APPLICATION OF CARBONATE ENVIRONMENTAL CONCEPTS TO SECONDARY RECOVERY PROJECTS

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ABSTRACT

Carbonate environmental concepts have been applied to a typical Permian dolomite reservoir. The Monahans Clearfork field, *Ward and Winkler Counties, Texas, was selected because the initial development was completed and the secondary recovery project was installed prior to the development of the carbonate environmental concept as an operational tool. The problem in the Monahans Clearfork Secondary Recovery Project is twofold. First, oil response to water injection has been less than originally anticipated. Second, as a result of early evaluation techniques, some productive zones were either cased off or not penetrated.*

The Clearfork reservoir was divided into five zones. The environmental dolomite types within each of the five zones ranged from supratidal to marine both vertically and laterally. Several marine dolomite types were found to be productive while the intertidal and supratidal were nonproductive in most cases. *When leached, however, the supratidal becomes an effective but limited reservoir. Net pay isopachs for each zone were constructed and serve to define field limits, pay quality, and continuity. The isopachs indicate the anticipated waterflood performance of each zone, the distribution of suspected thief zones, and wells and/or areas with additional hydrocarbon potential. A drilling and recompletion program currently underway should complete the evaluation of the Monahans Clearfork reservoir. If success continues, the program should result in a significant improvement in supplemental recovery performance as well as an increase in field reserves.*

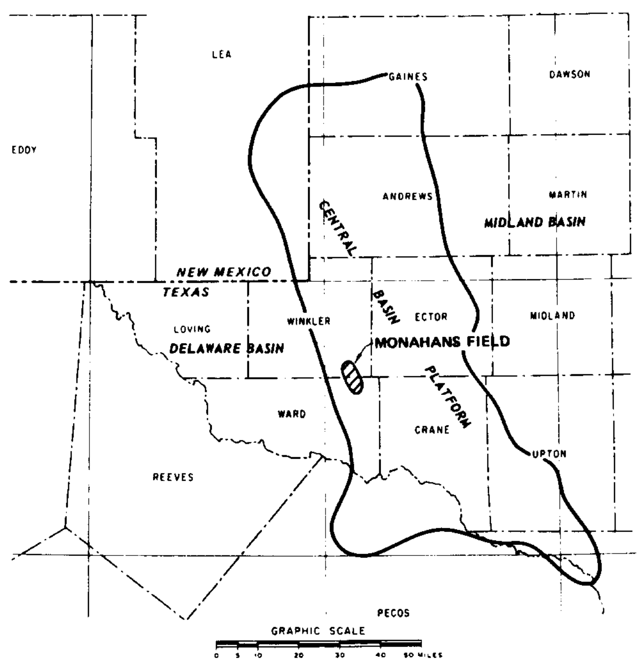
INTRODUCTION

The purpose of this paper is to discuss the advantages of applying carbonate environmental concepts to the re-evaluation of existing secondary recovery projects. The environmental approach results in a more accurate representation of reservoir distribution and quality. This provides a basis for plans to optimize the secondary recovery project and indicates potential field extensions and re-completions.

The Monahans Clearfork field was selected because the initial development was completed and the secondary recovery project was installed prior to the development of the carbonate environmental concept as an operational tool. A carbonate environmental study of the field was made, which resulted in several opportunities for increased and/or additional production.

FIELD HISTORY

The Monahans Clearfork field, Ward and Winkler Counties, Texas, is located on the west side of the Central Basin Platform as shown in Figure



WINKLER & WARD COUNTIES, TEXAS
Index Map Showing Location of Monahans Field

FIGURE 1—MONAHANS FIELD

No. 1. The field is 100% Shell and was discovered in August 1945 in an interval between the approximate depths of 4,700 and 5,100 ft. The Clearfork dolomite reservoir has an average net pay thickness of approximately 75 ft over a field area of 2,720 acres. Average porosity and permeability are 10% and 2.0 md, respectively. The Monahans Clearfork

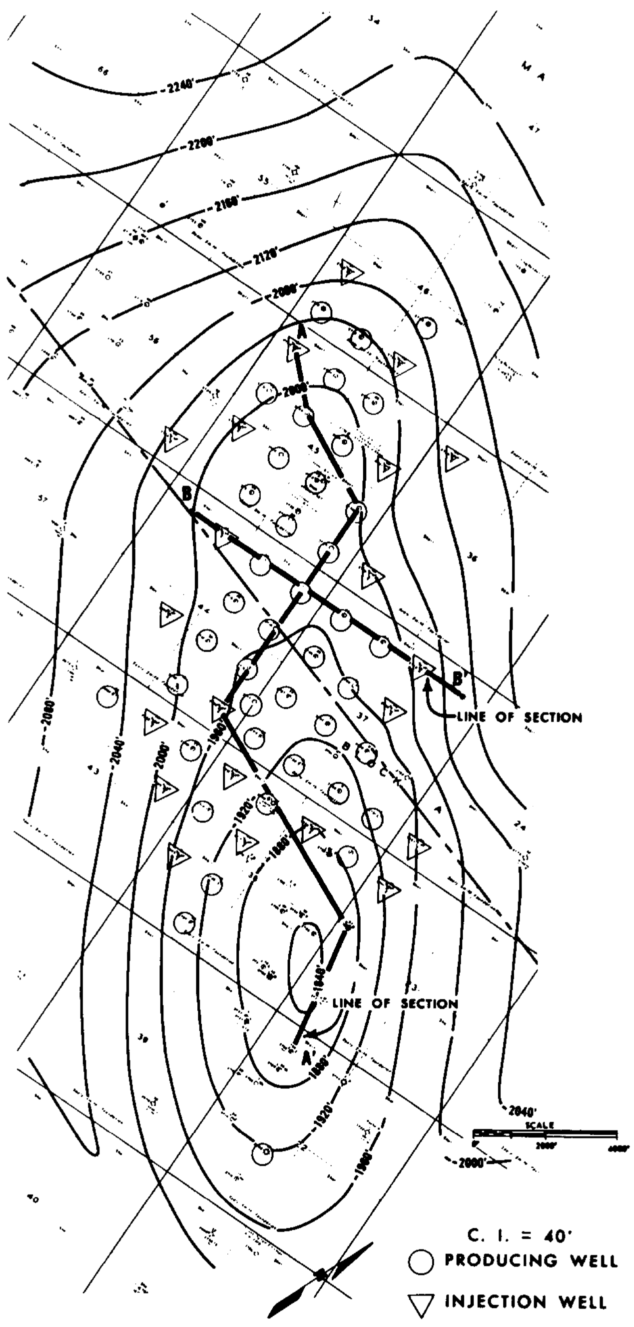


FIGURE 2—MONAHANS FIELD G-3 SUPRATIDAL CONTOURS

structure is a northwest-southeast doubly plunging anticline as shown in Figure No. 2. The reservoir was developed on 40-acre spacing until October 1959 when a pilot waterflood was initiated. In September 1962 the entire Monahans Clearfork field was converted to a supplemental recovery project.

The Clearfork supplemental recovery project is a peripheral waterflood with water injection wells located at irregular peripheral positions as shown in Figure No. 2. Wells without symbols on Figure No. 2 are either dry holes or wells not completed in the Clearfork. The original plan was to inject water at the lower structural positions under the assumption that, with good lateral continuity in the Clearfork, a unified flood front would be formed which would resemble natural water encroachment. From September 1962 to July 1969, 23,700,000 barrels of water were injected while the field produced 1,033,000 barrels of oil and 1,215,000 barrels of water. The problem in the Monahans Clearfork secondary recovery project is twofold. First, oil response to water injection has been less than originally anticipated with some 20,000,000 barrels of water that cannot be accounted for. Secondly, as a result of early evaluation techniques, some productive zones were either cased off or not penetrated.

GEOLOGY

The gross productive interval of the Monahans Clearfork (Permian, Leonard) averages about 400 ft in thickness and consists of four separate gross oil-bearing dolomite zones. The environmental dolomite types within each zone vary both vertically and laterally. The environment of deposition and the factors limiting the productive quality were defined by a study of slabs and thin-sections from 10 cored wells. The Dunham (1962) classification of carbonate rocks according to depositional texture is used exclusively in this study. The environmental types range from tidal flat to marine dolomites, and their characteristics are tabulated in Table 1.

The cross section shown in Figure No. 3 illustrates both the vertical and lateral variation in the environmental dolomite types. Only core data are used in this cross section. The most favorable reservoir qualities are confined to current deposited (non-muddy) restricted and open marine dolomites while the intertidal and supratidal dolomites contribute

ENVIRONMENTAL TYPE	DESCRIPTIVE CLASSIFICATION	TEXTURAL CHARACTERISTICS	POROSITY AVERAGE (PERCENT)	PERMEABILITY RANGE (MILLIDARCYS)
SUPRATIDAL	SLIGHTLY INTRACLASTIC MUDSTONE	Fine mud matrix with scattered intraclasts. Desiccation features and irregular laminations. Trace of discontinuous fractures. Usually unfossiliferous. Abundance of anhydrite.	10	0.1-1.0
	LEACHED SLIGHTLY INTRACLASTIC MUDSTONE	As above but anhydrite is highly leached.	15	0.1-100.0
INTERTIDAL	SLIGHTLY PELLETAL MUDSTONE	Fine mud matrix with few well-sorted, fine sand size pellets. Churned and mottled structures. Discontinuous fractures and stylolites abundant. Trace of small molluscs, ostracods, and forams.	5	0.1-1.0
RESTRICTED MARINE	INTRACLASTIC PELLETAL MUDSTONE	Fine mud matrix with scattered fine sand size pellets and poorly-sorted intraclasts. Churned and burrowed structures abundant. Trace of medium-size molluscs, ostracods, forams, and algae. Abundant nodular anhydrite.	6	0.1-1.0
	INTRACLASTIC PELLETAL WACKESTONE TO PACKSTONE	Abundance of well-sorted, fine sand size pellets and poorly-sorted intraclasts. Current oriented and/or current laminated. Very few medium-size molluscs, ostracods, forams and algae.	9	1.0-5.0
OPEN MARINE	SLIGHTLY FOSSILIFEROUS INTRACLASTIC WACKESTONE	Mud matrix with only a trace of pellets. Distinct increase in poorly sorted fossils and intraclasts. Some burrowing present. Fossils are larger and include traces of crinoids and echinoids. Abundance of nodular anhydrite.	5	0.1-1.0
	FOSSILIFEROUS INTRACLASTIC GRAINSTONE	Poorly sorted fossils and intraclasts. Current oriented and/or current laminated. Abundant fossils such as molluscs, pelecypods, crinoids, echinoids, bryozoa, ostracods, forams and algae. Porosity is destroyed locally by pore filling anhydrite.	10	0.5-100.0

TABLE 1—ENVIRONMENTAL DOLOMITE TYPES IN MONAHANS CLEARFORK FIELD, TEXAS

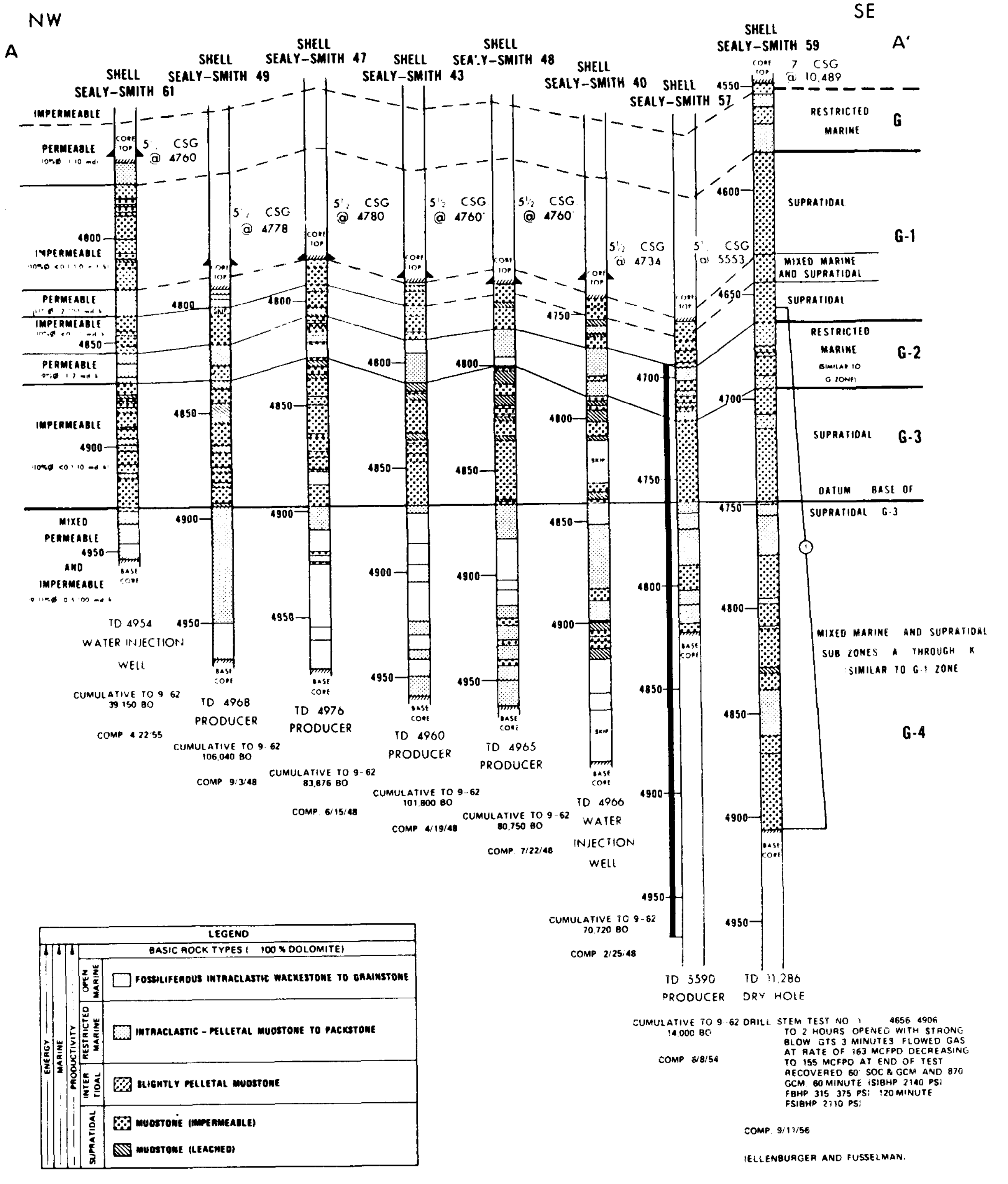


FIGURE 3—CORE CROSS SECTION A-A' MONAHANS CLEARFORK (DATUM-BASE OF SUPRATIDAL G-3 HORIZON)

hydrocarbons only locally. Where the supratidal dolomites have been leached, they can develop permeabilities of 10 to 100 times that of the current deposited marine dolomites. Several points illustrated by the cross-section are:

1. The entire vertical section in the Clearfork is characterized by cyclic marine to supratidal deposition.
2. The Clearfork changes laterally from dominantly impermeable tidal flat dolomites in the southeast to dominantly permeable shallow marine dolomites in the northwest.
3. The Clearfork reservoir can be divided into five separate zones based on the environmental interpretation, i.e., G, G-1, G-2, G-3 and G-4.
4. Productive current deposited restricted marine dolomites are found primarily in zones G and G-2.
5. Productive mixed marine (restricted and open) and nonproductive supratidal dolomites are found in zones G-1 and G-4. Supratidal dolomites are permeable locally.
6. The G-3 zone primarily consists of supratidal dolomite with discontinuous stringers of leached permeability.

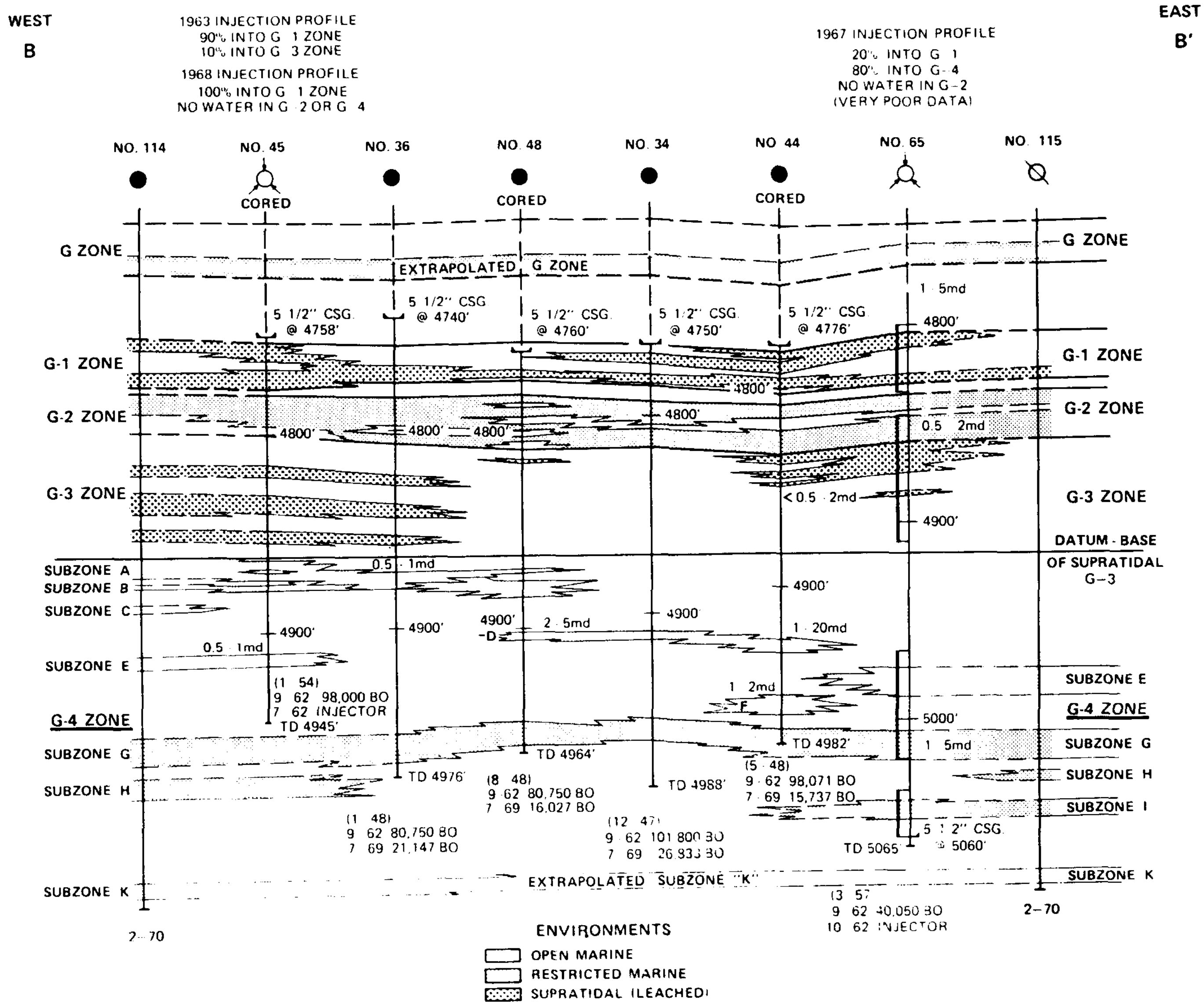


FIGURE 4—MONAHANS CLEARFORK WELL CROSS SECTION B-B'

7. Most of the highly permeable current deposited marine dolomites in the G-4 zone are restricted to wells located in the northcentral portion of the field.
8. The casing in all but one well is set below and not perforated in the G-zone which is thought to be productive.
9. The G-4 zone is not completely penetrated in the northwestern portion of the field.

Extrapolating the environmental types and their reservoir qualities to uncored wells proved to be difficult. Electrical surveys were utilized to obtain the gross thickness of each zone but could not be used to define net pay. Since the average porosity of the productive marine dolomites is approximately equal to the average porosity of the nonproductive supratidal dolomites, these two environmental types could not be differentiated with porosity tools. Therefore, in order to obtain net pay, only data indicative of permeability could be effectively utilized. These consisted of drillstem tests, tracer and temperature surveys, spinner surveys, production tests, etc. After assimilating all permeability data indicative of the net productive intervals within the gross zones defined by the electric logs, cross sections and maps showing the distribution of net pay were constructed.

A typical net pay cross section is shown in Figure No. 4. Notice that the G-4 zone has been further divided into subzones ("A" through "K") due to its extreme vertical and lateral discontinuity. Two possible undrained flank locations are also shown on the cross section which have been drilled. Net pay by zone and subzone was obtained from the cross sections, and 15 net pay isopachs were constructed. The net pay isopachs show the distribution and quality of pay in the four gross dolomite zones and the G-4 subzones. From each of the zonal isopachs it is possible to determine:

1. Areas or zones where waterflood response should be either positive or negative, and why.
2. The distribution of suspected thief zones.
3. Wells which have cased off net pay.
4. Wells which are not deep enough to have encountered all pay zones.
5. Undrained areas where new wells can be drilled.

Seven typical net pay isopachs are presented in this report. The G zone shown in Figure No. 5 consists of current deposited restricted marine dolomite; and, although net pay data are limited, the dolomite appears to be of similar productive quality throughout the field. Wells without legend symbols are open to this zone. The G zone may be a thief zone in the northwestern portion of the field where it is open but could be hydrocarbon-bearing in the central and southeastern portions of the field where it is cased off. *The G-1 zone* shown in Figure No. 6 is composed of both mixed marine (restricted and open) and supratidal dolomite types. Permeability

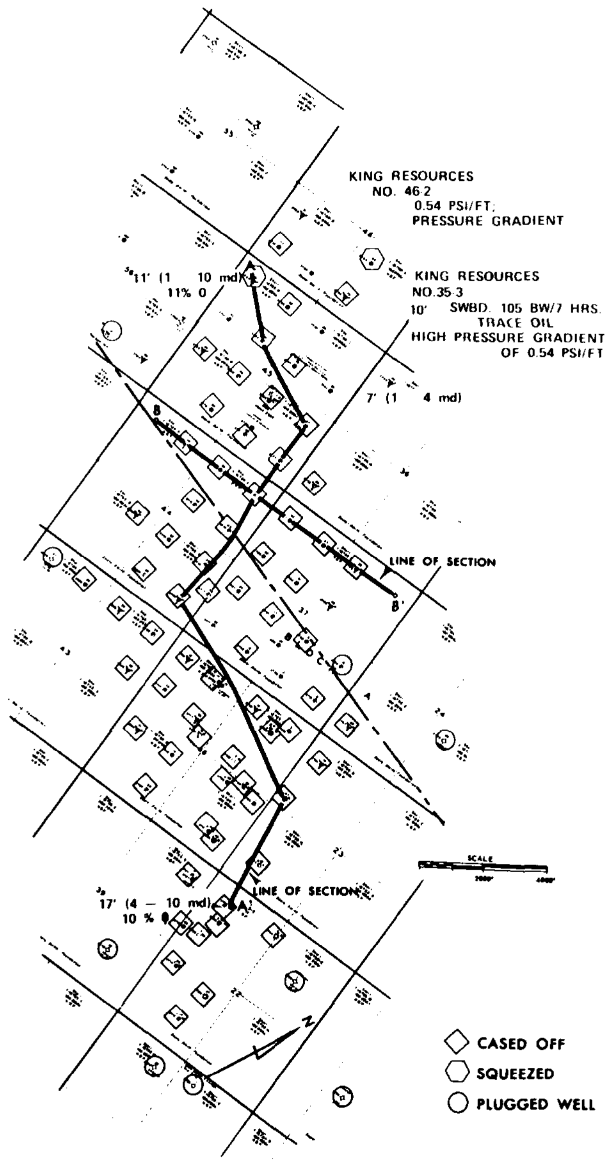


FIGURE 5—MONAHANS CLEARFORK G-ZONE

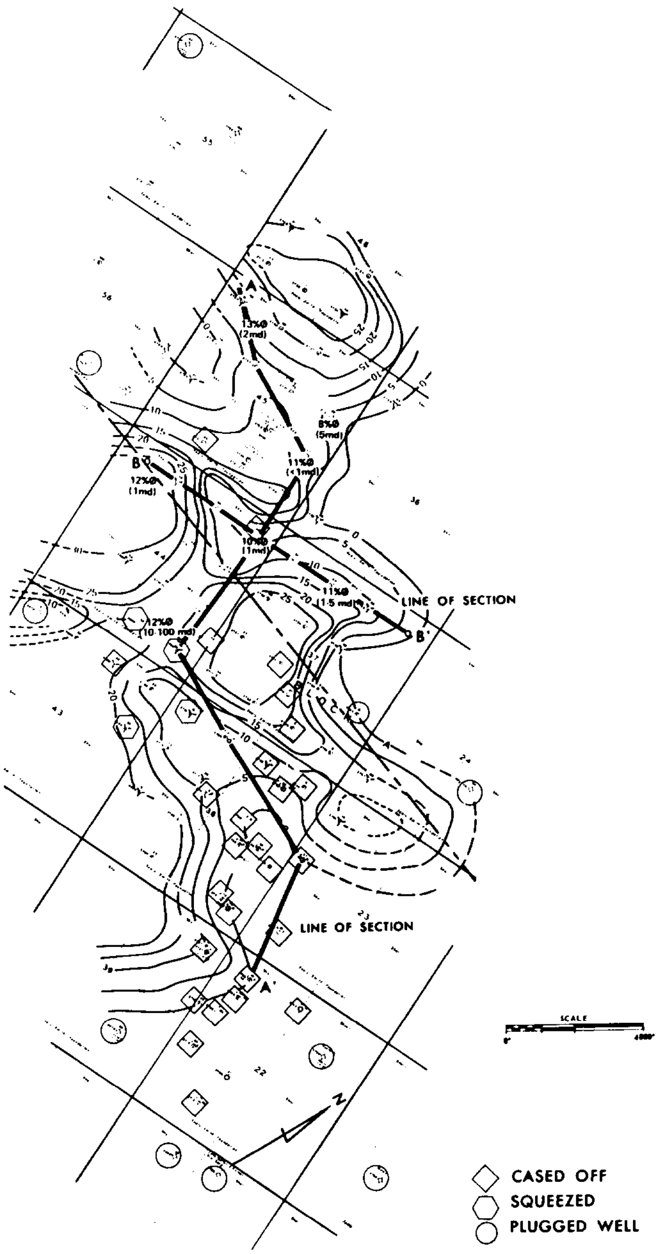


FIGURE 6—MONAHANS CLEARFORK G-1 ZONE NET PAY

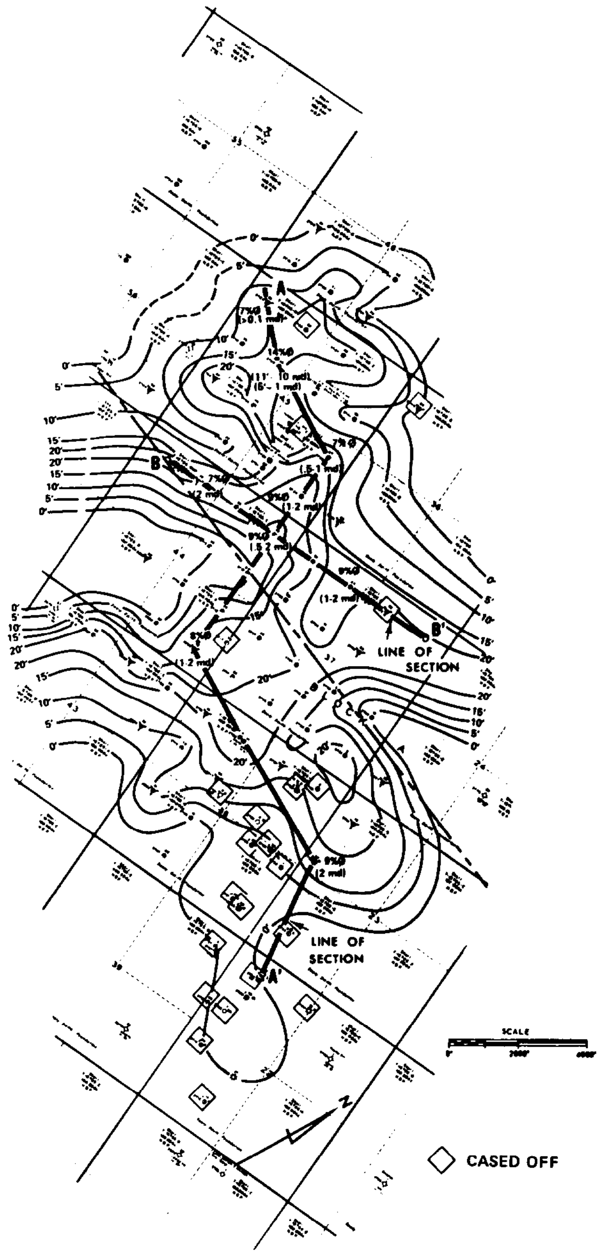


FIGURE 7—MONAHANS CLEARFORK G-2 ZONE NET PAY

in the current deposited mixed marine is usually well developed throughout the field, while the supratidal is only locally permeable. Again, wells without legend symbols are open to this zone. The G-1 zone is possibly a thief zone in the field. The results of the 1959 pilot waterflood indicated that 46% of the injected water was entering the G-1 zone and that water breakthrough in adjacent wells could occur in less than 30 days. Additional hydrocarbons in the G-1 zone may exist on the western flank of the field.

The *G-2 zone* shown in Figure No. 7 like the G zone consists primarily of current deposited restricted marine dolomite. The zone is continuous throughout the field and its reservoir quality is relatively consistent. The G-2 zone is open in most of the Clearfork wells and although productive, is not being effectively flooded. Overlying thief zones prevent the water from effectively entering the lower permeable G-2 zone. Undrained flank locations may exist to the northeast and southwest of the field. The

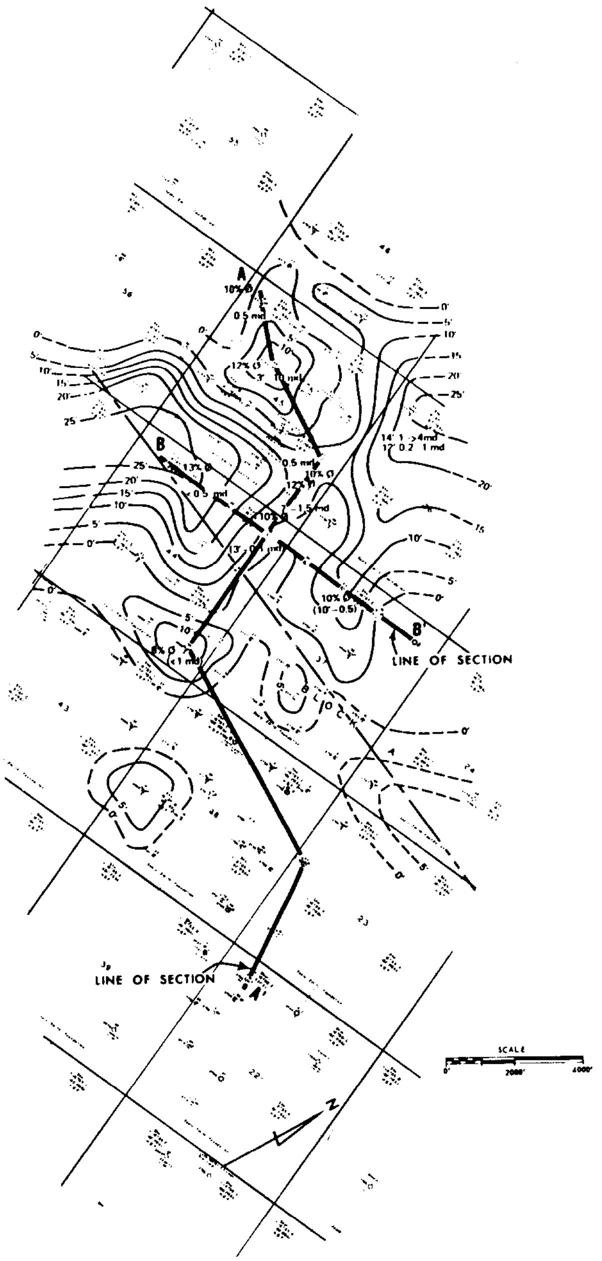


FIGURE 8—MONAHANS CLEARFORK G-3 ZONE NET PAY

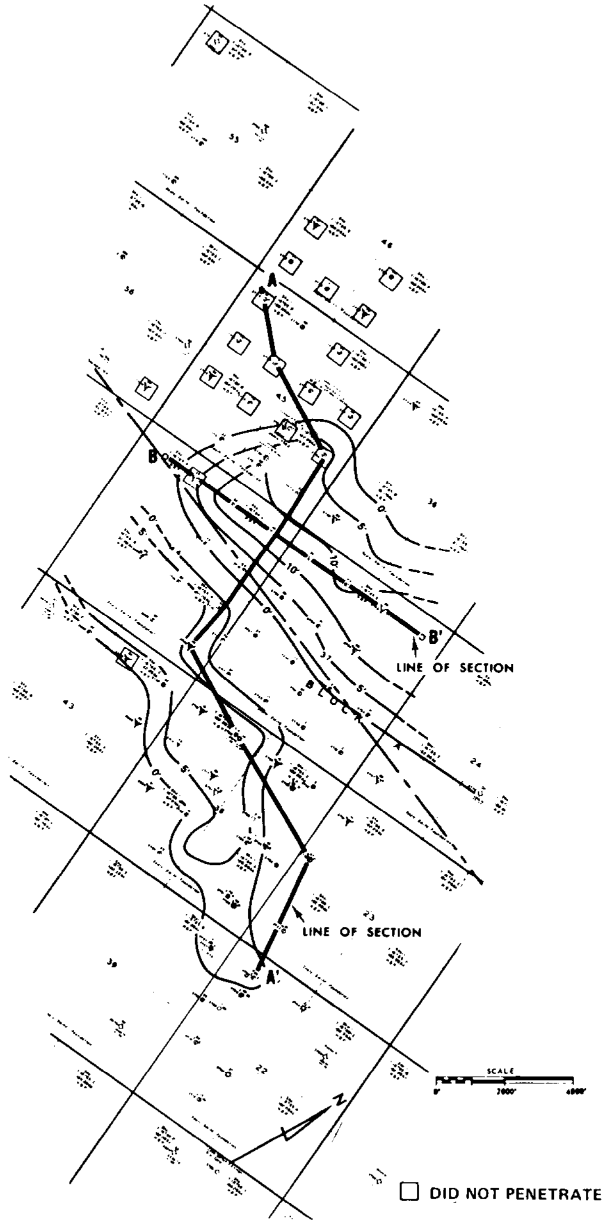


FIGURE 9—MONAHANS CLEARFORK G-4 SUBZONE "G" NET PAY

G-3 zone shown in Figure No. 8 is characteristically supratidal and is locally permeable. The local permeability is due to erratic leaching of anhydrite and dolomite. The G-3 zone is open in most of the wells and like the G-1 zone may have undrained locations on the north and southwest flanks of the field.

The *G-4 zone* is divided into 11 subzones denoted "A" through "K" (see Figure No. 4). The greatest areal distribution of continuous permeability is found in the lower G-4 subzones while the permeability in the upper subzones is more localized. Permeability development in the G-4 subzones appears to be oriented in a northeast to southwest direction across the central portion of the field perpendicular to the anticlinal strike direction. The G-4 subzones in the southeastern portion of the field are predominantly supratidal as are all other zones above the G-4 in this portion of the field. Only the net pay isopachs from the "G," "H," and "I"

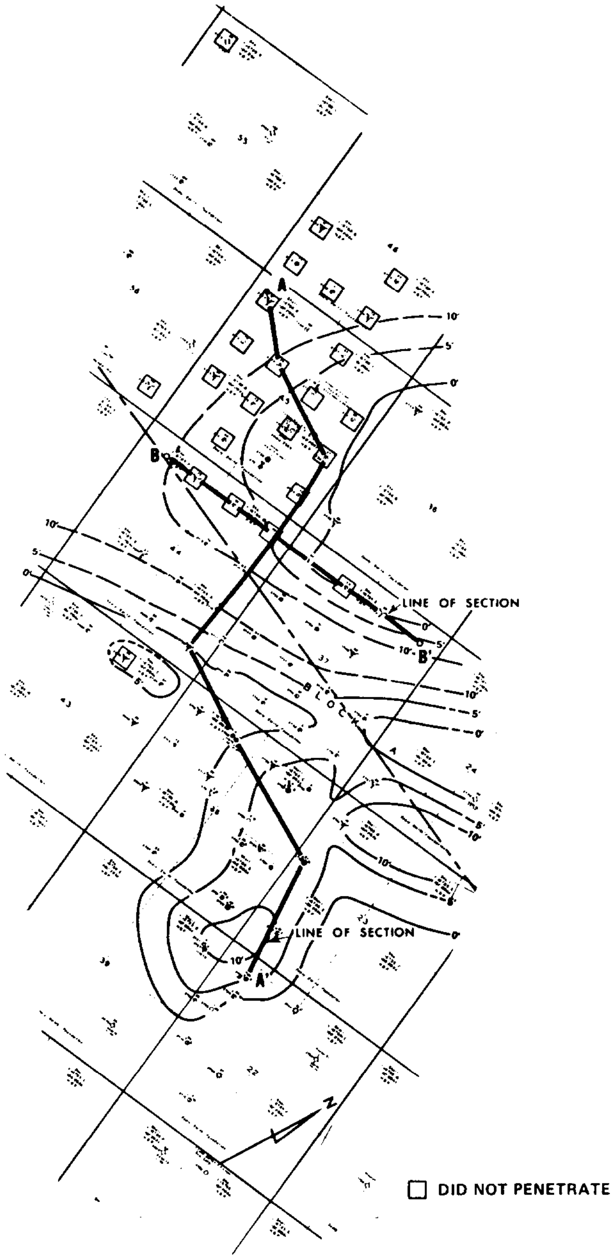


FIGURE 10 MONAHANS CLEARFORK G-4 SUBZONE "H" NET PAY

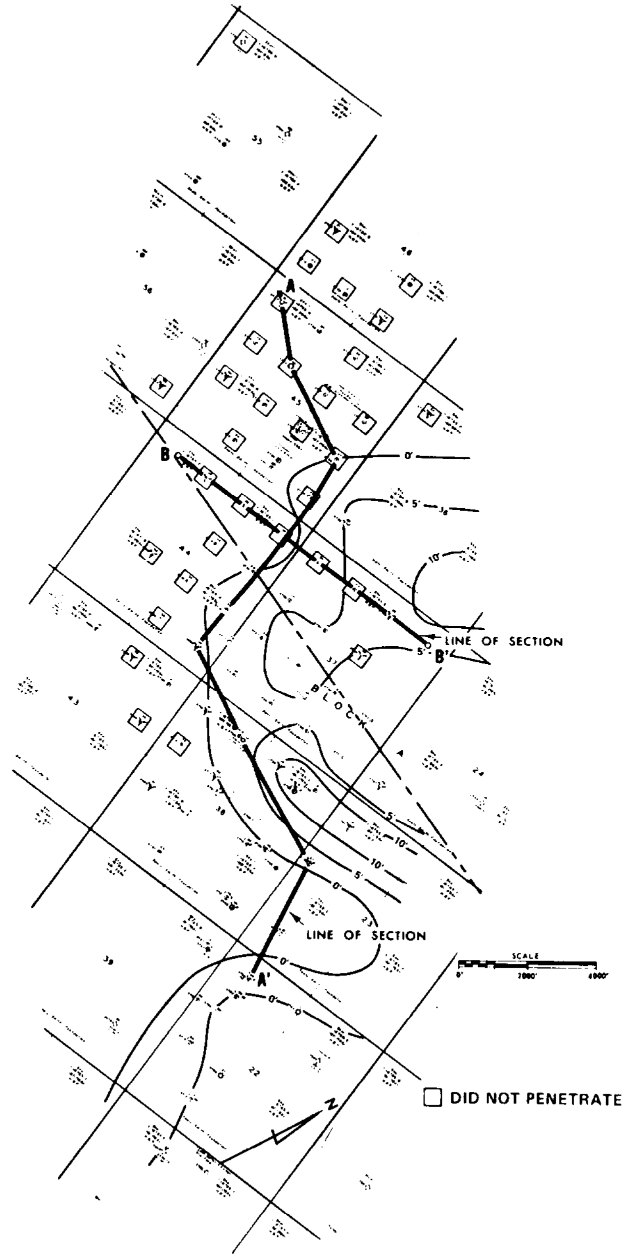


FIGURE 11—MONAHANS CLEARFORK G-4 SUBZONE "I" NET PAY

subzones are illustrated as examples of the permeability distribution and orientation in the G-4 zone. The "G," "H," and "I" subzones are all composed of current deposited restricted marine dolomite. The *"G" subzone* shown in Figure No. 9 has permeability developed within two separate channels crossing the central portion of the Clearfork structure in an east-west direction. Each permeable channel grades laterally into impermeable marine and/or supratidal dolomite. The "G" subzone has not been penetrated by all the wells within the channel area as seen by the figure legend. The *"H" subzone* shown in Figure No. 10 consists of current deposited restricted marine dolomite and is more widely distributed laterally than the "G" subzone. A channel is present in the central portion of the field, but the entire northern flank of the structure appears to be permeable as well. Some wells have not penetrated the productive "H" subzone as seen in Figure No. 10. The *"I" subzone* as shown in Figure No. 11 is also a current deposited restricted marine dolomite, and its areal distribution is relatively uniform along the northern flank with no apparent channels crossing the structure. There are several wells on the northern flank of the structure which have not penetrated the "I" subzone.

Two problems are apparent from the G-4 subzone isopachs. First, the net pay distribution and orientation within each of the G-4 subzones will require a different injection pattern from that of a uniformly distributed pay zone such as the G-2 zone. Secondly, the subzones cannot be successfully waterflooded until the wells that do not penetrate the entire G-4 zone have been deepened and all subzones evaluated.

SUMMARY

The application of carbonate environmental concepts to a typical West Texas Permian dolomite reservoir is presented in this paper. The benefit of such an environmental study to a company's economic interests is based upon two general premises: (1) that the environmental approach gives a better picture of the quality and continuity of individual pay zones for supplemental recovery, and (2) that this approach identifies specific wells and/or areas where untapped pay zones exist.

In the specific case of the Monahans Clearfork field, the reservoir was divided into five zones (G through G-4), and the G-4 zone was further divided into 11 subzones ("A" through "K"). The environmental dolomite types within the five zones ranged from supratidal to marine both vertically and laterally. The current deposited restricted and open marine dolomite types were found to be productive while the intertidal and supratidal were non-productive in most cases. When leached, however, the supratidal dolomite is an effective reservoir although limited in lateral distribution. Environmental dolomite types and consequently productivity vary both vertically and laterally in the Monahans Clearfork reservoir. Net pay isopachs for each zone and subzone were constructed and served to define the limits, quality, and continuity of the reservoir. The isopachs indicate the anticipated

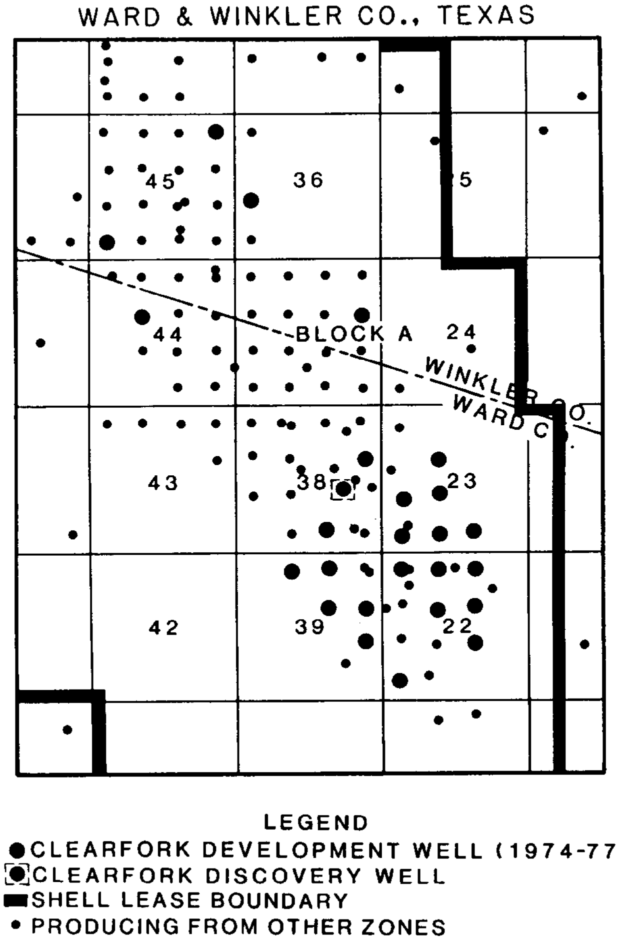


FIGURE 12—DRILLING PROGRAM, MONAHANS FIELD

waterflood performance of each zone as well as the distribution of suspected thief zones. The isopachs are also used to locate wells and/or areas with untapped hydrocarbons. Productive zones behind casing, zones not penetrated, and potential hydrocarbon accumulations on the flanks of the structure have been defined by the isopachs.

From 1970 to 1974 several Clearfork wells were recompleted with varying degrees of success. In mid-1974 a recompletion in the southeast portion of the field encountered near virgin reservoir pressures, and subsequent production history indicated reserves on the order of 80 to 100,000 barrels. A primary development drilling program was then initiated, which is continuing. To date some 20 wells have been drilled—all successes—with some 80 to 100,000 barrels per well estimated ultimate recoveries (see Figure No. 12).

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ACKNOWLEDGMENTS

The author thanks Shell Oil Co. for permission to publish this paper. Thanks are also due to P. J. Conrad and J. L. Williams of Shell Oil Co. for their contributions to the continued development of the Clearfork reservoir in West Texas.