Petroleum Open File Report POF 7-86

Petroleum Geology of the MC-3 Member, Mission Canyon Formation, Pierson Area, Southwestern Manitoba

By Muzaffar Husain and S.P. Halabura

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PREFACE

This study was undertaken in the fall of 1983 by S.P. Halabura, but was not completed when he left the Department in July 1984. Since that time additional drilling has taken place in the Pierson Area. M. Husain has revised and redone the maps, illustrations, and cross-sections and has compiled this report utilizing all available data.

This report includes all off confidential wells drilled and completed by December 31, 1986.

INTRODUCTION

The MC-3 Member of the Mission Canyon Formation represents a portion of one of the upper carbonate-evaporite cycles in the Mississippian stratigraphic sequence of southwest Manitoba. The lithologies are typical of sediments deposited in a shallow-water, moderate- to high-energy, carbonate-dominated inner shelf environment. The MC-3 Member and equivalent strata (Fig. 1) can be correlated across the northeast portion of the Williston Basin into adjoining regions of southeast Saskatchewan and north-central North Dakota.

The MC-3 Member is the principal producing zone within the Pierson study area (Fig. 2). Attempts to obtain additional ("leaked") oil from sandstones and siltstones of the overlying Jurassic Lower Amaranth "Red Beds" have also been made; however, these will not be discussed in this report, as the Lower Amaranth petroleum geology has been described by Barchyn (1982). The Pierson area has held the interest of petroleum geologists since the 1954 discovery of the first pool (MC-3a C Pool). The Pierson Field presently consists of four main Mission Canyon pools and one Lower Amaranth Pool; the South Pierson area is made up of four Mission Canyon pools and two Lower Amaranth pools.

Purpose

During the past 32 years, exploration efforts in the Pierson area have succeeded in delineating numerous pools. The picture that has emerged from drilling at Pierson is of a complex sedimentary sequence, with oil accumulations controlled by a number of different factors. The MC-3 Member and equivalent strata have been studied by numerous workers in southeast Saskatchewan and north-central North Dakota; (Fuzesy, 1960, 1966; Gerhard, 1978; Sando, 1978; Crabtree, 1982; Kent, 1979, 1983); however, detailed studies of the hydrocarbon potential of the MC-3 Member in southwest Manitoba are not available.

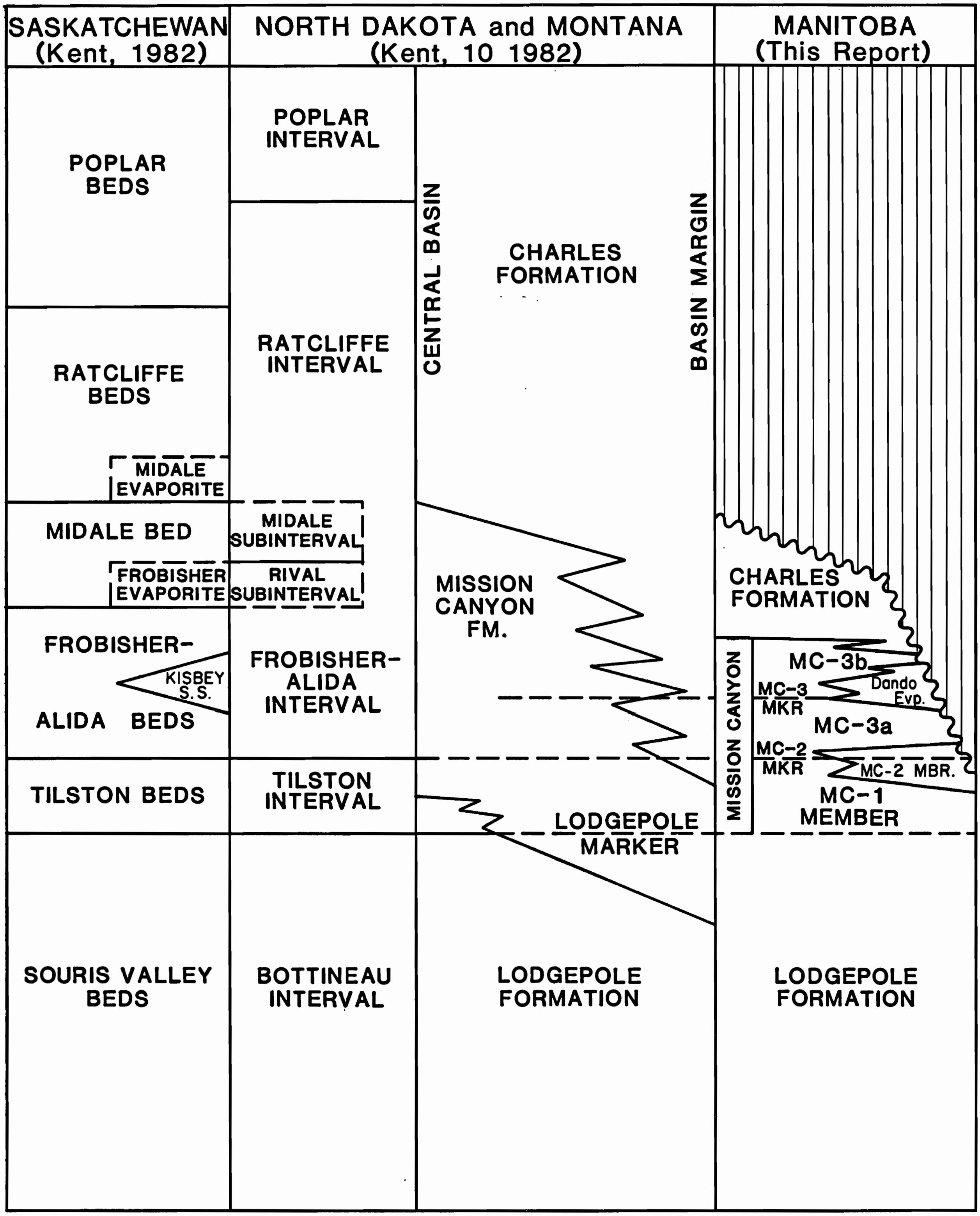


Figure 1: Regional Mississippian Stratigraphy

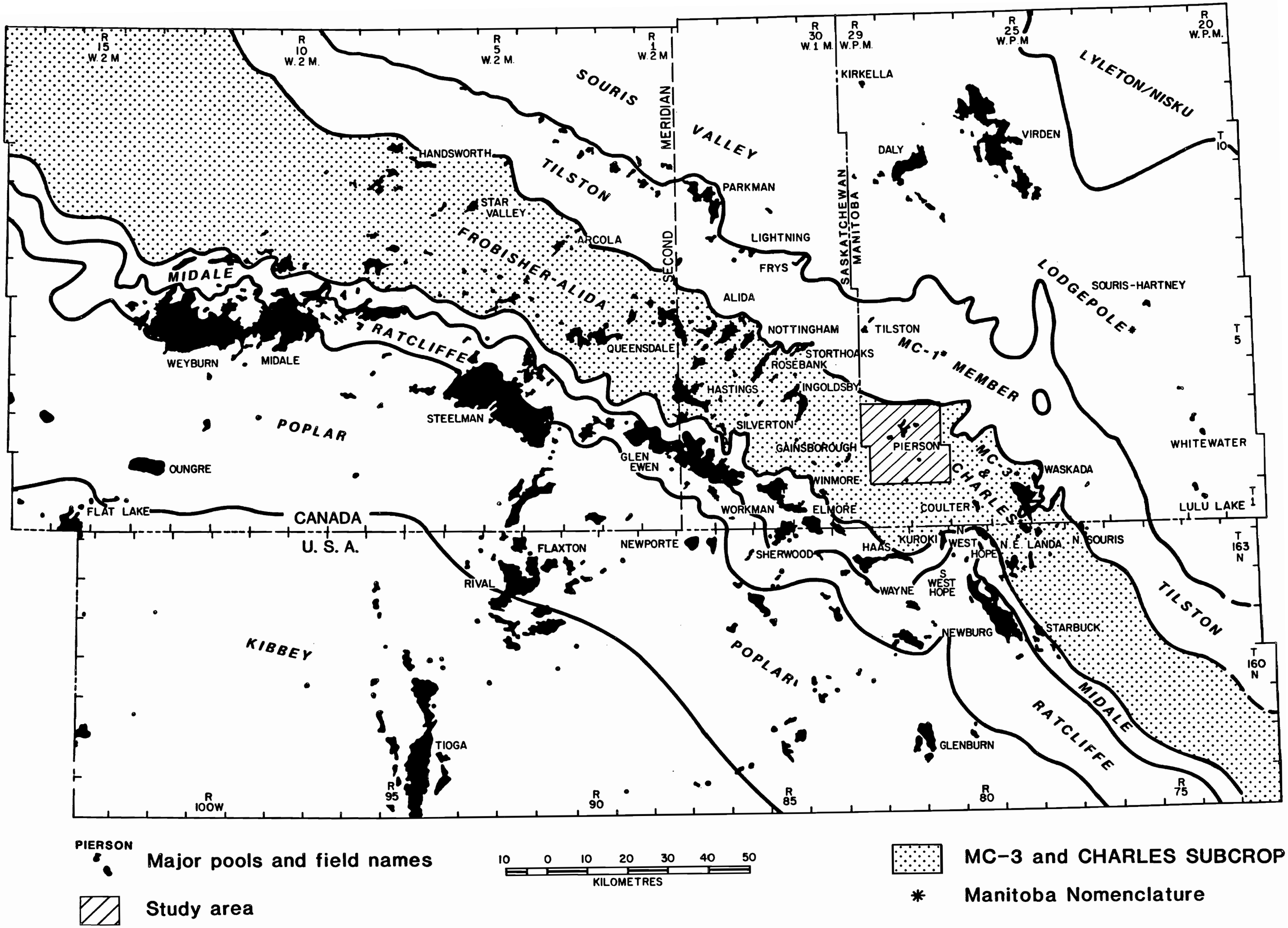


Figure 2: Area of Study and Mississippian Subcrop Belts

The purpose of this study is to outline the detailed stratigraphy, lithofacies, and factors controlling oil accumulation in the MC-3 Member of the Pierson area, and to evaluate the hydrocarbon potential of the MC-3 subcrop belt (Fig. 2). This study will attempt to:

- present a synopsis of past exploration activity in the area;
- describe regional stratigraphic relationships of the MC-3 Member in southwest Manitoba and adjoining areas;
- describe the lithofacies by means of core descriptions, log responses, and stratigraphic sections;
- present relevant data in the form of various structure and isopach maps and cross-sections; and
- propose a depositional model to aid in future exploration.

This report attempts to provide industry with a synthesis of data based on modern concepts of carbonate deposition. It is hoped that this study, will provide explorationists with new ideas concerning potential hydrocarbon traps within the MC-3 Member and thus aid in future exploration.

Study Area

The MC-3 Member is present over only a small portion of southwest Manitoba, an area of approximately 12 townships (Fig. 2). The Pierson study area, includes Townships 2 and 3, Ranges 28 and 29 WPM. Significant production from the MC-3 Member occurs only at Pierson and Waskada Fields (Townships 1 and 2, Ranges 25 and 26 WPM); limited production is also obtained from scattered one or two well areas. Study of the Mission Canyon Formation in the Waskada Field (Rodgers, PR 1-85) suggests that hydrocarbon entrapment in the Field is closely controlled by complex structure resulting from multiple episodes of salt solution and collapse; however, at Pierson, well-defined structure is lacking, and hydrocarbon entrapment is due mainly to variations in lithofacies. Abundant core and log data within the study area permit the reconstruction of paleoenvironments. The Pierson area is thus well suited for the development of regional exploration models which could be applied in other portions of the MC-3 subcrop belt of southwest Manitoba.

Regional Stratigraphic Setting

Figures 3 and 4 illustrate the regional stratigraphic terminology in current usage in southwest Manitoba and southeast Saskatchewan. The correlation of the Manitoba section with adjoining areas has been the focus of considerable debate, leading to the development of several sets of terminology utilizing different types of stratigraphic units.

The first recognition of Mississippian rocks in the subsurface of Manitoba was by Kerr (1949). Kerr assigned 275 m of rocks overlying Devonian strata in the 5-14-1-28 WPM well to the Mississippian Madison Formation. Further subdivision of the strata followed the terminology developed in the central and northeastern portions of the Williston Basin and from various outcrop type sections (McCabe 1959). This led to a four-fold division of the Mississippian; in ascending order the units are Bakken, Lodgepole, Mission Canyon, and Charles formations. This subdivision is based (by definition) on lithology. The Mission Canyon Formation was further subdivided by Thomas (1954) into five members, in ascending order, the MC-1, MC-2, MC-3, MC-4 and MC-5.

As exploration progressed and further studies were undertaken, it became apparent that Mississippian strata consisted of a complex cyclical sequence deposited as a series of transgressive-regressive couplets. The resultant lateral facies changes made application of the classical Formation/Member terminology difficult.

The cyclical and overall, regressive nature of the complex carbonate-evaporite sequence, coupled with the general basinward facies change from bioclastic and granular carbonates ("Mission Canyon" facies) to evaporitic carbonates and evaporites ("Charles" facies) has resulted in formation boundaries that are markedly diachronous (Figs. 3 and 4). This pronounced diachroneity led the Saskatchewan Geological Society to propose in 1956 a new, marker-defined stratigraphic succession of "Beds", each representing a single depositional cycle. As such, the "Tilston Beds" of Saskatchewan are approximately correlative with the combined MC-1 and MC-2 members of Thomas (1954), as defined by the marker at the top of the Lodgepole

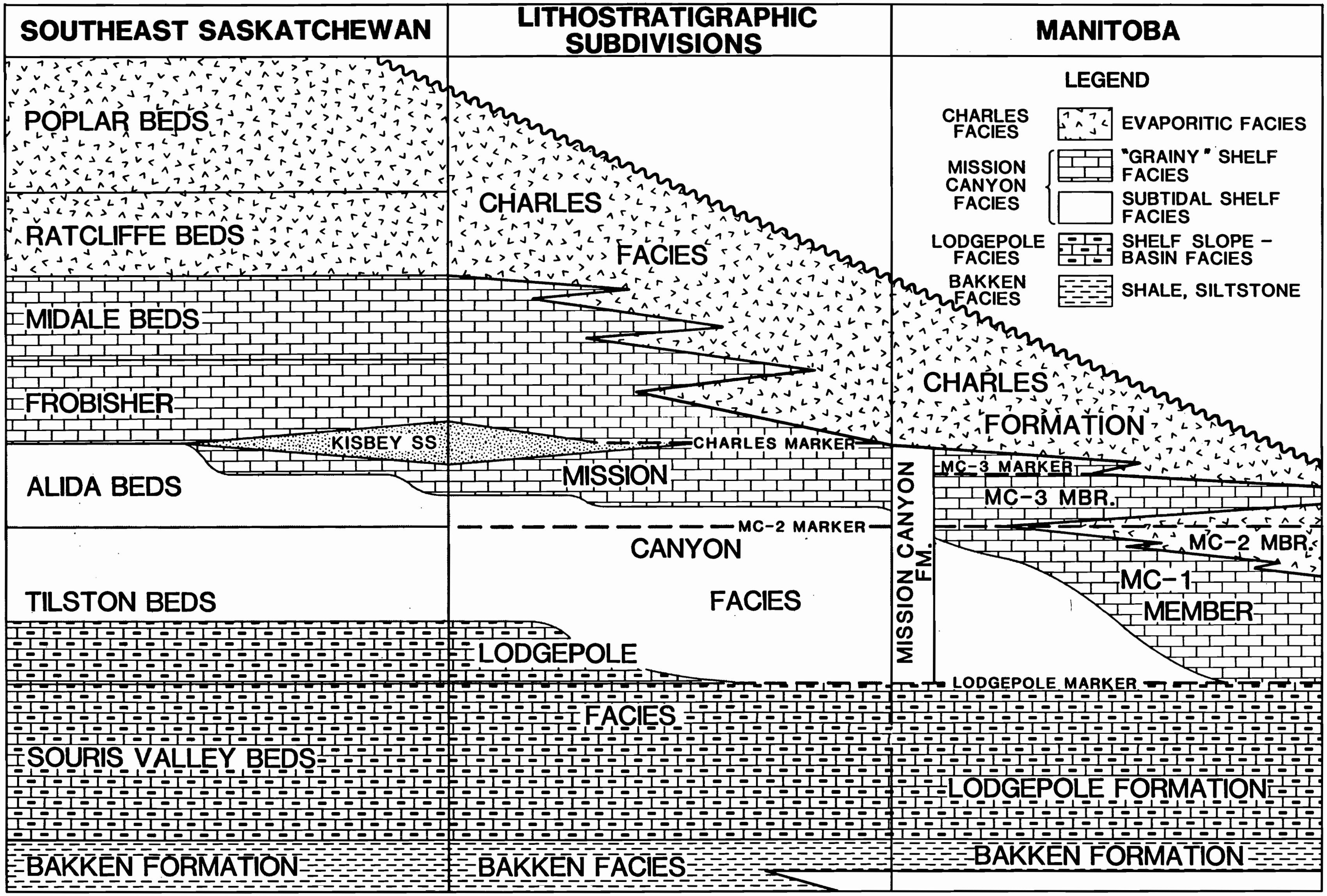


Figure 3: Lithostratigraphic Subdivision of Mississippian Rocks in Manitoba and Saskatchewan

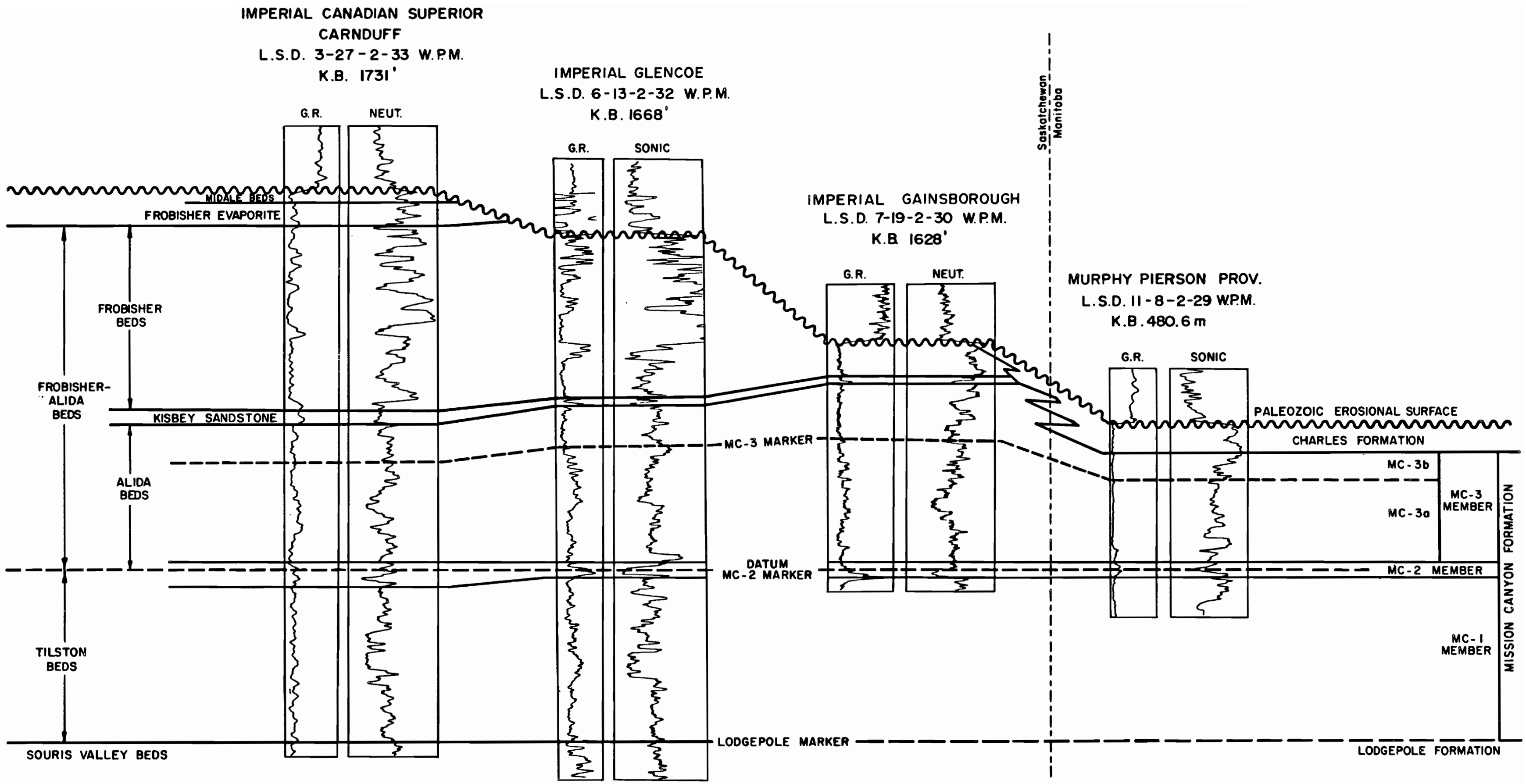


Figure 4: Regional Cross-Section, Manitoba to Saskatchewan

and the "MC-2 marker". The MC-3, 4, and 5 members are approximately equivalent to the middle to lower portions of the "Frobisher-Alida Beds" of Saskatchewan. Thus, two systems of nomenclature, one based on gross lithological character (the "Formation"), the second based on marker-defined intervals (the "Beds"), were introduced to geological usage (Fig. 3).

McCabe (1959) noted the usage of both "Beds" and "Formations", and retained a combined marker bed and lithologic subdivision applicable to that portion of the Mississippian sequence present in Manitoba (Fig. 1). The stratigraphic subdivisions proposed by McCabe did not include Thomas's MC-4 and MC-5 members, because facies changes to evaporite made correlation uncertain, so these members were included in the "Charles Formation". As designated in Manitoba the "Mission Canyon" and "Charles" formations are time-stratigraphically equivalent to the lower part of the type section of the Mission Canyon Formation.

Stratigraphic Subdivisions

From the previous examination of the history of stratigraphic nomenclature in the northeast segment of the Williston Basin, it is apparent that the subdivisions proposed by McCabe are satisfactory; however, with the increased amount of data available today, a modified system of stratigraphic subdivision can be employed. This modified terminology permits a more precise subdivision of the Mission Canyon succession with respect to multiple reservoir strata and allows more precise lithostratigraphic mapping. The principal changes include the definition of a medial "MC-3 marker", and an upper "Charles marker".

The lower boundary of the MC-1 Member is placed at the first non-argillaceous limestone above the uppermost argillaceous beds (i.e Lodgepole marker) of the Lodgepole Formation, with the upper boundary at the base of the argillaceous, evaporitic beds of the MC-2 Member. Where the MC-2 Member is not readily recognized as a distinct lithological unit due to decrease in evaporite content, the boundary is placed at the "MC-2 marker", and the MC-1 Member passes directly upward into the MC-3 Member (Fig. 3).

The MC-2 Member consists of the sequence of silty, argillaceous limestones, dolomites, and evaporites directly overlying the MC-1 limestone and directly underlying the MC-3 carbonates. The evaporite content of the Member decreases to the west so that in the western portion of southwest Manitoba, including the Pierson area, the MC-2 Member is typically a thin argillaceous unit (max. 7 m thick) and is subdivided into lower and upper zones by the "MC-2 marker", a distinct shaly response in mechanical logs.

The MC-3 Member can be subdivided into the "MC-3a beds" and the "MC-3b beds" by another thin shaly marker, the "MC-3 marker". To the east, in the Waskada area, this marker is correlative with the Dando Evaporite (Rodgers, PR 1-85). The MC-3 marker is not as well defined in log response as the "MC-2 marker" and is therefore more difficult to correlate, but nevertheless provides a correlatable sequence amenable to detailed stratigraphic analysis.

The top of the MC-3 Member is marked throughout much of southwest Manitoba by a poorly developed argillaceous unit occurring at the base of a sequence of evaporites and dolomites referred to as the "Charles Formation". The primary evaporitic beds of the Charles Formation are not to be confused with the anhydritic beds (secondary deposits) present immediately below the Paleozoic erosion surface and designated as the "altered zone".

The cross-sections in this report utilize this marker-defined terminology. Figure 4 illustrates the regional correlations of Mississippian Mission Canyon strata from extreme southeastern Saskatchewan to the Pierson study area.

The MC-3a and MC-3b beds of the MC-3 Member can be divided further into various porous zones separated by dense units. Such divisions are shown in the Great Northern Pierson 8-7-3-28 WPM well (Fig. 5) that has been chosen as a reference well for the Pierson study area. Its log displays the stratigraphic terms used in this report. The lithologic subdivisions of the MC-3 Member are based on the presence of correlatable porous beds with accompanying top and bottom dense beds. It should be noted that the subdivisions of this well are clearly defined, but in other wells the subdivisions are more subtle and correlations become somewhat uncertain.

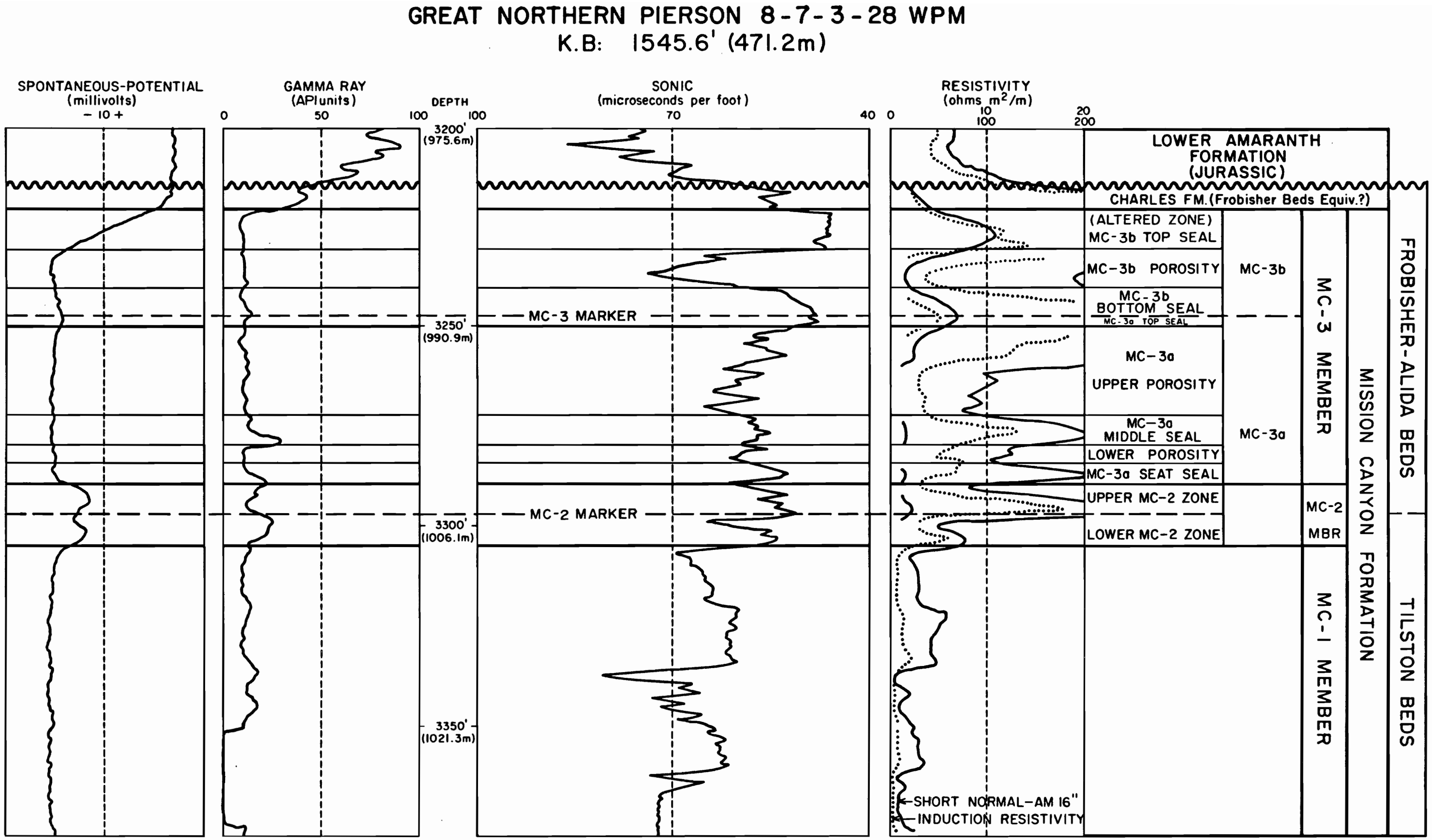


Figure 5: Reference (Type Log) Well, Great Northern Pierson 8-7-3-28 (WPM)

EXPLORATION HISTORY

The pools in the Pierson study area are shown in Figure 6 which depicts the pool boundaries, producing zones and pool codes that are in usage by the Petroleum Division of Manitoba Department of Energy and Mines.

The exploration history of the Mission Canyon pools is described in order of year of discovery.

Discovery Date	Pool	Pool Code
Pierson Field		
February 1954	MC-3a C	07 43C
November 1954	MC-3a A	07 43A
December 1954	MC-3b B	07 42B
October 1965	MC-3a B	07 43B
December 1966	MC-3b D	07 42D
South Pierson Field		
July 1961	MC-3b B	12 42B
July 1982	MC-3b A	12 42A
Other Areas		
November 1962	MC-3b A	99 42A
September 1980	MC-3 B	99 41B

Appendix I provides historical production data on individual wells in each pool in the study area.

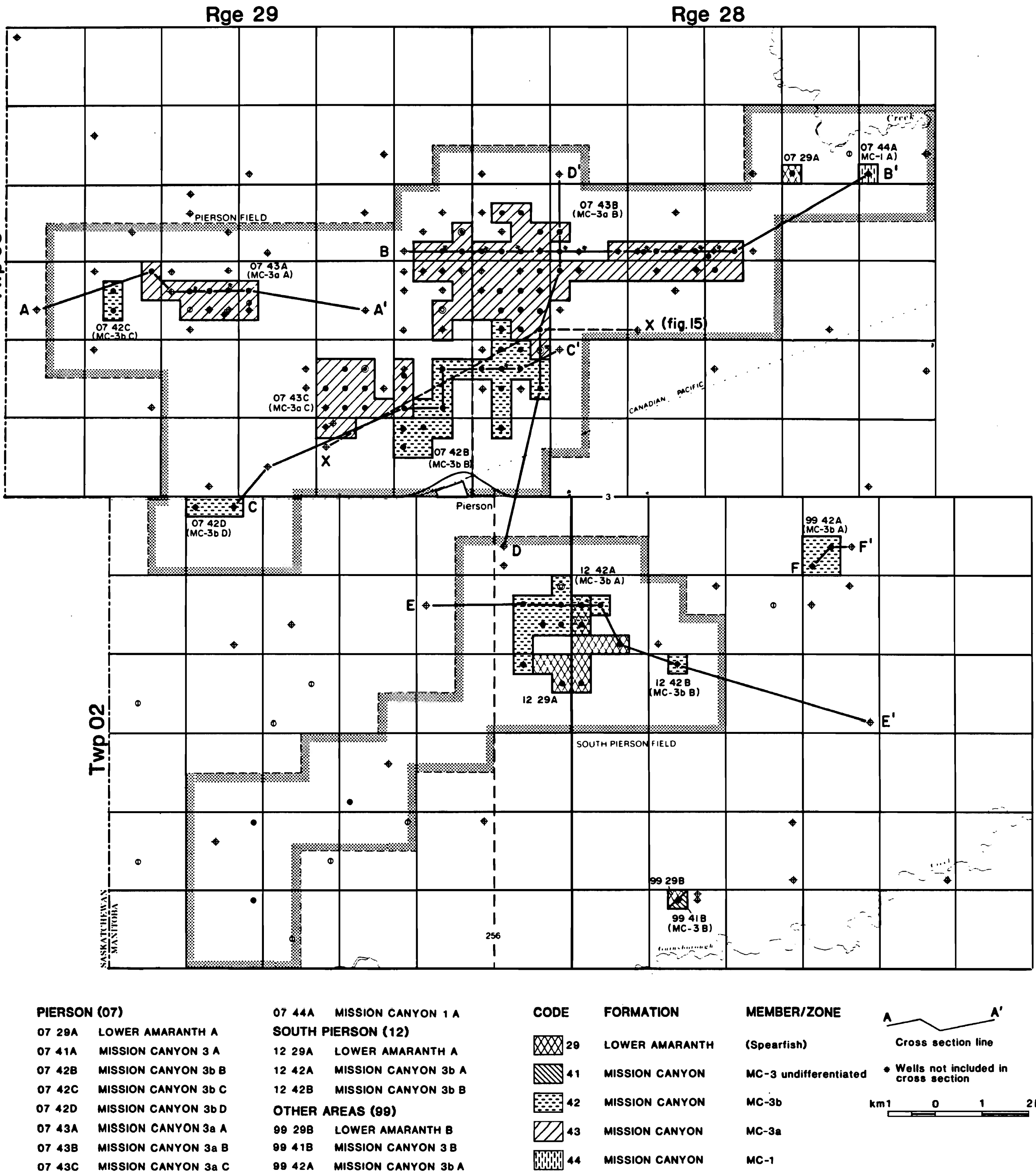


Figure 6: Pool Locations and Pool Codes of the Pierson Fields and Lines of Cross-Section

Pierson Field

MC-3a C Pool (07 43C)

(Fig. 18, cross-section C-C')

The Pierson Field discovery well, 7-11-3-29 WPM, was drilled by the California Standard Company (now Chevron), in February 1954 on a seismic anomaly and was completed in the MC-3a interval of the MC-3 Member. The well is still on production and as of December 31, 1986 had produced 23 791.4 m^3 oil and 38 705 m^3 water. Following the discovery of 7-11, California Standard (Chevron) drilled and completed five more wells by the end of 1954. These were 3-11, 4-11, 5-11, 6-11 and 10-11-3-29 WPM; three of these wells are still producers. Northern Development Co. drilled and completed 2-11-3-29 WPM in July 1954 and drilled and abandoned 8-11 in March 1955. Further development of the pool was done by Imperial Oil drilling 13-2, 5-12 and 12-12-3-29 WPM, all in 1954; of these only 5-12 is still a producer. Copperhead drilled and completed 11-11 in October 1977 and Tundra Oil and Gas drilled and completed 4-12 and 12A-12 in 1981, all of which are active producers.

As of December 31, 1986 this pool has nine active producers and has so far produced 119 977 m^3 oil and 408 785 m^3 water.

MC-3a A Pool (07 43A)

(Fig. 16, cross-section A-A')

Following the initial Pierson discovery, Imperial, in November 1954, drilled the 5-15-3-29 WPM well and completed it in the MC-3a interval. This became the discovery well for the Pierson MC-3a A Pool. Imperial abandoned the well in June of 1956, but Berry Petroleum re-entered the well in July 1974. After initial production of 725 m^3 oil, the well has also been used for salt water disposal since March 1975; the oil production, however, has been suspended since December 1981. Berry Petroleum drilled four additional wells (12-15, 7-16, 8A-16, 9-16-3-29 WPM) during the 1974-1975 period; of these, 12-15 and 9-16, are still producing. During the 1984-1986 period

Rideau Petroleum developed the pool further by drilling five additional wells, 6-16, 10-16, 11-16, 12-16 and 16-17-3-29 WPM. Three of these are active producers, 6-16 and 12-16 being abandoned. Currently this pool has five producers, and as of December 31, 1986 has produced a total of 26 007 m^3 oil and 74 026 m^3 water.

MC-3b B Pool (07 42B)

(Fig. 18, 19, cross-sections C-C' and D-D')

The third discovery was made in December 1954 by Imperial Oil. Imperial drilled the 6-7-3-28 WPM location on a seismic anomaly 2.45 km east of the MC-3a C pool and completed the well within the MC-3b interval, thus establishing the MC-3b B Pool. No further drilling was done until 1965, when King Resources drilled and completed the 15-7-3-28 WPM well. The third well, 8-7-3-28 WPM, which is also the reference (type) well (Fig. 5) for this report, was drilled in June 1976 by Great Northern Oil Co. From 1983 to 1985 Tundra Oil and Gas remained active in the development of this pool; a total of 12 wells were drilled. Of these, 5-7 and 7-7-3-28 WPM, were dry and abandoned, and 14-6-3-28 was abandoned after producing only 49 m^3 of oil. Currently 12 wells are on production, and to December 31, 1986 this pool has produced 29 145 m^3 oil and 57 404 m^3 water.

MC-3a B Pool (07 43B)

(Fig. 17,19, cross-sections B-B' and D-D')

The MC-3a B Pool was discovered in October 1965 by the King Resources Ltd. The 13-17-3-28 WPM well encountered oil within the MC-3a interval. The pool remained undeveloped until 1968 when Tacoma Petroleums initiated a large exploration and development program in the west half of Township 3 Range 28 WPM and the east half of Township 3 Range 29 WPM. Tacoma drilled a total of 25 wells in the area resulting in 12 oil producers from the MC-3a interval, primarily within a lower porous unit. During the period of 1982 to 1985 Tundra Oil and Gas, Canada Northwest Energy, A&B Resources and Quest Energy Corporation altogether drilled 15 additional wells to develop the pool.

Currently 12 wells are abandoned producers and 25 wells remain on production. As of December 31, 1986 the pool has produced 149 547 m^3 oil and 136 029 m^3 water.

MC-3b D Pool (07 42D)
(Fig. 18, cross-section C-C')

In December 1966 Chandler and Associates drilled and completed the 15-32-2-29 WPM well in the MC-3b interval, and this became the discovery well for the Pierson MC-3b D Pool. Cross-section C-C' demonstrates that the well produced oil from the MC-3b interval at an initial rate of 4.3 m^3 oil per day with 75% water cut. A decrease in production to 0.87 m^3 oil per day and 87% water cut by December 1967 led to suspension and eventual abandonment of the well in 1969. Total production was 427 m^3 oil and 3 025 m^3 water. In March 1967 Chandler drilled and completed the 13-32-2-29 WPM well in the MC-3b interval, which produced initially 6.6 m^3 oil per day with 44% water-cut, decreasing to 2.8 m^3 oil per day with 62% water cut by July 1967. It was also suspended in March 1969 at a production rate of 0.8 m^3 oil per day with 78% water-cut. Total production was 786 m^3 of oil, 2 786 m^3 of water. The third follow-up well, drilled by Chandler (2-4-3-29 WPM) was dry and abandoned. Total production of this pool is 1 213 m^3 oil and 5 811 m^3 water.

South Pierson Field

MC-3b B Pool (12 42B)
(Fig. 20, cross-section E-E')

In July 1961 Kissinger Petroleums drilled and completed the 14-20-2-28 WPM well in the MC-3b interval. This became the first well in the South Pierson Field and was designated the MC-3b B Pool. The well produced 2 359 m^3 of oil and 2 668 m^3 of salt water until its abandonment in 1964.

It was recompleted by Copperhead Petroleum Ltd. in October 1966 and was re-abandoned in August 1986. This well produced a total of 6 364 m^3 of oil and 21 055 m^3 of water.

MC-3b A Pool (12 42A)

(Fig. 20, cross-section E-E')

This pool was discovered in July of 1981 when Cobra Oil and Gas drilled the 12-30-2-28 WPM well. The well was completed in both the Lower Amaranth Formation and the MC-3b interval. The Lower Amaranth was subsequently sealed off and the well has been producing only from the MC-3b interval. Initial production was 5 m^3 of oil and 8 m^3 of water per day. The well has so far produced 4 385 m^3 of oil with 12 932 m^3 of water. Nine more wells have been drilled in the pool by Cobra and its successor, Lyleton Development Corp. At present, seven wells are on production, and to date this pool has produced 14 579 m^3 of oil and 31 429 m^3 of water.

Other Areas

MC-3b A Pool (99 42A)

(Fig. 21, cross-section F-F')

This pool is outside the South Pierson Field boundary and has been designated under "Other Areas" (Fig. 6). In November 1962 Plaza Oil and Gas drilled the 4-34-2-28 WPM location and tested the MC-3b interval with GTS in 40 min. TSTM and recovery of 73 m of gassy and muddy oil. Initial production of the well was 6.3 m^3 of oil per day, but this rapidly dropped to 1.4 m^3 of oil with 7.3 m^3 of water and the well was eventually abandoned in October 1964. Total production was 278 m^3 of oil and 1 268 m^3 of water at the time of abandonment.

In August 1976 Great Northern Oil drilled the 10-28-2-28 WPM well and a drill stem test of the MC-3b interval recovered 110 m of gassy and heavily oil cut mud. However, chances of making this a productive well appear to be marginal; the well is still suspended pending further evaluation or abandonment.

In June 1985, Bonus Petroleum drilled and completed the 6-34-2-28 WPM well in the MC-3b interval. The well tested 225 m of gas cut oil and has been on production since July of 1985 at an average rate of 24.6 m^3 of oil per month. Following this discovery Bonus drilled and abandoned the 7-34-2-28 WPM well in October 1985. The MC-3b interval in the 7-34 well is tight and the MC-3a is wet. At present, the 6-34-2-28 WPM well is the only active producer in this small pool, which has so far produced 908 m^3 of oil and 1 741 m^3 of water.

MC-3 B Pool (99 41B)

The 14-5-2-28 WPM location was drilled by Cobra Oil and Gas Corporation in September 1980. The well was initially completed as a Lower Amaranth producer and after three weeks of oil production declined to 1.5 m^3/d with 50% water cut. The well was subsequently completed in the MC-3 Member (undifferentiated), and was placed on production in January 1981. The production from this zone did also gradually decline to less than 3.0 m^3/month with high water cut. The well was shut-in in November 1982 and was abandoned in September 1986. The well produced a total of 208 m^3 of oil and 218 m^3 of water.

The above noted exploration history shows that numerous pools have been found in widely scattered locations, and that the development of these pools has not been uniform. Rather, drilling activity occurred in a sporadic manner.

GEOLOGY

Structure

The Pierson study area is located within the subcrop belt of the MC-3 Member of the Mission Canyon Formation (Fig. 2). Details of the subcrop are shown in Figure 7, a structure contour map of the Mississippian erosion surface, which also displays the boundaries and locations of each individual pool with respect to subcrop belts of MC-3a and MC-3b intervals.

Contours on the Mississippian erosion surface (Fig. 7) indicate a generally northwest trend, with the surface dipping regionally in a southwest direction at approximately 7 m/km. The structure is generally uniform; however, Sections 7 and 18 of Township 3, Range 28 WPM show a closed high, and isolated one-well closures are also found in Section 34 of Township 2, Range 28 WPM and in an area comprising Sections 11, 14, 15, 16, 17, 20 and 21 of Township 3, Range 29 WPM. The contours on the erosion surface reflect a combination of paleotopographic relief on the unconformity and later structural tilting and deformation.

The paleotopography of the erosion surface is best illustrated by the isopach of the overlying Lower Amaranth (Red Beds) Formation (Fig. 8). The top of the Lower Amaranth closely approximates a time-stratigraphic marker, and consequently "highs" on the erosion surface coincide with the "thins" of the Lower Amaranth. Caution must be used in interpreting Lower Amaranth isopach anomalies as paleotopographic features, because other factors can also affect the Lower Amaranth thickness, such as: local uplift or subsidence during Lower Amaranth time; differential compaction; and salt solution and collapse contemporaneous with Lower Amaranth deposition. Where "highs" on the erosion surface are coincident with, and of the same magnitude as, isopach "thins", the structural features on the erosion surface can be interpreted as paleotopographic features provided that those features show no associated Mississippian structure.

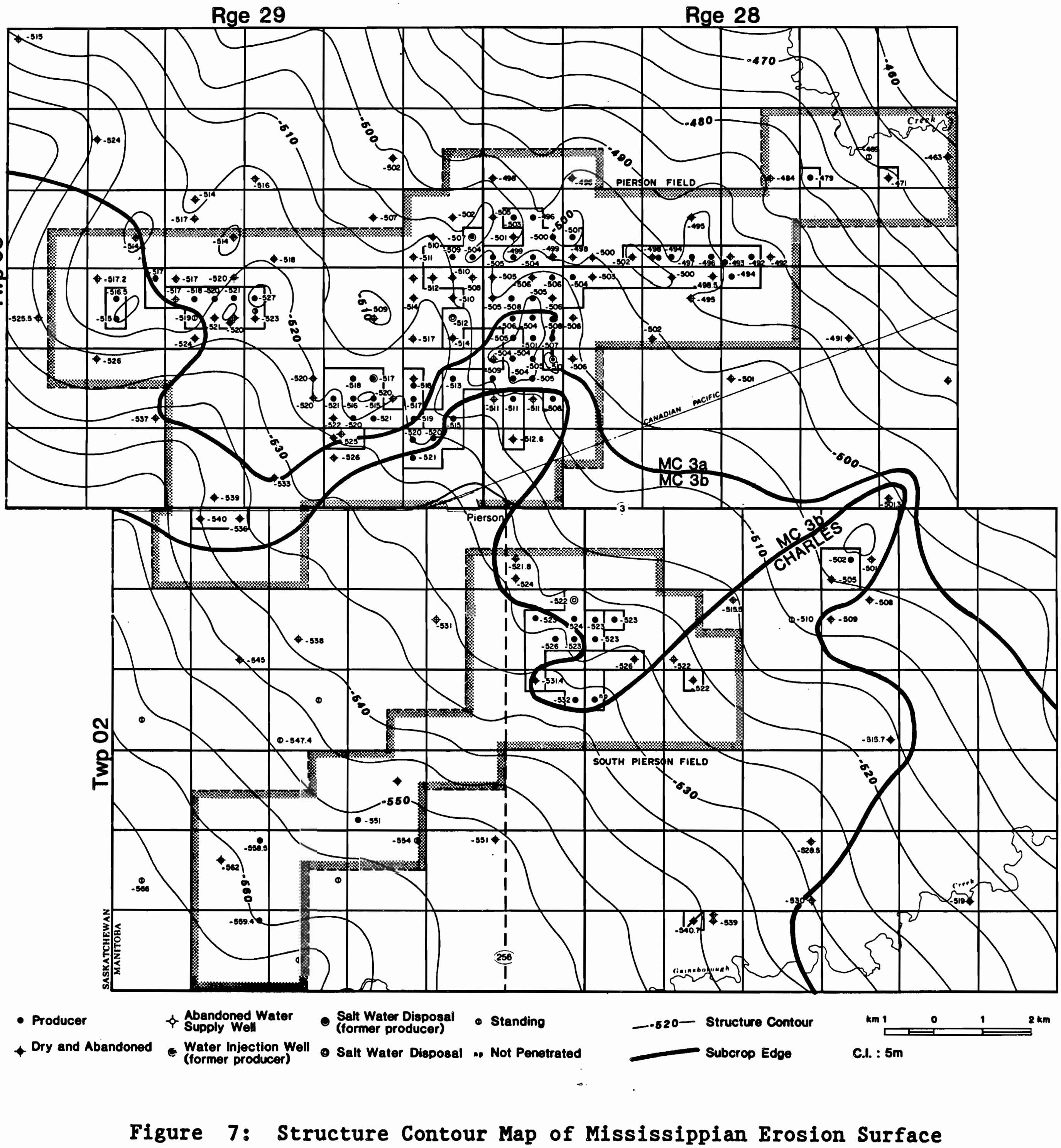


Figure 7: Structure Contour Map of Mississippian Erosion Surface

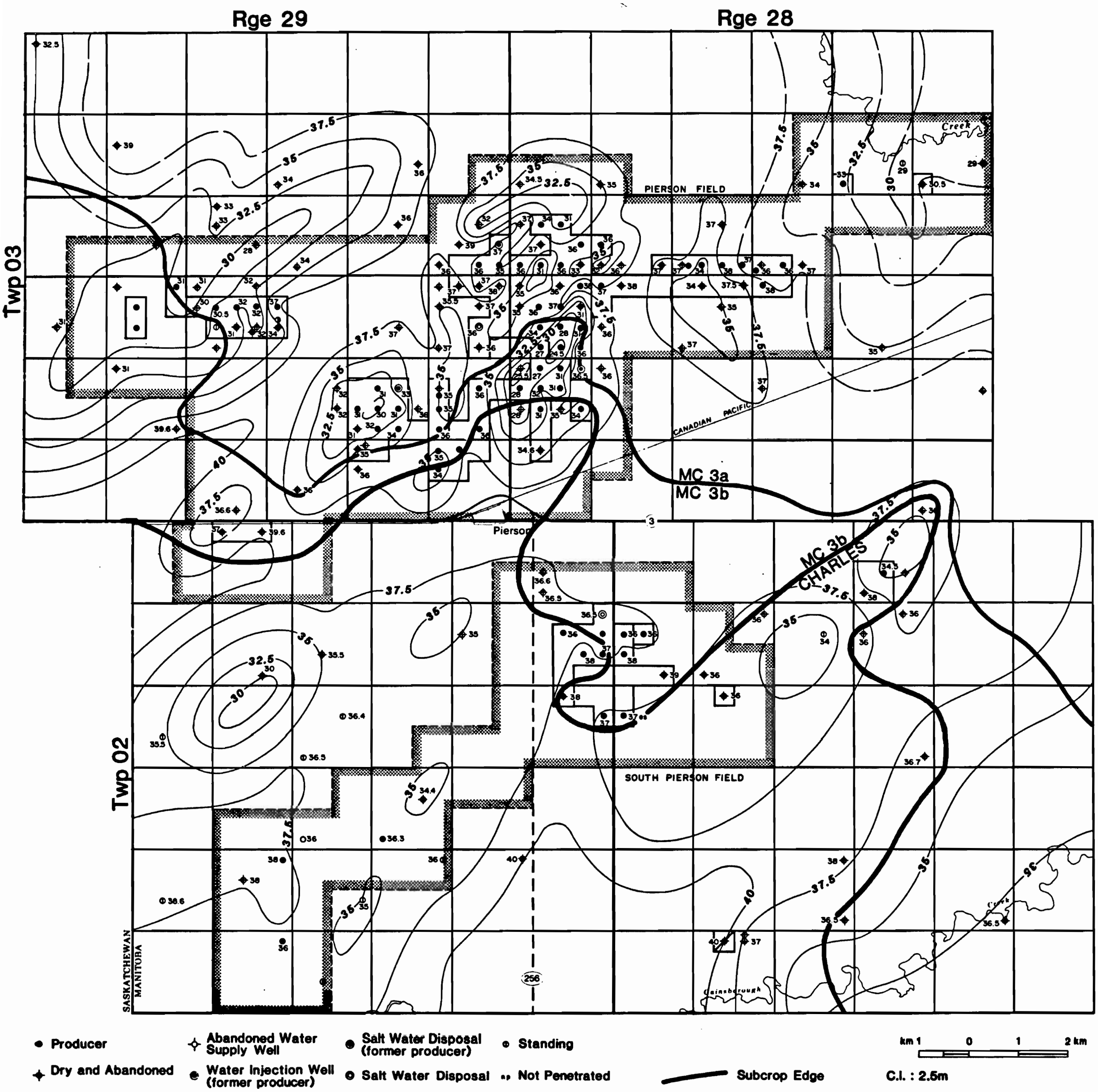


Figure 8: Isopach Map of Lower Amaranth Formation

Structure on the "MC-2 marker" (Fig. 9) defines the true present day structure and is more regular and uniform than the structure on the erosion surface. The MC-2 structure is regionally homoclinal with a northwest trend, and beds dipping southwest at about 10 m/km. However, an MC-2 "high" coincident with a high on the erosion surface occurs in the MC-3a A Pool area, and is indicative of minor post-erosion (Middle Jurassic?) uplift. Two one-well closures on the "MC-2 marker" in Sections 1 and 15 of Township 3, Range 29 WPM are not reflected by the erosional structure because they are truncated at the unconformity, indicating pre-erosion structural deformation.

A contour map of the first MC-3 porosity (either MC-3a or MC-3b) shows the effective top of the reservoir (Fig. 10). The porosity is controlled by the following factors:

a) paleotopography on the unconformity;
b) variations in thickness of the "altered zone" lying immediately beneath the unconformity; and
c) primary MC-3 lithofacies.

As might be expected the pattern of contours on the MC-3 porosity corresponds rather closely to the pattern of contours on the erosion surface (Fig. 7). The difference between the two sets of contours is due to variations in the thickness of the "altered zone". A comparison of the contours on the porosity and the Lower Amaranth isopach (Fig. 8) shows a coincidence (in the Pierson Field) of paleotopographic highs with porosity highs and oil accumulation. Detailed structural cross-sections (A-A' to F-F') across areas of oil accumulation show that porosity closures (as indicated by the thickness of oil column) commonly exceed paleotopographic closures indicating that diagenetic porosity variations have increased porosity closures on the paleotopographic highs.

The following are descriptions of the structural and paleotopographic features for each pool in the study area, beginning with the Pierson MC-3a A Pool.

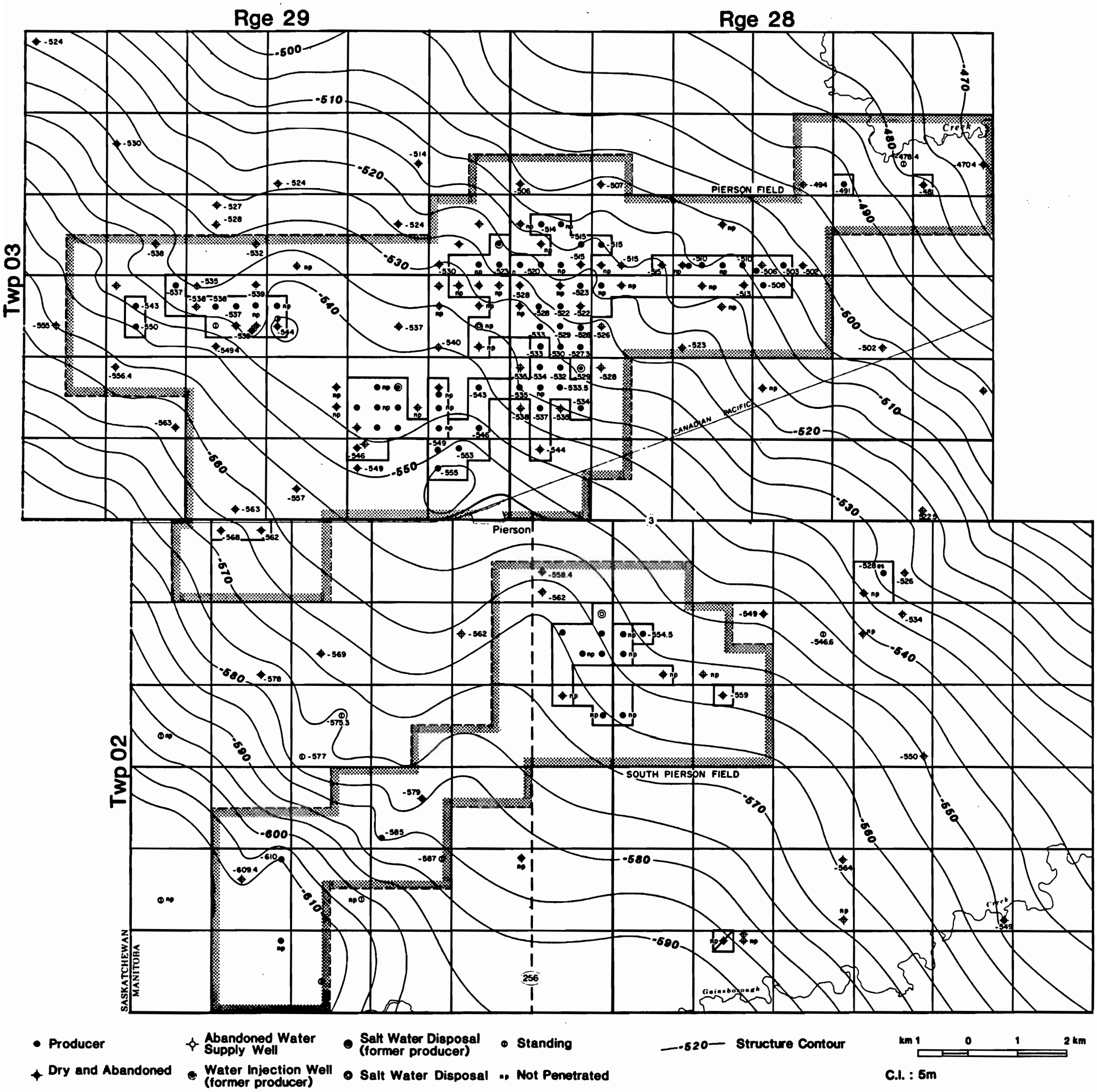


Figure 9: Structure Contour Map of MC-2 Marker

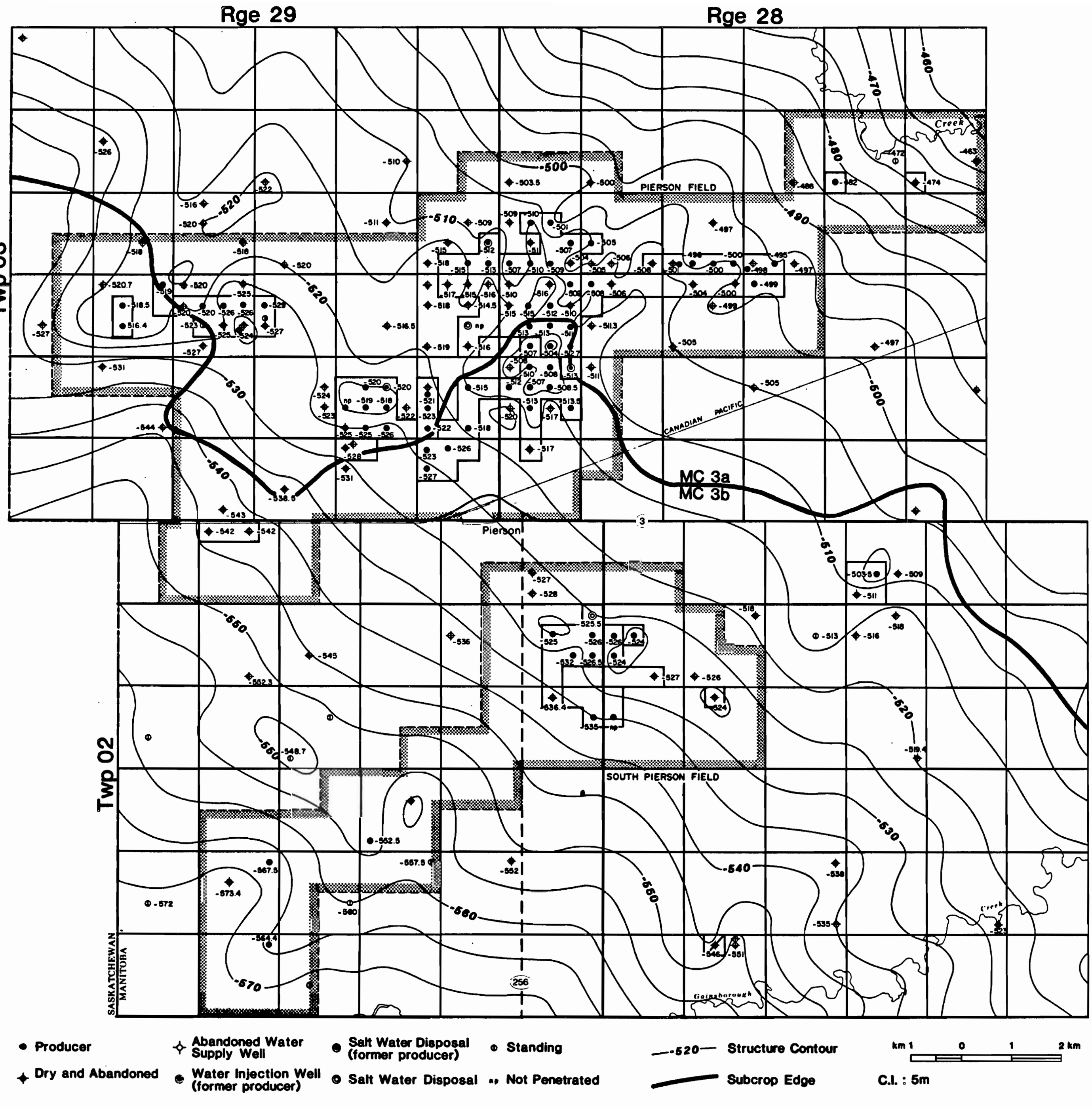


Figure 10: Contour Map of First Porosity of the MC-3 Member

Pierson Field

MC3a A Pool (07 43A)

This pool is situated on a subtle paleotopographic feature on the erosion surface (Fig. 7) and on a structural high on the "MC-2 marker" (Fig. 9). Two one-well closures are also evident in Figure 7. The cross-section A-A' (Fig. 16) also demonstrates the structure seen in Figures 7 and 9.

MC-3a B Pool (07 43B)

The pool lies on a complex series of minor Mississippian structural and erosional features directly updip from the MC-3a C and MC-3b B Pools. The structure map of the Mississippian erosion surface (Fig. 7) reveals the pool to be on a broad platform with minor highs and lows. Two small closures are present in Sections 16, 19, 20 and 21 of township 3, range 28 WPM. Also the pool does not show any pronounced structure on the "MC-2 marker" (Fig. 9). However, the isopach map of the Lower Amaranth Formation (Fig. 8) shows a broad thinning in sections occupied by this pool indicating a topographic high on the erosion surface.

MC-3a C Pool (07 43C)

Stucture maps of the Mississippian erosion surface (Fig. 7) and "MC-2 marker" (Fig. 9) are relatively uniform. However, a thinning of the Lower Amaranth Formation in Section 11-3-29 WPM is evident on the isopach map (Fig. 8) suggesting a minor high on the Mississippian erosion surface. A closed high in Section 11 of Township 3, Range 29 WPM is also evident in Figure 10, the contour map of the MC-3 porosity.

MC-3b B Pool (07 42B)

A closure on the Mississippian erosion surface (Fig. 7) is seen on the northeastern portion of this pool in Sections 7 and 18-3-29 WPM. The presence of this paleotopographic high is also indicated both by an overall broad thinning of the Lower Amaranth Formation (Fig. 8) over the east half of the pool and partly by a closed high on the MC-3 porosity map (Fig. 10). Cross section C-C' (Fig. 18) shows the preservation of the porous MC-3b interval below the "altered zone". Structure on the "MC-2 marker" does not indicate any anomaly over the pool area.

MC-3b D Pool (07 42D)

No structure is evident in this pool. The ispach map of the Lower Amaranth Formation (Fig. 8) also does not show any anomalous feature. The trap is therefore mainly stratigraphic due to facies changes and porosity destruction which is described later in the report (Fig. 18, cross-section C-C').

South Pierson Area

MC-3b A Pool (12 42A)

This pool does not show any anomalous feature on the Mississippian erosion surface (Fig. 7). Structure on the "MC-2 marker" (Fig. 9) is also very regular and homoclinal dipping to the southwest. The isopach map of the Lower Amaranth Formation (Fig. 8) as well does not display any thinning over and around the pool area. Two small closures, however, are noted on the MC-3 porosity contour map (Fig. 10). The trap is due mainly to facies change within the MC-3b interval (Fig. 20, cross-section E-E').

MC-3b B (12 42B), MC-3b A (99 42A) and MC-3 B (99 41B) Pools

These pools are single well completions and occur on a minor closure on the MC-3 porosity (Fig. 10). However, this minor closure has no bearing in the trapment of the hydrocarbon. The trap in these pools is due to an updip seal provided by the porosity pinchout (Figs. 20, 21, cross-sections E-E' and F-F').

Lithology

Representative cores from each field area were examined to determine the carbonate lithofacies present within the MC-3a and MC-3b intervals. The carbonate textures were described using Dunham's (1962) terminology (Fig. 11). No detailed petrographic or diagenetic studies were attempted. Porosity has been described using the terminology of Choquette and Pray, 1970 (Fig. 12).

In general, Mission Canyon rocks in the study area consist of limestones and dolomitic limestones displaying depositional features of a shallow to very shallow carbonate shelf environment. The presence of laminated carbonates and minor primary anhydrites, both as thin beds and nodules, suggests localized areas of low to moderate restriction, with elevated salinities and low energy levels. Argillaceous carbonates and thin silty to shaly laminae indicate periods of low depositional energy, coupled with the influx of minor amounts of terrigenous clastics. Mission Canyon strata display a well-defined sequence of transgressive and regressive pulses, though these rocks display an overall regressive character. The rock sequences are the product of an evolution from a low to moderate energy subtidal carbonate shelf environment to a restricted, very shallow water to possibly supratidal environment. The MC-3 Member has been regionally truncated by post-Mississippian pre-Jurassic erosion. Immediately beneath the unconformity, in most of the study area, porosity and fractures have largely been infilled with secondary anhydrite, and the limestones have been partially dolomitized. A sequence of shales, siltstones, and sandstones were deposited directly on this erosional surface during Jurassic time, and comprise the Lower Amaranth Formation.

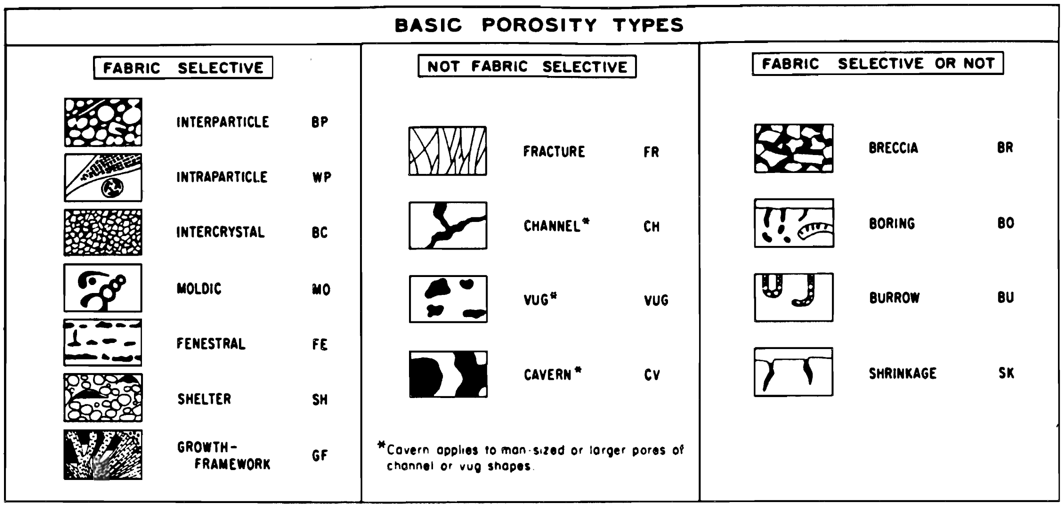


Figure 11: Dunham's Classification of Limestones (1962)

<table>
<tr><td colspan="6">Classification of limestones according to depositional texture</td></tr>
<tr><td colspan="4">Depositional texture recognizable</td><td></td><td>Depositional texture not recognizable</td></tr>
<tr><td colspan="4">Original components not bound together during deposition</td><td>Original components bound together during deposition</td><td rowspan="5">Crystalline carbonate (subdivide according to physical or diagenetic texture)</td></tr>
<tr><td colspan="3">Contains mud (fine silt and clay size particles)</td><td>Lacks mud</td><td rowspan="3"></td></tr>
<tr><td colspan="2">Mud-supported</td><td colspan="2">Grain-supported</td></tr>
<tr><td>Less than 10 percent grains</td><td>More than 10 percent grains</td><td></td><td></td></tr>
<tr><td>Mudstone</td><td>Wackestone</td><td>Packstone</td><td>Grainstone</td><td>Boundstone</td></tr>
</table>

Figure 12: Classification of Porosity Types in Carbonate (Choquette and Pray, 1970)

In the Pierson study area, a sequence of 6 lithofacies types has been established. This facies subdivision is based on the observation and description of primary sedimentary structures, grain type and size, and mineralogy in cores (Figs. 13 & 14). The six lithofacies of the MC-3 Member are:

A) bioclastic lime mudstone to wackestone;
B) coated grain packstone to grainstone;
C) non-coated grain packstone;
D) laminated lime mudstone to dolomite;
E) intraclastic to peloidal lime mudstone to wackestone; and
F) laminated dolomite-anhydrite-claystone.

Each lithofacies can be recognized on the basis of several distinctive textural features, and its naming is designed to correspond to these features.

Lithofacies A: Bioclastic Lime Mudstone to Wackestone

The distinguishing features of this lithofacies are:

1) bioclastic materials, primarily rugose corals;
2) predominantly micrite matrix;
3) "horsetail" microstylolites; and
4) development of metasomatic anhydrite.

The content of bioclastic material ranges from 5% to 20%. The bioclasts are poorly sorted in a matrix composed of mudstone and wackestone, based on Dunham's classification (Fig. 11). Mechanical breakage and disaggregation of corallites are evident in several cores. The breakage is interpreted to be mainly a syndepositional breakage by waves and storm agitation, because the corallites are filled commonly with micrite as opposed to various forms of carbonate cements. Also present are brachiopod, ostracod, foraminifera, and possibly trilobite fragments. These skeletal materials are commonly oriented horizontally to subhorizontally and their distribution is irregular throughout the facies.

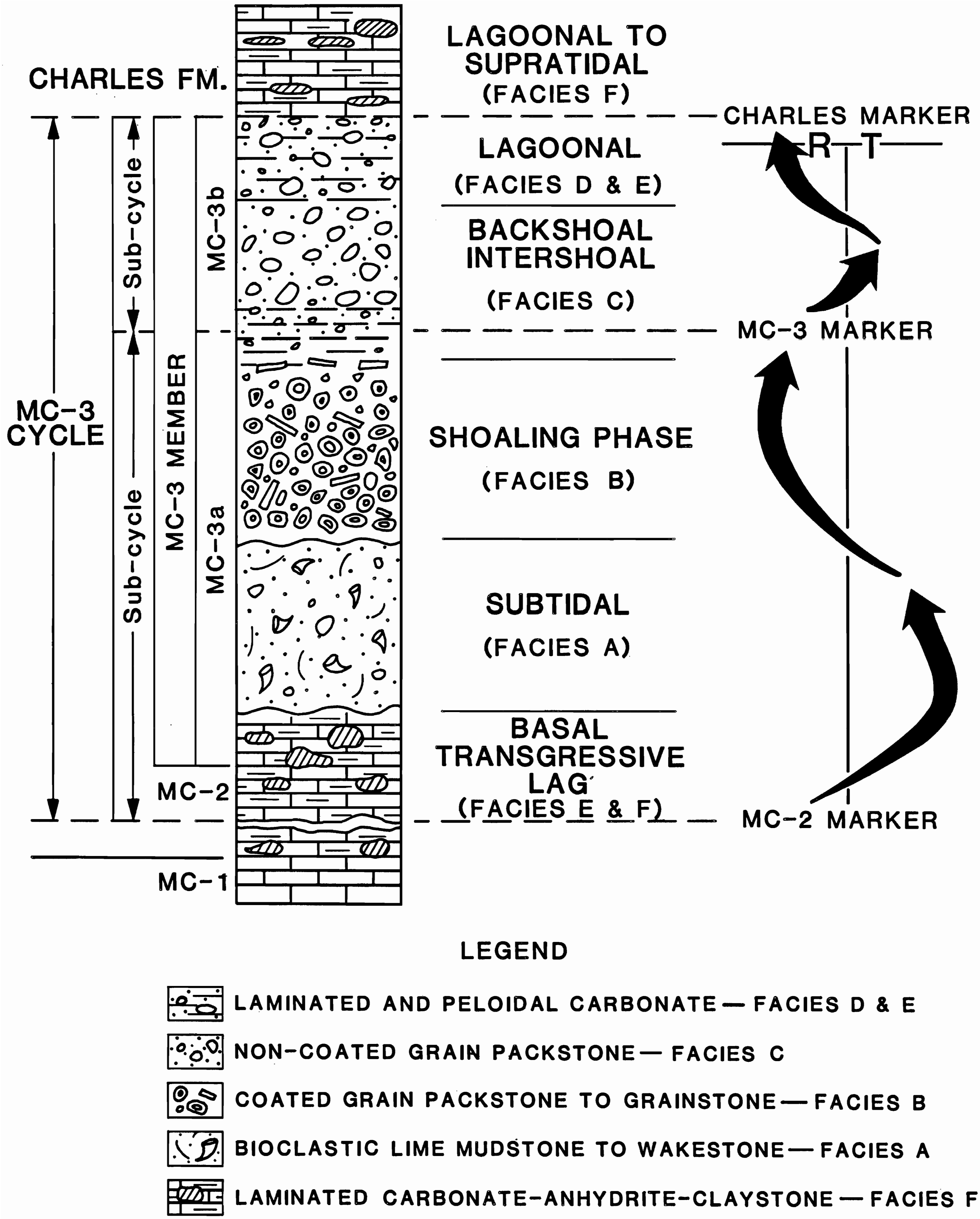
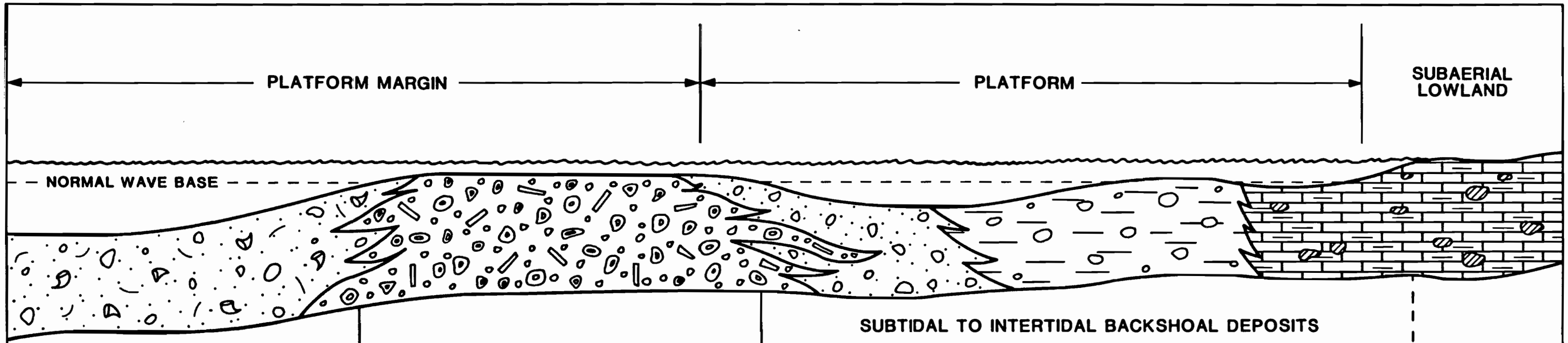


Figure 13: Depositional Environment of MC-3 Cycle



	SUBTIDAL FORESHOAL DEPOSITS (OPEN PLATFORM)	INTERTIDAL TO HIGH ENERGY SUBTIDAL SHOAL DEPOSITS	SUBTIDAL TO INTERTIDAL BACKSHOAL DEPOSITS: BACKSHOAL DEPOSITS	LAGOONAL DEPOSITS (DISTAL)	LAGOONAL DEPOSITS: EXPOSED MUD FLATS	LAGOONAL DEPOSITS (PROXIMAL) — MC-2 & CHARLES FACIES	SUPRATIDAL DEPOSITS (EVAPORITIC) — MC-2 & CHARLES FACIES
FACIES	BIOCLASTIC LIME MUDSTONE TO WACKESTONE (A)	COATED GRAIN PACKSTONE TO GRAINSTONE (B)	NON-COATED GRAIN PACKSTONE (C)	LAMINATED LIME MUDSTONE TO DOLOMITE (D)	INTRACLASTIC TO PELOIDAL LIME MUDSTONE /WACKESTONE (E)	LAMINATED DOLOMITE-ANHYDRITE-CLAYSTONE (F)	CHARLES FACIES
LITHOLOGY	LIMESTONE, GREATER THAN 75% MICRITE	LIMESTONE, PORE-FILLING ANHYDRITE	LIMESTONE, DIAGENETIC DOLOMITE	LIMESTONE, DOLOMITE, DOLOMITIC LIMESTONE	LIMESTONE	DOLOMITE, ARGILLACEOUS DOLOMITE, CLAYSTONE, ANHYDRITE	ANHYDRITE, ANDYDRITIC ARGILLACEOUS LIMESTONE & DOLOMITE
GRAIN TYPE: DEPOSITIONAL TEXTURE	BIOCLASTS PELOIDS	OOIDS, COMPOUND ACCRETIONARY PISOIDS & ONCOIDS, CRINOIDS, MICRITE CHIPS, MINOR PELOIDS, BIOCLASTS	PELOIDS, MINOR PISOIDS, OOIDS, MICRITE INTRACLASTS, RARE BIOCLASTS	PELOIDS, MICRITE CLOTS	MICRITE INTRACLASTS, BIOCLASTS, ALGAL INTRACLASTS	INTRACLASTS	
BEDDING AND STRUCTURES	LAMINATED TO BEDDED MICROSTYLOLITES	MICRITE LAMINAE (CRUSTS), POORLY DEFINED FINING UPWARD CYCLES, MICRITE INTRACLAST LAYERS	CRUDE HORIZONTAL BEDDING	ALGAL LAMINATE?		ALGAL LAMINATE	
BIOTA	CORALS (SOLITARY, RUGOSE) FORAMINIFERA, OSTRACODS, BRACHIOPODS	CRINOID OSSICLES, FORAMINIFERA	CRINOID OSSICLES	ALGAE		ALGAE	ABSENT

Figure 14: Depositional Model

The matrix of this lithofacies is primarily micrite. The micrite is very faintly laminated, and shows a slight waviness to more noticeable contortion of laminae, suggestive of soft-sediment deformation. When etched in acid, a faintly mottled, or clotted texture is apparent. The bedding ranges from finely laminated to thin bedded. Minor post-depositional compaction is evidenced by the presence of "horsetail" microstylolites, which are subhorizontal to horizontal and consist of an anastomosing pattern of dark organic and argillaceous-rich films.

Though not a primary depositional feature, dark brown, fibrous to bladed metasomatic anhydrite is abundant in this lithofacies, ranging from less than 1% of rock volume to in excess of 50%. The sites of nucleation for the anhydrite appear to be skeletal grains (such as rugose corals), or along vertical fractures. Some concentration of anhydrite along horizontal beds and laminations has occurred, although the dominant form is isolated floating masses of crystals.

The rocks of this lithofacies commonly are poorly porous. If porosity is developed, it is usually found in the following forms:

1) intraparticle, within the rugose corals;
2) moldic, after gastropod or coral skeletal grains;
3) fracture porosity, with minor solution enlargement of fractures to form channel porosity; and
4) intercrystalline micro-porosity within the micrite matrix.

The porosity, wherever developed, is always occluded by masses of dark brown metasomatic anhydrite resulting in poor permeability. The fracture and solution-enlarged fracture porosity is also occluded by metasomatic anhydrite. Therefore Lithofacies A is not considered to be an effective reservoir rock.

Lithofacies B: Coated Grain Packstone to Grainstone

The characteristic features of this lithofacies are:

1) the abundance of coated grains (ooids, pisoids and compound pisoids);
2) the presence of minor amounts of non-coated grains (oncoids and peloids), bioclastic materials, and crinoid ossicles;
3) grain-supported textures;
4) lack of significant micrite matrix; and
5) horizontally laminated, continuous to broken, micrite interbeds.

The coarse (greater than 2 mm) coated grains are the primary constituent of this lithofacies, comprising 75% to 90% of the rock. The grains display crude concentric laminations in transverse section. The coated grains are of two general forms. The principal form consists of rounded to oval, concentrically to irregularly coated grains or lumps, with the nucleus formed from agglomerated multiple grains and bioclastic debris. These coated grains (pisoids) may also be lumped together to form compound grains. The pisoidal texture of the rocks has resulted in the usage of the term "algal lump limestone" among operators in the Waskada-Pierson area. Less common are round to slightly oval, concentrically laminated pisoids with a structureless nucleus. The concentric lamination is poorly developed in most cases. Pisoids and compound pisoids are found in association, often without apparent bedding.

Non-coated grains comprise 10% to 25% of total grain content within the lithofacies. The non-coated grains are oval to irregular structureless pellets of micrite, and in literature have been variously named peloids, pellets, intraclasts, fecal pellets, and pelletoids. The irregular shape of these grains indicates the possibility of deformation during compaction.

Crinoid and foraminiferal debris make up a small percentage of total grain content. The crinoid ossicles commonly are disarticulated and occur as coarse blocky calcite crystals. The central cavity of crinoid columnals may be filled with calcite cement, anhydrite or micrite, and may also have been the site of solution removal in a few observed specimens. The foraminiferal tests appear to be biserial, and also are infilled with micrite. Brachiopod fragments occur in minor amounts.

The percentage of micrite in this facies is low and is found either agglomerated into irregularly formed lumps (peloids) or deposited as thin (up to 3 mm) horizontal laminae. The micrite beds are most abundant at the base of thin sequences of coated grains.

The following types of porosity are observed within this lithofacies:

a) intergranular porosity (commonly solution-enlarged);
b) intraparticle porosity developed as the result of grain solution;
c) fenestral porosity within and between individual micrite beds; and
d) shelter porosity preserved under micrite chips and/or laminae.

In some case, the pore sizes have been enlarged by solution processes, causing the creation of microvuggy channel porosity. Porosity ranges from 4% to 20%. Visual examination indicates that the majority of pore throats are interconnected, thus implying fair to very good permeability. Porosity in places is destroyed by secondary anhydrite.

Lithofacies B is one of the better reservoir facies of the Pierson study area.

Lithofacies C: Non-coated Grain (Pisoidal) Packstone

The main features of this lithofacies are:

1) predominance of non-coated grains (peloids) over coated grains (pisoids and compound pisoids);
2) grain-supported (packstone) texture;
3) micrite matrix; and
4) various forms of bedding and grain sorting.

Rocks of this lithofacies are similar to lithofacies B, but can be identified by the relative lack of coated grains and the abundance of a micritic matrix. Close interbedding of the two lithofacies is common.

The primary grain constituents are ovoid to subspherical structureless micrite pellets (peloids). The peloids, ranging from less than 1 mm to 3 mm in diameter, are grain-supported and commonly show grain-to-grain deformation such as pellet flattening. Coated grains constitute not more than 20% of grain volume, and are randomly admixed with non-coated grains. Rare beds of coated grain packstone are also noted. Crinoid ossicles constitute no more than 10% of grain volume.

The grains are in contact with each other, and thus the rock is classified as a packstone under the Dunham classification system. The matrix is micrite. Rare beds of grainstone are present, with porosity infilled by anhydrite cement. The micrite ranges from cryptocrystalline to microcrystalline, suggesting some degree of matrix recrystallization.

Though the dominant mineralogical constituent of this lithofacies is lime micrite, the micrite also occurs as thin interbeds. These micrite interbeds display some drape and deformation over underlying grain beds. Soft sediment deformation is also evident. Broken and fractured micrite beds (which are common in lithofacies E) are rare. The micrite beds also cap fining-upward beds of peloids.

Porosity in lithofacies C is either interparticle or intercrystalline (solution-enlarged pores within the micrite matrix). Larger pores are associated with grain-to-grain contacts. A very fine matrix porosity is present in the micrite. Anhydrite is the major agent of porosity destruction. Pervasive dolomitization of the matrix, with lesser degrees of dolomitization of the grains, is evident in some areas of the field, most commonly near the subcrop edge. The intercrystalline matrix porosity of such dolomites is enhanced improving its reservoir quality.

The rocks of lithofacies C form the principal reservoir of the Pierson MC-3a B Pool (07 43B). The reservoir quality varies considerably over a vertical section of this facies, as evidenced in 1-18-3-28 WPM well (Fig. 15), suggesting discontinuity in porosity and permeability.

Lithofacies D: Laminated Lime Mudstone to Dolomite

This lithofacies has following characteristics:

1) laminated to vaguely clotted micritic texture;
2) lack of bioclastic material;
3) lack of well-formed coated and/or non-coated grains; and
4) presence of metasomatic anhydrite.

The primary constituent of this lithofacies is micrite (lime mud) which ranges from massive to laminated and/or thinly bedded. Nodular bedding or "sedimentary boudinage" is also present and is characterized by the contortion of beds into ovoid, irregular masses which are either poorly linked or separated into discrete masses.

This lithofacies is characterized by the lack of skeletal and grain materials. A clotted (grumous) texture is apparent in slabbed and polished sections examined under a microscope; in some instances these clots appear to be poorly formed peloids.

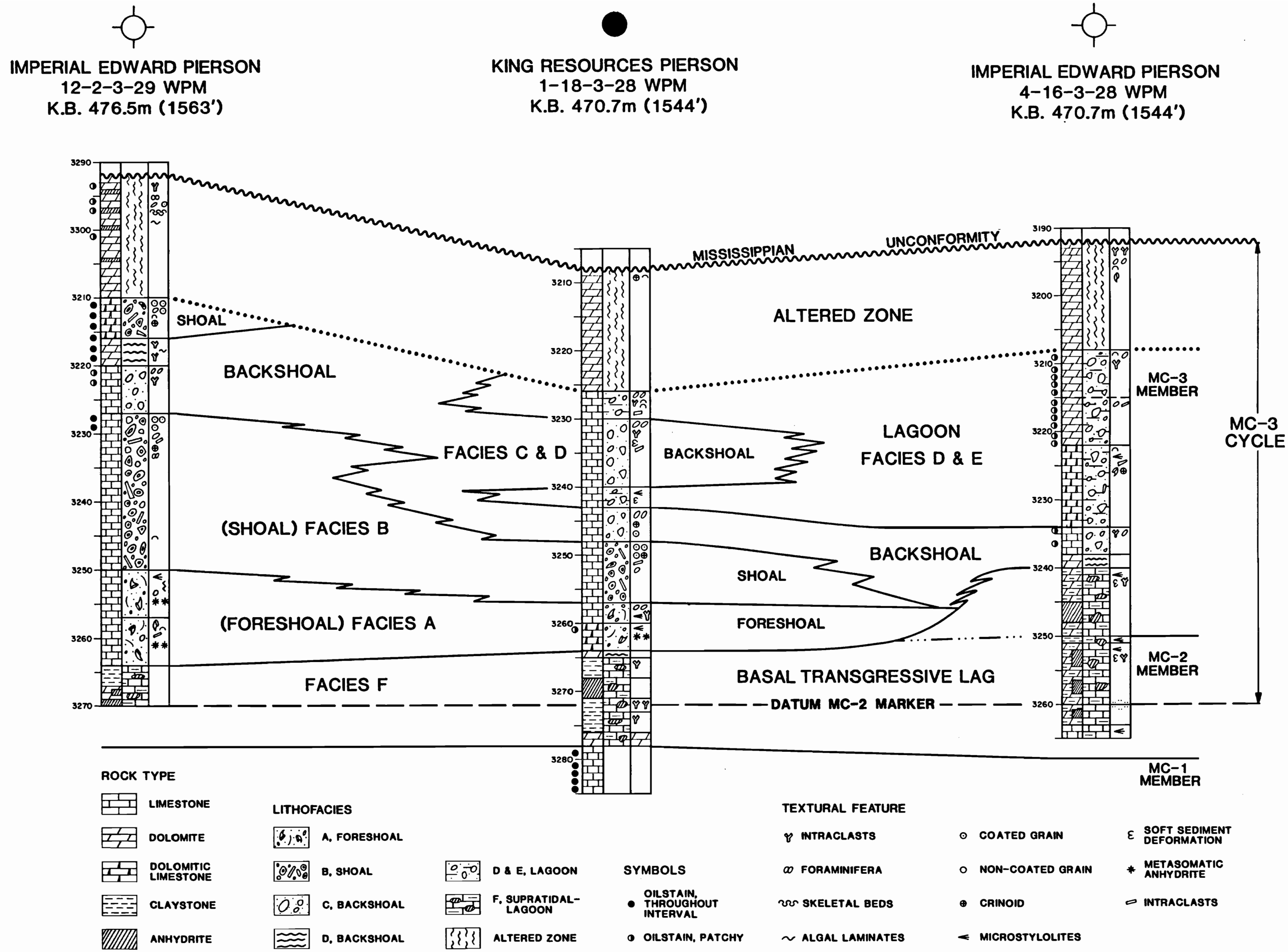


Figure 15: Cross-Section showing Facies Progression

Metasomatic anhydrite is a distinctive component of this facies. The anhydrite is identical to the metasomatic anhydrite found within lithofacies A, and occurs either as isolated clumps of bladed anhydrite crystals or as linked masses of crystals concentrated along vertical fractures.

This lithofacies in places consists of dense, crypto- to microcrystalline dolomites, and may display a dark brown, oil-stained appearance due to abundant encapsulated organic matter.

Porosity of the following types occurs in lithofacies D:

1) solution-enlarged intercrystalline (pinpoint);
2) fenestral ("sheet-crack") porosity associated with the edges of micrite clots; and
3) fracture porosity.

The porosity is poorly developed, sporadic in distribution, and considered ineffective. The rock has a chalky texture, indicating the presence of intercrystalline ("earthy") matrix porosity. This form of porosity is also ineffective due to the extremely small size of the pore throats. Lithofacies D is considered to be a poor reservoir.

Lithofacies E: Intraclastic to Peloidal Lime Mudstone to Wackestone

The main features of this facies are:

1) occurrence of micrite intraclasts and broken micrite beds;
2) presence of poorly formed non-coated grains (peloids) and minor occurrence of other grain material; and
3) development of crude bedding.

This lithofacies grades from a mudstone with partly "grainy" texture, to a wackestone with discrete intraclasts, peloids, and irregularly formed lumps. The dominant mineralogical constituent is micrite, both as matrix and as intraclasts. The micrite intraclasts range from fractured and broken micrite beds to horizontally bedded sheets of irregular, subangular to subrounded, discrete micrite clasts. These irregular clasts commonly grade into poorly formed ovoid to subrounded peloids.

Other types of grain materials, such as skeletal fragments, pisoids, and minor ooids are present randomly in amounts less than 10% of grain volume. Bioclasts such as rugose corals, brachiopods, and ostracods are the most common skeletal constituents. Thin beds of pisoid-rich packstones are rare.

The porosity types present in this facies are:

1) fenestral ("birdseye" and "sheet crack") porosity between individual intraclasts and intraclast beds, with minor solution enlargement of pores to form channel porosity;
2) solution-enlarged intercrystalline ("pinpoint") porosity within the micrite matrix;
3) intraparticle solution-enlarged porosity within micrite intraclasts; and
4) fracture and solution-enlarged fracture porosity.

Porosity is well developed within intraclast-rich intervals. The distribution of fenestral porosity is controlled by the orientation and grain-to-grain contact of the intraclasts and peloids. Since the intraclasts and peloids are horizontally bedded, the interconnection of the fenestral pores suggests good horizontal, but poor vertical permeability. The occlusion of pores by clear, secondary anhydrite is common.

The presence of the above forms of porosity suggests that the intraclastic-peloidal mudstone to wackestone facies has the potential of forming a favourable hydrocarbon reservoir. The abundance of micrite, however, may cause poor reservoir performance.

Lithofacies F: Laminated Dolomite-Anhydrite Claystone

Although the rocks of this lithofacies form part of the complete MC-3 depositional cycle (Fig. 13), they are transitional to the evaporitic units of both the underlying "MC-2" Member and the overlying "Charles" Formation, and are properly included in these units (Fig. 14).

The rocks of this lithofacies are characterized by the:

1) varying amounts of terrigenous clastic material;
2) presence of anhydrite intraclasts and nodules;
3) presence of "patterned dolomite"; and
4) complex interbedding of the above-mentioned lithologies.

A distinguishing feature of Lithofacies F is the terrigenous clastic content. These particles range in size from clay to fine silt. The clay is present as a matrix component within the dolomite, although it may also occur in thin silt-rich laminations. Clay also occurs as greenish grey, medium grey, and reddish grey laminated dolomitic claystones, which are recognizable as distinctive "spikes" on logs and are generally quite soft and friable. Hematite staining is common throughout the lithofacies.

Also present within this facies are several types of syngenetic anhydrite. The anhydrite occurs either as discrete beds of nodular bedded to massive, reddish brown to brownish grey anhydrite, or as irregular, subangular to subrounded clasts of anhydrite within a reddish brown to brownish grey claystone/dolomite matrix.

The "patterned dolomite" is medium to dark brown, cryptocrystalline, shaly, hematitic. This lithology occurs in minor amounts near the base of the MC-3 Member and at the top of the MC-2 Member and is generally thin to medium bedded, with algal laminites and contains minor amounts of dark brown metasomatic anhydrite. Structures similar to water-escape vents (teepee structures) have been noted.

Porosity is non-effective and as such, lithofacies F forms an effective seal for the MC-3 reservoir. The importance of this seal as a barrier to MC-1 water was emphasized in an unpublished report by Andrichuk and Edie (1967), who suggested that great care be taken by operators not to puncture the MC-2 Member, but rather to stop drilling as soon as the distinctive reddish stained, shaly rocks of this facies are recognized in samples.

Altered Zone

The altered zone is not a separate depositional lithofacies, but rather is a diagenetic feature related to processes which occurred at the Paleozoic unconformity surface. The altered zone displays distinctive lithological and textural characteristics, and is therefore described as a separate rock type. It ranges in thickness from less than 1 m to more than 20 m, and, if present in the north half of the study area, is always found directly under the unconformity surface (Fig. 15).

The altered zone is composed mainly of dolomites and anhydrites which are formed by the anhydritization and dolomitization of any of the previously mentioned lithofacies. The texture of the altered zone is dependent upon the parent lithofacies type. Relict textures of Lithofacies A through F have been observed. It is significant and interesting to note that the process of dolomitization did not destroy the primary depositional textures. The dolomites are generally dense though rare poor intercrystalline porosity is found in thin beds, which commonly are stained with dead residual oil.

Anhydrite is present in three forms within this facies:

1) clear crystalline anhydrite infilling vertical and horizontal fractures which are present throughout the dolomite;
2) white, crypto- to microcrystalline, subrounded anhydrite nodules interspersed throughout the dolomite; and
3) dark brown metasomatic anhydrite present as isolated crystals or individual rosettes, identical to the metasomatic anhydrite found in other lithofacies.

The clear anhydrite is late diagenetic in origin and is associated with the erosional surface, specifically with deposits of the early Lower Amaranth evaporitic strata. The thickness of anhydrite is directly related to the size of the fracture, and thus may appear as a massive anhydrite "bed" if the fracture is horizontal. The white nodular anhydrites are also secondary in origin and related to the unconformity. The brown metasomatic anhydrite represents a primary constituent of this lithofacies.

The altered zone, where present, forms the top seal for all the MC-3b and MC-3a reservoirs and plays a prominent role in hydrocarbon entrapment within the study area. In some areas, such as South Pierson, it is very thin and lies below the "Charles" Formation. The zone is generally impermeable, although the presence of oil staining in the dolomites and in fractured beds within the "altered zone" suggests that at places the zone may be an imperfect seal. The entrapment of oil within the overlying Lower Amaranth Formation offers direct evidence that the altered zone may in some areas allow limited upward migration of hydrocarbons.

INTERPRETIVE STRATIGRAPHY

Depositional Environments
(Figs. 13 & 14)

The carbonate rocks of the MC-3 Member of southwest Manitoba are characterized by (1) the preservation of primary lithology and depositional texture, (2) the lack of terrigenous clastic material as compared to the underlying Lodgepole Formation and the overlying Charles Formation, (3) the presence of discernable bedding characteristics, and (4) the complex lithofacies variations both in a vertical and lateral succession. Also noteworthy is the presence of a relatively restricted fauna, the lack of frame-building organisms, and the abundance of lime mud (micrite).

The particular set of lithological, textural and diagenetic characteristics found within the MC-3 intervals of the Pierson study area has been termed the "Mission Canyon Facies" by various authors including Gerhard et al. (1978) and Sando (1978). The "Mission Canyon Facies" represents a group of rocks which have been deposited under generally shallow water, low to moderate energy and normal marine to moderately restricted conditions. This contrasts with the deeper-water facies of the "Lodgepole" and the highly restricted shallow-water to possibly supratidal rocks of the "Charles" Formation. The relationship between these facies has been summarized in Figure 3, and has been modified from the Standard Facies Progression of Wilson (1975).

The Mission Canyon Formation is a portion of the Mississippian transgressive-regressive megacycle. This megacycle consists of a series of smaller scale transgressive-regressive cycles of which the MC-3 Member is a part and is referred to as the MC-3 cycle (Fig. 13). The depositional environments (Fig. 13) within which each lithofacies of the MC-3 Member was deposited during the MC-3 cycle have been interpreted on the basis of core examinations. Based on this interpretation a depositional model is proposed diagrammatically in Figure 14.

The depositional environments of the 6 lithofacies which are recognizable in core are briefly discussed individually.

Lithofacies A: Bioclastic Lime Mudstone to Wackestone

The skeletal mudstones to wackestones of Lithofacies A are interpreted as having been deposited in a low to moderate energy, normal marine to mildly restricted, subtidal environment. This interpretation is based on the following observations:

1. lack of winnowing of matrix micrite;
2. poor sorting and lack of grain-to-grain support of skeletal material; and
3. finely laminated to "clotted" micrite texture.

The above features point to deposition in a subtidal environment of low energy, close to wavebase, yet within the euphotic zone. The relatively restricted faunal assemblage implies slightly elevated salinity levels. This depositional environment was uniform, as this lithofacies is present throughout southwest Manitoba. Thickening in the western portion of the area indicates a deeper portion of the shelf.

Lithofacies B: Coated Grain Packstone to Grainstone

Lithofacies B, the coated grain packstone to grainstone, is interpreted as having been deposited in a moderate energy, shallow marine to possibly intertidal environment. The ooid and pisoid grains may have been deposited under variable energy conditions.

The presence of micrite crusts and intraclasts suggests precipitation of micrite under relatively low energy conditions, punctuated by periods of higher energy leading to destruction of these beds. The pisoids were deposited during these periods of high energy sedimentation. A decrease in depositional energy would again lead to micrite deposition. A pisoidal shoal may be composed of many such small-scale fluctuations. The absence of well defined crossbedding suggests that water movement and transport of coated grains at Pierson was minimal. During the period of maximum regression the marine shoals previously deposited may have undergone vadose diagenesis under subaerial conditions, thereby leading to the creation of the 'vadose' pisolite forms in conjunction with the more common marine pisoids.

The rocks of Lithofacies B represent the highest energy environment of any of the Mission Canyon facies and are found along a narrow band possibly paralleling the strike of an ancient shoreline. Within this band, zones rich in this facies are found in bodies tending perpendicular to the ancient shoreline.

Lithofacies C: Non-coated Grain Packstone

Lithofacies B commonly interdigitates with the non-coated grain packstones of lithofacies C. The rocks of lithofacies C were deposited under less agitated, more restricted conditions than the rocks of lithofacies B. The non-coated grains, or peloids, are believed to be fecal pellets. The more irregular "clots" of micrite suggest some form of agglomeration in low energy conditions. The scattered beds of micrite-free grainstones, and the presence of coated grains in small amounts throughout this facies may be the result of wave transport of shoal-generated grain materials (lithofacies B) into the lower energy, backshoal, peloid-dominated environment of lithofacies C by periodic storms. The lower depositional energy of the non-coated grain packstone lithofacies is also indicated by the increase in micritic matrix. Origin of the micrite is uncertain, but may be due to high amounts of algal activity within the backshoal to lagoonal zone.

In summary, it is believed that lithofacies C was deposited in a shallow-water, low energy, subtidal to lagoonal environment. The shoals may have acted as barriers to waves and tidal currents, thus creating a leeward expanse of quiet water that underwent agitation only during periodic storms. The sediments of lithofacies C appear to be the most seaward of a sequence of subtidal to intertidal backshoal deposits. The backshoal peloidal packstones grade landward into a complex sequence of what are herein interpreted to be lagoonal deposits deposited back from the shoal zone edge (Lithofacies D, E, and F, Fig. 14).

Lithofacies D: Laminated Lime Mudstone to Dolomite

Lithofacies D, the laminated to massive lime mudstone, is believed to have been deposited in low energy, restricted "ponds" which underwent periodic episodes of flooding and emergence. Indicators of low energy levels and stable rates of deposition include the presence of laminations, and the lack of grains which form in more agitated environments. The micrite is largely unstructured, and is present as irregular clots. The lack of skeletal material suggests restricted conditions hostile to the growth of organisms. The dolomite may represent either a primary precipitated dolomite, or a secondary dolomite formed by diagenetic processes.

Lithofacies E: Intraclastic to Peloidal Lime Mudstone to Wackestone

The rectangular micrite "chips" which characterize Lithofacies E appear to be derived from micrite beds. Two different depositional environments are postulated for this lithofacies:

1) in the case of thin to medium beds within typically lagoonal to backshoal sediments, the beds are the remains of emergent, desiccated, fragmented, and re-sedimented laminated micrites deposited within ephemeral ponds; and

2) in the case of thick beds which are composed primarily of bedded micrite intraclasts mixed together with peloids, minor pisoids, and skeletal debris, deposition may have occurred within "channels" flanking the shoal zones.

These thick intraclast and peloid-rich sequences may also be interpreted as being deposited in a shoal-flanking, marginal marine to emergent, environment. Similar deposits have been described by Lindsay and Roth (1982) and Elliott (1982).

Lithofacies F: Massive to Laminated Dolomite-Anhydrite Claystone

Lithologically, this facies is not part of the MC-3 (carbonate) Member although it belongs to the MC-3 depositional cycle (Fig. 13). It is transitional to and correlated with either the MC-2 Member or the "Charles" Formation (Fig. 14).

The rocks of lithofacies D grade into the laminated dolomites, anhydrites, and claystones of lithofacies F. The abundance of very fine clay to silt-size terrigenous clastic material points to the proximity of subaerial coastal lowlands. The clastic materials, being of very fine grain size and even distribution within host beds, may have been introduced into the carbonate platform by winds. The claystone beds are finely laminated, indicating very low rates of sediment deposition coupled with very low energy levels. Periodic episodes of agitation are possibly indicated by the presence of discrete anhydrite nodules, although these nodules may in fact have been precipitated within the substrate material.

Altered Zone

As stated earlier, the rocks of the altered zone are totally diagenetic in origin. The distinctive mineralogical and textural characteristics of the zone allow it to be mapped as a discrete entity throughout the map area. The conversion of primary limestone lithofacies to dense dolomites points to a supply of Mg ions, as found within hypersaline brines. The clear anhydrite ("satin-spar") that infills fractures and voids further supports this supposition. Hypersaline brines associated with the deposition of the Amaranth red beds and evaporites are believed to be the cause of the extensive alteration.

Depositional Model
(Fig. 14)

The purpose in studying depositional environments and compiling them into a depositional model is to allow exploration geologists to define the particular group of rocks within which petroleum reservoirs are found, and to predict areas where similar favourable lithofacies can be found.

In southwest Manitoba, the need for such attention to depositional sequences is acute because remaining oil accumulations probably are controlled primarily by stratigraphic factors rather than by structural or paleotopographic features. The purpose of this section is to document lithofacies variations in the MC-3 Member, and to determine their impact upon hydrocarbon entrapment.

The following observations can be made concerning the depositional environments of the MC-3 Member:

1) micrite, both as matrix and as a grain constituent, is abundant;
2) coated (pisoid) and non-coated (peloid) grains are abundant;
3) fauna are relatively sparse and restricted;
4) primary anhydrites are usually lacking; and
5) a complex interbedding of various lithofacies is evident.

Figure 14 shows a possible depositional model for the MC-3 Member in the Pierson area. A marine carbonate shelf, upon which was deposited a sequence of lenticular carbonate bodies, was present in southwest Manitoba during this period. The model is based on carbonate platform facies models proposed by Shaw (1964), Irwin (1965), and Wilson (1975). The general model is one proposed for present-day carbonate deposition on the Bahama Banks.

The model suggests that the climate would have been semi-humid, subtropical, with average water salinities only moderately elevated (42 ppm, or 20% above normal seawater), one-quarter the salinity necessary to induce anhydrite precipitation (Enos, 1983). This would explain the relative lack of primary evaporites except in the most restricted, shoreward environments. The simplest facies pattern in the Bahamas is a progression from soft pellet mud in the most shoreward regions to hard pelletal sand towards the seaward platform margins.

The progression of coated grain packstone to muddy peloidal packstones and "clotted" mudstones across depositional strike at Pierson is similar to the Bahama's transition from higher energy platform marginal sediments to platform interior lagoonal sediments.

The sediments of the Mission Canyon Formation display cyclicity in response to sea level fluctations due to either periodic tectonic fluctuations or periodic eustatic adjustments. The MC-3 Member in the Pierson study area represents the predominantly carbonate portion of one such transgressive-regressive cycle (Fig. 13). A transgressive-regressive "kickback" present in the upper third of the cycle may be considered to be a minor subcycle of the MC-3 cycle. The base of this subcycle is represented by the MC-3 marker. The "MC-2 marker" is taken to be the base of the MC-3 cycle and represents a thin clastic layer spread upon the exposed sediment surface during maximum regression (Elliott, 1983). The anhydritic, highly variable rocks of lithofacies F (upper MC-2) represent the initial slightly restricted deposits of the advancing transgressive pulse. These strata grade upwards into the more normal subtidal environments of lithofacies A. The peak of the transgression was reached prior to the onset of coated grain deposition, which marks the initiation of the period of active shoal development at the beginning of the regressive phase of the cycle. The content of coated grains is greatest over minor paleotopographic highs, in response to more agitated shoaling environments. The paleotopographic elevation is expressed in a thinning of the basal transgressive unit (lithofacies F). Within this shoal zone can be expected predominantly "grainy" sequences as opposed to the off-shoal "muddy" sequences of the foreshoal, lagoonal and intrashoal paleoenvironments.

The vertical lithostratigraphic succession in the Pierson area is consistent with the pattern expected in a predominantly shallowing (shoaling)-upward cycle (James, 1979). This vertical sequence is also apparent laterally, and is thus consistent with Walther's Law. In Figure 15, the shoal to backshoal to lagoon transition is apparent between the 12-2-3-29 WPM and 4-16-3-28 WPM wells.

TRAPPING MECHANISM

Regional entrapment in the Pierson study area is caused by the truncation of MC-3 reservoir beds at the Mississippian erosion surface. Trapping of oil is due also to the development of an impermeable cap (the 'Altered Zone') caused by dolomitization and anhydritization at the unconformity surface. The presence of the overlying Lower Amaranth "Red Beds" provides a secondary reservoir cap. Localization of oil accumulation within this regional stratigraphic trap is controlled by the following factors:

1) structural features within the Mississippian (true deformational structure);
2) local paleotopographically high areas on the Mississippian erosion surface;
3) porosity and permeability variations within the MC-3 Member due to lithofacies variation;
4) local preservation of reservoir beds within Mississippian erosional lows (MC-3a A & MC-3a B Pools); and
5) porosity closure and lateral porosity pinch-out due to the variations in thickness of the "altered zone" lying immediately beneath the unconformity.

All of these trapping mechanisms make the process of prospect generation and evaluation subtle and complex. The general prospect concepts noted for the Pierson area are similar to those used in exploring for Mississippian oil in southeast Saskatchewan (Edie, 1959; Martin, 1966) and other areas of southwest Manitoba.

Trapping mechanisms and depositional environments of lithofacies specific to each pool are discussed individually, beginning with the MC-3a A Pool.

Pierson Field

MC-3a A Pool (07 43A)

The reservoir rocks within the MC-3a interval are coated grain packstones and grainstones of lithofacies B, indicative of a shoal to backshoal paleoenvironment. Core analyses from several wells suggest that fractures may play a significant role in reservoir performance. Oil is trapped in a porous and permeable sequence of packstone and grainstone beneath a water-wet micritic zone called the MC-3a middle seal (Figs. 5 & 16, cross-section A-A'). This points to the importance of a favourable grainstone reservoir in trapping oil in a purely stratigraphic accumulation unrelated to the unconformity or paleotopographic closure.

MC-3a B Pool (07 43B)

This pool is the largest of the Pierson Field pools, and oil is trapped within backshoal to lagoonal rocks of the MC-3a interval. The pool is situated within the MC-3a subcrop belt. Cross-section B-B' (Fig. 17) displays two features significant to the trapping mechanism of this pool:

1) progressive updip truncation of porous reservoir beds at the erosion surface as shown in (from) 3-21-3-28 WPM and (to) 3-22-3-28 WPM wells; and
2) facies changes from porous reservoir rocks to non-reservoir rocks as evidenced in the 4-25-3-28 WPM well.

The reservoir strata consist of a variety of backshoal/lagoonal lithofacies displaying complex depositional inter-relationships; they have been dolomitized to varying degrees along the northern portion of the pool. This dolomitization could have been due to a syngenetic mechanism such as seepage reflux dolomitization (Adams and Rhodes, 1960). Considering the presence of the stratigraphically equivalent "Dando Evaporite" to the east, such a mechanism appears to be appropriate. Variations in erosional thickness of the MC-3a beds reflect the presence of more resistant shoal lithofacies within the MC-3a interval. The MC-3a B Pool is the result of erosional truncation, in which oil is trapped within porous beds progressively truncated against the Paleozoic unconformity, as well as by updip and lateral facies changes from reservoir to non-reservoir rocks. This pool is thus a stratigraphic trap.

The porosity in some cases has been enhanced by dolomitization. The wells of the MC-3a B Pool (relative to other MC-3a Pools) have the lowest water-oil ratio. This may be due to the presence of an effective seat seal and the lack of the water zone beneath the oil saturated beds.

MC-3a C Pool (07 43C)

The trapping of hydrocarbon in this pool is due mainly to changes in lithofacies. The coated grain packstone to grainstone of lithofacies B is the main rock type in the MC-3a C Pool reservoir beds. Thinning of the MC-2 Member suggests the presence of a positive feature in the pool area during MC-3 time which resulted in higher energy levels and the precipitation of well-winnowed, coated grain deposits comprising the reservoir strata of lithofacies B type. Oil is trapped within the MC-3a interval below the altered zone in a favorable reservoir facies (Fig. 18, cross-section C-C').

The wells of the MC-3a C Pool have displayed good production characteristics due to the thick grainstone reservoir. Water-oil ratios increase where the producing reservoir beds are in communication with lower water-wet beds.

MC-3b B Pool (07 42B)

The MC-3b B Pool reservoir rocks are part of a complex backshoal depositional facies (lithofacies B & C) occurring on the flank of the shoal present in area of the MC-3a C Pool. The MC-3b B Pool was initially believed to have been separated from the MC-3a C Pool by a structural low; but current drilling has shown that the MC-3a C Pool sits outside the subcrop belt of the MC-3b interval and the subcrop edge separates the two pools. Oil in the

MC-3b B Pool is trapped within the MC-3b porous interval. Structure on erosion surface (Fig. 7) and MC-3 porosity contour map (Fig. 10) indicate a closure within the pool area. The cross-section C-C' (Fig. 18) also displays the structural high within the pool. Water to oil ratio increases where oil bearing grainstone beds at the top of the shoal zone are in communication with water-wet grainstone near the base of the shoal zone.

MC-3b D Pool (07 42D)

Entrapment in the MC-3b D Pool is purely stratigraphic in nature. Oil is trapped in the MC-3b interval due to an updip destruction of porosity caused by dolomitization and anhydritization of reservoir rocks (altered zone) immediately below the erosion surface (Fig. 18, Cross section C-C'). Cross-section C-C' indicates that the updip 6-3-3-29 WPM well has no porous MC-3b interval. In both the downdip wells, 13-32 and 15-32-2-29 WPM, the same interval is found to be porous and was perforated. Reservoir lithofacies consist of non-coated grain packstones of a backshoal environment (Lithofacies C). The MC-3a interval, which is water wet in this pool, is composed mostly of bioclastic wackestones and mudstones indicative of a foreshoal environment (Lithofacies A)

South Pierson

MC-3b A Pool (12 42A)

Mississippian production in this pool is from the MC-3b interval (Fig. 20, cross section E-E'). The trap is due mainly to facies change within the MC-3b interval. The reservoir rocks consist of intraclastic to peloidal lime wackestone of Lithofacies E with interbeds of lime mudstone to dolomite of Lithofacies D. These rocks may have been deposited in a broad lagoonal environment.

MC-3b B (12 42B), MC-3b A (99 42A) and MC-3 B (99 41B) Pools

These pools are single well completions and the trap in all three is due to an updip seal provided by porosity pinchout (Fig. 20, 21; cross-section E-E', F-F'). A thick section of MC-3a, MC-3b, and a thin portion of Charles Formation is found. Cross-section E-E' (Fig. 20) and cross-section F-F' (Fig. 21) show a dense (altered) zone below the thin "Charles" beds. The productive zones occur within the MC-3b interval, with the updip seal provided by a combination of porosity destruction associated with a facies change to lagoonal carbonates, and with replacement by dense dolomite and evaporites of the "altered zone" as evidenced in 7-34-2-28 WPM (Fig. 21, cross-section F-F'). The reservoir rocks in the MC-3b B Pool are composed of non-coated grain packstone of Lithofacies C, and in the MC-3b A (other areas) Pool they consist of dolomitic mudstone to lime mudstone of Lithofacies D.

In the MC-3 B Pool (99 41B) the entrapment is purely stratigraphic in nature. Oil in the 14-5-2-28 WPM is trapped in the MC-3 Member (undifferentiated) due to an updip destruction of porosity caused by dolomitization and anhydritization of reservoir rocks (altered zone, 11 m thick) in the 15-5-2-28 WPM well. The 14-5 abandoned producer has 4 m of oil column starting at 546 m subsea, this interval in 15-5 being tight. The porosity in 15-5 is developed at 552 m subsea, 2 m lower than the oil-water contact in 14-5.

RESERVOIR CHARACTERISTICS

Reservoir characteristics for the pools in the Pierson study area are summarized below in Table 1 in chronological order. The reservoir parameters have been obtained from core analyses. Average porosity for all pools is 14%, with average permeability ranging from 10 to 14 md within the reservoir interval. However, porosities as high as 22% and permeabilities as high as 793 md have also been recorded in places.

The dominant reservoir lithofacies are the coated grain packstones to grainstones of Lithofacies B and the non-coated grain packstones of Lithofacies C. However, in the MC-3a A Pool (07 43A), reservoir beds in a few wells (as in 9-16-3-29) are dolomitized lime mudstone to wackestone (Lithofacies A). In the South Pierson MC-3b A Pool (12 42A) the reservoir rocks in some wells (11-30-2-28 WPM) are intraclastic to peloidal lime mudstones (Lithofacies E). In the MC-3b A Pool of other areas (99 42A) the reservoir beds belong to Lithofacies D.

Table 1

Pool	Producing Interval	Lithofacies	Avg. Weighted Porosity	Avg. Weighted Permeability
PIERSON FIELD				
MC-3a A (07 43A) 9-16-3-29 WPM	MC-3a	Bioclastic lime mudstone to wackestone (A)	14.8%	5.1 md
MC-3a B (07 43B) 16-18-3-28 WPM	MC-3a	Non-coated grain packstone (C)	13.6%	14.6 md
MC-3a C (07 43C) 10-11-3-29 WPM	MC-3a	Coated grainstone (B)	12.2%	3.2 md
MC-3b B (07 42B) 15-7-3-28 WPM	MC-3b	Non-coated grain packstone (C)	11.1%	48 md
SOUTH PIERSON FIELD				
MC-3b A (12 42A) 11-30-2-28 WPM	MC-3b	Intraclastic to peloidal Lime mudstone (E)	13.9%	4.6 md
MC-3b B (12 42B) 14-20-2-28 WPM	MC-3b	Non-coated grain packstone (C)	13.5%	7.4 md
OTHER AREAS				
MC-3b A (99 42A) 4-34-2-28 WPM	MC-3b	Dolomitic mudstone (D)	14.63%	18 md

Four types of porosity dominate the reservoir facies:

1. interparticle to fenestral porosity, with excellent horizontal permeability but lesser vertical permeability (common in Lithofacies B and C);
2) intercrystalline porosity, present in the muddier rocks of Lithofacies C as matrix porosity and as diagenetic porosity in the dolomitized rocks of Lithofacies D and E;
3) moldic to intraparticle porosity, often solution-enlarged; and
4) solution-enlarged fracture-channel porosity.

In general as the rocks get "grainier" and the content of micritic matrix decreases, porosity and permeability increase. The best reservoir zones are found in the packstone to grainstone beds of the shoal to backshoal environments. As the percentage of micrite matrix increases and the percentage of peloids relative to coated grains increases, reservoir characteristics tend to become poorer.

Within the intercrystalline matrix porosity common in the packstones and wackestones, permeabilities are lower due to the decrease in pore-throat diameter. The decrease in pore-throat diameter for this matrix porosity does not affect the overall rock porosity as indicated on logs; however, a decrease in effective porosity occurs. Also, a mixed pore system composed of coarse interparticle porosity and fine intercrystalline matrix porosity may result in erroneous determination of water saturation if this factor is not taken into account.

The micritic porosity may also cause problems in log interpretation due to the high irreducible water saturation found within the matrix porosity, thus causing low bulk resistivities in reservoirs that are capable of commercial oil production. This low resistivity leads to a calculation of water saturation which is apparently too high to permit oil production; however, the oil occurs in the coarser (more permeable) porosity, and can thus be produced economically. Average Rt of grainstones, such as the reservoir beds of the Pierson MC-3b B Pool (07 42B), is approximately 30 to 35 ohms, whereas the resistivities of the backshoal packstones to wackestones of the

Pierson MC-3a B Pool (07 43B) are 3 to 5 ohms. Care must be taken when examining old well logs for overlooked pay, as potential oil-bearing porosities may be mistaken for water-wet zones.

The reservoir is streaky in nature, with the better porosities and permeabilities found within the "grainier" packstone-grainstone beds. A plot of log permeability versus porosity shows considerable scatter with little evidence of any direct correlation between porosity and permeability. The severe scatter may be due to variations in porosity types and, hence differing reservoir characteristics over the producing reservoir interval. The reservoir beds of the Pierson study area are thus heterogenous and of a very complex nature in terms of reservoir characteristics. Using a 1 md permeability cutoff, porosity cutoffs can be seen to range from 7.0% to approximately 7.8%, a very high cutoff for a carbonate reservoir.

Rapid production declines coupled with rapid increases in water cut indicate a water drive as the source of reservoir energy. Most wells which have been producing for a longer period of time have water cuts averaging 75-80%. Rapid water-coning may occur in a newly producing well due to a number of different factors; the lack of seat seal, fracturing of the seat seal, poor completion, or a too-rapid rate of production. A common completion practice during the early period of field development involved the injection of hydrochloric acid at pressures equal to, or slightly greater than, reservoir formation pressures. This treatment may have reopened fractures or acidized channels down through carbonate seat seals into underlying water-wet porosity zones. In most cases, a well defined oil-water contact cannot be picked; rather, a mixed oil water transition zone is present.

Appendix 1 summarizes the production histories of wells in the various pools of the Pierson area. Average daily oil production for a well in the Pierson area is 1.56 m^3, with an average water-oil ratio of 4.46.

SUMMARY

1. The MC-3 Member comprises the uppermost portion of the Mission Canyon Formation in Manitoba. It is bounded at the base by the MC-2 Member and at the top either by the argillaceous and anhydritic carbonates of the "Charles Formation" or by the "altered zone" below the Mississippian erosion surface. Where the MC-2 Member is poorly developed, the boundary between the MC-3 Member and the MC-1 Member is placed at the "MC-2 marker". Where identifiable, the "MC-3 marker" is used to subdivide the MC-3 Member into the lower "MC-3a interval" and the upper "MC-3b interval".

2. The MC-3 Member consists of a sequence of lithofacies deposited on a shallow carbonate shelf. This shelf was present over much of southwest Manitoba, southeast Saskatchewan, and central North Dakota. The following lithofacies have been recognized in the Pierson study area:

   A. Bioclastic lime mudstone to wackestone (foreshoal);
   B. Coated grain packstone to grainstone (shoal);
   C. Non-coated grain packstone (backshoal);
   D. Laminated lime mudstone to dolomite (distal lagoon);
   E. Intraclastic to peloidal lime mudstone to wackestone (intertidal, tidal channel, and shoal flank); and
   F. Massive to laminated dolomite (proximal lagoon) found mainly in MC-2 Member and "Charles" Formation.

   The rocks show some signs of vadose diagenesis (vadose pisolites), however, more petrographic examination is necessary to confirm this interpretation.

3. Reservoir rocks in the Pierson pools are primarily coated grain packstones to grainstones of Lithofacies B (Shoal) and the non-coated grain packstones of Lithofacies C (Backshoal). Porosity is interparticle, moldic, and intercrystalline. Average reservoir porosity is 14% with average permeability of 10 to 12 md.

4. The multiplicity of trap types suggests that the Pierson and South Pierson Fields are a regional but discontinuous, hydrocarbon accumulation. All traps are primarily stratigraphic. Local traps, however, may occur where favourable reservoir facies are coincident with either paleotopographic highs as seen in Mc-3b B Pool (07 42B), or on the crests and flanks of true structural highs as evidenced in the MC-3a A Pool (Fig. 14, structure on the MC-2 marker).

From the previous analysis, it becomes apparent that some of the following conditions must be met in order to localize hydrocarbon accumulation within the regional trap formed by the truncation of the Mission Canyon Formation in the Pierson study area:

1) presence of favourable reservoir rocks, principally Lithofacies B and/or C;
2) Some form of updip and lateral seal development by (a) dense, impermeable rocks (altered zone), (b) truncation of reservoir rocks by the unconformity (erosion) surface.

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APPENDIX I

Production Data - Pierson Study Area (Twp: 2&3, Rge: 28&29 WPM)

PIERSON FIELD

Location	Initial On-Production Date	Abandonment Date	Avg. Daily Production (1st 12 months of production) (m^3/d) Oil	Water	Avg. Water Cut 1st 12 month Production (%)	Cumulative Production to Dec.31,1986 (m^3) Oil	Water	Average Water Cut (%)
		Pool: MC-3a A	Pool Code: 07 43A		Producing Interval: MC-3a			
05-15-3-29	Aug/74	Susp. Dec/81	3.4	11.3	77	3 280	16 102	83
12-15-3-29	Sep/75	-	4.4	7.4	63	2 356	5 751	71
07-16-3-29	Nov/74	Jun/82	10.7	9.9	48	4 800	18 633	80
8A-16-3-29	Oct/74	Jun/82	9.7	3.9	29	7 357	14 666	67
09-16-3-29	Sep/75	-	4.3	1.3	23	3 452	12 665	78
10-16-3-29	Nov/84	-	1.5	2.5	62	1 054	2 082	66
11-16-3-29	Jul/84	-	3.0	1.4	32	2 159	1 531	41
16-17-3-29	Dec/84	-	2.1	3.2	60	1 550	2 597	63
					TOTAL PRODUCTION:	26 007	74 026	
		Pool: MC-3a B	Pool Code: 07 43B		Producing Interval: MC-3a			
16-07-3-28	Jun/85	SWD Sep/86	1.0	2.4	70	386	1 052	73
13-15-3-28	Sep/84	-	0.7	0.1	13	1 245	734	37
14-16-3-28	Sep/68	Nov/76	1.3	2.0	60	1 951	2 074	52
16-16-3-28	Dec/83	May/86	1.2	0.2	14	626	1 200	66
13-17-3-28	Nov/65	-	5.3	1.1	18	21 432	11 003	34
14-17-3-28	Sep/68	Aug/69	0.6	4.5	88	19	156	89
01-18-3-28	Jan/66	-	3.0	3.7	55	11 136	16 161	59
02-18-3-28	May/83	-	1.1	2.0	65	1 586	2 969	65
06-18-3-28	Feb/85	-	0.8	2.2	75	508	1 498	75
07-18-3-28	Jul/84	-	2.7	3.5	57	2 021	1 712	46
08-18-3-28	Apr/85	-	1.5	1.5	50	735	639	46
09-18-3-28	Dec/65	Nov/84	1.7	6.9	80	551	2 645	83
10-18-3-28	Aug/84	-	2.4	0.2	8	1 178	305	20
11-18-3-28	Feb/85	-	0.8	1.1	56	305	550	64
12-18-3-28	Feb/68	Nov/72	2.4	0.2	6	1 667	962	36
16-18-3-28	May/83	-	2.4	0.1	4	3 115	916	23
01-19-3-28	Sep/84	Sep/86	0.6	1.8	74	184	574	76
02-19-3-28	Feb/68	-	7.8	0.2	3	17 141	9 489	36
03-19-3-28	Feb/83	-	2.1	1.1	34	2 389	1 100	31
04-19-3-28	Feb/68	-	7.9	0.2	3	17 380	9 426	35
08-19-3-28	Aug/84	-	0.9	1.1	54	820	963	54
10-19-3-28	Sep/68	-	5.6	0.2	3	14 390	8 158	36

APPENDIX I (cont'd)

Production Data - Pierson Study Area (Twp: 2&3, Rge: 28&29 WPM)

PIERSON FIELD

Location	Initial On-Production Date	Abandonment Date	Avg. Daily Production (1st 12 months of production) (m^3/d)		Avg. Water Cut 1st 12 month Production (%)	Cumulative Production to Dec.31,1986 (m^3)		Average Water Cut (%)
			Oil	Water		Oil	Water	
		Pool: MC-3a B	Pool Code: 07 43B		Producing Interval: MC-3a			
11-19-3-28	Nov/83	-	0.2	0.0	4	88	9	9
01-20-3-28	Feb/83	never produced, waiting on evaluation.						
05-20-3-28	Jan/83	-	2.9	0.5	21	2 729	584	18
01-21-3-28	Aug/84	-	2.3	0.2	8	1 079	202	16
02-21-3-28	Jul/68	-	4.5	0.2	4	10 461	2 224	17
03-21-3-28	Aug/84	-	1.2	4.0	79	611	1 928	76
4A-21-3-28	Aug/68	-	2.6	1.3	33	7 476	5 092	40
03-22-3-28	May/84	-	0.4	6.8	95	29	518	95
A4-22-3-28	Apr/84	-	2.0	0.1	5	1 374	72	5
02-13-3-29	Jul/78	Nov/83	0.4	11.5	96	198	6 177	97
14-13-3-29	Dec/77	Nov/83	0.3	6.5	95	151	4 632	97
15-13-3-29	Mar/77	Nov/84	1.3	6.0	82	1 068	13 066	92
01-24-3-29	Aug/84	-	1.7	15.0	89	1 303	8 311	86
02-24-3-29	Aug/77	-	5.9	0.3	5	17 726	13 528	43
08-24-3-29	Apr/71	SWD Oct/80	3.7	2.9	44	4 488	5 273	54
					TOTAL PRODUCTION:	149 547	136 029	
		Pool: MC-3a C	Pool Code: 07 43C		Producing Interval: MC-3a			
13-02-3-29	Jul/54	Sep/55	2.7	4.2	61	796	1 243	61
02-11-3-29	Oct/54	-	3.3	0.9	21	14 845	85 073	85
03-11-3-29	Nov/54	-	5.4	2.4	31	14 472	37 832	72
04-11-3-29	Mar/55	Sep/82	2.8	3.6	56	2 612	16 684	86
05-11-3-29	Feb/55	-	5.7	0.7	11	34 252	70 480	67
06-11-3-29	Jan/55	-	3.9	0.8	17	14 777	72 316	83
07-11-3-29	Feb/54	-	7.7	0.1	1	23 791	38 705	62
10-11-3-29	May/54	SWD Dec/58	3.6	1.2	25	1 589	695	30
11-11-3-29	Nov/77	-	1.6	0.8	33	2 473	20 167	89
04-12-3-29	Oct/81	-	1.3	8.3	86	2 214	15 405	87
05-12-3-29	Nov/54	-	5.3	6.9	57	6 328	43 335	87
A12-12-3-29	Nov/81	-	2.1	0.2	8	1 828	6 850	79
					TOTAL PRODUCTION:	119 977	408 785	

APPENDIX I (cont'd)

Production Data - Pierson Study Area (Twp: 2&3, Rge: 28&29 WPM)

PIERSON FIELD

Location	Initial On-Production Date	Abandonment Date	Avg. Daily Production (1st 12 months of production) (m^3/d) Oil	Water	Avg. Water Cut 1st 12 month Production (%)	Cumulative Production to Dec.31,1986 (m^3) Oil	Water	Average Water Cut (%)
		Pool: MC-3b B	Pool Code: 07 42B		Producing Interval: MC-3b			
14-06-3-28	Jul/85	May/86	0.3	8.1	96	49	1 356	96
06-07-3-28	Feb/55	-	3.8	8.0	68	2 393	11 890	83
08-07-3-28	Aug/76	-	2.1	0.8	27	179	53	23
10-07-3-28	Feb/84	-	2.6	3.5	58	1 725	2 390	58
11-07-3-28	Nov/83	-	7.2	0.1	1	5 887	1 798	23
12-07-3-28	Feb/84	-	3.3	2.6	44	1 960	2 790	59
14-07-3-28	Feb/84	-	2.1	0.0	2	1 449	73	5
15-07-3-28	Jan/66	-	1.6	2.1	56	9 768	15 162	61
03-18-3-28	Aug/84	-	2.3	12.3	84	2 214	11 223	84
12-01-3-29	Nov/85	-	0.7	1.3	66	218	403	65
13-01-3-29	Jul/85	-	3.4	3.7	53	1 529	2 069	58
14-01-3-29	Oct/85	-	1.7	6.8	80	676	2 926	81
02-12-3-29	Jun/85	-	1.3	11.2	90	334	3 847	92
10-12-3-29	Apr/84	-	1.75	1.4	46	766	1 426	65
					TOTAL PRODUCTION:	29 145	57 404	
		Pool: MC-3b D	Pool Code: 07 42D		Producing Interval: MC-3b			
13-32-2-29	Jun/67	Sep/69	2.1	4.6	68	786	2 786	78
15-32-2-29	Feb/67	Sep/69	1.7	12.1	87	427	3 025	87
					TOTAL PRODUCTION:	1 231	5 811	
		Pool: MC-1 A	Pool Code: 07 44A		Producing Interval: MC-1			
04-25-3-28	Jan/84	Jun/86	0.7	5.2	88	86	629	88
					TOTAL PRODUCTION:	86	629	

Production Data - Pierson Study Area (Twp: 2&3, Rge: 28&29 WPM)

SOUTH PIERSON FIELD

Location	Initial On-Production Date	Abandonment Date	Avg. Daily Production (1st 12 months of production) (m^3/d) Oil	Water	Avg. Water Cut 1st 12 month Production (%)	Cumulative Production to Dec.31,1986 (m^3) Oil	Water	Average Water Cut (%)
		Pool: MC-3b A	Pool Code: 12 42A		Producing Interval: MC-3b			
05-30-2-28	Jul/83	-	1.7	3.2	65	1 292	3 550	73
11-30-2-28	Jan/83	-	1.0	3.1	76	783	3 192	80
12-30-2-28	Sep/81	-	5.8	11.7	67	4 385	12 932	74
14-24-2-29	May/83	L.Am.Prod. Mar/84	0.4	5.5	93	37	529	93
07-25-2-29	Mar/84	-	2.7	4.9	64	1 386	4 367	76
08-25-2-29	Jan/84	-	3.3	1.2	27	2 105	1 425	40
09-25-2-29	Aug/83	-	3.8	1.6	29	3 004	2 857	49
11-25-2-29	Jul/84	-	3.8	2.7	42	1 587	2 577	62
					TOTAL PRODUCTION:	14 579	31 429	
		Pool: MC-3b B	Pool Code: 12 42B		Producing Interval: MC-3b			
14-20-2-28	Jul/61	Aug/86	3.9	3.7	48	6 364	21 005	77
					TOTAL PRODUCTION:	6 364	21 005	

OTHER AREAS FIELDS

Location	Initial On-Production Date	Abandonment Date	Oil	Water	Avg. Water Cut (%)	Cumulative Oil	Cumulative Water	Average Water Cut (%)
		Pool: MC-3b A	Pool Code: 99 42A		Producing Interval: MC-3b			
04-34-2-28	Jan/63	Oct/64	1.8	8.3	82	278	1 268	82
06-34-2-28	Jul/85	-	2.0	0.6	24	630	473	43
					TOTAL PRODUCTION:	908	1 741	
		Pool: MC-3 B	Pool Code: 99 41B		Producing Interval: MC-3 (undifferentiated)			
14-05-2-28	Jan/81	Sep/86	0.4	0.2	36	208	218	51
					TOTAL PRODUCTION:	208	218	

SUMMARY OF MISSION CANYON TOTAL PRODUCTION

TO DECEMBER 31, 1986

PIERSON FIELD

Pools	Oil	Water
MC-3a A	26 007	74 026
MC-3a B	149 547	136 029
MC-3a C	119 977	408 785
MC-3b B	29 145	57 404
MC-3b D	1 213	5 811
MC-1 A	86	629
Total	325 975	682 684

SOUTH PIERSON FIELD

Pools	Oil	Water
MC-3b A	14 579	31 429
MC-3b B	6 364	21 055
Total	20 943	52 484

OTHER AREAS

Pools	Oil	Water
MC-3b A	908	1 741
MC-3 B	208	218
Total	1 116	1 959
GRAND TOTAL	348 034	737 127

APPENDIX II

Well Data - Pierson Study Area (Twp: 2&3, Rge: 28&29 WPM)

Location	K.B. (m)	Top of Lower Amaranth (subsea) (m)	Top of Mississippian (subsea) (m)	Top of MC-3b Porosity (subsea) (m)	Top of MC-3a Porosity (subsea) (m)	Top of MC-2 (subsea) (m)	Top of MC-2 Marker (subsea) (m)	Top of MC-1 (subsea) (m)
14-05-2-28	466.3	500.7	540.7	546.0	554.2	n.p.	n.p.	n.p.
15-05-2-28	463.6	502.0	539.0	551.3	561.7	n.p.	n.p.	n.p.
01-09-2-28	465.7	493.5	530.0	535.3	546.0	n.p.	n.p.	n.p.
16-09-2-28	461.5	490.5	528.5	538.2	550.4	561.4	564.0	566.9
01-11-2-28	456.0	482.5	519.0	523.0	535.2	546.5	549.0	554.7
12-19-2-28	466.4	492.0	n.p.	n.p.	n.p.	n.p.	n.p.	n.p.
14-20-2-28	465.0	486.0	522.0	524.0	535.0	554.6	559.0	562.6
01-22-2-28	459.0	479.0	515.7	519.4	525.0	547.5	550.0	553.0
12-27-2-28	464.0	473.0	509.0	516.0	522.0	n.p.	n.p.	n.p.
15-27-2-28	462.0	472.0	508.0	518.0	521.3	533.0	534.0	537.0
10-28-2-28	465.3	476.0	510.0	513.0	527.1	545.0	546.6	549.7
04-29-2-28	464.3	486.0	522.0	526.0	n.p.	n.p.	n.p.	n.p.
16-29-2-28	467.5	479.5	515.5	518.0	525.0	547.0	549.0	553.5
02-30-2-28	467.7	487.0	526.0	527.3	539.7	n.p.	n.p.	n.p.
05-30-2-28	467.0	485.0	523.0	524.0	536.0	n.p.	n.p.	n.p.
11-30-2-28	467.0	487.0	523.0	524.0	536.5	552.0	554.5	558.0
12-30-2-28	467.6	487.0	523.0	525.4	533.4	n.p.	n.p.	n.p.
04-34-2-28	464.2	467.0	505.0	511.0	517.9	n.p.	n.p.	n.p.
06-34-2-28	464.0	467.5	502.0	503.5	510.5	n.p.	n.p.	n.p.
07-34-2-28	463.2	466.0	501.0	508.8	510.8	524.0	526.0	530.3
16-05-2-29	478.6	523.4	559.4	564.4	580.4	n.p.	n.p.	n.p.
06-07-2-29	481.6	527.4	565.7	569.4	574.9	n.p.	n.p.	n.p.
11-08-2-29	480.6	524.4	562.0	573.4	583.4	608.4	609.4	612.4
16-08-2-29	477.5	520.5	558.5	567.5	574.5	608.3	610.0	615.0
08-09-2-29	473.5	521.5	558.5	560.0	571.5	n.p.	n.p.	n.p.
16-10-2-29	471.0	518.3	554.3	557.5	562.0	584.0	587.0	590.0
16-11-2-29	469.0	511.0	551.0	552.0	460.0	n.p.	n.p.	n.p.
04-15-2-29	475.3	515.0	551.0	552.2	555.7	582.2	585.0	587.7
10-15-2-29	472.0	514.0	548.4	560.0	565.0	578.0	579.0	581.0
04-21-2-29	480.8	511.0	547.4	548.7	556.0	574.0	577.0	579.0
10-21-2-29	477.3	506.5	543.0	550.3	557.7	573.7	575.3	577.7
09-24-2-29	465.9	495.0	532.0	534.6	n.p.	n.p.	n.p.	n.p.
14-24-2-29	469.6	493.4	531.4	536.4	n.p.	n.p.	n.p.	n.p.
07-25-2-29	468.7	488.3	526.3	528.3	541.3	n.p.	n.p.	n.p.
08-25-2-29	468.5	486.5	523.5	526.5	537.5	n.p.	n.p.	n.p.
09-25-2-29	466.3	488.0	524.0	525.7	538.7	n.p.	n.p.	n.p.
11-25-2-29	470.1	487.0	523.0	525.0	537.0	555.0	558.0	560.0
16-25-2-29	468.5	485.5	522.0	525.5	535.5	n.p.	n.p.	n.p.

e = eroded
n.p. = not penetrated

APPENDIX II (cont'd)

Well Data - Pierson Study Area (Twp: 2&3, Rge: 28&29 WPM)

Location	K.B. (m)	Top of Lower Amaranth (subsea) (m)	Top of Mississippian (subsea) (m)	Top of MC-3b Porosity (subsea) (m)	Top of MC-3a Porosity (subsea) (m)	Top of MC-2 (subsea) (m)	Top of MC-2 Marker (subsea) (m)	Top of MC-1 (subsea) (m)
10-18-3-28	473.7	468.0	505.0	e	512.0	520.0	522.0	525.0
11-18-3-28	474.4	472.0	508.0	e	515.0	525.6	527.6	532.6
12-18-3-28	473.0	470.0	505.0	e	515.0	n.p.	n.p.	n.p.
13-18-3-28	471.7	470.0	505.0	e	510.0	525.0	528.0	530.0
15-18-3-28	472.4	470.0	506.0	e	516.0	n.p.	n.p.	n.p.
16-18-3-28	472.5	468.0	506.0	e	509.0	521.0	522.5	525.5
01-19-3-28	473.4	466.0	499.0	e	504.0	517.0	519.0	524.0
02-19-3-28	472.4	468.0	504.0	e	509.0	n.p.	n.p.	n.p.
03-19-3-28	474.3	468.0	499.0	e	510.0	518.0	520.0	n.p.
04-19-3-28	473.6	469.0	505.0	e	507.0	n.p.	n.p.	n.p.
06-19-3-28	474.0	464.0	501.0	e	511.0	n.p.	n.p.	n.p.
08-19-3-28	473.0	464.0	500.0	e	507.0	514.0	515.0	517.0
10-19-3-28	473.6	465.0	496.0	e	501.0	n.p.	n.p.	n.p.
11-19-3-28	472.9	469.0	503.0	e	510.0	513.0	514.0	518.0
12-19-3-28	474.3	468.0	505.0	e	509.0	n.p.	n.p.	n.p.
01-20-3-28	471.3	465.0	502.0	e	508.0	513.0	515.0	518.0
03-20-3-28	473.3	464.0	500.0	e	506.0	514.0	515.0	517.0
04-20-3-28	471.8	466.0	498.0	e	505.0	n.p.	n.p.	n.p.
05-20-3-28	474.8	465.0	501.0	e	505.0	512.0	515.0	517.0
01-21-3-28	469.8	459.0	496.0	e	500.0	507.0	510.0	513.0
02-21-3-28	469.0	459.0	497.0	e	500.0	n.p.	n.p.	n.p.
03-21-3-28	470.0	460.0	494.0	e	498.0	508.0	510.0	513.0
04-21-3-28	471.5	461.0	498.0	e	501.0	508.5	n.p.	n.p.
10-21-3-28	469.0	458.0	495.0	e	497.0	n.p.	n.p.	n.p.
02-22-3-28	471.2	455.0	492.0	e	497.0	500.0	502.0	505.0
03-22-3-28	469.3	456.0	492.0	e	495.0	500.0	503.0	507.0
04-22-3-28	470.0	457.0	493.0	e	496.0	503.0	506.0	509.0
04-25-3-28	464.6	440.5	471.0	e	474.0	479.0	481.0	483.5
08-25-3-28	463.6	434.0	463.0	e	463.0	469.4	470.4	476.4
04-26-3-28	469.7	446.0	479.0	e	482.0	489.0	491.0	493.0
08-26-3-28	464.6	440.0	469.0	e	472.0	476.4	478.4	483.4
02-27-3-28	467.2	450.0	484.0	e	488.0	491.0	494.0	500.5
04-29-3-28	473.5	461.0	496.0	e	500.0	505.5	507.0	510.0
04-30-3-28	475.5	463.5	498.0	e	503.5	506.0	506.0	508.0
12-01-3-29	473.4	487.0	521.0	527.0	534.6	553.0	555.0	558.0
13-01-3-29	473.3	485.0	520.0	523.0	528.7	546.7	549.0	552.7
14-01-3-29	473.2	483.0	520.0	526.0	531.0	551.0	553.0	556.0
12-02-3-29	477.0	490.0	526.0	531.0	535.0	548.0	549.0	n.p.

e = eroded
n.p. = not penetrated

APPENDIX II (cont'd)

Well Data - Pierson Study Area (Twp: 2&3, Rge: 28&29 WPM)

Location	K.B. (m)	Top of Lower Amaranth (subsea) (m)	Top of Mississippian (subsea) (m)	Top of MC-3b Porosity (subsea) (m)	Top of MC-3a Porosity (subsea) (m)	Top of MC-2 (subsea) (m)	Top of MC-2 Marker (subsea) (m)	Top of MC-1 (subsea) (m)
12-26-2-29	471.2	495.0	531.0	536.0	546.0	559.0	562.0	564.0
06-28-2-29	479.0	502.5	538.0	545.0	553.0	568.0	569.0	574.0
02-29-2-29	481.0	515.0	545.0	552.3	562.0	577.0	578.0	582.0
13-32-2-29	480.8	503.3	540.3	542.1	552.5	565.8	567.7	n.p.
15-32-2-29	482.0	493.4	533.0	539.7	542.7	559.3	561.0	564.7
04-36-2-29	469.0	487.5	524.0	528.0	539.0	559.0	562.0	564.0
05-36-2-29	468.8	485.2	521.8	527.0	537.6	555.3	558.4	561.4
04-01-3-28	462.5	465.3	501.3	Charles facies and/or altered zone		520.5	522.5	525.5
14-06-3-28	471.9	478.0	512.6	517.0	527.0	542.0	544.0	546.0
05-07-3-28	471.7	483.0	511.0	520.0	524.0	535.6	538.0	540.3
06-07-3-28	472.4	480.0	511.0	513.0	519.4	534.6	537.4	539.5
07-07-3-28	471.6	476.0	511.0	517.0	522.4	532.0	535.0	538.0
08-07-3-28	471.0	474.0	508.0	513.5	519.6	532.0	534.0	536.7
10-07-3-28	471.5	474.0	505.0	508.5	517.5	531.5	533.5	536.0
11-07-3-28	472.8	472.0	504.0	507.0	516.0	530.0	n.p.	n.p.
12-07-3-28	472.0	481.0	509.0	512.0	517.5	532.0	535.0	538.0
13-07-3-28	472.0	478.5	504.0	508.0	517.0	534.0	535.0	537.5
14-07-3-28	471.4	477.0	504.0	510.0	514.6	533.0	534.0	536.6
15-07-3-28	470.0	474.0	505.0	508.0	513.9	531.0	532.0	535.2
16-07-3-28	471.9	473.5	510.0	e	513.0	527.0	529.0	531.6
13-08-3-28	471.7	470.0	506.0	e	511.0	525.8	528.3	530.8
12-10-3-28	468.5	464.0	501.0	e	505.3	n.p.	n.p.	n.p.
02-14-3-28	466.0	456.0	491.0	e	497.0	500.0	502.0	506.0
13-15-3-28	468.4	456.0	494.0	e	499.0	505.0	508.0	511.0
04-16-3-28	470.6	465.0	502.0	r	505.0	521.0	523.0	527.0
10-16-3-28	470.3	460.0	495.0	e	499.0	n.p.	n.p.	n.p.
14-16-3-28	471.0	466.0	500.0	e	504.0	n.p.	n.p.	n.p.
16-16-3-28	466.8	461.0	498.5	e	500.0	510.0	513.0	515.0
05-17-3-28	469.5	470.0	506.0	e	511.3	523.6	526.0	528.0
13-17-3-28	473.0	467.0	504.0	e	508.4	n.p.	n.p.	n.p.
14-17-3-28	472.7	465.0	503.0	e	506.0	n.p.	n.p.	n.p.
01-18-3-28	470.6	471.0	507.0	e	512.7	524.8	527.0	530.0
02-18-3-28	472.0	476.5	501.0	504.0	513.0	527.0	530.0	532.0
03-18-3-28	472.0	478.0	505.0	507.0	516.5	532.0	533.0	535.0
06-18-3-28	470.5	472.0	506.0	513.5	517.7	530.5	532.5	534.0
07-18-3-28	473.0	476.0	504.0	513.0	515.0	527.0	529.0	531.0
08-18-3-28	471.7	477.0	508.0	511.0	513.0	524.0	526.0	528.0
09-18-3-28	470.6	475.0	506.0	e	510.0	520.0	522.0	524.0

e = eroded
n.p. = not penetrated

APPENDIX II (cont'd)

Well Data - Pierson Study Area (Twp: 2&3, Rge: 28&29 WPM)

Location	K.B. (m)	Top of Lower Amaranth (subsea) (m)	Top of Mississippian (subsea) (m)	Top of MC-3b Porosity (subsea) (m)	Top of MC-3a Porosity (subsea) (m)	Top of MC-2 (subsea) (m)	Top of MC-2 Marker (subsea) (m)	Top of MC-1 (subsea) (m)
13-02-3-29	476.0	490.0	525.0	528.0	533.0	545.0	546.0	549.0
06-03-3-29	479.8	497.0	533.0	e	538.5	554.7	557.0	560.0
02-04-3-29	482.2	502.4	539.0	543.0	546.2	561.0	563.0	566.3
01-08-3-29	484.0	497.4	537.0	544.0	546.0	561.0	563.0	566.0
13-08-3-29	488.9	495.0	526.0	531.0	539.5	554.0	556.5	559.5
08-10-3-29	478.5	488.0	520.0	e	523.0	n.p.	n.p.	n.p.
09-10-3-29	478.0	488.0	520.0	e	524.0	n.p.	n.p.	n.p.
02-11-3-29	476.0	487.0	521.0	e	526.0	n.p.	n.p.	n.p.
03-11-3-29	475.2	488.0	520.0	e	525.0	n.p.	n.p.	n.p.
04-11-3-29	476.7	491.0	522.0	e	525.0	n.p.	n.p.	n.p.
05-11-3-29	477.6	490.0	520.7	e	520.8	n.p.	n.p.	n.p.
06-11-3-29	474.3	486.0	516.0	e	519.0	n.p.	n.p.	n.p.
07-11-3-29	475.5	484.0	515.0	e	518.0	n.p.	n.p.	n.p.
08-11-3-29	473.4	484.0	520.0	e	522.0	n.p.	n.p.	n.p.
10-11-3-29	475.2	484.0	517.0	e	520.0	n.p.	n.p.	n.p.
11-11-3-29	475.2	487.0	518.0	e	520.0	n.p.	n.p.	n.p.
02-12-3-29	472.4	479.0	515.0	518.0	526.0	544.0	546.0	549.0
04-12-3-29	475.0	483.0	519.0	e	522.0	544.0	n.p.	n.p.
05-12-3-29	474.0	482.0	517.0	e	523.0	n.p.	n.p.	n.p.
10-12-3-29	474.6	477.0	513.0	515.0	525.0	540.0	542.0	546.0
12-12-3-29	472.1	483.0	518.0	e	521.0	n.p.	n.p.	n.p.
02-13-3-29	473.4	478.0	514.0	e	516.0	n.p.	n.p.	n.p.
04-13-3-39	474.0	480.0	517.0	e	519.0	540.0	540.0	n.p.
07-13-3-29	474.0	476.0	512.0	e	514.7	n.p.	n.p.	n.p.
10-13-3-29	474.9	473.0	510.0	e	514.5	n.p.	n.p.	n.p.
12-13-3-29	474.0	478.5	514.0	e	518.0	n.p.	n.p.	n.p.
14-13-3-29	475.8	475.0	512.0	e	517.0	n.p.	n.p.	n.p.
15-13-3-29	474.3	473.0	510.0	e	515.0	n.p.	n.p.	n.p.
16-13-3-39	474.6	470.0	508.0	e	516.0	n.p.	n.p.	n.p.
07-14-3-29	483.0	472.0	509.0	e	516.5	536.0	537.0	540.0
05-15-3-29	481.0	489.0	523.0	e	527.0	541.0	544.0	546.0
12-15-3-29	480.6	490.0	527.0	e	529.0	n.p.	n.p.	n.p.
03-16-3-29	482.0	492.4	524.0	527.0	531.5	548.0	549.4	552.5
06-16-3-29	484.0	488.5	519.0	523.0	527.5	540.2	542.0	545.4
07-16-3-29	482.0	490.0	521.0	e	525.0	n.p.	n.p.	n.p.
08-16-3-29	479.0	488.0	520.0	e	524.0	537.0	539.0	543.0
09-16-3-29	482.0	489.0	521.0	e	526.0	n.p.	n.p.	n.p.
10-16-3-29	481.0	488.0	520.0	e	526.0	536.0	537.0	540.0
11-16-3-29	482.7	487.5	518.0	e	520.0	536.0	538.0	542.0

e = eroded
n.p. = not penetrated

APPENDIX II (cont'd)

Well Data - Pierson Study Area (Twp: 2&3, Rge: 28&29 WPM)

Location	K.B. (m)	Top of Lower Amaranth (subsea) (m)	Top of Mississippian (subsea) (m)	Top of MC-3b Porosity (subsea) (m)	Top of MC-3a Porosity (subsea) (m)	Top of MC-2 (subsea) (m)	Top of MC-2 Marker (subsea) (m)	Top of MC-1 (subsea) (m)
12-16-3-29	486.2	487.0	517.0	e	520.0	537.0	538.0	541.0
13-16-3-29	486.2	486.0	517.0	e	520.0	534.0	535.0	539.0
16-16-3-29	481.2	488.0	520.0	e	525.0	538.0	539.0	543.0
06-17-3-29	487.6	490.4	515.0	516.4	529.4	548.4	550.0	553.4
11-17-3-29	488.5	489.5	516.5	518.5	527.5	544.5	546.3	550.0
13-17-3-29	489.3	489.7	517.2	519.7	525.7	542.7	544.3	547.7
16-17-3-29	485.0	486.0	517.0	e	519.0	535.0	537.0	541.0
06-18-3-29	492.0	494.5	525.5	527.0	536.0	553.0	555.0	558.0
07-20-3-29	488.6	484.0	514.0	517.8	519.6	535.0	538.0	542.0
08-21-3-29	482.2	486.0	514.0	e	518.0	531.0	532.0	536.0
11-21-3-29	483.7	484.0	517.0	e	520.0	526.0	528.0	531.0
14-21-3-29	484.0	481.0	514.0	e	516.0	526.0	527.0	531.0
03-22-3-29	480.4	484.0	518.0	e	520.0	n.p.	n.p.	n.p.
10-23-3-29	478.5	471.0	507.0	e	511.0	523.0	524.0	528.0
01-24-3-29	474.3	469.0	504.0	e	513.0	521.0	523.0	526.0
02-24-3-29	474.0	473.0	509.0	e	515.0	n.p.	n.p.	n.p.
04-24-3-29	475.2	475.0	511.0	e	518.0	528.0	530.0	533.0
06-24-3-29	475.2	471.0	510.0	e	515.0	n.p.	n.p.	n.p.
08-24-3-29	475.5	470.0	507.0	e	512.0	n.p.	n.p.	n.p.
10-24-3-29	475.5	470.0	502.0	e	509.0	n.p.	n.p.	n.p.
08-26-3-29	477.6	466.0	502.0	e	510.0	512.0	514.0	516.0
04-27-3-29	484.0	482.0	516.0	e	522.0	524.0	524.0	527.0
12-29-3-29	493.2	485.0	524.0	e	526.0	529.0	530.0	533.0
13-31-3-29	498.3	482.5	515.0	e	520.3	522.0	524.0	527.0

e = eroded
n.p. = not penetrated