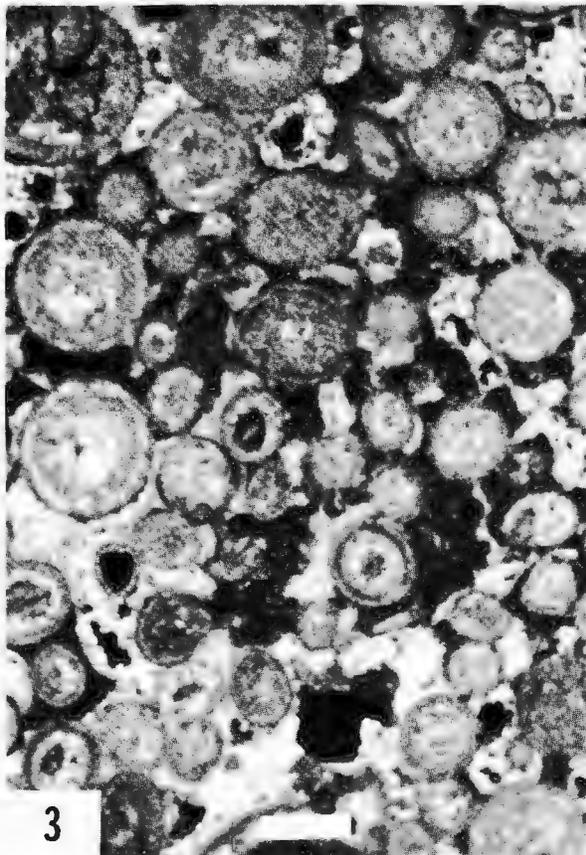
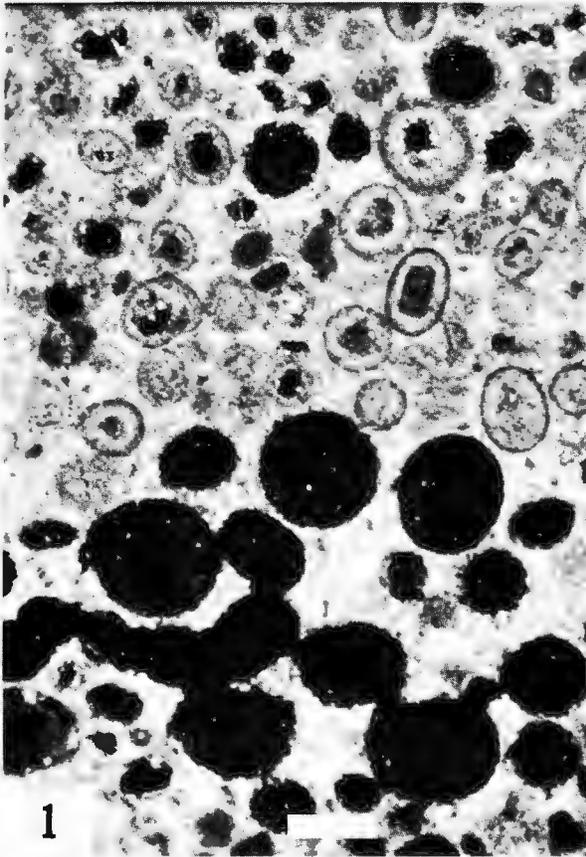


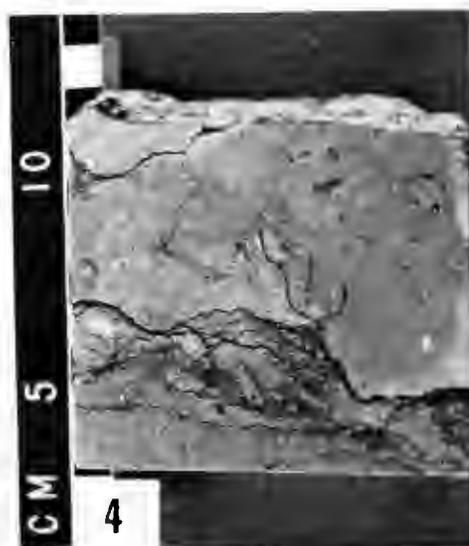
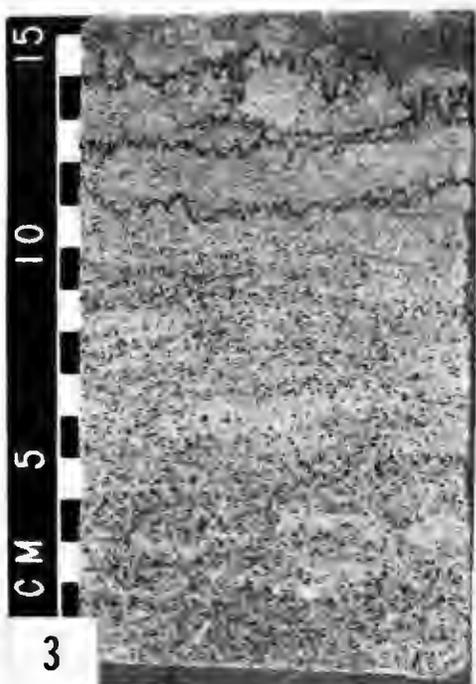
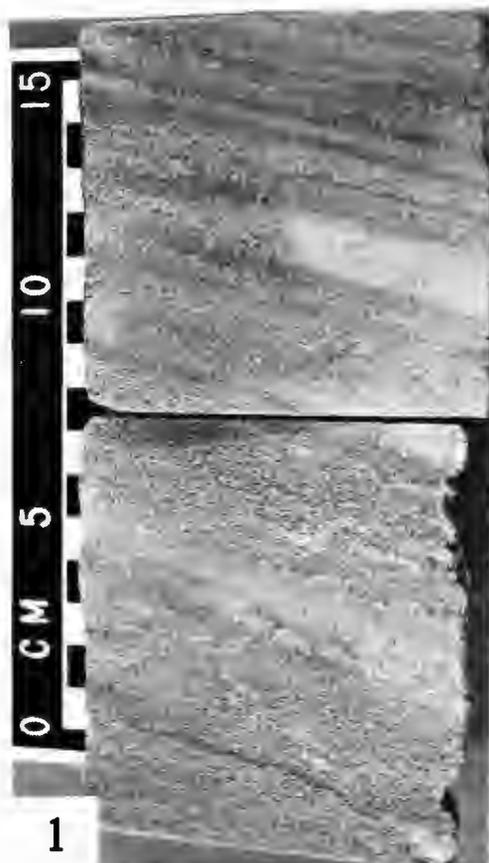
Figure 13.- Representative photographs of cores.

- 1.- Cross-bedding shown by alternating ooid and oomold layers (molds are black). From Vopat A-3 core at 2834 ft. (864 m.).

- 2.- Lenses of alternating ooid and oomold layers. White echinoderm fragments outline the skeletal lenses. From Vopat A-3 core at 2828 ft. (862 m.).

- 3.- Scattered oomolds (black) in an ooid grainstone. From F. Princ 1 core at 2809 ft. (856 m.).

- 4.- Fossil wackestone underlying oolite showing pyrite (dark gray) and clay along the stylolites (black). From F. Princ 1 core at 2812 ft. (857 m.).



posed of alternating ooids and oomolds (Fig. 12-1, 13-1). Another structure is lenses of alternating layers of ooids and oomolds (Fig. 13-2), observed in both the Vopat A-3 core and the F. Princ 1 core. These lenses become indistinct in places, grading to a texture of scattered oomolds in an ooid grainstone (Fig. 13-3). This is observed only in the F. Princ 1 core. Both cores contain an ooid grainstone layer up to 3 ft. (1 m.) thick in the middle of this lithology. It appears as a nonporous layer on neutron-porosity logs from most wells in the Wilson Creek Field. Another structure consists of skeletal lenses. Although fossil fragments are scattered throughout this lithology, occasional lenses of packed skeletal debris are observed. These lenses are small (usually smaller than the width of the core or 9 cm.) and the elongated fossils such as brachiopods are often aligned parallel to the lens. The lenses are especially abundant near the top of the ooid packstone of the F. Princ 1 core (Fig. 12-2).

The textures and structures of this lithology vary over the area of the Wilson Creek Field. The Vopat A-3 core and rotary samples from the southern and central parts of the field have good cross-bedding and long lenses of ooid-oomold layers. No micrite and fewer fossils are observed in this area. The F. Princ 1 core and rotary samples from around the field (especially to the north) have slightly different structures. No cross-bedding, only scattered molds, and abundant ooid packstone (with skeletal grains) are present in these locations. The oolitic lithology is also thinner here. The ooid-oomold grainstone facies varies from 6 to more than 40 ft. (2.0 to 12.5 m.) thick in the Wilson Creek Field.

Several wells around the field have variations of the oolitic lithology. From the well Borell B-2, 12 (SW, 20-14-10) there are rotary

samples of fossiliferous ooid grainstone to fossiliferous oomold grainstone. The third core described, from Beisel 1 (Texaco), (NEc SE, 6-14-11) contains a markedly different Captain Creek lithology. This is chiefly an ooid-oomold packstone interbedded with a lithoclast-pelletoid packstone. Fossil skeletal debris is abundant at the base of the core. The lithoclasts are dark gray shale and light gray dolomite, and are commonly abraded.

Fossil Wackestone

The fossil wackestone lithofacies underlies the oolitic lithology in every core and set of drilling samples examined. The constituents of this lithofacies are: brachiopods, echinoderms, fusulinids, molluscs, fenestrate bryozoans, and calcispheres (?); chiefly as unabraded particles. These constituents occur in subequal amounts. Some pelletoids and rare intraclasts are also observed in the F. Princ 1 core at 2812 ft. (857 m.) (Fig. 14-1).

The fossil wackestone (Dunham, 1962) is entirely matrix supported, grains comprising 10-30% of the rock. The matrix is micrite, except in a burrow observed in the F. Princ 1 core at 2812 ft. (857 m.) where coarse calcite spar is observed with micrite (Fig. 14-2). This calcite spar is the chief diagenetic feature, and fills voids in the micrite of the burrow. This lithology occurs over the entire Wilson Creek Field area, and is usually 1 to more than 5 ft. (0.5 to 1.5 m.) thick. In places the fossil wackestone grades to a fossil packstone with minor intergranular spar in the micrite matrix.

Lime Mudstone

This lithofacies is observed in a few field wells and in most wells outside the field. Pelletoids and intraclasts are the only grains

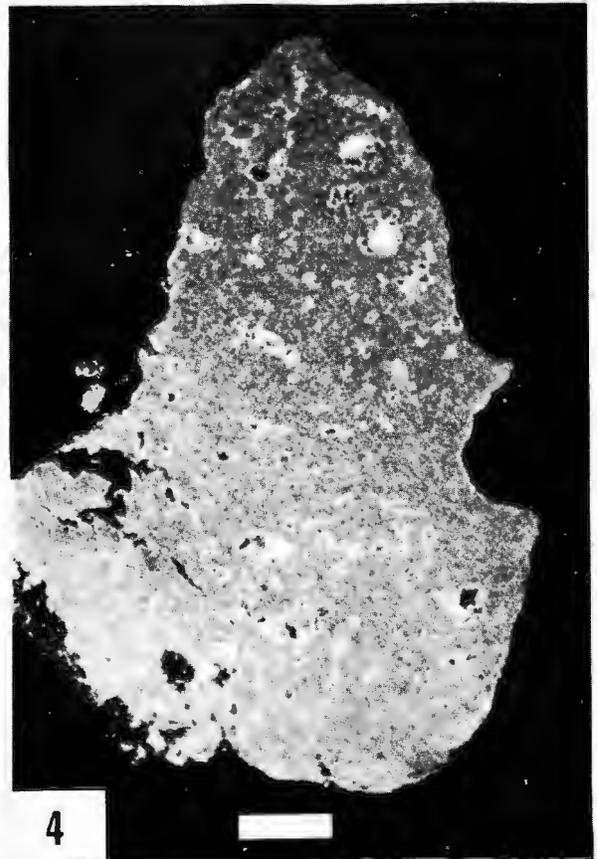
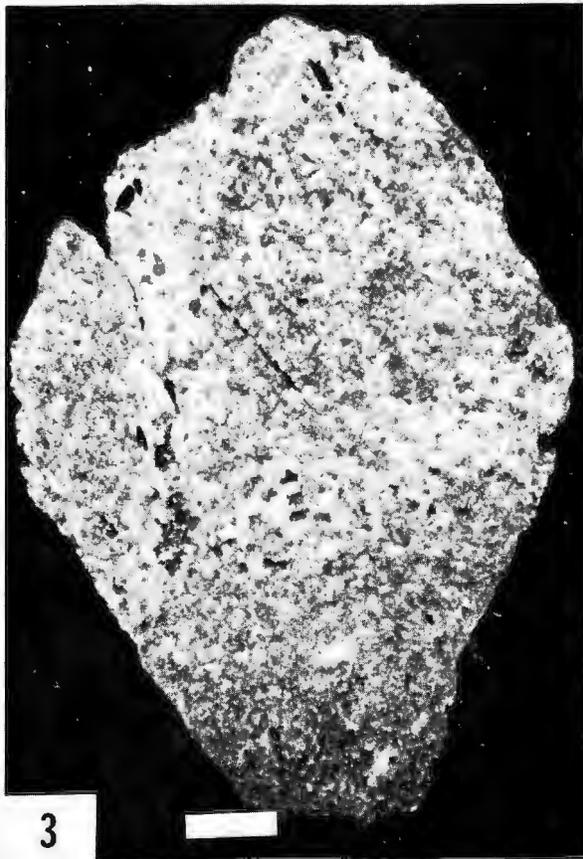
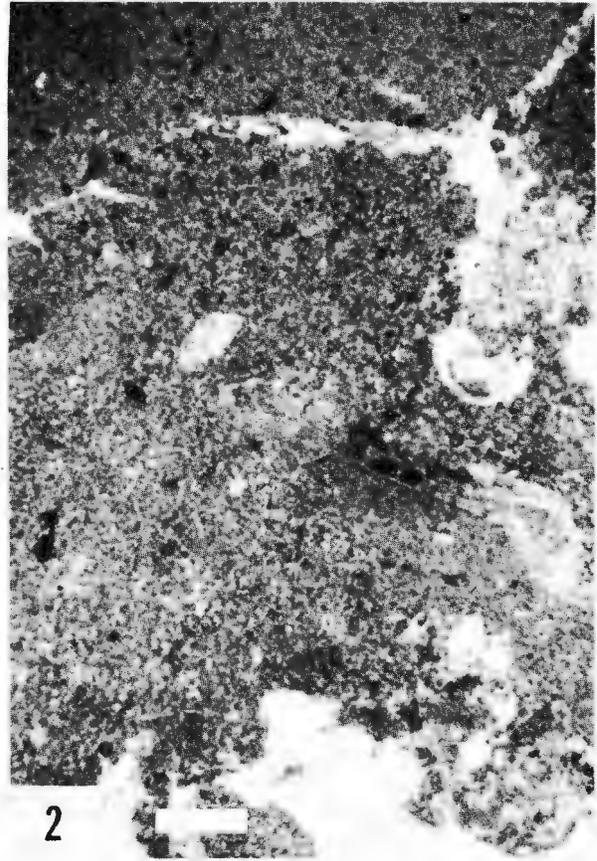
Figure 14.- Photomicrographs of the fossil wackestone and lime mudstone.

- 1.- Fossil wackestone showing fusulinid (top), bryozoan (bottom), pelletoids (dark gray), intraclast (lower center), echinoderm (upper center), small brachiopods, and calcispheres (?). From F. Princ 1 core at 2812 ft. (857 m.) (x-nicols; 40x); scale = 0.5 mm.

- 2.- Burrow detail with the unaltered wall at top. From F. Princ 1 core at 2812 ft. (857 m.) (x-nicols; 40x); scale = 0.5 mm.

- 3.- Recrystallized pelletoid mudstone showing clots (dark gray). Rotary drilling sample from well Pasek 1 (Palmer), 3-14-11, at 2795 ft. (852 m.) (x-nicols; 40x); scale = 0.5 mm.

- 4.- Possible fenestral fabric. Rotary drilling sample from well Stratman 1 (Eldorado), 32-14-11, at 2899-2906 ft. (884-886 m.) (x-nicols; 40x); scale = 0.5 mm.



observed in this mudstone fabric. These comprise less than 10% of the rock, and the matrix is entirely micrite. The pelletoids have been diagenetically altered to indistinct clots (Fig. 14-3) in a micrite matrix. The micrite is partly recrystallized to microspar in some examples.

Well Stratman 1 (32-14-11) contains a lime mudstone with possible fenestral fabric (Fig. 14-4). This appears as calcite spar filling matrix-supported voids. This fabric is, however, visible only in cuttings and cannot be confirmed. It may be solution cavities filled with calcite cement. This is the only primary sedimentary structure observed in this lithology, which occurs over most of the Wilson Creek area, except in areas of thick oolite accumulation. It varies from 0 to 3 ft. (0 to 1 m.) thick.

Two wells from which rotary samples of the Captain Creek were observed contained no ooid-oomold grainstone. Well Hines 3 (23-14-11) contains a fossil wackestone with the ooid grainstone and lime mudstone lithologies absent. Well Stratman 1 (32-14-11) contains a pelletoid-fossil wackestone to packstone, overlain by a pelletoid wackestone to mudstone. Combined with other driller's logs and radioactivity logs around the area, these wells were useful in determining the extent of the ooid-oomold grainstone lithology.

Environments of Deposition

Facies of the Captain Creek Limestone

The lithologic sequence of the Captain Creek Limestone in the Wilson Creek Field is interpreted as resulting from deposition of carbonate sediment in a progressively shallowing, or shoaling-upward, environment. From the preceding discussion, the lithologies in the Wilson Creek Field, from the base upward, may be summarized as follows:

- (1) Fossiliferous, burrowed lime wackestone with a typical "open marine" shelf fauna; may be packstone in places
- (2) Ooid-oomold grainstone with large, low angle (less than 25°) cross-beds or indistinct lenses; some fossiliferous ooid packstone at top
- (3) Lime mudstone with "clotted" texture, probably recrystallized pelletoid mudstone; some fenestral fabric, no fossils

In areas where oolite was not formed, the section may consist of (1) and (3), but usually only (1). Gray shale occurs directly above and below unit (1) in these wells. Unit (3) and overlying Eudora Shale (gray) are absent in areas of thickest oolite accumulation.

Wilson (1975) describes the carbonate facies pattern which applies to deposition on a gently sloping shelf adjoining an abrupt shelf margin. Newell (1953), Irwin (1965), Horowitz and Potter (1971), and others have described a similar sequence. Three of Wilson's facies are strikingly similar to the Captain Creek lithologies. The shelf environment - open circulation belt produces a fossil wackestone to packstone. This environment is below wave base, usually deeper than 65 ft. (20 m.). Burrows and fragmented or whole fossil remains are common. This is a good description of the lower facies in the Wilson Creek Field. The second facies of importance is formed in a shoal environment with agitation by waves. This occurs in a zone of constant wave action, usually from 10 meters below to just above sea level. A lithology which commonly forms there is an ooid grainstone with overpacked fabric, large, high angle (avalanche) uni-directional cross-beds, and few if any fossils. This facies corresponds to the porous producing zone, the oolite facies of the Wilson Creek Field. Wilson's third facies forms in restricted marine shelf lagoons, an environment which is protected from vigorous water circulation. One type of rock formed in this setting is

a bioturbated, pelleted mudstone to wackestone with occasional fenestral fabric. This implies deposition in very restricted bays and ponds. The upper facies of the Captain Creek is very similar to this facies. The absence of any fossils in the former might be due to an inhospitable (hot, hypersaline) environment.

The sequence of environments, normal marine, oolite shoal, restricted lagoon, in the Captain Creek Limestone has been described in other rock sequences. Smith (1972) and Wilson (1975) have described a typical shoaling-upward shelf cycle that has many features in common with the Wilson Creek lithologic sequence. Todd (1976) described a similar sequence for the San Andres Formation in West Texas. Deposition in the study area is discussed in terms of Wilson's model.

Depositional Model

During time of Vilas Shale deposition, terrigenous mud was deposited over all but the highest areas of central Kansas from a source area to the north in Nebraska (Watney, personal communication). Near the Wilson Creek Field, the shale thins from about 10 ft. (3 m.) to less than 3 ft. (1 m.) toward the center of the field. The bathymetric ridge in the area of later oolite deposition may have prevented mud from accumulating there, because of wave or current action. The water must have been fairly shallow. After deposition of this mud, water depth increased slightly and normal marine-open circulation was established. Deposition of the fossil wackestone facies occurred over the entire area during this period of deeper water, with little thinning over the ridge because of the weakness of marine currents.

Subsequent shallowing of water was the beginning of the shoaling phase of deposition. Gradual decrease of water depth probably resulted

from sedimentation. When the bottom reached wave-base, agitation caused formation of oolitic deposits. An initial small lobe of oolite was gradually built into a shoal. In the Bahama Banks, oolite shoals form near bathymetric prominences, where waves from offshore agitate the water and calcium carbonate coating of grains occurs (Illing, 1954).

The underlying surface on which the upper Lansing Group was deposited was also important in controlling deposition. The structural map of the base of the Captain Creek oolite (Fig. 15) is very similar to a map of the structure on the top of the oolite (Fig. 18), except for filling-in of low areas by thick oolite deposition. The high ridge which underlies the northern part of the field was probably a topographic ridge formed above the deeper Ellsworth fault (Cole, 1975) at the time of Lansing deposition (the small fault on the southwest side of the field is a post-depositional feature). The steep southward slope of the surface beneath the Captain Creek may be an expression of the deeper fault plane, with the upthrown side on the north. The fact that the fault does not cut the Lansing surface indicates draping of Lansing units over the steep slope and later inactivity of the fault in this immediate area. The fault probably parallels thickest oolite development, bending southeastward around Sec. 27 (T14S-R10W), and northwestward to the west of Sec. 23 (T14S-R11W). No land was directly behind the fault ridge, so "offshore", as used here, indicates deeper water from which currents traveled. Offshore is inferred to have been to the south for two reasons. First, deeper paleostructure in that direction probably indicates deeper bathymetry at the time of deposition. Second, the isopach map (Fig. 7) includes two lobes of thick oolite extending from the field northward. In modern bars, lobes like these extend

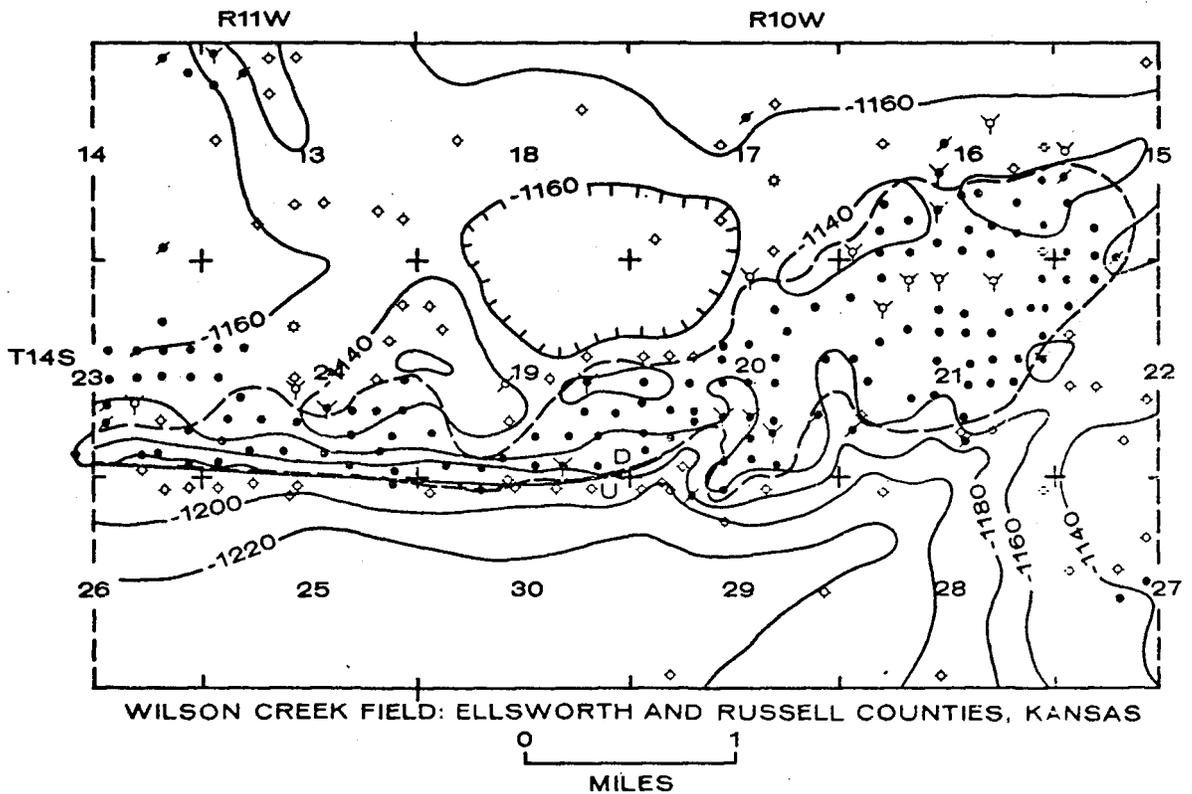


Figure 15.- Structural map of the base of the Captain Creek oolite (sub-sea elevations). Contour interval is 20 ft. Dashed line represents limits of production from the Captain Creek oolite. .

leeward from the shoal into a shallow lagoon, perpendicular to the direction of bar-elongation (Bathurst, 1975). If the Captain Creek oolite lobes are sedimentary, as suggested here, a back-shoal environment may have existed to the north. Modern oolite bars are asymmetric in cross-section because of these "spillover" lobes (Ball, 1967); this feature is present in the Wilson Creek Field also, as shown in section A-A' (Fig. 10).

Tidal channels are a common feature of modern oolite bars where currents move across the bar. The re-entrants indicated on contour maps of the oolite facies of the Captain Creek Limestone (Fig. 7) and on the outline of the productive area of the field may be such features. On the south side of the field, these are present in the southwest quarter of Sec. 20 (T14S-R10W), and the south half of Sec. 21 (T14S-R10W). On the north, a re-entrant is present in the center of Sec. 19 (T14S-R10W), and less obvious ones are present to the east. Well Borell B-2, 12 (SW, 20-14-10) penetrates an abraded fossil-oid packstone facies that may have originated as sediment reworked by currents from the area off of the oolite shoal and deposited in a tidal channel.

Areal variations in the oolite itself may give indications of depositional environments in the Wilson Creek Field. Wells such as Vopat A-3, near the crest of the oolite shoal have thick intervals of oolite with few fossils and no micrite. Abundant cross-beds are also present as seen in core from this well (Fig. 13-1). The location of this well was near the windward margin of the bar, where waves broke and high energy conditions caused transport of mud leeward of the shoal as well as movement of ooids in lobes covered by submarine dunes. Wells to the north of the shoal-crest have thinner intervals of oolite, abundant

lenses of fossil fragments, and no well developed cross-beds. The limestone in the core from the F. Princ well becomes increasingly micritic near the top, indicating lower energy conditions leeward of the shoal-crest where lime mud might be deposited.

The sediment in the Beisel 1 core (6-14-11) was formed in a slightly different environment. The abundant ooids were deposited in a spillover lobe northward from the main part of the bar, or were part of another oolite shoal. The rounded lithoclasts of shale and dolomite were shed from older rocks outcropping on an uplifted area to the west. These clasts were reworked and spread eastward by currents during deposition of the Lansing oolite. Shale partings indicate influx of terrigenous sediment from outside the area of oolite deposition, probably to an area of more restricted water circulation.

After a period of time during which the oolite shoal thickened and accreted northward, continued decrease of water depth by sedimentation caused cessation of oolite thickening. The whole central Kansas shelf area may have shallowed at this time, causing increased restriction of circulation. This would prevent currents from continuing to produce high energy conditions. The increased restriction caused lower energy conditions and an area of hot, saline, shallow water. These are the conditions for Wilson's (1975) terminal phase of the shoaling cycle. The upper part of the Captain Creek Limestone in this area is composed mostly of pelletoid grains and lime mudstone. Presence of possible fenestral fabric in some lime mudstone from this interval (Fig. 14-4) may indicate subaerial exposure (Shinn, 1968). The highest parts of the oolite shoal were at sea level and no pellet-mud could be deposited there. This marked the end of the shoaling cycle which was followed by

an increase in water depth, possibly due to sea level rise or to regional subsidence.

The increased water depth allowed influx of terrigenous mud forming the Eudora Shale. Absence of this unit over areas of thickest oolite accumulation might mean that those areas were above wave base which prevented deposition of mud. Eudora Shale marks the beginning of the next transgressive phase of deposition and the overlying Stoner Limestone represents a return to conditions of normal marine-open circulation of water. The areas of no oolite accumulation near the field were either in the shallow marine shelf environment or were areas of very shallow, back-shoal lagoons throughout deposition of the Captain Creek Limestone. These areas correspond to bathymetrically lower areas on the sea bottom. Even these relatively deeper areas probably were shallow, compared to modern seas, as Kansas was a shallow, epeiric, shelfward extension of the Anadarko Basin of Oklahoma (Rascoe, 1962). Local changes in slope and wave breaks were, however, sufficient to produce contrasting energy conditions and consequently, contrasts in adjacent sediment facies.

Comparison to Modern Oolitic Sediments

Most sediment features of the Wilson Creek Field are found in modern oolitic sediments. A well known oolite accumulation occurs on the Great Bahama Bank, as described by Newell (1951; 1955), Newell, et. al. (1960), Purdy (1963), Purdy and Imbrie (1964), Ball (1967), and Bathurst (1969; 1975). In cross-section, the Bahama Bank rises to near sea level at the outer edges. The water depth increases gradually to a maximum near the center of the bank. Slightly bankward of the precipitous drop to deeper water off the bank is a prominent, shallow,

rocky area where extensive ooid sand deposits girdle the bank. The deposits are in the form of discrete bars, usually about 1 mile (1.6 km.) long in a belt 3 to 4 miles (4.5 to 6.5 km.) wide. The bars are separated by tidal channels, and are elongate parallel to the bank margin (perpendicular to the direction of offshore wave approach). Vigorous tides cause large dunes and ripples to be developed. Vegetation is sparse and the number of different types of organisms on these bars is much lower than in the lagoons behind the shoals.

These features are all present in the Captain Creek oolite of Wilson Creek Field. The size of the body of oolite is not as large as some of the largest oolite shoals south of Andros Island, but it compares favorably with shoals on the western margin of the bank. Bahaman oolite is usually free of lime mud and has fewer fossils than surrounding sediment, similar to the Wilson Creek Field oolite. Large cross-beds in the Vopat A-3 core correspond to submarine dune development at the time of deposition (Imbrie and Buchanan, 1965). Behind the crests of the Bahaman oolite bars, spillover lobes extend bankward. These resemble the lobes of Captain Creek oolite north of the field. Bankward of the Bahaman bars, marine grass grows on the more stable lobes in a lower energy environment than that of the bar fronts. Lime mud is deposited in patches. This might be the origin of the packstone fabric at the top of the oolitic zone in the core from the F. Princ 1 well. There are fewer types of fossils in the Captain Creek oolite, compared to the underlying fossiliferous wackestone; this compares to a similar situation in the Bahaman oolite.

An important control on deposition on the Bahama Bank is the presence of Pleistocene limestone ridges near the margins. Waves breaking

over these cause local agitation of the seawater and deposition of aragonite as coatings on grains. This circumstance may have applied to the Captain Creek oolite in the Wilson Creek Field as well, because of the role of the fault ridge in providing local bathymetric relief (Fig. 16).

Other modern oolite deposits which are of similar character to those on the Bahama Bank are numerous: two occurrences are the Yucatan peninsula of Mexico and the Gulf of Batabano, Cuba. On the eastern coast of Yucatan there is a wide, mobile belt of oolitic sediment seaward of Blanca and Nichupte Lagoons. Barrier beaches protecting the lagoons also consist of ooid sand. The belt of oolite is elongate parallel to a break in bottom topography, as in the Wilson Creek Field. A similar elongate oolite shoal occurs at the southeastern edge of the Gulf of Batabano, Cuba (Bandy, 1964; Bathurst, 1975). The shoal is a thin back-reef deposit, protected from the full force of oceanic waves. These and other modern occurrences have the essential characteristics of the Captain Creek oolite in the Wilson Creek Field.

Comparison to Other Upper Pennsylvanian Oolite Deposits

Numerous other upper Pennsylvanian oolites occur in Kansas, especially in the Lansing and Kansas City Groups. An examination of a surface oolite outcrop is of importance in recognizing similar features in the subsurface.

The Universal Atlas Cement Company quarry near Independence, Kansas, is the location of an oolitic facies in the Drum Limestone of the Kansas City Group. Zeller's (1968) description of the Corbin City Limestone Member and its location indicates that the quarry is probably

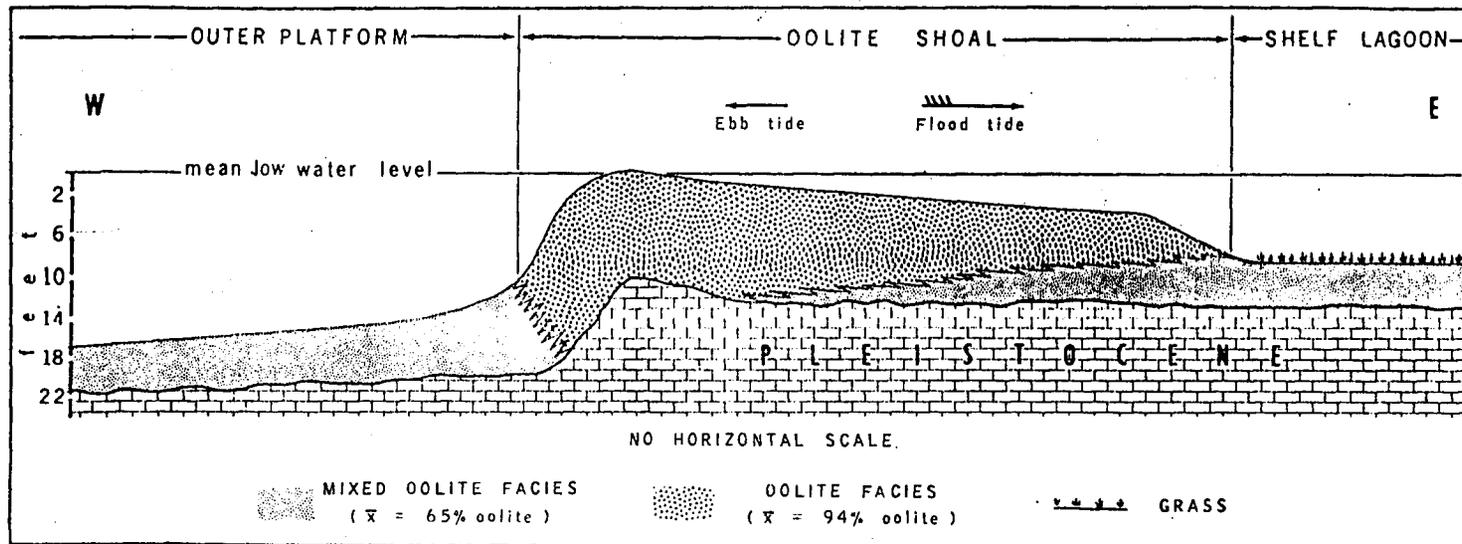


Figure 16.- Idealized relationships in South Cat Cay-Sandy Cay Bahaman oolite shoal. The steepness of the western slope of the Pleistocene limestone ridge may be due in part to the cliffing action of the sea as it rose to its present level. The Wilson Creek oolite is thought to have formed under similar circumstances, except that the underlying ridge was formed above a buried fault scarp. From Purdy (1961), p. 61.

in this member of the Drum. The Drum at this locale is a fossiliferous, cross-bedded, oolitic limestone, approximately 30 ft (9.1 m.) thick.

Three sections were measured in the quarry walls, and three lithologic subdivisions were recognized, based on cross-bed sets (Fig. 17). These subdivisions were not physically traced across the quarter-mile wide quarry; rather, correlations are based on similarity of units and relative position in the sequence. Alternating layers of dark, silty lime mudstone and dark gray shale form the quarry floor. The layers are 0.5 to 1.5 ft. (.1 to .4 m.) thick. This is probably the Dewey Limestone Member of the Drum Limestone. The lower two parts of the oolitic sequence, comprising the majority of the oolite, consist of from 4 to 9 individual tabular cross-bed sets. The cross-beds consist of ooid packstone or grainstone layers interbedded with layers of fossiliferous packstone. The cross-beds are marked by 1 to 5 cm. thick layers of coarse skeletal debris, usually of brachiopods, molluscs, and echinoderms. The ooid layers include as much as 50% fossil debris. The cross-bed sets range in thickness from 40 to more than 200 cm. The cross-beds dip uniformly to the southeast about 25°. The upper part of each section consists of much less skeletal debris, or nearly all oolite in thinner sets of cross-beds with alternating (opposing) dip directions. The opposite dips form a herringbone structure and indicate ebb and flood currents in a tidal flow system (Boersma, 1969). Total thickness of this unit is unknown because it forms the top of the quarry.

An interpretation of this deposit is aided by some observations about the quarry and about a nearby roadside outcrop of the same limestone. The thickness of the quarry unit ranges from 6 to more than 9 meters (20 to 30 ft.) at the center. In a roadside outcrop to the

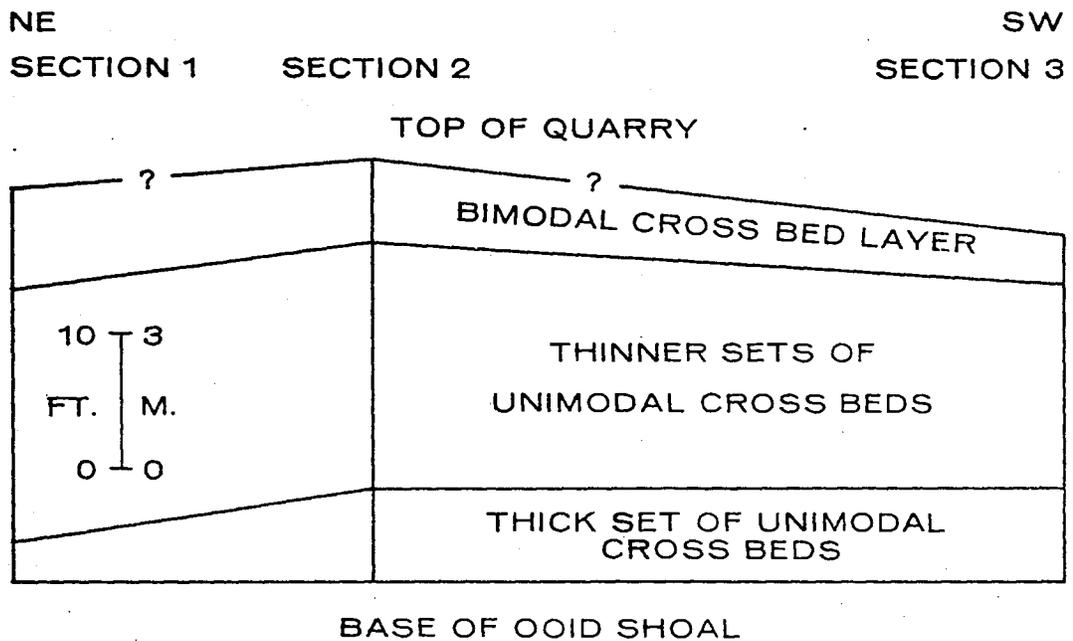


Figure 17.- Stratigraphic cross-section of 3 measured sections in the Universal Atlas Cement Company Quarry near Independence, Kansas. Base of the quarried limestone is the datum. Not to horizontal scale.

northeast, approximately 4 meters (13 ft.) of the unit is exposed. The quarry is located on the crest of a small structure in the subsurface Arbuckle Group, and a slightly domed floor is observed in the center of the quarry.

Heckel (1975) indicates the presence of a Missourian shoreline south of this area in Oklahoma. Elongation of offshore ooid shoals is generally east-west, and cross-beds dip uniformly southward to shallower water (as in the Bahama Bank oolites). Observed elongation of the Drum Limestone in the Independence quarry is generally northeast-southwest, and cross-beds dip southeastward. It is probable that the Arbuckle structure was present and provided a bathymetric high over which the Drum was deposited. Offshore currents from the north caused wave agitation and development of an oolite deposit on this high. Lobes of oolite are preserved as the lower tabular cross-bed sets. Sedimentation caused buildup to near sea level and northwest-southeast tides produced the opposing-dip cross-beds at the top.

Features such as the underlying topographic high during deposition, large uni-directional sets of cross-beds, and bar-elongation perpendicular to wave and current movement are inferred for both the Drum and Captain Creek oolites. The importance of underlying structure, in bar location is clear. Although the Drum Limestone is much more fossiliferous, it formed in an environment similar to that of the Captain Creek. Salinity, water temperature, or perhaps a greater water depth in the former area might have been more conducive to prolific growth of organisms. The tidal cross-beds at the top of the Drum Limestone might result from a nearshore environment where very shallow water allows currents to affect the oolite, or from the absence of channels in the

Drum oolite shoal. The Captain Creek oolite may not have been close enough to a shoreline for tidal currents to cause extensive herringbone cross-beds, or, alternatively, weaker ebb currents may have been confined to channels.

Alternative Interpretations

Oolitic tidal deposits or eolianite dunes are two other possible environments in which the Captain Creek oolite could have been deposited. Tidal channel bars and tidal delta sheet sands are typical deposits and an example of each is discussed. General characteristics of eolian ooid dunes are compared to the Captain Creek oolite of the Wilson Creek Field.

At the south end of the Tongue of the Ocean on the Great Bahama Bank, oolite shoals are elongated parallel to tidal current flow. These tidal bars are grouped together into distinctive, larger, oolitic sand deposits (Illing, 1954). The bars fan out in shallow water from the deeper Tongue of the Ocean. The rarity of these bars compared to the other type of oolite shoals on the bank and the distinctive linear groupings of individual bars into larger sheets makes it unlikely that the Captain Creek oolite is this type of deposit. The dips of cross-beds in the Bahaman tidal bars are believed to be mostly parallel to the direction of bar elongation. They range from parallel to perpendicular, however, as tidal currents can sweep over, and travel along, the sand bars (Bathurst, 1975). Variable directions of dip of cross-bedding are not observed in the Captain Creek oolite, even though the true direction of dip is unknown for lack of oriented cores or dipmeter logs (Fig. 13).

There are oolitic carbonate sands among the modern deposits in the Persian Gulf (Bathurst, 1975). Near such islands as Abu Dhabi, there

are enormous oolite sand deltas at the mouths of tidal channels. These oolite deposits occur just landward of a conspicuous dropoff in the seafloor where there is a line of breakers. Numerous megaripples, or submarine dunes, of 200 to 300 meters (650 to 1000 ft.) wavelength are present near the outer boundary of the deltas. In many places, bare limestone is exposed on the seafloor, and the oolite deposit is very thin. The composition of these sands is at least 60% ooids, the remainder being mostly abraded fragments of molluscs. While the megaripples are elongate forms like the oolite in Wilson Creek Field, they are quite a bit smaller. The thin Persian Gulf oolites are sheet-like, and do not form elongate lenses. The close relation of these deposits to the nearby islands and to a sabhka complex on the shore of the islands does not have a counterpart in the Wilson Creek Field area. The Persian Gulf tidal oolites are not an attractive analog to the oolite of the Wilson Creek Field. The few similarities of these oolites seem to be features common to most shallow marine oolites: megaripple bedforms producing high angle cross-beds, a conspicuous slope change seaward of the oolite, and the great abundance of ooids relative to other types of grains.

Eolian carbonate sand dunes in the Bahamas also contain abundant ooids. Ball (1967) indicates that these are like the ooid bars on the nearby outer banks. They formed during the last Pleistocene interglacial period when high sea level flooded the shallow water on the bank; the deposits were later left above water as the sea level fell. Wind reformed the bars into huge dunes. Some important characteristics of the eolianites (Wilson, 1975) are: 1) steep cross-beds dipping shoreward in large sets, dips usually 25-45°; 2) preserved dune forms;

3) cross-bed ribbing caused by differential cementation of layers (coarser layers do not hold water for good CaCO_3 cementation and weather deeper than fine sand layers); and 4) surface exposure features including soil zones, root casts, and snails.

Absence of preserved dune forms and steep cross-beds in the Captain Creek oolite suggests that it is not an eolianite. Large patches of micrite in the upper part of the F. Princ 1 core would probably have been winnowed from the deposit by winds. The cross-bed ribbing with deeper weathering in coarser layers is analogous to ooid-oomold layering in the Wilson Creek Field oolite. It is probable that this differential weathering can occur in the vadose zone with no surface exposure, as in eolianites.

Freeman (1962) describes quiet water ooids near Laguna Madre, Texas. These form in a quiet, shallow lagoon which is protected from waves by a barrier bar system. Freeman, in suggesting a mode of origin for these ooids, indicates that lack of mechanical polish of these ooids precludes abrasion that would occur on a high energy shoal. The high degree of asymmetry in the coatings of these ooids indicates a lack of the constant motion which produces spherical ooid lamellae (Bathurst, 1975). This asymmetry, the abundant associated mud, and the lack of cross-beds make it unlikely that the Wilson Creek oolite formed in this type of environment.

Diagenesis

The sequence of post-depositional modifications of the Captain Creek Limestone in the Wilson Creek Field is important in understanding some observed features of the limestone. After deposition, while the oolite was submerged, a submarine (fibrous) aragonite cement coated most

oids. This cement did not fill the inter-oid voids, allowing water flow. The oolite was subsequently in a vadose or phreatic environment, allowing fresh water to percolate through the more porous and permeable oolite layer (as opposed to the dense associated limestones). Wilson (1975) indicates that exposed oolite on the Bahama Bank has a ribbed texture caused by alternating layers of small ooids (cemented) and layers of large ooids (loose). Water moves through the more permeable coarse ooid layers dissolving ooids (Fig. 12-1). This water may have deposited intermold cement protecting the molds and replaced the aragonite ooids and fibrous cement with a fine calcite spar in the Captain Creek oolite, as well as in the Bahaman oolite. As previously discussed, measurements indicate that the oomolds are larger than the remaining whole ooids, accounting for originally closer grain packing in the ooid layers. The oomolds correspond to the larger ooids which were leached after deposition. With continued burial, phreatic or connate subsurface water solutions deposited more of the medium-crystalline, blocky spar cement, filling most of the inter-oid voids. The cement filling the fossil wackestone burrow voids and lime mudstone fenestral voids was probably the same cement as in the oolite (Figs. 14-2, 4).

Partial recrystallization of the entire Captain Creek Limestone is indicated by several diagenetic features. Microspar replaced some micrite, especially in the lime mudstone lithology (Fig. 14-3). Pellets, intraclasts, and matrix were all recrystallized. The fibrous cement in the oolite was partly recrystallized to anhedral calcite. Fine calcite in the ooids was also partly recrystallized to the coarser anhedral calcite in some ooids.

Compaction from overburden and tectonic stresses probably produced the stylolites and fractures in the Captain Creek Limestone. The stylolites are present throughout Wilson Creek Field. The fractures, however, are confined to the oolite and present only in linear zones (Fig. 20). These may have been related to stress along the fault on the south side of the field. Crushed oomolds along the stylolites indicate the molds were present before the pressure-solution occurred which formed the stylolites. A few of these crushed molds and a few fractures contain a coarse ferroan dolomite like that filling many molds (Fig. 12-4). The dolomite emplacement clearly followed mold development, compaction, and tectonic stresses. The dolomitization preceded migration of oil into the oolite, between Permian and Cretaceous time (See Oil Migration section).

PETROLEUM GEOLOGY OF THE WILSON CREEK FIELD

Structural Attitude and Thickness of the Captain Creek Limestone

The Captain Creek Limestone in the Wilson Creek Field is an east-west elongated oil reservoir (Fig. 18). A small down-to-north fault with a maximum throw of about 15 ft. (5 m.) is present on the southern side of the field. The structural high in Secs. 24 (T14S-R11W) and 19 (T14S-R10W) of Figure 18 is not productive. The oolitic zone rises in the subsurface to an even higher elevation southeast of the field, in Sec. 27 (T14S-R10W). The lack of oil production on these high areas indicates that stratigraphic control of oil entrapment is important in Wilson Creek Field. The configuration of the top of the zone is similar to that of the base of the zone (Fig. 15). Re-entrants in the contours on the north and south sides of the field are common to both maps, but the shape of the upper surface of the limestone is smoother than the base. The Ellsworth Anticline ridge topography is well expressed in the abrupt steepening of dip at the south side of the field.

The porous oil reservoir rock in the Wilson Creek Field comprises most of the oolitic facies of the Captain Creek Limestone (Fig. 19). Figure 19 closely resembles the map of thickness of total oolite interval (Fig. 7) because the intervals of low-porosity oolite facies in the field are thin and uniformly present over the entire area. Re-entrants or "channels," on the porosity map (Fig. 19) closely coincide with similar features on the structural map (Fig. 18), indicating the presence of less porous oolite in topographically low areas. This reinforces the interpretation of these features as the mouths of "tidal channels" in which less oolitic facies would have been deposited originally. Wells in the thick porous intervals in Secs. 24 (T14S-R11W)

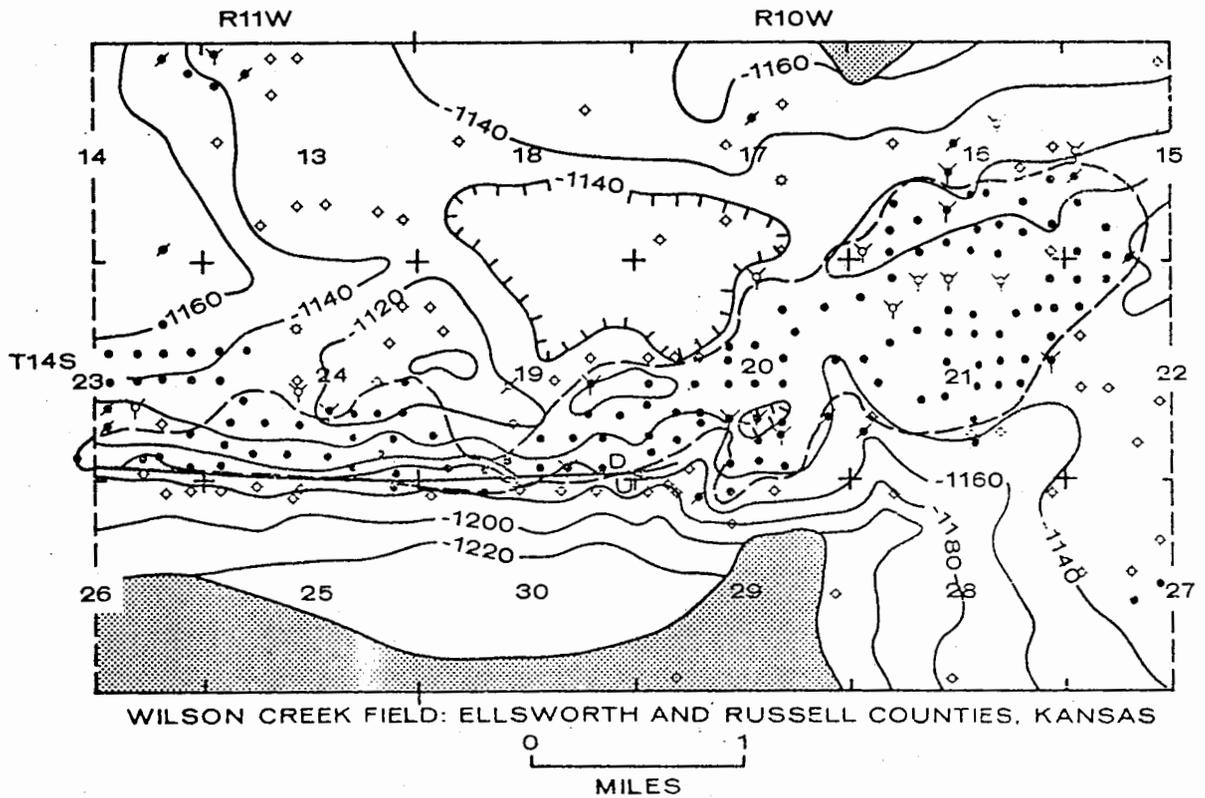


Figure 18.- Structural map of the top of the Captain Creek oolite (sub-sea elevations). Contour interval is 20 ft. Dashed line represents limits of production from the Captain Creek oolite. Shading represents areas of no oolite deposition.

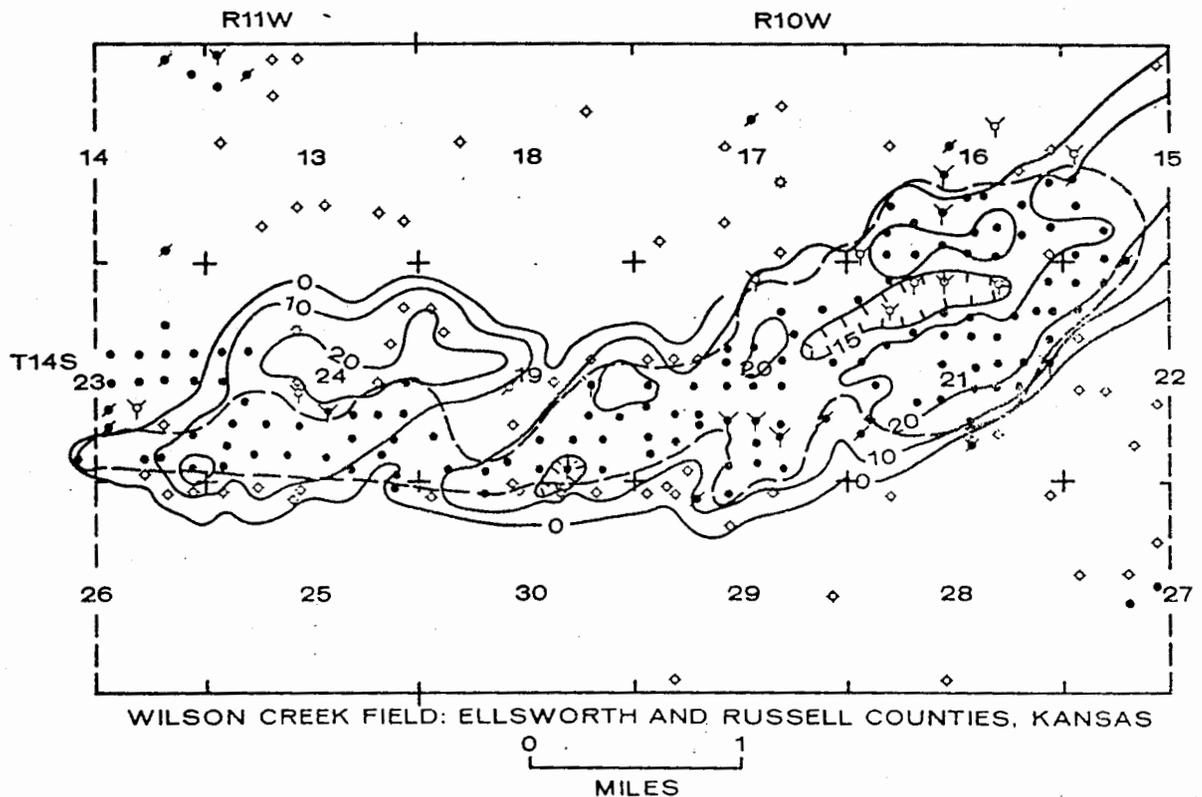


Figure 19.- Map of thickness of porous interval in the Captain Creek oolite. Contour interval is 10 ft. Dashed line represents limits of production from the Captain Creek. Neutron radioactivity logs were used to determine thickness of porous rock. Sections of the oolite with porosity lower than 15% are excluded from porous rock thickness, because such sections do not yield much oil.

and 15 (T14S-R11W), as well as in the thin strip of porous oolite surrounding the field, are not productive because of low permeability or lack of hydrocarbon recovery.

Petrophysics of the Reservoir Rock

Cores and rotary drilling samples indicate that the reservoir rock of the Wilson Creek Field is an ooid-oomold grainstone. Porosity occurs almost entirely as oomolds. Microscopic permeability in the rock results from connections of moldic pores through tiny intercrystalline passages in the calcite cement of the grainstone. Macroscopic permeability results chiefly from vertical fractures in the reservoir rock which are concentrated in several linear trends. Subhorizontal stylolites may also allow fluid movement, but they are usually choked with residual clay.

Core analyses from two wells in the field are different and illustrate the difference in producing characteristics of dissimilar facies. Vopat A-3 (Rupe), 21-14-10, was completed for an initial potential of 120 BOPD, no water, from 20 ft. (6.1 m.) of oil saturated rock. This is considered very profitable rate of production. F. Princ 1 (Texaco), 20-14-10, although penetrating 12 ft. (3.7 m.) of oil stained Captain Creek oolite, would produce only small amounts of water and is considered dry. The core from the Vopat well has bulk porosities of 19 to 27%, with an average of 22%; and the F. Princ core has a range of bulk porosities of 5 to 24%, with an average of 16%. Both wells have sufficient bulk porosity to contain adequate quantities of oil, although the porosity of the Vopat well is somewhat better. Of greater importance is the difference in permeability. The Vopat core has permeabilities ranging from 3 to 64 millidarcies, with an average of 19 md. Permeability of the F.

Princ core ranges from less than 0.1 to 3.4 md., with an average of 0.5 md. Apparently, this low permeability will not yield oil in sufficient quantity for commercial production.

Differences in textures and sedimentary structures of the two cores account for the differences in permeability. The macroscopic structures observed range from cross-bedded ooid-oomold layers, through large and small lenses of ooid-oomold layers, to a complete scattering of widely-spaced molds in an ooid grainstone (Fig. 13). The following is a visual comparison of structures and textures and corresponding values of permeability in both of the cores cited above:

<u>Permeability (md.)</u>	<u>Macroscopic Texture</u>
greater than 10	Cross-beds and long (greater than 20 cm.) lenses of ooids and molds;
1 to 10	Medium (5 to 20 cm.) lenses and closely-spaced, scattered molds;
0.4 to 1	Short (less than 5 cm.) lenses and small widely-scattered molds;
less than 0.4	Ooid grainstone (greater than 90% ooids), few molds;

It is probable that the closely-spaced molds in the cross-beds and the long, continuous moldic layers account for greater permeability in the cross-bed layers. The strongly aligned layering of the rock would result in a highly directional permeability. Scattered molds and small lenses of highly moldic pores would not be very permeable because the pores are separated by a greater length of very small intercrystalline pore throat connections. The Vopat well core contains abundant cross-beds in thick sets. In contrast, the F. Princ well core is not cross-bedded; rather, it contains small lenses of grains and scattered molds.

High energy depositional processes caused development of good cross-bedding in the sediment in the area of the Vopat A-3 well. The F. Princ well core, from the northern margin of the field, is not productive because of the lower energy conditions which prevailed during deposition. It may be that low permeability dry holes around the Wilson Creek Field penetrated rocks with textures similar to that of the Princ well core, small lenses and scattered molds. The low permeability areas that correspond to the tidal channel re-entrants mentioned above may be explained by the presence of skeletal debris in the oolitic zone, as in well Borell B-2, 12 (20-14-10). The scattered moldic pores in rocks with this composition are not well interconnected and fluid movement through them is slow.

Permeability in the porous reservoir rock is also affected by other post-depositional features. Stylolites are common in both cores. Some are porous like fractures and are stained by oil. These may have allowed fluid movement except where they contain residual clay. Vertical fractures are present in both cores. Observed in thin section, these are oil-stained, with rare coarse dolomite cement lining the wall. These fractures are probably scattered across the field, but there is evidence of two linear zones of concentrated, interconnected fractures. The fractures are inferred from driller's logs and from production tests (Fig. 20). Loss of fluid circulation and increased drilling rate occur in wells along the zones. These wells all produce fluids at a high rate, as indicated by 1973 well-production tests. Wells located a few hundred feet from these fracture zones produce fluids at much lower rates, in some cases, several times lower. Well Borell B-2, located along the fracture zone, had fluid production of 85.7 BOPD and 85.7 BWPD

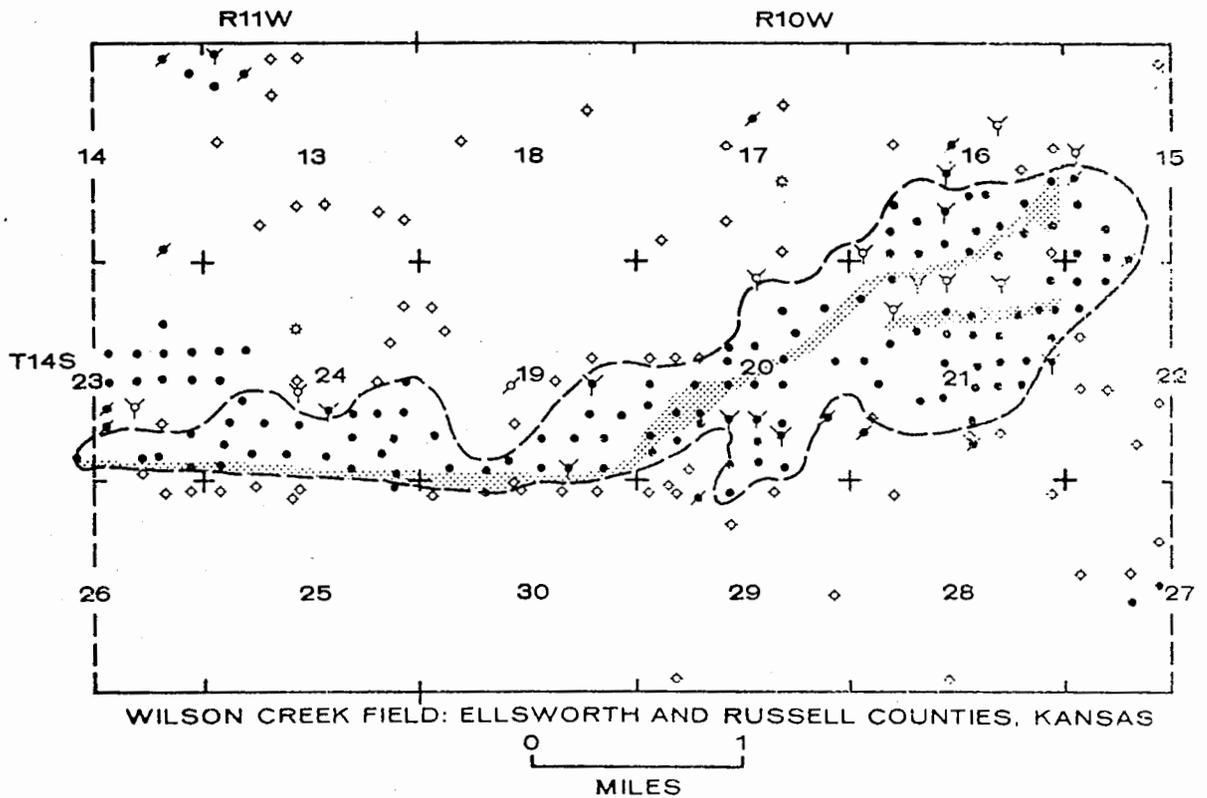


Figure 20.- Map of the fracture zones (shaded) in the Captain Creek Limestone delineated by high fluid capacity wells and driller's logs. Dashed line represents limits of production from the Captain Creek oolite.

in the 1973 well test. Well Borell B-1, located 700 ft. (215 m.) from no. 2 and about 900 ft. (275 m.) from the fracture zone, produced only 1.8 BOPD and 2.7 BWPD in the same test. The fracture zone in the western part of the field corresponds to the fault in the oolitic limestone, and may be a result of stress along this fault.

Oil Entrapment and Migration

Hydrodynamics

Water in the subsurface is able to move through porous rocks for great distances if pores are sufficiently interconnected. Structurally high features in the subsurface such as anticlines often contain hydrocarbons located above water. If the water is at rest (hydrostatic equilibrium), hydrocarbon-water contacts will be horizontal and the less dense hydrocarbons will occupy the highest part of the structure. This assumes that, at the level of water production, capillary pressure equals zero (Amyx, *et al.*, 1960). However, if the water is in motion (hydrodynamic equilibrium), the oil-water contact will be tilted downward in the direction of flow; the hydrocarbons will be displaced down-structure in the direction of flow, if the flow is sufficiently strong.

Wells in the Wilson Creek Field for which driller's logs, core analyses, and resistivity logs are available were used to calculate the elevation of the oil-water contact. Figure 21 is a map of the oil-water contact in the Wilson Creek Field. Southward tilting in the western and northeastern parts of the field indicates general north-to-south movement of water. There is evidence for northwestward movement of water into the southeastern part of the field by the oil-water tilt. The presence of a dry hole in the field, K. Vopat 1 (SE SE SE, 16-14-10), may be explained by observing that the oil-water contact in that well is

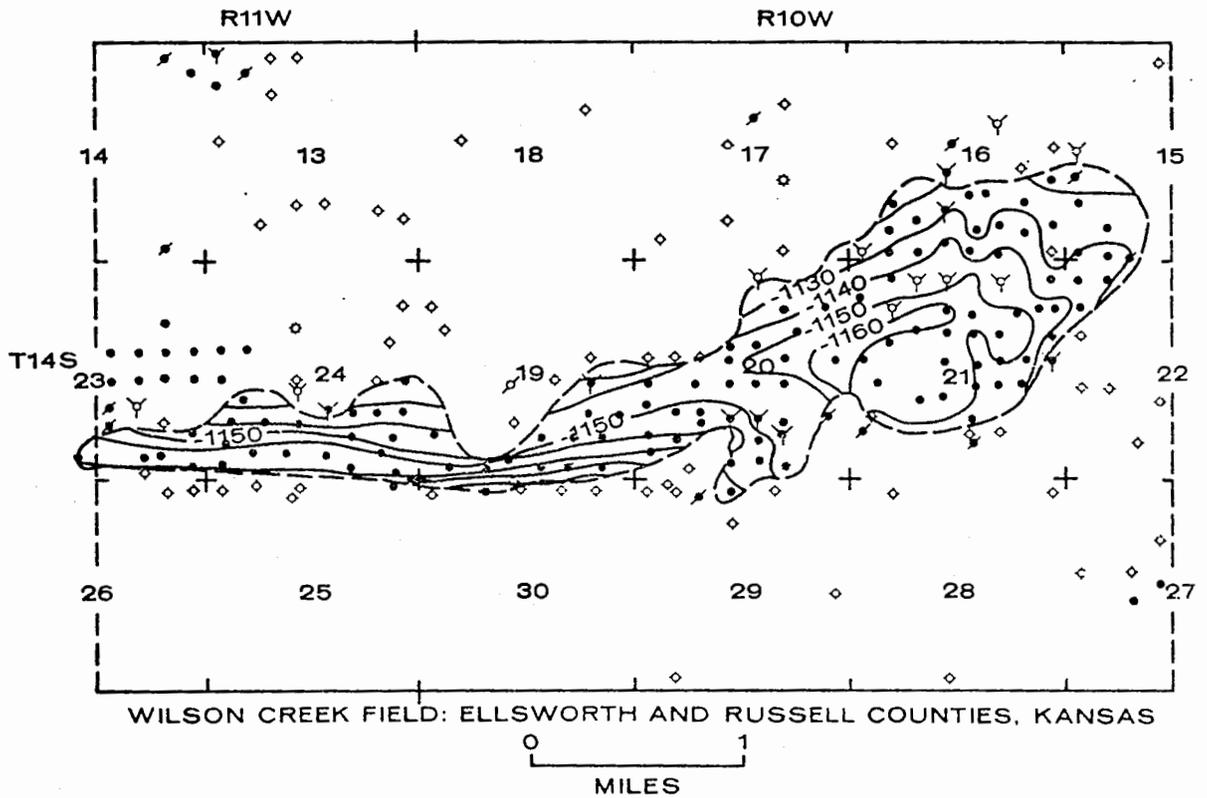


Figure 21.- Map of the oil-water contact in the Captain Creek oil-producing interval. Contour interval is 10 ft. Dashed line represents limits of production from the Captain Creek oolite.

above the top of the producing zone; therefore, the well produces only water. Sections C-C' and D-D' (Figs. 22 and 23) show the structural attitude of the Captain Creek oolite and the approximate position of the oil-water contact. There is a hydrodynamic entrapment at the northern end of the field in C-C'. In D-D', the updip oil trap is a permeability barrier (feathered edge).

Water under pressure in the subsurface will move from areas of high head (hydrostatic pressure) to areas of low head. Recognizing the static height to which water will rise in wells allows a map of the potentiometric surface to be constructed; water should flow downdip in directions perpendicular to the contours, that is, from high head to low head, regardless of structural attitude of the permeable rock body. Hubbert (1953) indicates the height (h) of water in a well is calculated as follows:
$$h = z + \frac{P}{(\rho)g}$$
, where z = subsea elevation of the datum at the measurement point, P = water pressure of the unit, ρ = density of the formation water, and g = gravitational constant. Initial shut-in-pressures (ISIP) from drill-stem tests (DST) of the Captain Creek oolite in the Wilson Creek Field were combined with subsea elevations of the top of the formation to calculate the potentiometric surface (Fig. 24). The map shows potential movement of water southward across the field in the western and northeastern parts of the field, and movement northwestward into the field from the southeast. Larson (1971) indicates that water in subsurface Pennsylvanian strata flows off the high Central Kansas Uplift areas into the Salina Basin on the east and the Sedgwick Basin on the southeast. This agrees fairly well with water flowing from adjacent high areas into the Wilson Creek Field and out through the low area to the south (29, 30-14-10) and east (15-14-10).

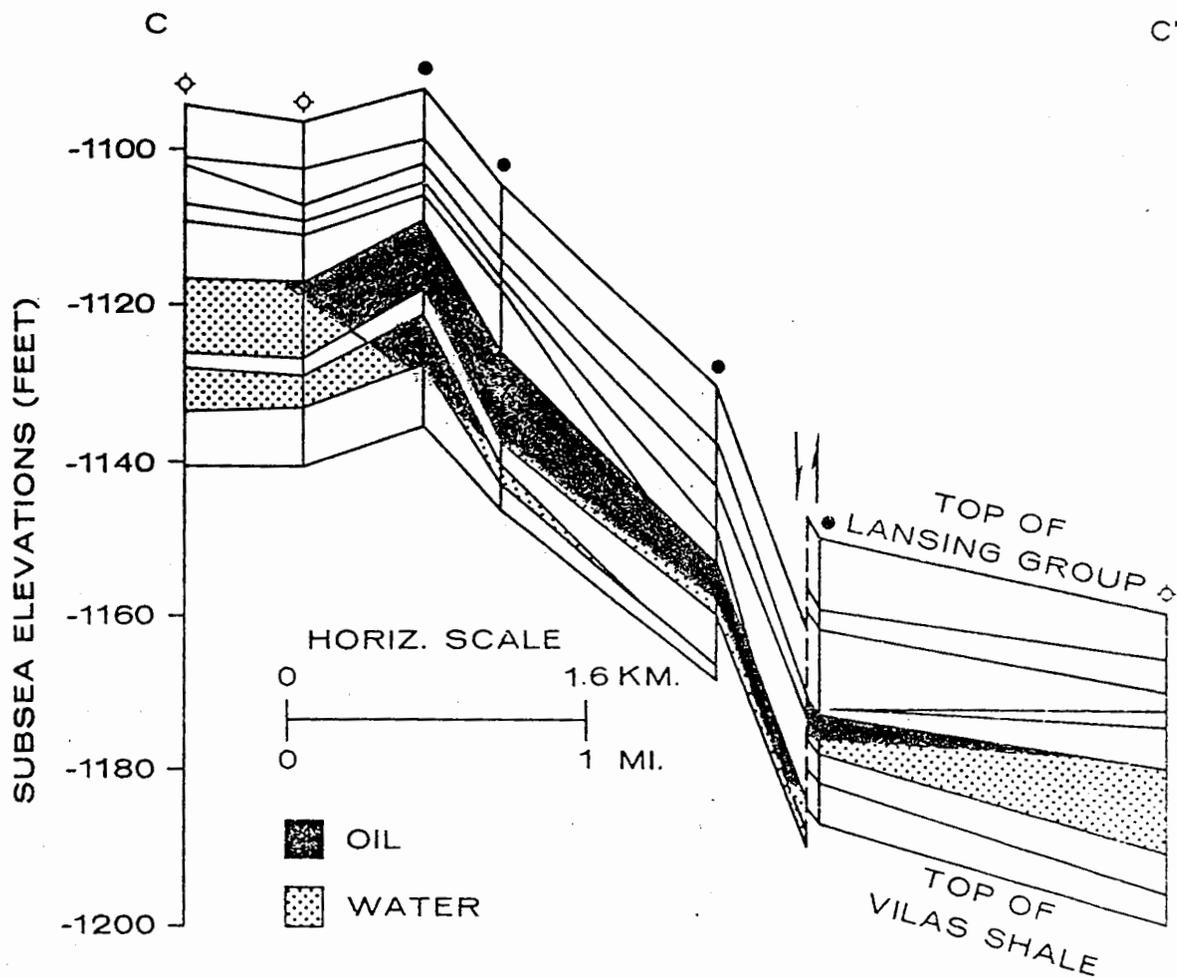


Figure 22.- Structural cross-section in the Wilson Creek Field. Vertical exaggeration is 66 times. The oil-producing zone is shaded. See Figure 9 for location of section.

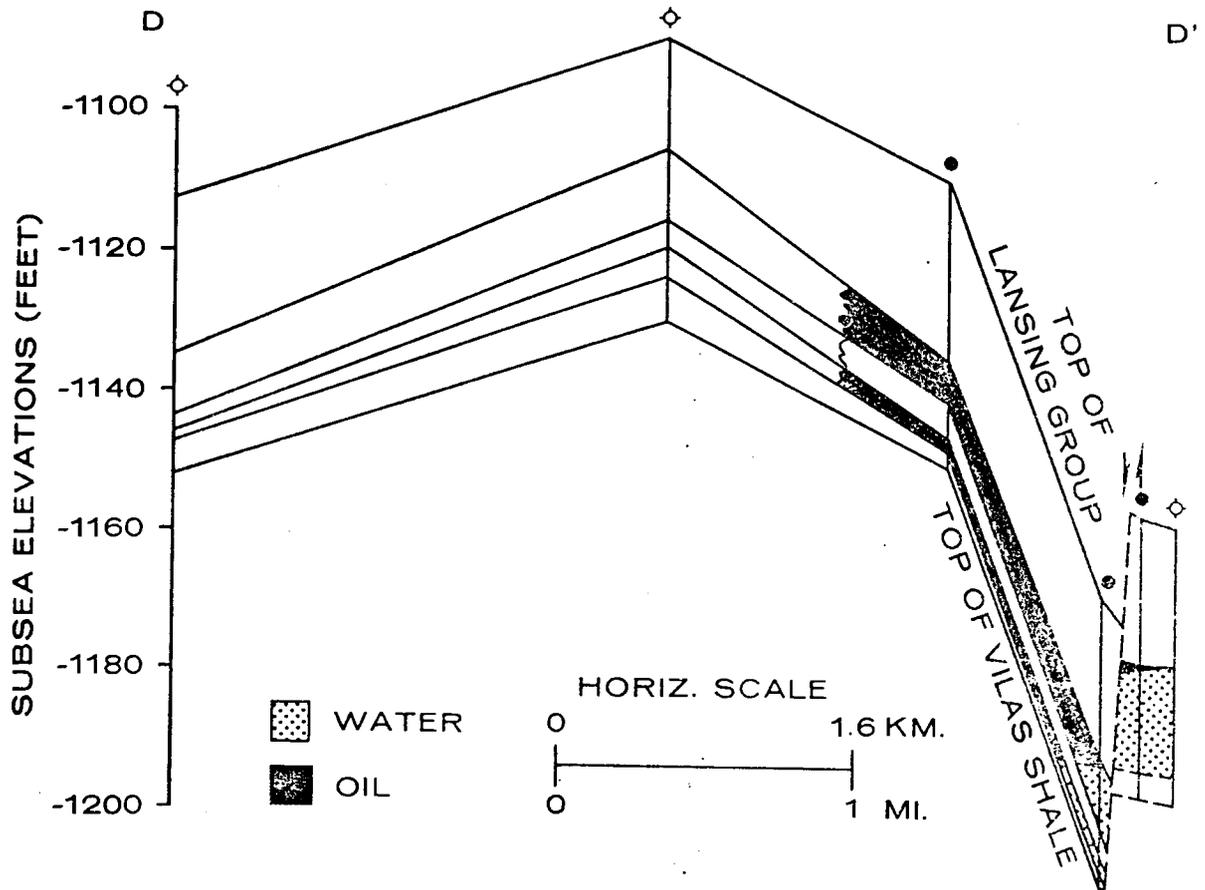


Figure 23.- Structural cross-section in the Wilson Creek Field. Vertical exaggeration is 66 times. The oil-producing zone is shaded. Impermeable rock updip is not shown, even though it may contain oil. See Figure 9 for location of section.

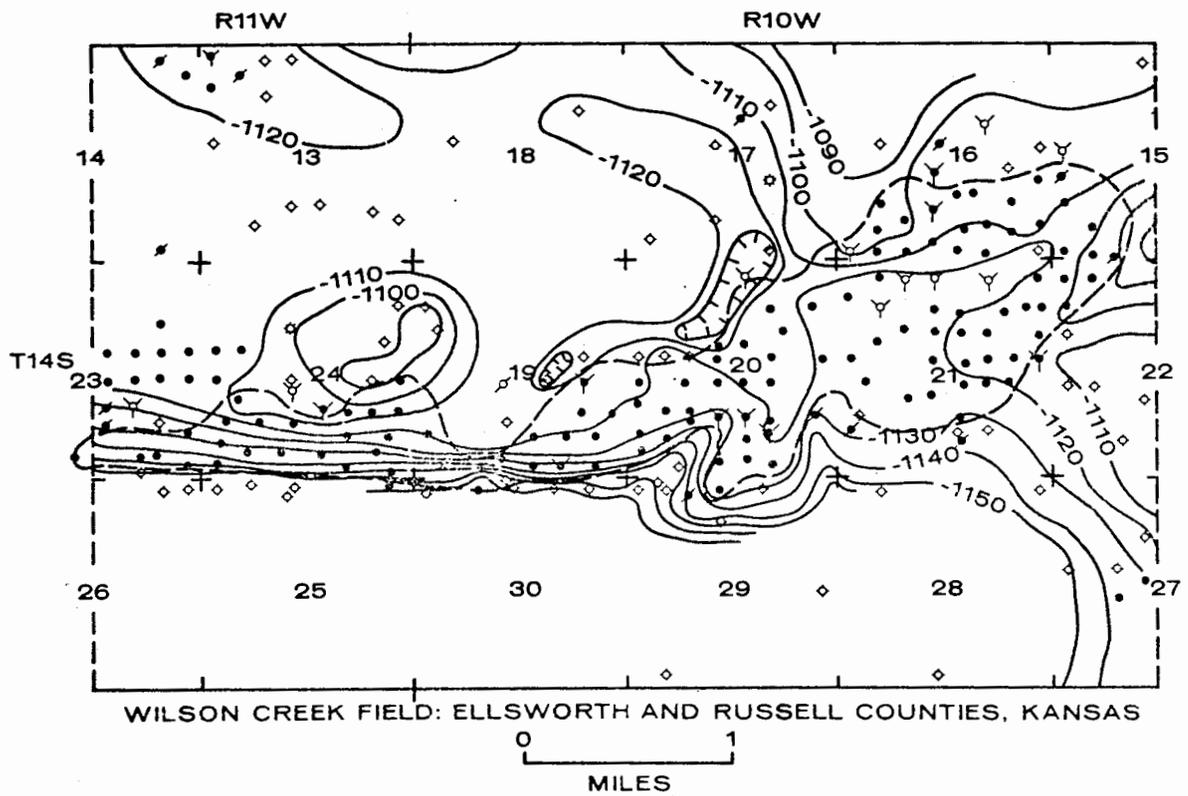


Figure 24.- Map of the potentiometric surface for the Captain Creek oolite (subsea elevations). Contour interval is 20 ft. Dashed line represents limits of production from the Captain Creek oolite.

The oil-water contact is tilted in the direction of hydrodynamic flow, at least over part of the field. Figure 25 is a map of the initial shut-in-pressure (ISIP) from drill-stem tests in wells drilled before 1974 in the area. Areas of near zero ISIP probably indicate little fluid movement, and the map of the potentiometric surface suggests water moves around some of these areas. Structurally high areas such as Secs. 24-14-11, 17, 19, 20, 22, and 27-14-10, which have near zero ISIP are probably areas of low permeability through which fluids do not pass. These may be important in trapping the oil. Areas of higher permeability (higher ISIP) are "channels" through which water may move, trapping oil in the present configuration. Areas of low permeability (low ISIP) and, correspondingly, little fluid movement are shown in Figure 26 (shaded). These contrast with channels (unshaded) of relatively high ISIP where fluids may flow. It is suggested that oil in the Wilson Creek Field is prevented from moving updip by the areas of low permeability and by flow of water through the channels. Stone and Haeger (1973) indicate that zones of lessened permeability commonly allow water to flow through at reduced rates, but that capillary pressure prevents oil from entering these same zones. This may occur in the areas of lower permeability of the Wilson Creek Field. The hydrodynamic entrapment theory has been postulated to apply to many other oil fields, including others in western Kansas (Hubbert, 1953; Berg, 1972; Stone and Haeger, 1973; Berg, 1975).

Several limitations must be considered in interpreting the maps of hydrodynamic pressures (Figs. 24, 25). Shut-in-pressures are often taken from a larger interval than just the Captain Creek Limestone. This additional interval is usually only several feet of dense limestone

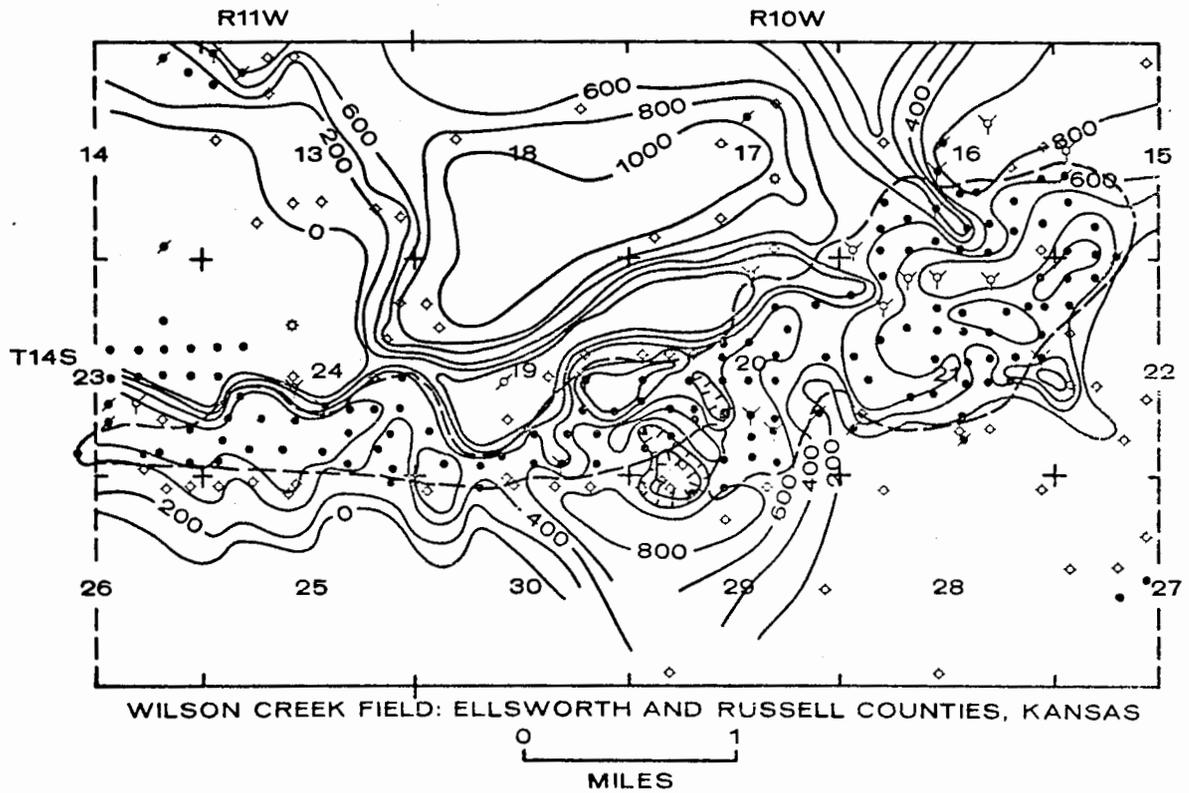


Figure 25.- Map of initial shut-in pressures from drill-stem tests taken in the Captain Creek oolite. Contour interval is 200 psi. Dashed line represents limits of production from the Captain Creek oolite.

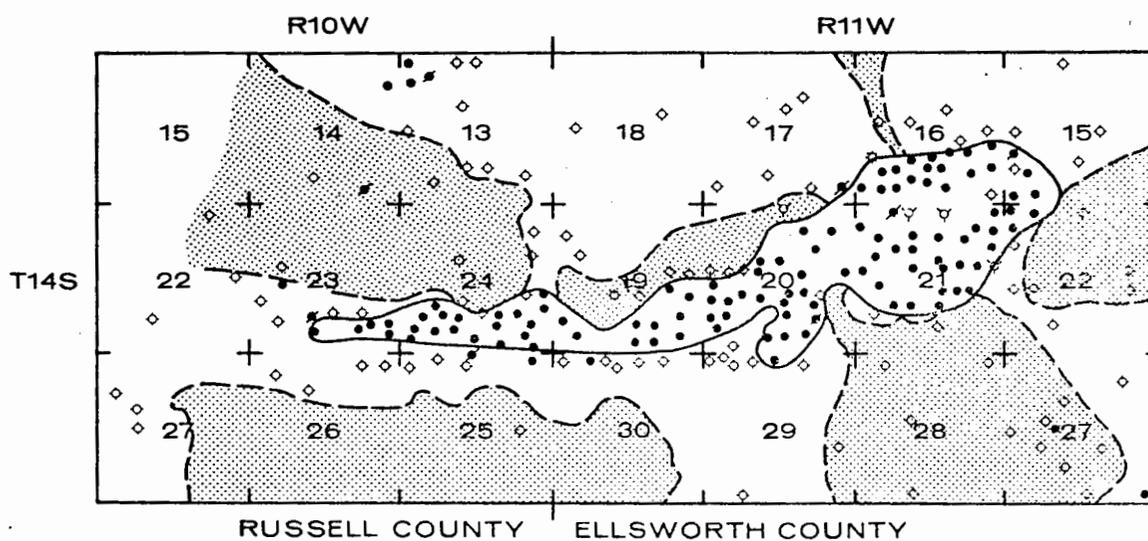


Figure 26.- Map showing areas of low initial shut-in-pressure (shaded) around the Wilson Creek Field taken from drill-stem tests. Solid line represents limits of production from the Captain Creek oolite.

and shale. It is assumed that the DST's were made accurately with good equipment. Wells drilled later in the development of the Wilson Creek Field may have shut-in-pressures affected by fluid withdrawal from earlier nearby producing wells. Wells drilled after 1973 were not used to contour the ISIP map or calculate potentiometric surface elevations. An assumption is made that the density of water used in the calculations of water pressure is uniformly applicable to the average for brines from the Lansing-Kansas City formations in the Ellsworth County area.

It is possible that the map of ISIP (Fig. 25) represents a surface of more abrupt permeability changes than are implied by the contours. For instance, well Riverview 1, a dry hole with an ISIP of 105 psi. is located approximately 700 feet from well Borell A-1, which produced until 1973 with an ISIP of 905 psi. Although the difference is contoured as a gradual change, an abrupt barrier may be present between the two wells. In view of the nature of the permeability contrast (scattered molds versus lenses and cross-beds), however, a gradual change is more likely.

Other Trapping Mechanisms

The only other plausible explanation for the downdip displacement of oil in the Wilson Creek Field would be the presence of a complete permeability and/or porosity barrier. ISIP values indicate that many parts of the updip trap are areas of low permeability, but the high ISIP's in the "channel" areas, the presence in the area of hydrodynamic gradients, and the tilt of the oil-water contact indicate hydrodynamic entrapment is also present. As the porosity-thickness map (Fig. 19) indicates, most areas outside of the field have low porosity in the Captain Creek.

Oil Migration

Gussow (1954) outlined a principle of differential oil and gas entrapment in which oil was segregated from gas in traps after long distance migration through porous carrier beds. He believes that most oil in formations of large areal extent migrated from source beds in deeper basins. Walters (1958) applied this theory to the prolific Arbuckle oil fields of central Kansas. He indicated that oil migrated from the area of Oklahoma (basinward) in mid-Permian time after mobilization in Pennsylvanian time, with 2-3,000 feet of overburden having been necessary to flush oil from the source beds. Later readjustments of oil in the Arbuckle traps due to westward tilting helps explain the present pattern of gas and oil entrapment in these reservoirs on the Central Kansas Uplift.

Similar reasoning may be applied to hydrocarbon accumulations in the Lansing-Kansas City Groups of central Kansas. According to Walters (1958, Fig. 20) after the overburden was present, long distance migration could have occurred. This migration may have been in mid- to late-Permian for Lansing-Kansas City units, in the northward direction, as indicated in Figure 27. Walters assumes that oil would migrate in the direction opposite to regional dip of units of a certain age at that time. Lack of oil shows in the Salina Basin north of the Wilson Creek Field and the presence of oil on the south side of most stratigraphic traps in central Kansas probably indicate that major oil migration was from the south, although Lansing oil may not have migrated very far (Walters, personal communication).

In the Wilson Creek Field area, oil probably occupied the highest structures to the north and to the southeast of the field after the

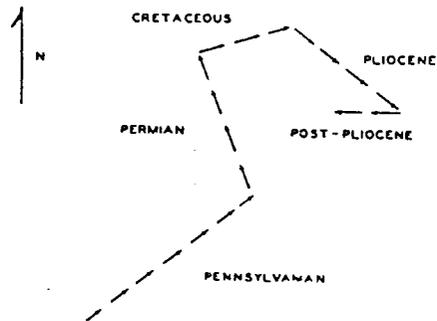


Figure 27.- Sketch showing horizontal component of forces tending to cause migration of oil and gas in Arbuckle beds during indicated times. Oil in Lansing and Kansas City beds may have migrated in a similar pattern from Permian to present. Arrows oppose dip of beds of indicated ages. From Walters (1958), Fig. 20.

Permian migration. Cretaceous and Pliocene readjustments of oil eastward (Fig. 27) might have allowed more oil to move to the higher areas southeast of the field. Driller's logs in the areas of lower permeability north of the field indicate oil shows in the Captain Creek Limestone. At some time after long distance oil migration, height of the Wilson Creek oil column was sufficient to cause oil to "leak" from the main reservoir into these updip, low permeability areas by capillary pressure. This may have occurred after Cretaceous time, since some overburden would have been necessary to produce the pressure needed for this secondary migration.

The regional post-Pliocene tilt of beds to the south and west in the midcontinent region is suspected of having caused the present hydrodynamic conditions. As the pressure gradients shown in Figure 24 indicate, water moves primarily southward through the main part of the field, and northwestward from the higher Ellsworth Anticline in the southeastern part of the field. This water may have flushed oil from the higher areas downdip, with some remaining in the present Wilson Creek Field. The presence of lower permeability areas to the north and southeast of the field has probably caused the oil to remain in its present configuration much as corks are prevented from moving up a tube of down-flowing water at a constriction in the tube (Levorsen, 1967).

ENHANCED OIL RECOVERY IN THE WILSON CREEK FIELD

Importance of Enhanced Oil Recovery

The importance of enhanced oil recovery lies in obtaining oil remaining in reservoirs after initial primary recovery by natural flow and by pumping which would not have been obtained otherwise. This aspect of oil recovery is intended to include repressuring, waterflooding, and any of a variety of tertiary recovery processes. At present, the Wilson Creek Field is in the mature stage of primary production. Several operators have converted poorly producing oil wells or dry holes into water-input wells, especially near the zones of highest permeability (fractures). This has not been an orderly effort at improved waterflooding, as would be necessary to drive large quantities of oil efficiently to producing wells. It is desirable to begin an enhanced oil recovery project as soon as is economically possible in the life of a field to increase profits and produce oil that would not be recovered if reservoir pressure of the field were left to decline with production. Because of conservation and economics, the chief operator of the field (L.G. Stephenson) has decided to conduct a secondary oil recovery project for the Captain Creek Limestone (Lansing-Kansas City 30' zone in the producers' terminology). Attempts are being made to unitize the field under one operator so that an efficient waterflood may be developed without regard to lease boundaries. If economics allow, a tertiary recovery project may proceed after this.

It is important to estimate the amount of oil in the reservoir available for recovery by enhanced methods. Van Slyke (1974) estimated the probable ultimate primary and secondary oil recovery in the Wilson Creek Field. The author modified these figures to consider only the

Captain Creek zone. A tertiary recovery oil resource "target" also may be calculated knowing the initial stock tank barrels (STB) of oil originally-in-place.

Van Slyke assumed that the Captain Creek Limestone contributes to the primary production for a radial distance of 660 feet from each producing well. Accordingly, measuring the reservoir volume depicted by the porosity-thickness map (Fig. 19) and considering oil saturation of the reservoir at stock tank (surface) conditions, results in the calculation of volume of oil originally-in-place = 20,522,800 STB. Extrapolating the production decline rates for leases in the field on the basis of established or anticipated rates of decline gives the primary oil recovery to be expected in the future. Adding this oil to that produced as of the end of 1973, Van Slyke indicated 4,677,200 STB ultimate primary oil recovery from all producing zones. Approximately 85-90% of the oil produced from the field is from the Captain Creek Limestone, indicating about 4,100,000 STB ultimate primary recovery from this zone. Of this, approximately 3,800,000 barrels of oil have been produced from this main pay zone up to the beginning of 1977.

The secondary reserves to be obtained from Lansing-Kansas City reservoirs are difficult to establish. Van Slyke indicates that successful Kansas waterflooding operations may increase reserves by as much as 50-100% of the ultimate primary oil recovery. Assuming a reserve factor for secondary recovery which is 75% of primary recovery, the incremental increase in oil recovery by secondary processes is estimated to be approximately 3,075,000 STB for the Captain Creek oolitic reservoir.

Adding the primary and secondary ultimate reserves gives 7,175,000 STB of oil to have been recovered after secondary operations are completed. This leaves 3,375,000 STB to be recovered after 1976, during the expected 10-12 years of remaining life for secondary recovery operations. The amount of oil to be left in the reservoir after this stage is estimated by subtracting the primary and secondary ultimate oil recovery from initial oil-in-place. This value is 13,347,800 STB of oil, which may be considered a target for tertiary recovery operations. Possible recovery of even a fraction of this makes it attractive to consider tertiary recovery operations for the Wilson Creek Field.

Reservoir Characteristics in Engineering Design

Geological factors which affect the movement of fluids in the subsurface must be considered in designing an enhanced oil recovery project. These factors may be considered on three scales: microscopic textures; megascopic features observed in cores and rotary drilling samples, or inferred from logs; and features occurring on a well-to-well or field-wide scale. These factors relate closely to one another and are critical to engineering design.

Several features observed in thin sections of cores from the Wilson Creek Field are important to fluid movement in the reservoir. Wardlaw (1976) indicates that mercury injected under pressure into water-wet carbonate rocks as a nonwetting fluid, analogous to oil, is not completely expelled when pressure is released if the ratio of size of pores to size of pore-connections is large. In contrast, the typical tube-shaped pore-connections of sandstones expel much more mercury on reduction of pressure. Oomoldic porosity (Fig. 12-1) in the Captain Creek Limestone, with sheet-like pore-connections through intervening crystal-

line calcite cement, is an example of a carbonate pore structure similar to that discussed by Wardlaw (1976). Oil in these pores is more difficult to move through the very small sheet-like connections because of capillary pressure. Similarly, displacement of this oil by other fluids is more difficult than it would be in the tube-like sandstone pore networks. Consequently, more residual oil will be left in the oomoldic reservoir rock. Several features observed in thin section are better observed in cores and logs from the Wilson Creek Field. Ooid-oomold layers comprising cross-bedding in good productive areas in the field (as in the Vopat A-3 core, Fig. 13-1) strongly affect fluid movement as they are a form of stratification of the reservoir into high and low-permeability layers. Oil and water are present in the moldic layers and these fluids move along individual layers at a much greater rate than across the layers. Upon reaching a boundary between sets of cross-beds, they may move along this somewhat permeable boundary into an adjoining cross-bed set. At the top of the productive zone, oil may be isolated from more dense injected water which will move downward, along dipping cross-beds leaving lighter oil at the top. These cross-beds probably dip northward as previously mentioned. This isolated oil would reduce the oil recovered in a water- or chemical-flood project. Lenses of moldic pores in an "oolitic" matrix tend to retard fluid movement because the boundaries of an oomold lens are much less permeable than the lens itself. Scattered moldic pores in an ooid grainstone (as in the F. Princ core) are the least permeable of the porous lithologies described here and are common in dry holes in low-permeability areas around the field. Where present in the field, this texture effectively blocks fluid movement. The dense oolitic zone in the middle of the Captain

Creek often has this texture, and it may be entirely oolitic with almost no porosity. This zone will prevent almost completely the movement of fluid between overlying and underlying porous zones. Oil present in this zone will surely be bypassed in a waterflood and tertiary recovery fluids injected into the reservoir probably will not cross it.

Other features in the cores are also important to design of an enhanced recovery project. Stylolites, which are present throughout the cores, are subhorizontal, fairly tortuous, slightly permeable paths for fluids, but these may cause bypassing of some oil in surrounding less permeable rock if they are avenues of fluid flow. Fractures greatly increase the rate of fluid movement, especially where they are concentrated in zones of multiple fractures (Fig. 20). These zones could greatly distort an oil bank or micellar slug moving through the reservoir, because pumping or injection wells in these zones move fluids along the zones at much higher rates than through the rest of the reservoir. Fluid movement near these zones must be carefully monitored to prevent loss of expensive chemicals from a carefully designed oil displacement bank of fluids.

Many features in cores and logs may be mapped on a field-wide scale, or at least their general areas of occurrence delineated. The southern and southeastern parts of the field are productive from permeable cross-beds and lenses of the Captain Creek, as in the Vopat A-3 well (Figs. 13-1, 2). The producing zone in the northern part of the field is less cross-bedded and has more scattered moldic pores and oolitic zones (Fig. 13-3). Wells in this area are less permeable than those farther south, but still are productive. Areas of low permeability around the field are obstructions to the movement of fluids espe-

cially in the "tidal channel" areas. These linear features crossing the oil reservoir are zones of fairly low porosity with little recoverable oil; they may very effectively "compartmentalize" the reservoir. The dense oolitic zone between the two oomoldic (productive) zones is present over almost all of the field (Figs. 10, 11). Areal, the porosity of this zone is quite varied and ranges from near zero to about 15%. This, too, is a possible block to homogeneous flow of fluids through the rocks. Positions of the fracture zones as inferred from well-test data, are well determined. This is absolutely necessary for a successful operation of an enhanced recovery project.

Other field-wide factors of importance are structure, thickness, and hydrodynamics. The structural shape of the top of the zone of production (Fig. 18) shows the low area on the south side of the Wilson Creek Field and fairly uniform higher elevations in the rest of the field. The map of porosity-thickness indicates that the zone is lens-like with the thickest interval roughly paralleling the northern margin of the field. A factor which is neglected in planning some recovery projects is the presence of a fluid pressure gradient altering the path of flow of fluids in a reservoir. Strange and Talash (1976) indicate that a pressure gradient across the Salem low-tension waterflood test area (Illinois) caused injected fluids to move partly out of the test pattern, instead of sweeping oil to the producing well. Water flow in the reservoir drastically altered the expected flow path of injected fluids. The hydrodynamic gradient in the Wilson Creek Field will also alter the flow of fluids injected into the Captain Creek Limestone. It is probable that injection and pumping in a direction which is parallel

to general hydrodynamic flow will produce the best results, especially for a tertiary recovery project, where slugs of fluids must be kept intact to be most effective.

Some factors of general interest in an enhanced oil recovery project may be derived from core analyses and production records. For good producing wells in the Wilson Creek Field, the average permeability = 19 md.; average porosity = 19.1%; average connate water saturation = 26-35%; average produced-oil gravity = 39.1° API; and average depth to the Captain Creek = 2800 ft. Initial shut-in-pressures in the main part of the field vary because of the gradient but are, on the average, about 500 psi. The original oil saturation was about 65% of the pore space, and will decrease to about 45% after primary production. Van Slyke (1974) indicates that production records for individual leases producing from the Captain Creek (30' zone) show a normal rate of decline, typical of a depletion (solution gas drive) type reservoir. It is expected that some type of partial water-drive exists because of the hydrodynamic pressures noted above. Production of water along with the oil may be a result of this.

Recommendations

The Wilson Creek Field is currently being considered for repressuring and waterflooding in the Captain Creek (30' zone). The field is operated by several oil producers with some injection of water taking place at random. The field should be unitized under a single operator in order to produce the maximum amount of oil in an efficient manner without regard to tract boundaries. Higher rates of legally allowable production, consolidation of equipment, and possible exemption from proration may also be gained from unitization.

Van Slyke (1974) suggests that the Wilson Creek Field should be repressurized along the fracture zones as the first step in installation of a waterflood. After this, he suggests driving oil updip (northward) and concentrating oil by gravitational segregation. Water-input wells should be located along the northern margin of the field to prevent further migration.

Van Slyke's proposed waterflood possibly should be modified to conform to the hydrodynamic gradient in the Wilson Creek Field. A peripheral type of fluid injection pattern may be more advantageous. From Figure 20, the fracture zones are in the middle to northern part of the field in Secs. 16, 20, 21 (T14S-T10W) and at the south end of the field in T14S-R11W. In the eastern part of the field, flooding should proceed from the southeastern margin of the field northward to the fracture zones. The entire northern margin of the field should be lined with water injection wells driving oil southward to the fracture zones. This will cause fluid movement parallel to flow of water in the field. The present high fluid-capacity wells along the fracture zones should be converted to producing wells (Fig. 28). Driving oil with the flow of water downdip in the western end of the field will not be hampered by density contrast, because the dip of the bed is less than 1° , which should not cause significant gravity-segregation of oil against the flow of fluids.

The Captain Creek (30' zone) in the Wilson Creek Field has several characteristics that make it an attractive candidate for tertiary recovery. National Petroleum Council (1976) lists several criteria to be met for a CO_2 flood. The temperature (95°F), depth (2800 ft.), oil gravity (39°API), and lack of a strong water drive indicate that the

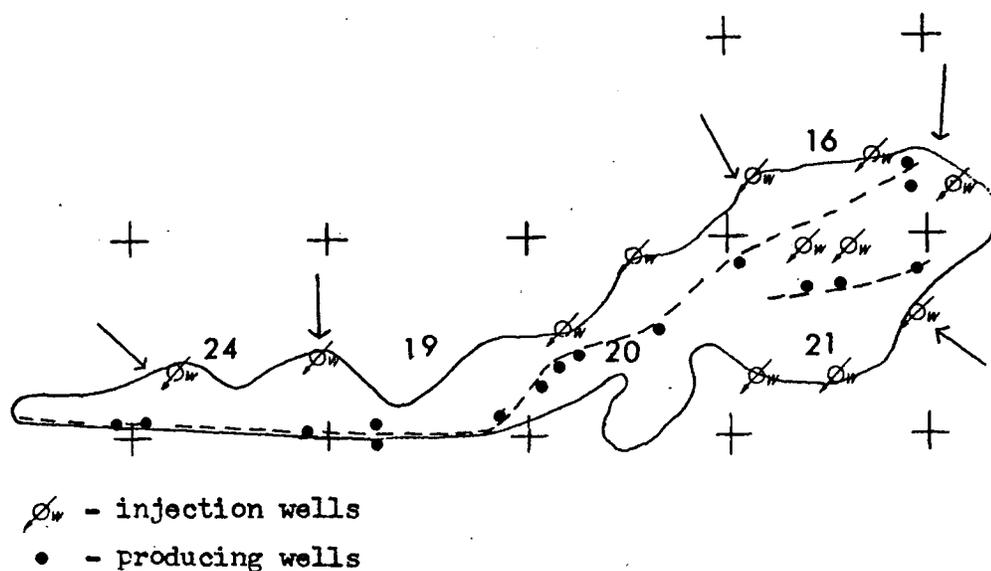


Figure 28.- Wilson Creek Field map showing proposed enhanced oil recovery injection-production pattern. Arrows outside the field boundary are the directions of hydrodynamic gradients. Dashed lines are the fracture zones. Symbols are actual wells but represent areas of injection or production. Limitations of space prevented showing all wells. See text for discussion.

Captain Creek meets these screening criteria well. In addition, the carbonate reservoir rock may be partly dissolved by CO_2 in water solution during CO_2 injection, increasing the ability of the rock to transmit fluids. Laboratory tests must be made to determine whether or not CO_2 is miscible with the Captain Creek oil. If this is the case, a combination CO_2 -water flood should be considered for this producing interval. Initiating a CO_2 -flood right after primary production may allow greater ultimate oil recovery than if a tertiary project (including CO_2) is begun only after the field is waterflooded. Currently attractive cost-sharing arrangements, with operators and governmental agencies such as the U.S. Energy Research and Development Administration (E.R.D.A.) acting as co-participants in tertiary recovery pilot projects, make this option particularly appealing.

The high gravity (API) of the oil precludes application of a thermal recovery process, and the carbonate lithology of the reservoir is more amenable to flooding by CO_2 than by a micellar-fluid process. The large ratio of pore-to-pore connection sizes may drastically affect the mobility ratio of various native and injected fluids in the oomoldic reservoir rock. This potential problem needs further study. Regardless of the process used, the flood should be designed to follow the natural hydrodynamic gradient present and should be carefully monitored near the fracture zones for indications of early breakthrough of injected fluids or other unpredictable anomalies. It is also recommended that fluids be injected both above and below the dense oolitic zone in the middle of the Captain Creek. Otherwise, injected fluids may not cross the dense zone in many areas, and oil which is not contacted will be bypassed and left unproduced.

SUMMARY

The main producing formation in the Wilson Creek Field, the Captain Creek Limestone, is an elongate lens of oolitic limestone. This limestone was deposited as a marine oolite shoal, the location of which was controlled by a fault in the underlying Arbuckle Group. The Captain Creek Limestone (locally known as the Lansing 30' zone) consists of three distinct lithologies which suggest shallowing environments of deposition: (from the base upward) normal-salinity open-marine; high-energy oolite shoal; and restricted lagoon. Diagenetic features include calcite cement of two ages, ooid dissolution, microspar replacement of micrite, coarse dolomite filling molds, stylolites, and fractures. Initial submarine (fibrous) cementation was followed by vadose dissolution of ooids, phreatic calcite cementation, and calcite replacement of certain constituents. Compaction features were followed by dolomite emplacement.

The reservoir rock of the Captain Creek consists of ooid-oomold grainstone, with chiefly oomoldic porosity. Permeability is formed by interconnection of the pores through crystal boundaries and fractures. Cross-bedding of alternating ooid-oomold layers comprises the best, most highly permeable producing rock. Less continuous lenses of ooid-oomold layers are somewhat productive, and scattered moldic pores in an oolitic limestone form a porous but non-productive (impermeable) rock. Hydrocarbons in the field are contained by a combination-type trap. The Field is located slightly off-structure; less permeable rocks at the field margin prevent oil from moving updip. Updip areas of good permeability have downdip hydrodynamic gradients which hold oil off-structure and cause tilting of the oil-water contact.

Original oil-in-place in the Wilson Creek Field is estimated as more than 20 million stock-tank barrels (STB) in the Captain Creek Limestone reservoir, of which more than 4 million barrels will be ultimately recovered by primary production methods. This leaves more than 16 million STB of oil as a target for enhanced recovery processes. Features of importance in the design of a flood project for the Wilson Creek Field include structural attitude, thickness, the presence of fracture zones, hydrodynamic gradients, and internal variability of the reservoir rock. It is proposed to utilize the natural flow of water around the field to sweep oil efficiently to producing wells in the fracture zones.

Knowledge of the location and extent of porous oolitic zones in a sedimentary province such as central Kansas will facilitate discovery of oil and gas traps which are similar to that of the Wilson Creek Field. Permeability barriers and/or hydrodynamic gradients in oolitic formations along the flanks of the Central Kansas Uplift may cause trapping of large quantities of oil and gas. Detailed studies of Lansing-Kansas City oolitic zones in Kansas are needed to locate areas which would be attractive for drilling.

REFERENCES

- Amyx, J.W., Bass, D.M., Jr., and R.L. Whiting, 1960, Petroleum Reservoir Engineering, Physical Properties: McGraw-Hill Co., New York, N.Y., 610 pp.
- anonymous, 1976, Table B Oil Report for Kansas: Kansas Corporation Commission, Conservation Division, January to December 1976.
- Ball, M.M., 1967, Carbonate Sand Bodies of Florida and the Bahamas: *Journal Sed. Petrology*, vol. 37, p. 556-591.
- Ball, S.M., 1959, Stanton Limestone in Northeastern Kansas: *Compass*, vol. 36, no. 4, p. 279-288.
- Bandy, O.L., 1964, Foraminiferal Biofacies in Sediments of Gulf of Batabano, Cuba and Their Geological Significance: *Amer. Assoc. Petroleum Geologists Bull.*, vol. 48, p. 1666-1679.
- Bathurst, R.G.C., 1969, Bimini Lagoon: *in*, Field Guide to Some Carbonate Rock Environments, Florida Keys and Western Bahamas: H.G. Multer, (ed.), Farleigh Dickinson University, p. 62-66.
- _____, 1975, Carbonate Sediments and Their Diagenesis: *Developments in Sedimentology* 12, Elsevier Co., Amsterdam, 658 pp.
- Berg, R.R., 1972, Oil Column Calculations in Stratigraphic Traps: *Trans. Gulf Coast Assoc. Geol. Societies*, vol. 22, p. 63-66.
- _____, 1975, Capillary Pressures in Stratigraphic Traps: *Amer. Assoc. Petroleum Geologists Bull.*, vol. 59, no. 6, p. 939-956.
- Boersma, J.R., 1969, Internal Structure of Some Tidal Megaripples on a Shoal in Westerschelde Estuary, the Netherlands: *Geologie en Mijmbouw*, vol. 48, p. 409-414.
- Chelikowski, J.R., and V. Burgat, 1974, Structures and Convergence of the Formations in the Lansing Group, Wilson County, Kansas: *Kansas Acad. Science Transactions*, vol. 50, p. 89-96.
- Cole, V.B., 1975, Subsurface Ordovician-Cambrian Rocks in Kansas: *Kansas Geol. Survey Subsurface Geology Series* 2, 18 pp.
- Compton, R.R., 1967, *Manual of Field Geology*: John Wiley and Sons, New York, N.Y., 378 pp.
- Dickson, J.A.D., 1965, A Modified Staining Technique for Carbonates in Thin Section: *Nature*, vol. 205, p. 587.
- _____, 1966, Carbonate Identification and Genesis as Revealed by Staining: *Journal Sed. Petrology*, vol. 36, no. 2, p. 491-505.

- ✓ Dunham, R.J., 1962, Classification of Carbonate Rocks According to Depositional Texture: in, A Symposium On Classification of Carbonate Rocks, Amer. Assoc. Petroleum Geologists Memoir no. 1, p. 108-121.
- Eardley, A.J., 1951, Structural Geology of North America: Harper Bros., New York, N.Y., 624 pp.
- Eastwood, W.P., 1958, Stratigraphy of the Captain Creek Limestone (Missourian) of Eastern Kansas: unpublished M.S. Thesis, University of Kansas, 159 pp.
- ✓ Ebanks, W.J., Jr., 1974, Future Prospects for Kansas: Oil and Gas Exploration and Production: Kansas Geol. Survey Journal, July, 1974, 36 pp.
- Freeman, T., 1962, Quiet Water Oolites from Laguna Madre, Texas: Journal Sed. Petrology, vol. 32, p. 475-483.
- Gussow, W.C., 1954, Differential Entrapment of Oil and Gas: A Fundamental Principle: Amer. Assoc. Petroleum Geologists Bull., vol. 38, no. 5, p. 816-853.
- ✓ Harbaugh, J.W., and W. Davie, 1964, Upper Pennsylvanian Calcareous Rocks Cored in Two Wells in Rawlins and Stafford Counties, Kansas: Kansas Geol. Survey Bull. 170, pt. 6.
- Heckel, P.H., 1972, Pennsylvanian Stratigraphic Reefs in Kansas, Some Modern Comparisons and Implications: Geol. Rundschau, vol. 61, pt. 2, p. 584-598.
- ✓ _____, 1975, Stratigraphy and Depositional Framework of the Stanton Formation in Southeastern Kansas: Kansas Geol. Survey Bull. 210.
- ✓ _____, 1977, Significance of Vertical Sequence, Lateral Change, and Phosphatic Black Shale Facies in Upper Pennsylvanian Cyclic Deposits of Midcontinent, North America: Amer. Assoc. Petroleum Geologists Bull., in edit.
- _____, and J.M. Cocke, 1969, Phylloid Algal-Mound Complexes in Outcropping Upper Pennsylvanian Rocks of the Mid-Continent: Amer. Assoc. Petroleum Geologists Bull., vol. 53, no. 5, p. 1058-1074.
- Horowitz, A.S., and P.E. Potter, 1971, Introductory Petrography of Fossils: Springer-Verlag, New York, N.Y., 202 pp.
- Hubbert, M.K., 1953, Entrapment of Petroleum under Hydrodynamic Conditions: Amer. Assoc. Petroleum Geologists Bull., vol 37, p. 1954-2026.
- Illing, L.V., 1954, Bahamian Calcareous Sands: Amer. Assoc. Petroleum Geologists Bull., vol. 38, p. 1-95.

Imbrie, J., and H. Buchanan, 1965, Sedimentary Structures in Modern Carbonate Sands of the Bahamas: Soc. Econ. Paleontologists and Mineralogists, spec. pub. no. 12, p. 149-172.

Irwin, M.L., 1965, General Theory of Epeiric Clear Water Sedimentation: Amer. Assoc. Petroleum Geologists Bull., vol. 49, no. 4, p. 445-459.

Larson, T.G., 1971, Hydrodynamic Interpretation of Mid-Continent: in, Future Petroleum Provinces of the United States - Their Geology and Potential: Cram (ed.), Amer. Assoc. Petroleum Geologists Memoir 15, p. 1043-1046.

Levorsen, A.I., 1967, Geology of Petroleum: Freeman and Sons, San Francisco, p. 333-382.

Merriam, D.F., 1963, The Geologic History of Kansas: Kansas Geol. Survey Bull. 162, 317 pp.

_____, and W.R. Atkinson, 1955, Tectonic History of the Cambridge Arch in Kansas: Kansas Geol. Survey Oil and Gas Invest. 13, p. 1-28.

Moore, R.C., 1949, Divisions of the Pennsylvanian System in Kansas: Kansas Geol. Survey Bull. 83, p. 1-203.

_____, J.C. Frye, J.M. Jewett, W. Lee, and H.G. O'Connor, 1951, The Kansas Rock Column: Kansas Geol. Survey Bull. 89, p. 1-132.

Morgan, J.V., 1952, Correlation of Radioactivity Logs of the Lansing and Kansas City Groups in Central Kansas: Amer. Inst. Mining Metallurgy Petroleum Engineers Petr. Trans., vol. 195, p. 111-118.

National Petroleum Council, 1976, Carbon Dioxide Flooding Process: in, Enhanced Oil Recovery - An Analysis of the Potential for Enhanced Oil Recovery from Known Fields in the U.S., 1976-2000, Appendix E.

Newell, N.D., 1933, The Stratigraphy and Paleontology of the Upper Part of the Missouri Series in Eastern Kansas: unpublished Ph.D. dissert., Yale University, 247 pp.

_____, 1935, Geology of Johnson and Miami Counties, Kansas: Kansas Geol. Survey Bull. 21, pt. 1, p. 1-150.

_____, 1951, Organic Reefs and Submarine Dunes of Oolite Sand Around the Tongue of the Ocean, Bahamas: Geol. Soc. Amer. Bull. 62, p. 1466-1488.

_____, 1953, The Permian Reef Complex of the Guadalupe Mountains Region, Texas and New Mexico: Freeman and Sons, San Francisco, 236 pp.

_____, 1955, Bahamian Platforms: Geol. Soc. Amer. Spec. Papers 62, p. 303-315.

- _____, Purdy, E.G., and J. Imbrie, 1960, Bahamian Oolitic Sand: Jour. Geol., vol. 68, p. 481-497.
- Oakes, M.C., 1940, Results of Recent Field Studies in Osage, Washington, and Nowata Counties, Oklahoma: Amer. Assoc. Petroleum Geologists Bull., vol. 24, p. 716-730.
- Parkhurst, R.W., 1959, Surface to Subsurface Correlations and Oil Entrapment in the Lansing and Kansas City Groups (Pennsylvanian) in Northwestern Kansas: unpublished M.S. Thesis, University of Kansas, 71 pp.
- Purdy, E.G., 1961, Bahamian Oolite Shoals, in, Geometry of Sandstone Bodies: Peterson and Osmond (ed.), Amer. Assoc. Petroleum Geologists, Tulsa, Oklahoma, p. 53-62.
- _____, 1963, Recent Calcium Carbonate Facies of the Great Bahama Bank, Sedimentary Facies: Jour. Geol., vol. 71, p. 472-497.
- _____, and J. Imbrie, 1964, Carbonate Sediments, Great Bahama Banks: Guidebook for Field Trip No. 2, Geol. Soc. Amer. Convention 1964, New York, N.Y., 66 pp.
- Rascoe, B., Jr., 1962, Regional Stratigraphic Analysis of Pennsylvanian and Permian Rocks in Western Mid-Continent, Colorado, Kansas, Oklahoma, and Texas: Amer. Assoc. Petroleum Geologists Bull., vol. 46, no. 8, p. 1345-1370.
- Shinn, E.A., 1968, Practical Significance of Birdseye Structures in Carbonate Rocks: Jour. Sed. Petrology, vol. 38, no. 1, p. 221-224.
- Smith, D.L., 1972, Stratigraphy and Carbonate Petrology of the Mississippian Lodgepole Formation in Central Montana: Ph.D. dissert., University of Montana, 143 pp.
- Stone, D.S., and R.L. Haeger, 1973, Importance of Hydrodynamic Factors in Formation of Lower Cretaceous Combination Traps: Big Muddy-South Glenrock Area, Wyoming: Amer. Assoc. Petroleum Geologists Bull., vol. 57, p. 1714-1733.
- Strange, L.K., and A.W. Talash, 1976, Analysis of Salem Low Tension Waterflood Test: Soc. Petroleum Engineers Improved Oil Recovery Symposium Proceedings, Tulsa, Oklahoma, p. 605-610.
- Todd, R.G., 1976, Oolite Bar Progradation, San Andres Formation, Midland Basin, Texas: Amer. Assoc. Petroleum Geologists Bull., vol. 60, no. 6, p. 907-925.
- Van Slyke, J.R., 1974, Reserve Estimate, Operating Profit Analysis in the Wilson Creek Field, Ellsworth and Russell Counties, Kansas: for L.G. Stephenson Co., unpublished report submitted March 15, 1974.

Wagner, H.C., 1954, Geology of othe Fredonia Quadrangle, Kansas: U.S. Geol. Survey Geology Quadrangle Map 49.

_____, and L.D. Harris, 1953, Stratigraphy of Outcropping Pennsylvanian rocks of the Fredonia Quadrangle, Kansas: U.S. Geol. Survey Oil and Gas Invest. Chart OC 48.

Walters, R.F., 1946, Buried Pre-Cambrian Hills in Northeastern Barton County, Central Kansas: Amer. Assoc. Petroleum Geologists Bull., vol. 30, no. 5, p. 660-710.

_____, 1958, Differential Entrapment of Oil and Gas in Arbuckle Dolomite of Central Kansas: Amer. Assoc. Petroleum Geologists Bull., vol. 42, no. 9, p. 2133-2173.

Wardlaw, N.C., 1976, Pore Geometry of Carbonate Rocks as Revealed by Pore Casts and Capillary Pressure: Amer. Assoc. Petroleum Geologists Bull., vol. 60, no. 2, p. 245-257.

Watney, W.L., in prep., Lithofacies Distribution of the Lansing and Kansas City Groups, Northwest Kansas and Southwest Nebraska: Kansas Geol. Survey Bull., for 1977.

Weaver, C.E., 1958, Clay Petrology of Upper Mississippian-Lower Pennsylvanian Sediments of Central United States, pt. II; Geologic Interpretation of Argillaceous Sediments: Amer. Assoc. Petroleum Geologists Bull., vol. 42, p. 272-309.

Wilson, F.W., 1957, Barrier Reefs of the Stanton Formation (Missourian) in Southeast Kansas: Kansas Acad. Science Trans., vol. 60, p. 429-436.

_____, 1957b, Algal Reefs of the Stanton Formation in Southeast Kansas: Guidebook of 21st Field Conference, Kansas Geol. Society.

Wilson, J.L., 1975, Carbonate Facies in Geologic History: Springer-Verlag, New York, N.Y., 471 pp.

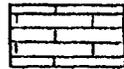
Zeller, D.E. (ed.), 1968, The Stratigraphic Succession in Kansas: Kansas Geol. Survey Bull. 189, 81 pp.

APPENDIX I

CORE DESCRIPTIONS AND ANALYSES

LEGEND

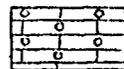
Scale: 1" = 2'



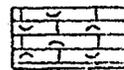
LIMESTONE



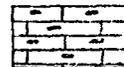
OOLITIC LIMESTONE



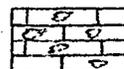
OOMOLDIC LIMESTONE



FOSSILIFEROUS LIMESTONE



PELLETOID LIMESTONE



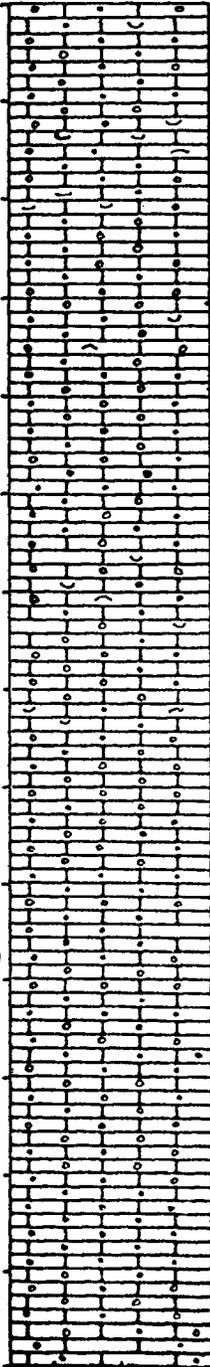
LITHOCLAST LIMESTONE



SHALE

Glen Rupe Vopat A-3
C E2 NE SW 21-14-10W
KB elev. 1686'

Depth
2825'



buff oily ooid-oo-mold grainstone w/lo-ang. (10-20°)
x-bed. consist. of alternating ooid-mold lyrs.

same w/scattered small lenses of brach., crinoids, &
fusilinids

buff oily ooid-oo-mold grainstone w/x-bed. & large
(>20 cm.) lenses of alt. lyrs.; molds sltly. larger
than ooids

2830'

same w/ a few stylolites

buff oily ooid-oo-mold grainstone w/medium (10-20
cm.) lenses and thin x-bed.; absence of skeletal
lenses to base

2835'

same w/medium lenses, no x-bed.

same w/ thin x-bed. & small (<10 cm.) to medium
lenses of alt. lyrs.(as above)

Note: This core consists of $\frac{1}{2}$ ' pieces taken at 1' intervals.

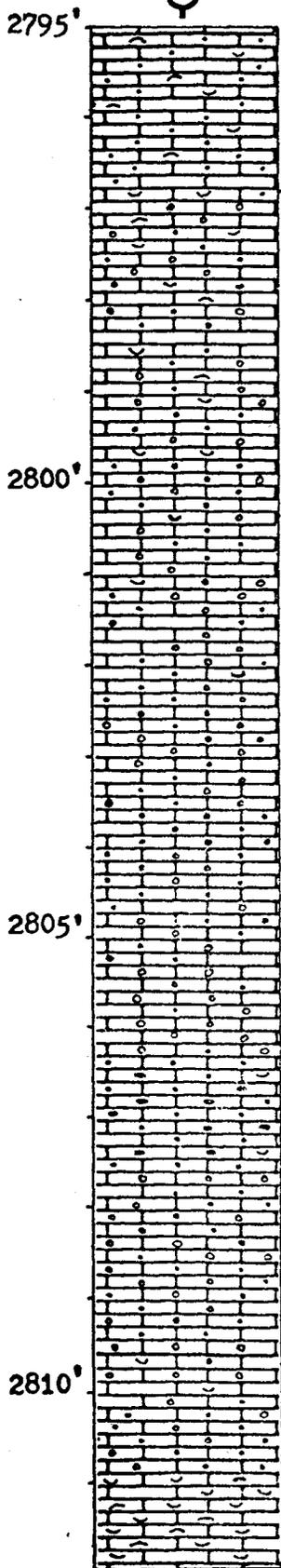
Glen Rupe Vopat A-3
Whole Core Analysis

Average Permeability	= 19 md.
Average Porosity	= 22.2%
Average Residual Oil Saturation	= 7.5%
Average Total Water Saturation	= 28.1%
Average Oil Gravity	= 37° API
Average Connate Water Saturation	= 22%

DEPTH (Feet)	MAX. PERMEABILITY (md.)	POROSITY (%)	RESIDUAL SATURATION (% pore space)	
			OIL	WATER
2825-26	20.0	20.0	7.0	20.9
2826-27	8.6	21.2	6.2	17.7
2827-28	20.0	21.9	7.0	18.6
2828-29	37.0	20.6	8.4	22.1
2829-30	22.0	21.7	9.8	26.1
2830-31	22.0	23.5	8.2	30.9
2831-32	22.0	19.3	7.8	31.3
2832-33	4.0	27.5	7.2	32.0
2833-34	64.0	23.7	10.4	17.9
2834-35	19.0	24.2	5.2	36.3
2835-36	17.0	22.7	8.5	32.4
2836-37	7.8	21.2	4.6	33.2
2837-38	4.7	21.7	5.9	42.0
2838-39	6.2	24.4	7.7	33.1
2839-40	16.0	19.7	8.5	26.6

The Texas Co. Frank Princ 1
SW SE NW 20-14-10W
KB elev. 1660'

Depth 



lt.-gy. fos. ooid packstone (minor molds); abundant brach., crinoids, bryozoans, also stylolites

buff oily ooid-oo-mold grainstone; minor fos.; molds widely scattered

2800' buff oily ooid-oo-mold grainstone w/medium (10-20 cm.) lenses; a few stylolites and vertical fractures

2805' buff oily ooid-oo-mold grainstone w/small (<10cm.) to medium lenses; stylolites & small lenses of fos.

2805' 1' lyr. of pelletoid-ooid grainstone; minor brach. & intraclasts(?)

2810' buff oily ooid-oo-mold grainstone w/medium to large (>20 cm.) lenses; a few stylolites scattered throughout

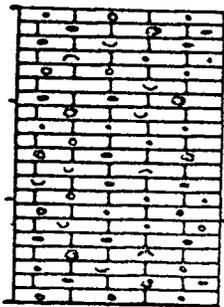
2810' wh. fos. wackestone, burrowed, w/brach., crinoids, fusilinids, bryozoans, algae, gastropods; several small pyrite nod.; small clay lam.

The Texas Co. F. Princ 1
 Whole Core Analysis

DEPTH (Feet)	MAX. PERMEABILITY (md.)	POROSITY (%)	RESIDUAL SATURATION (% pore space)	
			OIL	WATER
2795.0-96.5	0.5	5.2	4.1	72.5
2796.5-97.7	0.5	18.0	19.8	48.6
2797.7-99.5	0.6	21.5	22.5	32.5
2799.5-01.2	0.2	23.6	16.6	40.8
2801.2-02.2	3.4	22.1	7.7	34.5
2802.2-03.6	2.4	21.8	14.0	37.4
2803.6-05.0	0.5	16.4	5.7	67.7
2805.0-06.1	0.7	15.5	4.3	73.5
2806.1-07.0	0.5	14.4	4.7	67.6
2807.0-08.0	<0.1	7.0	2.0	78.6
2808.0-09.4	<0.1	14.3	1.3	77.0
2809.4-11.0	0.6	13.0	0.0	82.2

The Texas Co. Beisel 1
NEc SE 6-14-11W
KB elev. 1783'

Depth 



2340'

gy. ooid-oo-mold packstone interbed. w/coarse lithoclast-pelletoid packstone; fossiliferous w/brach., crinoids, algae, fusilinids; minor clay laminae, some stylolites; clasts are hematite, shale, & dolo.

same w/less clay & stylolites

gy. ooid-oo-mold packstone interbed. w/fine to medium lithoclast-pelletoid packstone; less fos., clay lam., & clasts than above

APPENDIX II

Research Procedures

Thin sections were chosen from the Vopat A-3 and F. Princ 1 core where macroscopic textural changes were noted. Those sections showing good separation of ooid and oomold layers were point-counted for grain size and packing (percentage of grains in the oolitic versus oomoldic layers). More than 300 counts were made on each slide in an imaginary grid pattern. Visual estimates were made of the constituent (coarse grain) composition of various slides from diagrams by Compton(1967). Rotary drilling samples of the lithologies were chosen for thin section where such samples could be positively identified for depth. Samples outside the map areas in the text were used to delineate the limits of the oolitic limestone and identify various lithologies of the Captain Creek Limestone.

A technique described by Dickson(1965; 1966) was used to stain for dolomite. The samples were inserted in a 1.5% HCl bath for initial etching. The samples were removed after 15 seconds and placed in a solution of alizarin red S and potassium ferricyanide in 1.5% HCl for about 60 seconds. This was followed by 10 to 15 seconds in a solution of alizarin red S in 1.5% HCl to bring out the stain color. Calcite stained red, and ferroan dolomite stained blue. Any non-ferroan dolomite would not have taken the stain.

APPENDIX III
GEOLOGIC MAP DATA

- 'W' indicates B zone produced only water.
- 'O' indicates fully oil saturated productive B zone.

1 initial shut-in pressure measured in B zone
2 elevations of potentiometric surface for B zone

* before well number indicates cuttings samples were examined

T14S R10W

Lease(Operator)	Well	Location, Section	KB elev.	Oolitic Zone			Porosity Thickness	ISIP (psi)	Potent. elev.	O/W Contact
				Top	Base	Thickness				
Foran(LGS)	*1	SW SW SW 15	1718	-1134	-1156	22	22	785 ¹	-1115 ²	
	2	SE SW SW 15	1733	-1137	-1159	22	22	736	-1119	
Hanzlicek(Siegel)	*1	NE NE NW 15	1782	-1150	-1168	18	14			
Hanzlicek(Koch)	*1	C NW SW 15	1747	-1117	-1139	22	20	612	-1102	W
	*2	SW SW NW 15	1758	-1121	-1142	21	17	753	-1103	W
	*3	SW NW SW 15	1728	-1122	-1146	24	22			
Baker(LGS)	1	SW SE SW 16	1719	-1124	-1148	24	22	845	-1103	
	2	C SE SW 16	1707	-1125	-1145	20	19	620	-1110	
	3	NW SE SW 16	1713	-1109	-1130	21	20	656	-1093	
	4	C E2 E2 SW 16	1716	-1116	-1145	19	17	208		-1130
	5	NE NE SW 16	1733	-1127	-1143	16	7	801	-1107	
Baker A(LGS)	1	C NW SW SE 16	1724	-1121	-1141	20	19	130		-1129
	2	NE SW SE 16	1749	-1126	-1154	28	27	600	-1112	-1134
	3	C W2 SW SE 16	1728	-1123	-1147	24	20	628		-1134
	4	SW NW SE 16	1716	-1125	-1142	17	13	737	-1107	-1127
	5	SE SW SE 16	1741	-1134	-1154	20	20	718	-1117	-1147
Bultman(LGS)	1	W2 SE NW SE 16	1751	-1113	-1135	22	11			
Hlaus(LGS)	1	SE SE NW 16	1742	-1130	-1147	17				
Hlaus(Ward)	1	NE SW NE 16	1763	-1131	-1151	20	6	815	-1111	
Soukup(LGS)	1	SW SW SW 16	1716	-1117	-1134	17	13	765	-1098	-1127
	2	SE SW SW 16	1720	-1119	-1143	24	24	700		-1134
	3	NE SW SW 16	1722	-1109	-1132	23	19	600	-1095	
	4	SE NW SW 16	1740	-1118	-1139	21	14	536	-1105	W
Soukup A(LGS)	1	SE SW NW 16	1739				8	86		
K. Vopat(LGS)	1	SE SE SE 16	1734	-1129	-1153	24	19	276	-1124	W
	2	NW NE SE 16	1763	-1117	-1141	24	14			W

T14S R10W

Lease(Operator)	Well	Location, Section	KB elev.	Colitic Zone			Porosity Thickness	ISIP (psi)	Potent. elev.	O/W Contact
				Top	Base	Thickness				
K. Vopat(LGS)	3	SW NE SE 16	1753	-1117	-1136	19	15	533	-1104	
	4	C W2 SE SE 16	1740	-1122	-1146	24	17	536	-1110	
	5	E2 NE SE 16	1733				22	620		
	6	NE SE SE 16	1726	-1117	-1139	22	19	300	-1109	
Macek(Rupe)	1	SE SE SE 17	1709	-1120	-1132	15	15	584	-1108	-1127
Sibrava(Ehrlich)	1	NW SW NE 17	1739	-1141	-1157	16	14	1011	-1116	
Soukup(Dolechek)	*1	SE SE NW 17	1728	-1149	-1165	16	7	1047	-1123	
Svara(Bell)	1	E2 NW SE 17	1749	-1131	-1147	16		924	-1108	
Svara(Rupe)	1	SE SW SE 17	1707	-1140	-1149	9	5	789	-1137	W
Zaloudek(Bell)	1	NE SE SW 17	1701					871		
Hunter(Ash)	1	SE SW NW 18	1706	-1135	-1147	12	9	847	-1114	
Sibrava(Bell)	1	NW SE NE 18	1706	-1144	-1154	10		675	-1128	
Adamek(Ash)	1	SE SE NE 19	1684	-1129	-1149	20	20	810	-1105	
	2	SW SE NE 19	1683	-1133	-1152	19	13	333	-1126	
Borell A(LGS)	1	NW NE SE 19	1678	-1120	-1139	19	17	905		-1133
	2	SE NE SE 19	1678	-1136	-1154	18	18	820	-1116	
Borell C(LGS)	1	N2 SE SE 19	1683	-1144	-1163	19	18	577		-1155
	2	C S2 SE SE 19	1680	-1156	-1172	16	15	720	-1138	
	3	SE SW SE 19	1671	-1160	-1178	18	11	380	-1152	
	4	NE SW SE 19	1674	-1130	-1151	20	19	490	-1119	
	5	SW SW SE 19	1677	-1142	-1163	21	16	540	-1129	0
	6	SW NE SE 19	1678	-1131	-1151	20	19	410	-1122	
	7	NW SW SE 19	1680	-1125	-1145	20	17	450	-1115	
Cook(Gemini)	*1	SW NW NW 19	1680	-1112	-1132	20	20	910	-1089	

T14S R10W

Lease(Operator)	Well	Location, Section	KB elev.	Oolitic Zone			Porosity Thickness	ISIP (psi)	Potent. elev.	O/W Contact	
				Top	Base	Thickness					
Cook(LGS)	1	NE SW NW 19	1671	-1105	-1127	22	17	810	-1085		
	2	E2 E2 SW 19	1687				5	74			
	3	NW SW SW 19	1678	-1133	-1148	15	4	578	-1119	-1142	
	4	C S2 SW SW 19	1672	-1171	-1187	16	10	645	-1155		
	5	C SE SW 19	1683	-1147	-1162	15	13	505	-1135	-1155	
	6	SW SE SW 19	1682	-1192	-1209	17	12	528	-1180		
Riverview(Ash)	1	NE NW SE 19	1684	-1134	-1144	10	6	105	-1133	W	
Borell B(LGS)	1	SW NW SW 20	1679	-1130	-1148	18	15	733			
	2	SE NW SW 20	1661	-1142	-1158	16	14	803	-1122		
Borell B-2(LGS)	4	SE NE SW 20	1667	-1139	-1154	15	13	314	-1130		
	5	ap SW NE SW 20	1656	-1144	-1159	15	15	838		-1156	
	6	NE NE SW 20	1677	-1144	-1161	17	17	680	-1129		
	7	W2 W2 SW 20	1676	-1140	-1158	18	14	455	-1130		
	8	C SW SW 20	1676	-1151	-1167	16	16	610	-1136	0	
	9	N2 N2 SW 20	1660				13	520			
	10	NE SW SW 20	1673	-1147	-1161	14	13	589	-1133		
	*11	SE SE SW 20	1648	-1139	-1154	15	13	736	-1121		
	Wenceslaus(LGS)	1	NW NW SW 20	1675	-1111	-1131	20	20	549	-1098	0
	Kratky(LGS)	1	SW NW SE 20	1671	-1141	-1160	19	17	759	-1122	
2		E2 W2 SE 20	1676	-1132	-1154	22	18	710	-1115		
4		NE NW SE 20	1686	-1136	-1157	21	17	471			
5		NW NW SE 20	1686	-1136	-1156	20	17	685	-1119		
6		SW NE SE 20	1686	-1137	-1155	18	16	201	-1133	W	
*7		SW SW SE 20	1649	-1138	-1153	15	13	662	-1122		
8		NW SW SE 20	1675	-1139	-1158	19	17	616	-1124	0	
*9		SE SW SE 20	1681	-1136	-1156	20	18	662	-1120		
Pekarek(LGS)		*1	SE SW NE 20	1693	-1134	-1155	21	18	762	-1115	0
	2	N2 S2 NE 20	1697	-1129	-1150	21	18	674		0	
	3	W2 SW NE 20	1686	-1128	-1147	19	19	522		0	

T14S R10W

Lease(Operator)	Well	Location, Section	KB elev.	Colitic Zone.			Porosity Thickness	ISIP (psi)	Potent. elev.	O/W Contact
				Top	Base	Thickness				
Pekarek(LGS)	4	SE SE NE 20	1680	-1144	-1165	22	16	416		
	5	SE NW NE 20	1694	-1130	-1147	17	16	575	-1116	-1140
	6	NW NW NE 20	1694	-1135	-1150	15	14	177	-1132	W
F. Prino(Texaco)	1	SW SE NW 20	1660	-1136	-1151	15	12			-1144
Prino(Rupe)	1	E2 SE NW 20	1681	-1130	-1145	15	15	445	-1121	
	2	S2 S2 NW 20	1660	-1143	-1154	11	7	753	-1125	W
	3	SW SW NW 20	1682	-1127	-1148	21	14	692	-1110	
	4	SE SE NW 20	1669	-1124	-1147	23		458	-1114	
Vlcek(Rupe)	1	S2 NE NE 20	1691	-1134	-1152	18	18	427	-1124	
Stiles(B & K)	1	W2 W2 SE 21	1676	-1141	-1160	19	0			-1142
Vopat A(Gorski)	1	C W2 NW NW 21	1706			18?	18	83		
	2	SW SW NW 21	1691	-1138	-1159	21	20	616	-1123	0
	*3	SE SE NW 21	1694	-1131	-1154	23	21	492	-1120	0
	4	SE NE NW 21	1690	-1136	-1155	19	16	480		
	5	NW NW SE 21	1691	-1122	-1149	27	20	503		
	6	N2 N2 SE 21	1698	-1130	-1144	14	13	569	-1117	
	*7	C E2 SW NW 21	1686	-1134	-1156	22	21	533		
	*8	NW SE NW 21	1701	-1134	-1150	22	16	447	-1124	0
	*9	NW NE NW 21	1712	-1132	-1150	18	14	582	-1118	
	10	NE NE NW 21	1709	-1138	-1151	13	13	164	-1135	-1147
	11	NE SE NW 21	1686	-1138	-1156	18		400		
	12	NE NW SE 21	1695	-1123	-1146	23		343	-1116	-1147
	13	SE NW NW 21	1701	-1135	-1156	21		643	-1120	
	14	NE NW NW 21	1713	-1135	-1156	21		690		
	15	SW NW SE 21	1677	-1136	-1151	15	10			-1147
L. Vopat(B & K)	1	W2 W2 SW 21	1669				19	710	-1124	
Vopat A(Rupe)	1	N2 NW SW 21	1686	-1137	-1157	20	19	745		
	2	C W2 NE SW 21	1688	-1124	-1156	32	23	690		

T14S R10W

Lease(Operator)	Well	Location, Section	KB elev.	Colitic Zone			Porosity Thickness	ISIP (psi)	Potent. elev.	O/W Contact
				Top	Base	Thickness				
Vopat A(Rupe)	3	C E2 NE SW 21	1686	-1133	-1160	27	20	550	-1120	-1155
Vopat B(Rupe)	1	S2 NW SW 21	1677	-1141	-1160	19	19			
Vopat D(LGS)	1	SW SW NE 21	1703	-1128	-1155	27	23	725	-1110	-1150
	2	SW SE NE 21	1717	-1123	-1146	23	19	530		0
	3	NE SE NE 21	1723	-1130	-1147	17	15	500		
	4	NE SW NE 21	1712	-1130	-1152	22	22	690	-1113	-1152
	5	SW NW NE 21	1715	-1137	-1158	21	20	690	-1120	0
	6	C S2 N2 NE 21	1724	-1130	-1150	20	19	690		
	7	NE NW NE 21	1739	-1131	-1151	20	14	328	-1124	-1146
	8	NE NE NE 21	1728	-1125	-1152	27	24	725	-1107	
	*9	SW NE NE 21	1735	-1125	-1150	25	21	525	-1113	-1142
	10	SE SE NE 21	1715	-1131	-1137	6	6	556	-1118	W
	*11	SE NE NE 21	1709	-1123	-1146	23	22	438		
	12	SE SW NE 21	1700	-1127	-1149	22	21	344	-1120	0
	13	NW SW NE 21	1700	-1134	-1153	19		419		-1150
Vopat G(LGS)	1	NW NW SW 22	1698	-1133	-1148	15	14	978	-1108	
	2	NW SE SW 22	1692					100		
Vopat B(Gorski)	1	E2 NE SW 22	1712	-1133	-1147	14		55		
Vopat E(Gorski)	*1	NW NW NW 22	1709	-1129	-1153	24	24	522	-1117	
	2	SW NW NW 22	1712	-1136	-1157	21	20	429	-1126	
	3	NE NW NW 22	1732	-1134	-1153	20	19	429	-1124	
Vopat(Rupe)	1	NW SW NW 22	1695				67	715		W
Vodraska(Borell)	1	NE SE NW 27	1667				27	72		
	2	NW NE SW 27	1660	-1125	-1140	15		20	-1136	W
	3	SW SW NW 27	1676					20		
	4	SE NE SW 27	1666	-1134	-1143	9		77	-1134	W
	5	E2 E2 W2 27	1666	-1132	-1139	7				
	6	SW SE NW 27	1668					42		

T14S R10W

Lease(Operator)	Well	Location, Section	KB elev.	Oolitic Zone			Porosity Thickness	ISIP (psi)	Potent. elev.	O/W Contact
				Top	Base	Thickness				
Kepka (LGS)	1	NE NE NE 28	1679	-1136	-1147	11		65	-1136	
Allan	1	SE SE SW 28	1640	-1177	-1193	16				
Soukup(Borell)	1	NE NE NW 29	1642	-1158	-1173	15	14	751	-1140	
	2	NW NE NW 29	1672				14	370		
	3	NW NW NW 29	1663				7			
	5	SE NE NW 29	1641					905		
	6T	NE NW NW 29	1674	-1176	-1190	14		272	-1171	W
Vopat(Borell)	1	NE NE SE 29	1629	-1211	-1215	4				
Vopat(LGS)	*1	N2 NW NE 29	1672	-1153	-1170	17	8			W
W. Kratky(LGS)	1	NW NE NE 30	1677				10	760		
	2	N2 NW NE 30	1669	-1171	-1182	11	9	727		
Miller(Ash)	1	ap NE NE NW 30	1647	-1178	-1194	16	16			W
	2	NW NW NW 30	1665					710		
	3	NE NE NW 30	1679	-1165	-1183	18	17	450	-1159	W
	4	NW NE NW 30	1682	-1178						

T14S R11W

Lease(Operator)	Well	Location, Section	KB elev.	Oolitic Zone			Porosity Thickness	ISIP (psi)	Potent. elev.	O/W Contact
				Top	Base	Thickness				
Eschbaugh(D & B)	*2	NW NW NW 13	1736	-1138	-1148	10		565	-1123	
	3	SW NW NW 13	1742					292		
	4	C E2 NW NW 13	1741					890		
	5	NW NE NW 13	1726					242		
	7	C W2 E2 NW 13	1720					102		
Frevert(D & B)	1	SW NW SE 13	1703					258		
	2	C W2 E2 SE 13	1694					56		
	2A	SE NE SW 13	1704					93		
Dlabal(LGS)	1	SE SE NE 23	1683	-1151	-1158	7	0	0		
Hines(Saline Bas.)	4	SE SE SW 23	1680	-1174	-1189	15	11	265	-1169	
Princ(LGS)	1	NE SE SE 23	1663	-1149	-1167	18	15	687	-1132	
	2	W2 E2 SE 23	1669	-1142	-1161	19	6	154	-1123	
	3	SE SE SE 23	1657	-1178	-1214	36	30	690	-1161	
	4	W2 SE SE 23	1672	-1172	-1193	21	12	630	-1157	
Small(LGS)	1	W2 W2 SE 23	1680	-1151	-1166	15	10	674	-1135	
	2	SE SW SE 23	1675	-1172	-1180			402	-1163	
J. Kratky(LGS)	1	NE SW SE 24	1679	-1134	-1147	13	11	635	-1119	
	2	C W2 SW SE 24	1681	-1141	-1161	20	18			
	3	SE SW SE 24	1676	-1172	-1185	13	10	577	-1158	
	4	C W2 SE SE 24	1669	-1152	-1166	14	6	360	-1144	-1157
	5	NW SE SE 24	1666				8	20		
Sebesta(Ash)	1	SE NE NE 24	1686	-1117	-1134	17		847	-1096	W
Sebesta(LGS)	1	NE NE SW 24	1681					71		
	2	E2 E2 SW 24	1681	-1127	-1148	21	19	694	-1110	
	3	C SE SW 24	1678	-1149	-1170	21	19	625	-1134	-1164
	4	NW SW SW 24	1661	-1150	-1165	15	15	610	-1135	-1159
	5	E2 SW SW 24	1680	-1156	-1177	21	20	780	-1137	

T14S R11W

Lease(Operator)	Well	Location, Section	KB elev.	Oolitic Zone			Porosity Thickness	ISIP (psi)	Potent. elev.	O/W Contact
				Top	Base	Thickness				
Sebesta (LGS)	6	W2 E2 SW 24	1679	-1124	-1148	24	24	640	-1109	
	7	C W2 SW 24	1674	-1130	-1148	18	18	590	-1116	-1141
	8	C N2 SW 24	1678	-1127	-1146	19	19	840	-1106	
	9	E2 NE SW 24	1680	-1128	-1146	18	18	600	-1114	
	*10	SW SW SW 24	1673	-1167	-1194	27	13	590	-1153	
Sebesta A(LGS)	*2	SE SW NW 24	1683	-1127	-1146	19	17	58	-1127	W
	3	NE SE NW 24	1686	-1130	-1151	21	20	736	-1117	W
Stoppel(LGS)	1	NE NE SE 24	1678	-1107	-1126	19	19	713	-1090	
	2	SW NE SE 24	1672	-1118	-1134	16	16	647	-1103	
	3	SW NW SE 24	1683	-1118	-1138	20	17	765	-1100	
	4	SE NW SE 24	1682	-1115	-1132	17	16	620	-1100	O
	5	SE NE SE 24	1674	-1121	-1142	21	14	474	-1110	-1132
Stoppel(Rupe)	1	C SE NE 24	1680	-1114	-1132	18	15	660	-1112	-1120
Beisel(Ash)	*1	NE NE NW 25	1685	-1191	-1205	14	2	771	-1174	W
	2	NW NW NW 25	1671	-1181	-1195	14	6	505	-1165	W
	3	NE NW NW 25	1680	-1171	-1186	16	13	486	-1160	
Beisel(Pro. Serv.)	1	ap NE NE NW 25	1679							
Kratky B(Ash)	*1	N2 NE NE 25	1673	-1169	-1181	12	4	302		W

APPENDIX IV

HIGH FLUID CAPACITY WELLS

¹based on last reported well test results in October 1973

²initial production pumping

Well	Location	Present ¹		IPP ²	
		BOPD	BWPD	BOPD	BWPD
K. Vopat 5(LGS)	E2 NE SE 16-14-10	40.0	182.0	109.0	88.0
K. Vopat 6(LGS)	NE SE SE 16-14-10	27.0	153.0	62.0	?
Cook 6(LGS)	SW SE SW 19-14-10	9.6	950.4	47.0	40.0
Borell B 2(LGS)	SE NW SW 20-14-10	85.7	85.7	90.0	0.0
Borell B-2 3(LGS)	SW NE SW 20-14-10	10.8	349.2	200.0	0.0
Borell B-2 6(LGS)	NE NE SW 20-14-10	123.1	82.0	150.0	20.0
Borell B-2 7(LGS)	W2 W2 SW 20-14-10	54.1	54.1	120.0	38.0
Borell B-2 9(LGS)	N2 N2 SW 20-14-10	36.0	204.0	120.0	0.0
Pekarek 1(LGS)	SE SW NE 20-14-10	265.6	398.4	64.0	3.0
Vopat D 5(LGS)	SW NW NE 21-14-10	114.0	279.0	197.0	0.0
Vopat D 9(LGS)	SW NE NE 21-14-10	52.8	427.2	40.0	25.0
Princ 3(LGS)	SE SE SE 23-14-11	138.0	414.0	106.0	16.0
Sebesta 10(LGS)	SW SW SW 24-14-11	42.0	649.0	165.0	0.0