Petroleum Open File Report POF 11-90

Regional Geology and Petroleum Potential of the Lower Amaranth Formation, Coulter-Pierson Area, Southwestern Manitoba

By Muzaffar Husain

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Winnipeg, 1990

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INTRODUCTION

The Lower Amaranth (Red Beds) Formation, described as the Lower Amaranth Member of the Amaranth Formation by McCabe (1956), is present over a large area of the Manitoba portion of the Williston Basin (Figures 1 and 2). Monthly oil production in excess of 17 000 m^3 (107 000 bbl) is obtained from discontinuous, fine grained sandstone and siltstone beds in the lower portion of this formation in the Waskada and South Pierson Fields in southwestern Manitoba. Limited production also occurs in and around the Coulter Field. This oil production accounts for approximately 27 percent of the monthly (March, 1990 data) production of 62 840 m^3 (395 260 bbl) in southwest Manitoba. The remaining 73 percent is produced from Mississippian rocks. This report describes the geology of the Lower Amaranth Formation in the Coulter-Pierson area and compares it to that of the Waskada and South Pierson areas. An interpretation of the depositional environment for the Lower Amaranth mudstone-siltstone-sandstone sequence is presented as is a discussion of the hydrocarbon potential.

STUDY AREA

The study area is located in the extreme southwest corner of Manitoba on the northeast flank of the Williston Basin (Figure 1). It includes 9 townships, (Twp. 1-3, Rge. 27-29; Figure 2) and is bounded by the Canada-U.S.A. border to the south and the Manitoba-Saskatchewan border to the west. In this report the study area is also referred to as "Coulter-Pierson" area.

PURPOSE AND METHOD OF STUDY

The purpose of this study is; 1) to provide a compilation of available well data, 2) to give a synopsis of past and present exploration, development and oil production activity in the area, 3) to describe the regional geological setting, 4) to outline the detailed stratigraphy, sedimentation, factors and problems related to oil accumulation, 5) to present the environment of deposition of the lithofacies, 6) to analyse hydrocarbon trapping mechanisms, 7) to evaluate the hydrocarbon potential with respect to lithofacies of the Lower Amaranth Formation in the "Coulter-Pierson" area, 8) to provide explorationists with new ideas concerning potential hydrocarbon traps and problems related to well completion, and 9) to aid explorationists in future exploration for hydrocarbons in the Lower Amaranth Formation in southwest Manitoba.

The report includes data from 272 wells drilled to June 30, 1989. Lithologic descriptions and related characteristics were obtained from a study of 327 metres of drill core from 16 selected wells in the study area. Production history was compiled from material submitted by the operators. Well log data were picked and calculated from electric and gamma ray logs. Porosities and permeabilities were determined from core analyses available in technical well files.

Two structure and four isopach maps (1:50 000) were constructed to illustrate geological information in the study area. Four regional cross-sections are presented to show the distribution of the Lower Amaranth Formation in the Coulter-Pierson area. Six cross-sections illustrating thickness, pattern and continuity of reservoir facies in each pool are presented.

EXPLORATION AND PRODUCTION HISTORY

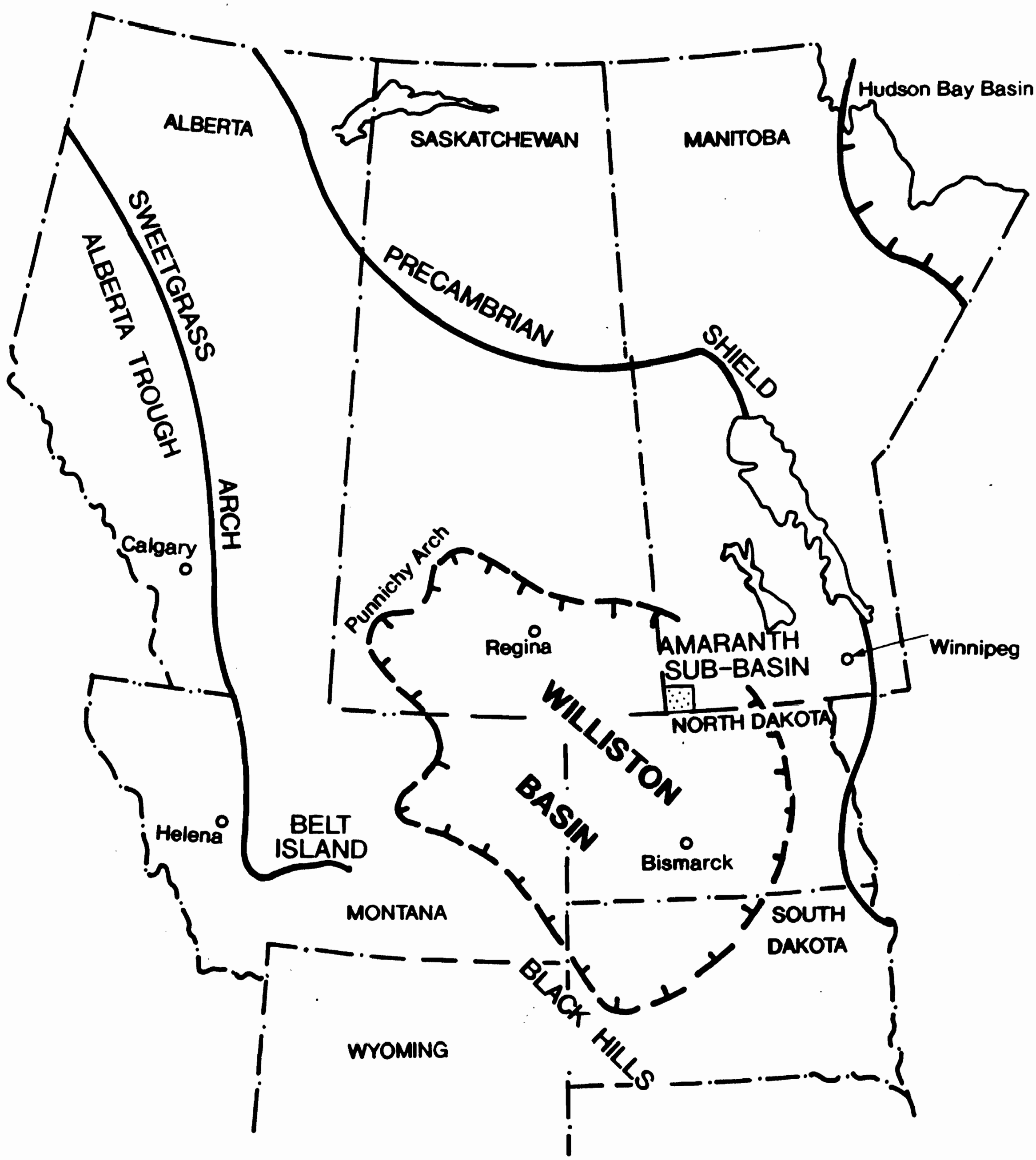
Oil production from the Mississippian Mission Canyon Formation has continued for 30 years in southwestern Manitoba. Exploration for oil in the Lower Amaranth Formation in the Coulter-Pierson area commenced as a result of discovery and subsequent development of the Waskada Lower Amaranth A Pool in 1980 by Omega Hydrocarbons Ltd. Based on limited well data, the geology and petroleum potential of the Waskada-Pierson area was described by Barchyn (1982).

Three oil fields, Coulter, Pierson and South Pierson, have been designated in the study area (Figure 3, in pocket). Lower Amaranth oil production is restricted mainly to the Coulter and South Pierson fields and two small pools outside these field boundaries that are designated under "Other Areas". Production in the Pierson Field is from the Mission Canyon Formation. Figure 3 (in pocket) shows Lower Amaranth pool boundaries and pool codes as designated by the Petroleum Branch of Manitoba Energy and Mines.

In September of 1981 Lyleton Corporation discovered oil in the Lower Amaranth Formation at the 12-30-2-28 WPM well and established the first Lower Amaranth Pool in the South Pierson Field. Previous production from the field was from the Mississippian Mission Canyon Formation. Because of low productivity and completion difficulties, development of this pool was limited.

In December 1982 Newscope Resources Ltd. drilled and completed the 11-21-1-27 WPM well establishing the first Lower Amaranth Pool in the Coulter Field. In the first 12 month period the well produced 238 m^3 of oil and 4 261 m^3 of water (94% water cut). Subsequent to this discovery seven wells were drilled in the pool within a one year period. Average water cut in the Coulter Field is 88 percent.

In June 1983, Rideau Petroleums Ltd. completed 14-27-1-28 WPM well and established the Other Areas Lower Amaranth "D" Pool. Three additional wells were drilled, but because of low productivity and high water cut the pool was abandoned in June 1987.



SEDIMENTARY BASINS

STUDY AREA

Figure 1: Location of the Williston Basin and major tectonic elements. (Modified from: Carlson, 1968; Christopher, 1984).

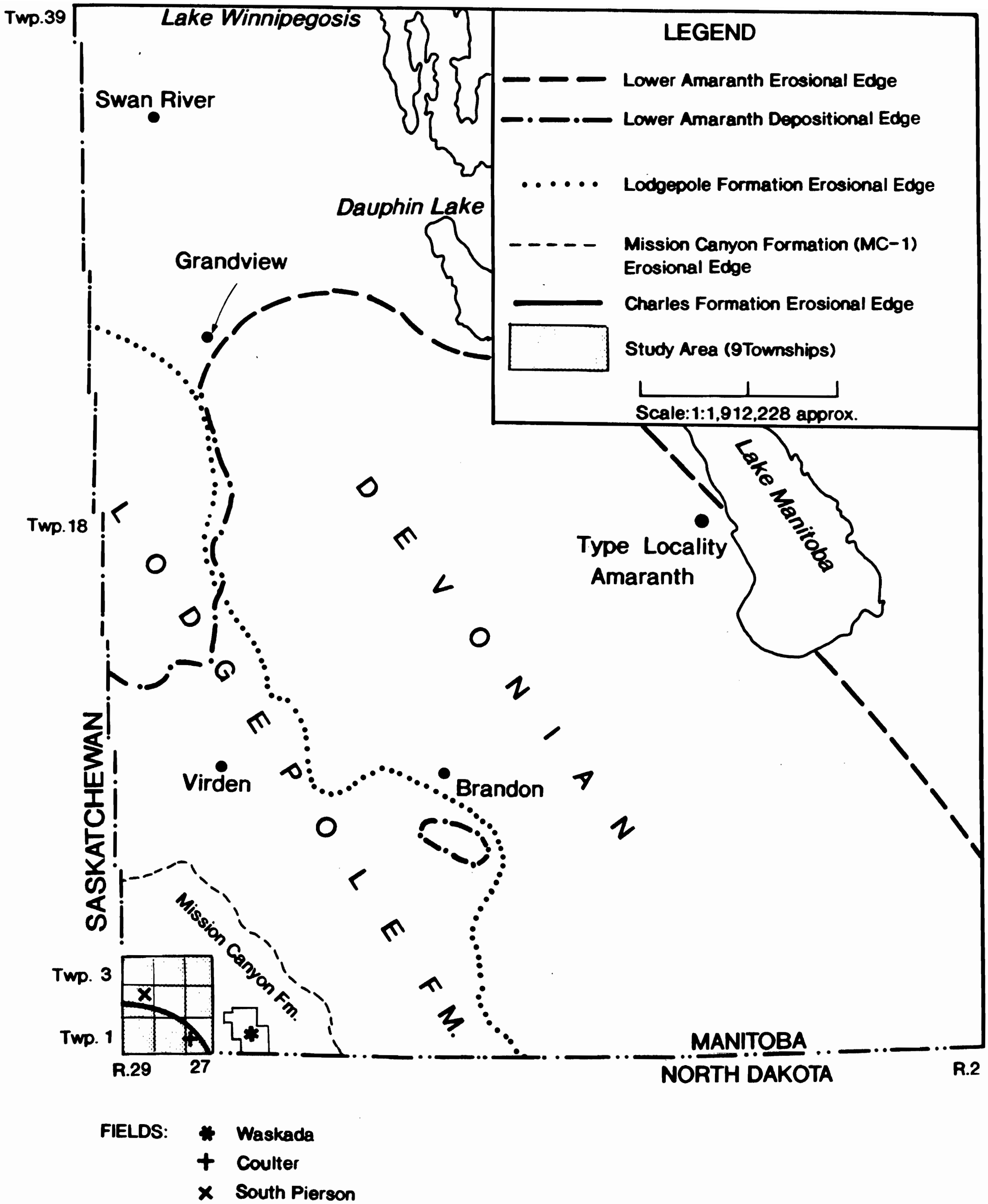


Figure 2: *Location of study area and distribution (subcrop edges) of Amaranth and Paleozoic formations in southwestern Manitoba. (Modified from: Stott, 1955; McCabe, 1956: Hansen, 1987).*

In 1985, Home Oil Company made a significant discovery in the Lower Amaranth Formation at 16-8-2-29 WPM well, with initial production rate of 9.9 m^3/d (62 bopd), a very high rate for Manitoba production. This resulted in an active delineation and development program in the South Pierson Field. To date Home has drilled 23 wells in the area; 16 are producing.

The exploration and development history of each pool in the study area is described in Table 1, and Table 2 provides historical production data on individual wells in every pool of the study area..

TABLE 1
EXPLORATION AND DEVELOPMENT HISTORY

FIELD	POOL	POOL CODE	DISCOVERY DATE	DISCOVERY WELL	NO. OF WELLS DRILLED	PROSPECTS FOR ADDITIONAL DEVELOPMENT*
Pierson	A	07 29A	Feb/84	04-26-3-28	1	Nil
Coulter	A	11 29A	Dec/82	11-21-1-27	8	6
South	A	12 29A	Sept/81	12-30-2-28	7	4
Pierson	B	12 29B	Dec/85	16-08-2-29	14	19
	C	12 29C	June/87	06-19-2-29	2	3
	D	12 29D	Jan/88	04-01-2-29	1	2
	E	12 29E	Dec/86	06-07-2-29	1	2
Other	B	99 29B	Dec/80	14-05-2-28	1	Nil
Areas	D	99 29D	June/83	14-27-1-28	4	Nil

* based on 16 hectare spacing

TERMINOLOGY

The term "Amaranth" was first proposed by Kirk (1929) for the reddish-brown siltstones and dolomitic shales that occur near the town of Amaranth, Manitoba (Figure 2). This sequence occurs at the base of the Mesozoic section. It was later traced by Wickenden (1945) from the type locality into the subsurface and was formally defined as the "Amaranth Formation" at 2-9-8-26 WPM and 14-15-9-3 WPM wells. The Amaranth sequence was subdivided by Stott (1955) into the Upper Amaranth Unit, composed mainly of evaporites, and the Lower Amaranth Unit, comprising mudstone in its upper part and siltstone with sandstone in its lower part. McCabe (1956) redefined the "unit" as a "member" and Hansen (1987) followed the "member" terminology. Barchyn (1982), Rodgers (1986), and Husain and Halabura (1987) described the Lower Amaranth sequence not as a "lower member" of the Amaranth Formation, but rather as the "Lower Amaranth Formation".

The Lower Amaranth sequence has not been formally named according to the Code of Stratigraphic Nomenclature. Nevertheless, in this report the term "Formation" is used, in an informal manner, for the Upper and Lower Amaranth sedimentary rock sequences.

TABLE 2
LOWER AMARANTH PRODUCTION DATA
COULTER PIERSON AREA
(Twp: 1, 2 & 3; Rge: 27, 28, 29 WPM)

Field	Pool Code	Location WPM	Date On Prod.	Date Aband.	1st 12 mo. Prod. m^3 Oil	Water	Avg. Wtr Cut 1st 12 mo. Prod. %	Cumm. Prod. to Dec. 31, 1989 (m) Oil	Water	Avg. Wtr Cut %
Pierson	07 29A	04-26-3-28	Feb/84	Nov/87	42	112	72	42	112	72
				Total Production from Pierson "A" Pool				**42**	**112**	
Coulter	11 29A	13-16-1-27	Mar/83		279	91	24	1 175	205	15
		09-20-1-27	Feb/83		537	2 580	83	717	3 316	82
		11-20-1-27	Mar/83		68	4 645	98	71	4 645	98
		11-21-1-27	Dec/82		238	4 261	94	1 341	30 976	96
		A12-22-1-27	Mar/83		53	77	59	53	77	59
		03-29-1-27	Apr/83		103	204	66	549	338	38
		01-30-1-27	Mar/83		460	78	14	1 287	231	15
		09-30-1-27	Nov/83	Nov/85	100	1 062	91	100	1 062	91
				Total Production from Coulter "A" Pool				**5 294**	**40 850**	
South Pierson	12 29A	12-19-2-28	Apr/86		49	2	4	100	2	2
		02-30-2-28	Jan/83	Nov/83	11	432	97	11	432	97
		12-30-2-28	Sep/81	Jun/82	1 386	2 769	66	1 386	2 769	66
		03-24-2-29	Mar/88		67	60	47	67	60	47
		08-24-2-29	Dec/87		456	87	16	995	141	12
		09-24-2-29	Jun/82		867	4 360	83	6 407	39 741	86
		14-24-2-29	Jul/84	Sep/86	234	623	72	347	898	72
				Total Production from S. Pierson "A" Pool				**9 313**	**44 043**	
	12 29B	06-04-2-29	Mar/87	SWD, Mar/88	115	827	88	115	827	88
		14-04-2-29	Jul/88		2 123	1 020	32	2 888	1 219	30
		16-05-2-29	May/86		2 721	2 305	46	6 749	6 692	49
		08-08-2-29	Aug/88		2 967	5 897	66	4 011	7 510	58
		16-08-2-29	Dec/85		2 152	900	29	6 130	1 393	18
		04-09-2-29	Aug/88		1 808	5 098	73	2 326	7 251	76
		12-09-2-29	May/88		3 023	646	17	4 639	978	17
		14-09-2-29	Mar/88		2 093	12 730	86	3 558	25 734	88
		16-09-2-29	Oct/87		2 742	399	13	6 267	871	12

TABLE 2 (continued)

Field	Pool Code	Location WPM	Date On Prod.	Date Aband.	1st 12 mo. Prod. m^3 Oil	Water	Avg. Wtr Cut 1st 12 mo. Prod. %	Cumm. Prod. to Dec. 31, 1989 (m) Oil	Water	Avg. Wtr Cut %
		06-10-2-29	Aug/88		1 647	6 497	80	2 266	9 445	80
		08-10-2-29	Dec/87		1 374	8 470	86	2 326	19 250	89
		16-10-2-29	Oct/86	Sus. May 87	-	251	100	-	251	100
		04-15-2-29	May/86		2 412	172	6	8 180	780	8
		06-17-2-29	Oct/88		843	3 559	81	969	4 507	82
		04-21-2-29	Sep/86		-	142	100	-	742	100
		10-21-2-29	Mar/87		-	62	100	-	62	100
				Total Production from S. Pierson "B" Pool				**50 424**	**87 512**	
	12 29C	06-19-2-29	Jun/87		1 420	19	1	3 332	39	1
				Total Production from Pierson "C" Pool				**3 332**	**39**	
	12 29D	04-01-2-29	Jan/88		85	1 363	94	85	1 363	94
				Total Production from Pierson "D" Pool				**85**	**1 363**	
	12 29E	06-07-2-29	Dec/86	Sus. Jul/87	42	700	94	42	700	94
				Total Production from Pierson "E" Pool				**42**	**700**	
Other Areas	99 29B	14-05-2-28	Dec/80	Jan/81 (Recomp MC3-b)	47	46	49	47	46	49
				Total Production from Other Areas "B" Pool				**47**	**46**	
	99 29D	13-26-1-28	Aug/83	Jun/87	442	1 636	78	1 064	3 029	74
		15-26-1-28	Jul/83	Oct/85	58	1 060	95	58	1 060	95
		14-27-1-28	Jun/83	Jun/84	169	771	82	169	771	82
		05-34-1-28	Dec/83	Oct/84	82	2 443	97	82	2 443	97
				Total Production from Other Areas "D" Pool				**1 373**	**7 303**	
				Total Cumm. Production from Lower Amaranth Reservoir in the Coulter-Pierson Area				**69 952**	**181 968**	

REGIONAL GEOLOGICAL SETTING

The Williston Basin extends over southeastern and south-central Saskatchewan, the southwestern corner of Manitoba, most of North Dakota, northwestern South Dakota and northeastern Montana (Figure 1). The sedimentary strata comprises three major lithological successions separated by major angular unconformities. The lithological sequences are; a) Paleozoic carbonates and evaporites, b) Mesozoic terrigenous clastics interbedded with carbonates and evaporites, and c) Cenozoic clastics with minor carbonates and evaporites. Basinward thickening of sediments contemporaneous with basin subsidence has resulted in the formation of a sedimentary wedge that dips to the southwest (McCabe, 1959).

Geological studies to date have confirmed that many Paleozoic formations in the Manitoba portion of the Williston Basin were progressively exposed to erosion and almost all of the Mesozoic formations are (in turn) in contact at their bases with these Paleozoic formations (Stott, 1955; McCabe, 1959; Carlson, 1968; Christopher, 1984).

Figure 4 illustrates the regional stratigraphic terminology in current usage in southwestern Manitoba, southeastern Saskatchewan and North Dakota. The correlation of the Lower Amaranth Formation with equivalent rock units in adjoining areas is discussed in detail in the section entitled "stratigraphy".

Paleozoic and Mesozoic strata are separated by a prominent angular unconformity representing a period of erosion between the Mississippian and deposition of Lower Amaranth strata (Stott, 1955). The Amaranth Formation overlies older rocks that range in age from Mississippian to Ordovician and locally Precambrian (Manitoba Energy and Mines, Geological Map of Manitoba, 1979).

The Manitoba portion of the Williston Basin is characterized by minor basinward (southwestward) tilting, slow basin subsidence, and localized structural disturbance as a result of salt solution superimposed on the overall subsidence of the basin (McCabe, 1959). Major local salt solution occurred periodically from the Devonian to the Cretaceous, resulting in removal of the Devonian Prairie (salt) Formation and subsequent collapse of the overlying Paleozoic and/or Mesozoic strata (Hansen, 1987).

During the Jurassic, the Williston Basin was separated from the Alberta trough by the Sweetgrass Arch, bordered to the north-northwest by the Punnichy Arch in southern Saskatchewan and to the east by the Precambrian Shield (Christopher, 1984; Figure 1). The Williston Basin attained several different shapes and configurations from late Paleozoic to early Cretaceous (Hansen, 1987). During deposition of the Amaranth Formation, the basin had two distinct elements. A northeasterly-trending trough or sub-basin (extending from northern Wyoming and South Dakota to North Dakota and into southwestern Manitoba) formed the Amaranth Embayment or sub-basin (Figure 2). A second trough extended northwest from the depositional centre of the basin (in North Dakota and northern Montana) into southern Saskatchewan (Christopher, 1984; Hansen, 1987). In pre-Lower Amaranth time, the Manitoba portion of the Williston Basin was a very low-lying, uniform, peneplained surface with few minor ridges and valleys controlled primarily by the structure of the underlying strata (McCabe, 1956).

A topographic map (Figure 7, in pocket) displays relief on the Mississippian erosional surface prior to deposition of the Lower Amaranth Formation. This unconformable surface dips gently basinward (to the southwest). The Lower Amaranth sedimentary rocks were deposited on this unconformable surface, and their thickness controlled by Mississippian topography and possibly also by minor syndepositional tectonic activity (McCabe, 1956).

AMARANTH SEDIMENTATION

In Manitoba, Amaranth sedimentary rocks consist of: 1) a basal red bed sequence (Lower Amaranth Formation) containing interbedded mudstone, siltstone and fine- to medium-grained sandstone, and 2) an upper anhydrite unit (Upper Amaranth Formation) with interbedded carbonate (Hansen, 1987). In the study area the Amaranth Formation overlies the Mississippian Charles and Mission Canyon formations with angular unconformity and underlies the Jurassic Reston Formation (Figure 5).

At least four transgressive-regressive cycles occurred during the Jurassic Period. Successive transgressive events extended progressively farther eastward across western Canada. Sedimentary rocks of the Amaranth Formation were deposited during the first (Lower to Middle Jurassic) transgressive-regressive cycle (Stott, 1955). Irregularities in the erosional surface of Mississippian rocks were filled, and widespread red sediment was deposited. Clastic sediments of the Lower Amaranth Formation are believed to be derived from the Precambrian Shield, to the north and east, and from Paleozoic red bed sequences (Lyleton and Ashern formations) exposed at the basin margin (Stott, 1955). At the end of this clastic sedimentation, shallow marine evaporites of the Upper Amaranth Formation were precipitated.

Following deposition of the Amaranth Formation, Middle Jurassic seas regressed resulting in exposure and possible erosion of the Upper Amaranth Formation, in southwestern Manitoba, along the basin margin (Stott, 1955; Hansen, 1987). Stott (1955) postulated a disconformity between the Upper Amaranth Formation and the overlying Reston Formation. The Reston Formation was deposited during the second transgressive-regressive cycle (Figure 5).

The depositional environment of the Lower Amaranth Formation is described in detail in the section of the report entitled "depositional environment".

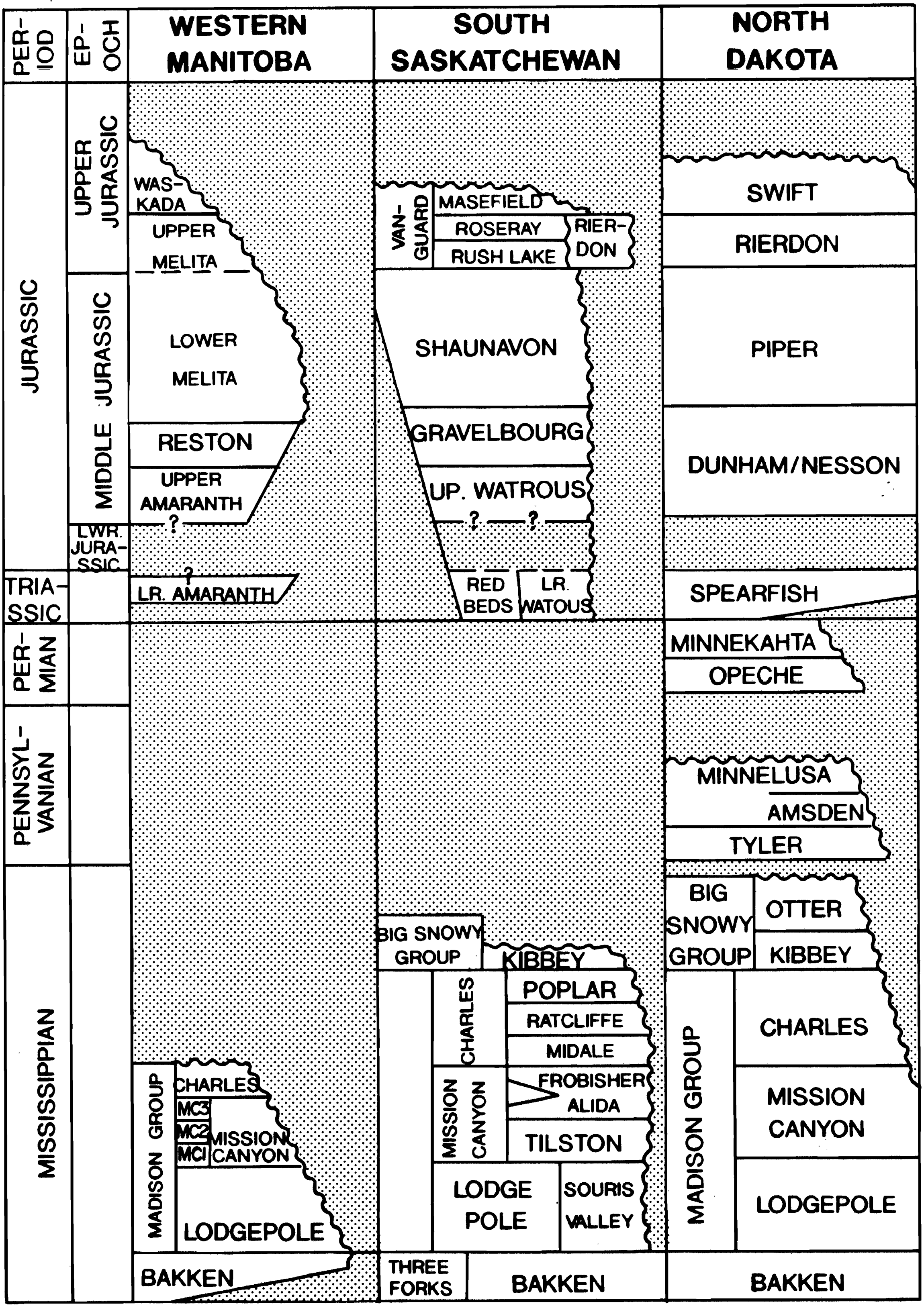


Figure 4: Stratigraphic Nomenclature Chart. (Modified from Carlson, 1968).

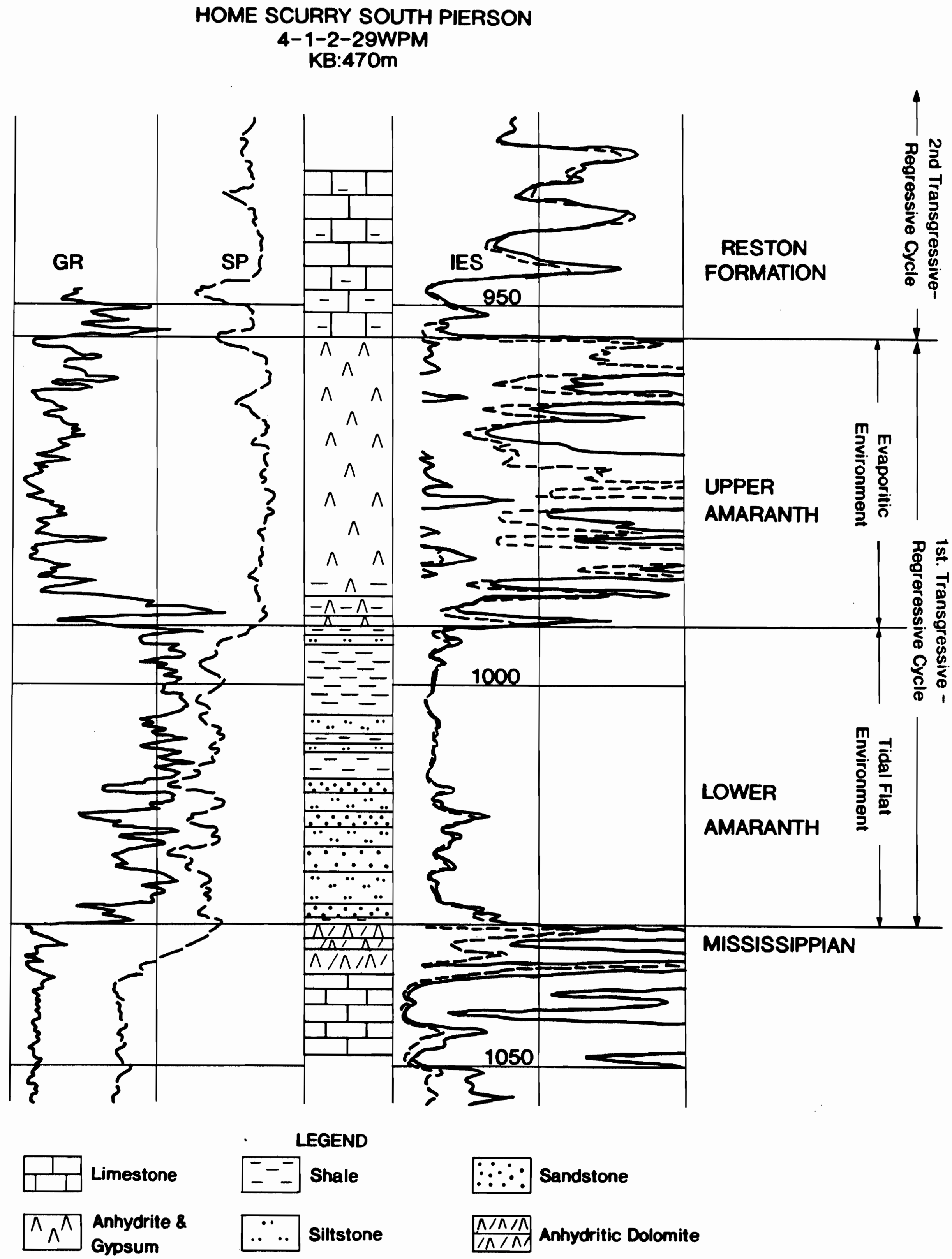


Figure 5: Stratigraphic subdivisions of Amaranth Formation in southwestern Manitoba. (Modified from Stott, 1955; Hansen, 1987).

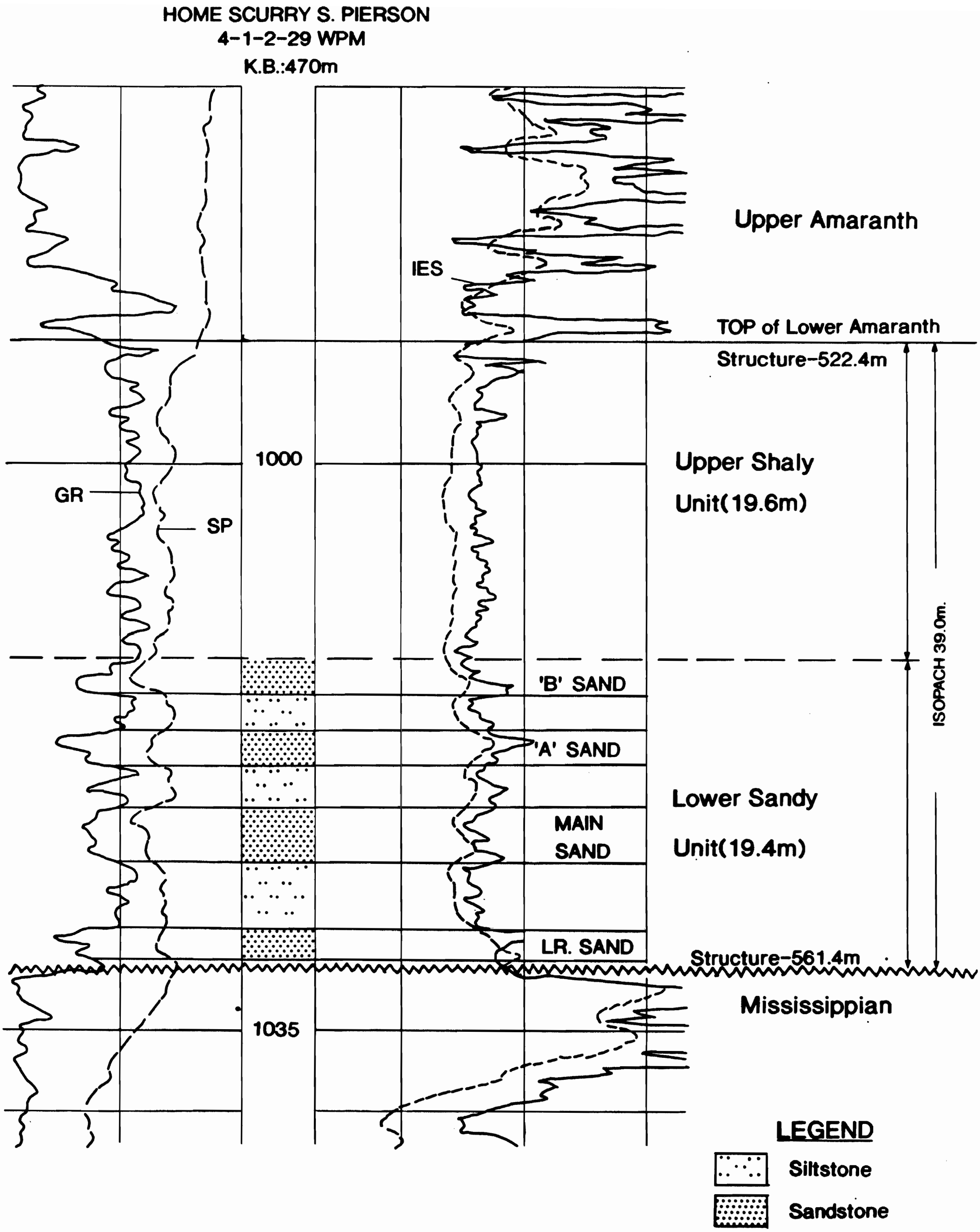


Figure 6: *Type log of Lower Amaranth Formation showing subdivisions and best sand development in the Coulter-Pierson area. (Modified from: Barchyn, 1982).*

GEOLOGY OF LOWER AMARANTH FORMATION

STRATIGRAPHY

The Lower Amaranth Formation is the stratigraphically lowermost part of the Jurassic/Triassic succession in Manitoba. Based on regional correlation and detailed lithological comparison the Lower Amaranth Formation is considered to be stratigraphically equivalent to the Lower Watrous Formation of southeast Saskatchewan and Spearfish Formation of North Dakota. As such, these formations are considered the oldest rocks of the Mesozoic sequence in the Williston Basin (Francis, 1957; Christopher, 1984; Figure 4). Because of the lack of diagnostic fossils, the age of the Lower Amaranth, and its stratigraphically equivalent strata, has been a subject of continuous debate for fifty years (Wickenden, 1945; Imlay, 1947; Schmitt, 1953; McCabe 1956; Francis, 1957; Carlson, 1968; Christopher, 1984). Most recently the Lower Amaranth, Lower Watrous and Spearfish formations have been placed at the Triassic level in the Williston Basin Stratigraphic Nomenclature Chart (Geological Society of America, 1987).

In southwestern Manitoba the Lower Amaranth Formation unconformably overlies Ordovician, Silurian, Devonian and Mississippian formations (Figure 2). In the study area the Lower Amaranth Formation lies on the Mississippian erosional surface. In the southern and southwestern portion of the study area, the Lower Amaranth Formation is underlain by a thin erosional wedge of Mississippian Charles strata composed of anhydrite and anhydritic dolomite (Figures 8 and 9, in pocket). In the north and northeastern portion of the map area, the Lower Amaranth overlies the MC-3 or MC-2 members of the Mississippian Mission Canyon Formation (Figures 2, 7 and 9 in pocket).

The topography of the Mississippian erosional surface controls the distribution and thickness variation of reservoir rocks in the Lower Amaranth Formation. In the study area, the thickness of the Lower Amaranth varies from a minimum of 25 m in the centre of the Pierson Field to a maximum of 46 m in the south of the Coulter Field. Thickness generally increases basinward. Several elongated, sub-parallel belts are indicated by the isopach map that shows an overall northeast trend (Figure 9, in pocket).

MECHANICAL LOG RESPONSES

Figure 6 and cross-sections A-A' to I-I' (Figures 15-24, in pocket) illustrate the well defined log picks of the top and base of the Lower Amaranth Formation. The Lower Amaranth Formation interval has a definite signature on all types of mechanical logs. For example, Lower Amaranth strata show very low resistivity in sharp contrast to the very high resistivity of underlying Paleozoic rocks, and the overlying Upper Amaranth Formation. Sonic logs, gamma-ray (GR) logs and Spontaneous Potential (SP) curve also show sharp variations in ΔT, API and MV values respectively at the upper and lower contacts of the Lower Amaranth Formation.

Log responses (especially gamma ray and electric logs) are also used to subdivide the Lower Amaranth Formation into lower sandy and upper shaly units and to identify the sandstone subunits in the lower sandy unit (Fig. 6). Sandstone and/or siltstone that defines the top of the lower sandy unit is identified by the lower API in the gamma ray logs and higher resistivity in electric logs as compared to higher API and lower resistivity shown by overlying mudstone beds of the upper shaly unit. Similarly individual sandstone subunits are picked by lower API and higher resistivity responses than those shown by siltstone beds (Figures 6, 15-24 in pocket).

LITHOLOGY AND CHARACTERISTICS

Lower Amaranth Formation

In the study area, the Lower Amaranth Formation comprises very unique lithological sequences of mudstone, siltstone and sandstone. The formation is subdivided into two distinct units, an upper shaly and a lower sandy unit.

The main characteristics of the formation as noted in core from the study area are: 1) reddish-brown colour, 2) wavy- to lenticular-bedding, 3) presence of anhydrite nodules and blebs, 4) presence of scattered siltstone lenses and/or interclasts, 5) parallel- and/or cross-laminations; and 6) presence of locally preserved mud cracks.

Lower Sandy Unit

In the study area, the lower sandy unit ranges in thickness from 6 to 20 m. In township 3 of range 27-29 WPM it ranges from 6 to 12 m thick whereas in the southern part of the map area it is approximately 12 to 20 m thick.

The lower sandy unit consists of reddish-brown siltstone and sandstone with anhydrite blebs and nodules and silty mudstone stringers. The sandstone is generally very fine- to fine-grained and locally medium- to coarse-grained. The siltstone is commonly massive with fine grained sandstone stringers and/or interclasts. Mudstone stringers are also common in the upper part of the unit. The contact with the underlying Mississippian carbonates and evaporites is sharp in all types of mechanical logs, as well as in drill cores.

The contact with the overlying upper shaly unit is sharp and readily identified in gamma ray, sonic and induction logs, and in drill cores. In areas, where the lithology near the upper contact becomes gradational (i.e. from shaly siltstone in the upper part of the lower unit to silty mudstone in the lower portion of the upper unit) identifying the upper contact in drill core becomes somewhat subtle.

The main characteristics of the unit are:

1. gross lithology is siltstone;
2. lenticular bedding;
3. abundance of anhydrite nodules and blebs;
4. thin shale laminae;

5. presence of up to (4) sandstone subunits in a fining upward sequence;
6. sandstone subunits occur at different stratigraphic positions;
7. sandstone are discontinuous and lense shaped;
8. sandstone is locally cross-bedded and grains are mostly subrounded to rounded and rarely subangular;
9. sandstone grain size ranges generally from very fine to fine and locally from medium to coarse;
10. siltstone interclasts and/or lenses are locally developed; and
11. abundance of subrounded to rounded noncemented 'frosted' medium to coarse quartz grains.

In the study area, the lower sandy unit contains up to four sandstone subunits of variable thickness (0.5 to 5.0 m) designated "lower", "main", "A" and "B" sands (Figure 6). Each subunit is separated by tight siltstone beds. Where the "B" sand is present its top defines the upper contact of the lower sandy unit; where it is not developed the top of the unit is picked from the siltstone response in mechanical logs.

Individual sandstone subunits are illustrated in the log for 4-1-2-29 well, which exhibits the best sandstone development (Figures 6 and 21, in pocket). Logs provide the primary means to infer and interpret the presence and quality of individual sandstone subunits. The distribution patterns of each subunit is presented in cross-sections A-A' to I-I' (Figures 15-24 in pocket).

Based on regional mapping and ten stratigraphic cross-sections the "lower", "A" and "B" sandstone subunits are sporadically and discontinuously distributed in the study area. These sandstone subunits are not generally stratigraphically equivalent and therefore not necessarily correlatable. Each of the sandstone subunits grades laterally to siltstone or interbedded shale and sandtone (Barchyn, 1982).

The "main" sandstone subunit is generally present throughout the study area. The "main" subunit is composed of very fine- to fine-grained sandstone to siltstone to shaly siltstone. The quality (siltiness and shaliness) of this subunit deteriorates, and its thickness thins, to the north in township 3 and in areas outside the established pools (Figures 11, and 15-18, in pocket).

Upper Shaly Unit

In the study area the thickness of the upper shaly unit ranges from a minimum of 13 m to a maximum of 26 m. The unit is generally composed of reddish-brown to greenish-brown mudstone. Bands of dolomitic and shaly siltstone occur close to the contact with the lower sandy unit. Based generally on gamma ray log response the percentage of siltstone appears to be variable and in some wells the upper unit is devoid of siltstone (cross-sections A-A' to I-I', in pocket). The contact with overlying massive anhydrite beds of the Upper Amaranth Formation is sharp.

The main characteristics of the unit are:

1. gross lithology is mudstone;
2. dolomitic and shaly siltstone stringers common in lower part;
3. wavy bedding at places;
4. scattered anhydrite blebs in lower part;
5. parallel laminations; and
6. presence of scattered siltstone lenses and/or interclasts in lower part.

RELATIONSHIPS BETWEEN UPPER SHALY AND LOWER SANDY UNITS

1. colour of both units is the same;
2. the contact between the two units is somewhat transitional;
3. percentage of silt decreases from lower sandy unit to upper shaly unit;
4. percentage of sandstone decreases from lower sandy unit to upper shaly unit;
5. percentage of anhydrite decreases from lower sandy unit to upper shaly unit;
6. lower sandy unit has lenticular bedding whereas the lower portion of the upper shaly unit has wavy bedding;
7. Hansen (1987) reported locally preserved mud cracks in the upper shaly unit.

STRUCTURE: (Figures 7 and 8)

In southwestern Manitoba a major erosional unconformity lies between Mesozoic and Paleozoic formations. Structure maps on geological formations are moderately regionally similar. Therefore only the isopach of each successive overlying formation reveals the geological history of underlying formations. Tectonic activity and/or solution of the Devonian Prairie (salt) Formation (McCabe, 1956, 1959) and subsequent collapse of overlying formations can be observed in isopachs of these formations. Structural highs and lows in the Mesozoic sediments could be due to differential compaction and draping over local topographic highs on eroded Paleozoic rocks. Mesozoic strata trend northwest with a regional dip to the southwest at approximately 7 m/km (Figures 7 and 8, in pocket).

Topographic contours on the Mississippian surface reflect a combination of paleotopographic relief on the unconformity, and later tilting and possible deformation (Figure 7, in pocket). Topographic features in Sections 7 and 18 of Township 3, Range 28 WPM show a closed high in association with the Mission Canyon oil pools in the Pierson Field and a few isolated one-well closures are found in the map area. These anomalies are not reflected by structure on the top of the Lower Amaranth Formation (Figure 8, in pocket) indicating them to be related with only Mississippian topography.

The structure on the Lower Amaranth Formation (Figure 8, in pocket) is more uniform than that on the Mississippian surface. A few scattered small closures are present. Although the structure on the top of the Lower Amaranth Formation appears to reflect the Mississippian surface, the undulating topography of the Lower Amaranth Formation is generally less pronounced than that of the Mississippian surface.

ISOPACH: (Figures 9-12, in pocket)

The paleotopography of the Mississippian erosional surface in the study area is best illustrated by the isopach of the overlying Lower Amaranth (Red Beds) Formation (Figure 9, in pocket). The top of the Mississippian surface is reflected in the thickness variations in the Lower Amaranth Formation. The top of the Lower Amaranth Formation closely approximates a time-stratigraphic marker (McCabe, 1956, 1959), and consequently topographic highs on the Mississippian surface coincide with the thinnest parts of the Lower Amaranth Formation (Sections 7, 18; Township 3, Range 28 WPM). However, caution must be used in interpreting Lower Amaranth isopach anomalies as paleotopographic features because other factors such as local uplift or subsidence during Lower Amaranth time, and differential compaction and/or salt solution and subsequent collapse of the underlying Mississippian formations contemporaneous with Lower Amaranth deposition can also affect Lower Amaranth thicknesses.

Figure 10 (in pocket) is an isopach map of the total sandstone (including all subunits) present in the lower sandy unit; sandstone thickness was determined from well logs and core analyses. In the northern portion of the study area (Township 3, Range 27-29 WPM) sand thickness ranges from 1m to 3.5 m, whereas to the south thicknesses up to 9.5 m are observed (4-1-2-29 WPM, Figure 6). Numerous small elongated and subparallel sandstone lobes are present in the southern portion of the map area. Sandstones are best developed in the western portion of the South Pierson Field where the pattern and the thicknesses of individual sandstone subunits are established.

Since the "main" sandstone subunit is the only subunit that is present throughout the study area, a separate isopach map of the "main" sandstone subunit has also been constructed (Figure 11, in pocket). It indicates few broad thins with several isolated sub-parallel thicks within the thins. Thicknesses range from zero in the northwestern corner to 6 m in the southwestern corner of the study area. An anomalous eight metre thick "main" sandstone subunit is noted in the 14-15-1-28 WPM well. Isopach of this subnunit does not reflect the structures on top of either the Mississippian erosion surface nor the Lower Amaranth Formation.

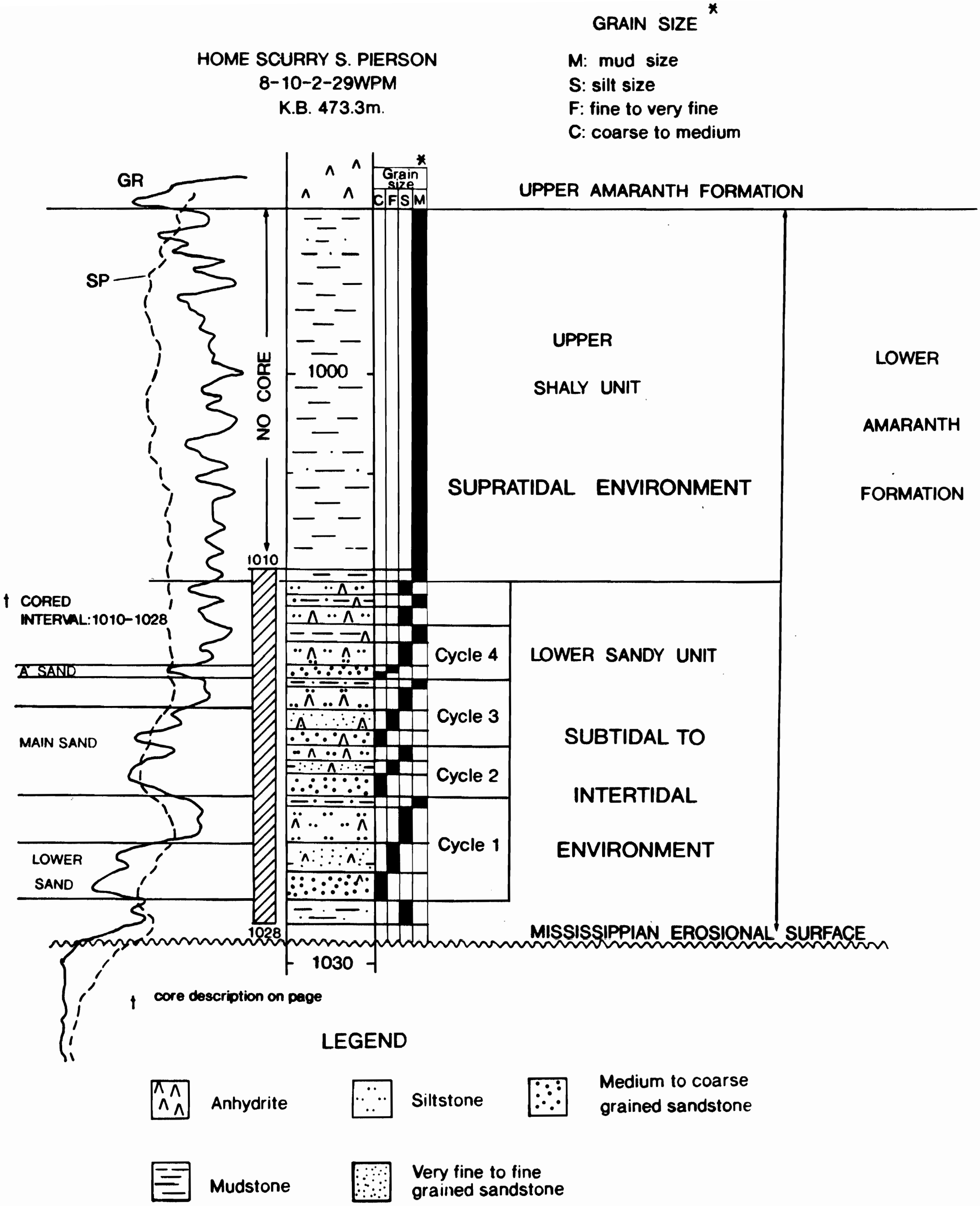


Figure 13: Depositional environment and rock sequence of Lower Amaranth Formation showing repeated cycles of fining upward sequences in the Coulter-Pierson area. (Modified from: Klein, 1977).

INTERPRETIVE STRATIGRAPHY

DEPOSITIONAL ENVIRONMENT (Figures 13 and 14)

Understanding of the depositional history of a rock sequence requires examination and interpretation of observed sedimentary characteristics, related textures and gross lithology. The purpose in studying depositional characteristics and compiling them into a model is to assist explorationists to define the particular group of rocks within which known petroleum reservoirs are developed and to predict areas where similar lithofacies may be found.

For any reservoir rocks, development of a depositional model provides a framework in which the size, geometry, continuity, quality and flow regimes of the reservoir can be placed. This leads to a better understanding of the reservoir and greatly assists in an on-going exploration or development program.

In southwest Manitoba, the need for a depositional model is acute because oil accumulations in the Lower Amaranth Formation are likely controlled primarily by more subtle stratigraphic factors rather than by structure.

In this section, existing interpretations of depositional environments of the Lower Amaranth Formation and equivalent strata are compiled and compared. Based on consideration of these interpretations, and on information collected from drill core examination in the Coulter-Pierson area, a depositional model is proposed.

PREVIOUS INTERPRETATIONS

The Lower Amaranth Formation in Manitoba and its equivalent strata in Saskatchewan (Lower Watrous Formation), and in North Dakota (Spearfish Formation), have been studied by numerous workers. Each has attempted to interpret the depositional environment based on observations of the sedimentary characteristics of the formations. Below is a brief historical background of these interpretations.

Spearfish Formation

Imlay (1949) stated that the red beds of the Spearfish Formation were marine and the initial deposits of a sea that had spread eastward and southward around a large island in an area of central Montana in early Middle Jurassic. The presence of gypsum suggested a fairly hot and arid climate on lands bordering the sea.

Wallace (1967) described the "Saude Member' of the Spearfish Formation as an onlapping transgressive siltstone, shale and sandstone sequence with 'frosted' quartz grains and anhydrite blebs deposited in a growing basin. Frosted quartz grains were interpreted as wind blown, the sands continental in origin and the anhydrites as playa lake deposits. The character and distribution of the "Saude Member' are similar to those of the Lower Amaranth Formation especially in the vicinity of the U.S.A.-Canada border.

Lower Watrous Formation

Carlson (1968) suggested that the Lower Watrous Formation was deposited in a non-marine to restricted marine environment. Christopher (1984) proposed a marine environment and stated that subaerial exposure of large regional flats during regressions would have contributed to widespread formation of the red beds. This process would have been supplemented by introduction of terra rosa from the uplands in periodic (episodic) flash floods (Christopher, 1984).

Lower Amaranth Formation

Stott (1955) interpreted the Lower Amaranth rock sequence as a restricted shallow marine deposit. He suggested more arid conditions existed in southwestern Manitoba during Lower Amaranth time resulting in preservation of residual iron compounds that gave the rock sequence the red colour. Normal circulation of sea water was hindered by numerous remnants of old limestone beds, and under restricted conditions calcium sulphate was precipitated around the perimeter of the Manitoba portion of the Williston Basin. Absence of coarse clastics indicated that the surrounding land mass was low lying. The red beds were derived from reworking of older red beds (Lyleton and Ashern formation) or from a regolith. He suggested that any rain in semi-arid country would produce flash floods that could transport regolith material to the basin.

McCabe (1956) suggested an arid climate under a terrestrial oxidizing environment rather than a marine environment for deposition of the Lower Amaranth Member ('Lower Amaranth Formation'). In addition, he attributed the presence of contorted structures with irregular patches of fine bedded and crossbedded sediments, and slickensides to be probably indicative of a terrestrial or transitional environment. In his opinion, marine sediments would probably show more uniform bedding than that found in rocks deposited under terrestrial conditions. The pronounced frosting and pitting of most of the sand grains support a terrestrial source for the sandstone. The roundness, sphericity and well sorted nature of the sand grains and presence of some unaltered feldspar grains are indicative of an arid aeolian environment of transport. He believed anhydrite in form of irregular to rounded patches to be clastic and apparently derived from break-up of primary anhydrite layers somewhere on the land mass. Such occurrences of anhydrite indicate periodic marine inundations alternating with dry periods when evaporite pans were formed in low lying areas. Red shales in the upper part of the Lower Amaranth Member probably indicate the first stages of marine transgression, which was culminated by the widespread marine evaporitic deposits of the Upper Amaranth Member (Upper Amaranth Formation).

Barchyn (1982) related the deposition of the Lower Amaranth Formation to an environment ranging from dominantly continental to marine under intermittent shallow re-

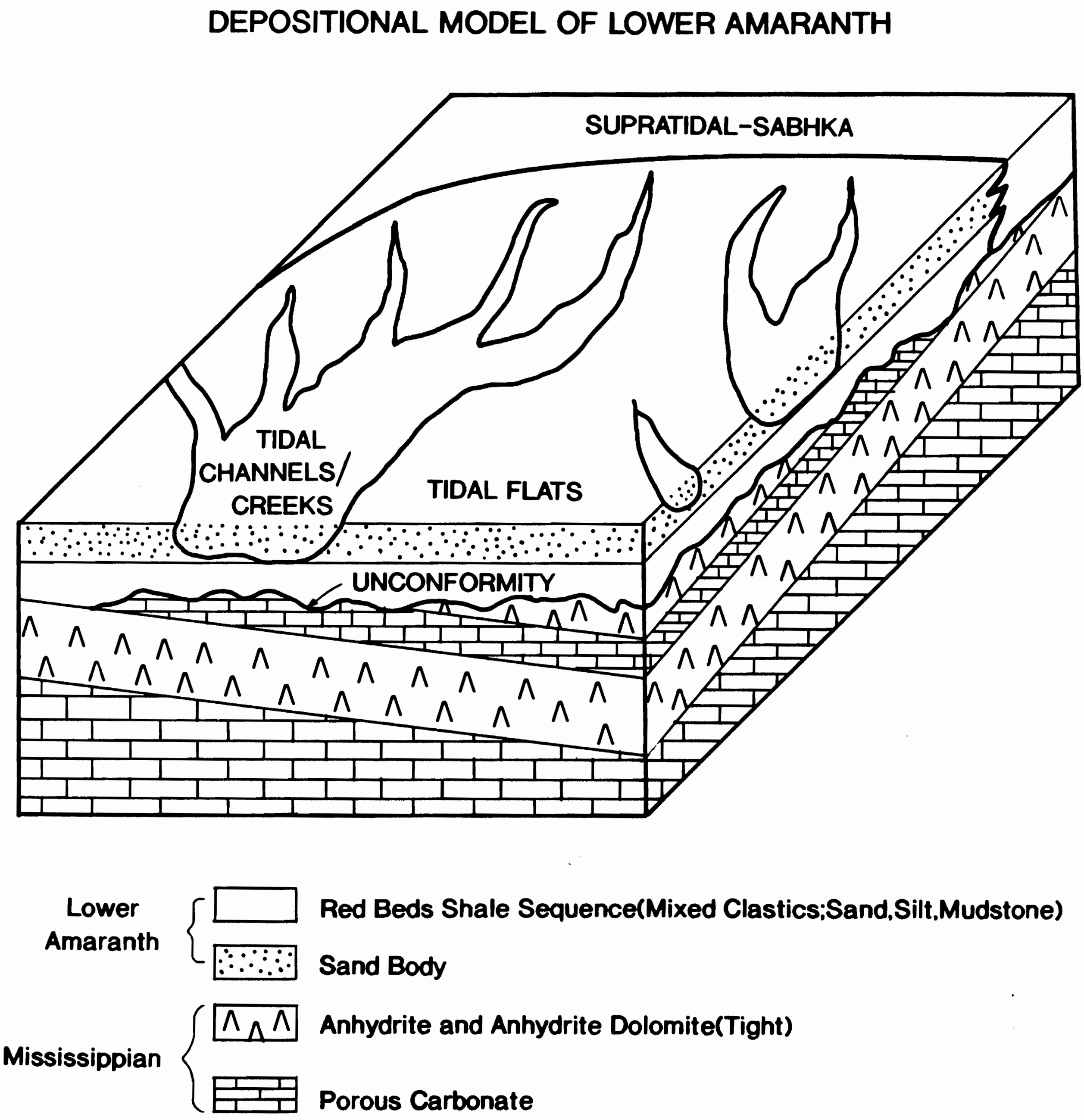


Figure 14: *Depositional model of Lower Amaranth Formation in the Coulter-Pierson area. (Modified from: Weimer, 1981; Kooyman, 1989).*

stricted conditions representing the initial stages of a major transgression of Jurassic seas. The complex clastic lithology of the lower sandy unit suggested a period of highly variable depositional conditions followed by more stable conditions for the mudstone lithology in the upper shaly unit. He suggested that the cyclical fining upward sequence of sandstone beds were fluvial deposits on an intermittently emergent mud flat. Mechanical reworking of these sediments is widespread and the pseudo-brecciated appearance could be the result of desiccation and redeposition of partially indurated laminated or massive sands. The occurrence of anhydrite nodules suggest hypersaline conditions were closely associated with deposition or they were products of diagenesis. An alternative depositional mechanism for the Lower Amaranth Formation could be winnowing of sediments by wave action in shallow marine conditions.

Hansen (1987) studied the Lower Amaranth Member ('Lower Amaranth Formation') in much more detail than any of the previous workers. She suggested a depositional environment for each of the sedimentary facies observed during a detailed core study. She also subdivided the Lower Amaranth Member into two units, an upper shaly and a lower sandy unit. Characteristics and associated environments for each unit are given below:

Upper Shaly Unit (Mudstone facies)

1) ripple-laminations indicate low energy shallow water conditions, 2) wavy- and lenticular-bedding originated in a tidally influenced environment, and 3) locally developed mud cracks resulted form periodic wetting and drying in a mud flat setting.

Lower Sandy Unit (siltstone-sandstone facies)

1) presence of minor glauconite in sandstone indicates marine sedimentation, 2) abundant frosted coarse quartz grains indicate an aeolian transport, 3) nodular anhydrites are the products of deposits in sabkha to supratidal settings, 4) subarkose sands with feldspar grains suggest an arid climate, which retarded the weathering process, 5) repeated fining upwards sequences are indicative of a cyclic marine process, 6) locally developed coarse grained sandstone are the products of deposition in tidal channels in the subtidal environment, and 7) the bulk lithology is siltstone.

Hansen (1987) compared the depositional environment of the Lower Amaranth Member with that of a modern low-energy tidal flat on the Colorado Delta. Here, silty clay and fine grained sands are supplied to the north coast of the Gulf of California by the Colorado River. A featureless mud plain grading into a broad, shallow, low-dipping, subtidal plain has developed within a prevailing arid climate. Sediments deposited in the subtidal to lower intertidal zone are composed of laminated silty clay with thin (1 mm) bands of silt to fine sand at regular intervals. The intertidal zone is dominated by wavy, interlaminated silty clay, silt and shaly silt.

According to Hansen (1987) the Lower Amaranth rocks sequence was deposited on a broad featureless tidal flat, similar to the setting along the northeast coast of the Gulf of California, under the following conditions:

1. the basal reddish-brown siltstones overlying the Mississippian unconformity were deposited in a supratidal mud flat to Sabkha type setting along the restricted margin of the Manitoba portion of the Williston Basin. Nodular anhydrite was formed by the displacive growth of the sediments.
2. very fine grained subarkose was deposited in very shallow water below wave base.
3. locally developed coarse- to medium-grained subarkose was deposited in tidal channels in a fining upward sequence.
4. gradual recession of water from the tidal flat resulted in deposition of the wavy to lenticular bedded siltstones with very fine grained sandstones and mudstones associated with fluctuating current energy in an intertidal zone. Wavy to lenticular bedding structures formed under the influence of small waves and tidal currents on the tidal flat.
5. aeolian processes responsible for 'frosted' quartz grains remained active throughout deposition of the sedimentary rocks of the lower sandy unit.
6. with further progradation of the tidal flat, mudstones with minor siltstones of the upper shaly unit were deposited in a supratidal mud flat setting. This setting was, in part, subaerially exposed where locally preserved mud cracks formed.
7. sedimentation of the upper shaly unit was eventually terminated. Seas became increasingly hypersaline and the extensive anhydrite sequence of the Upper Amaranth Member ('Upper Amaranth Formation'), was precipitated.

Kooyman (1989) suggested a tidal flat depositional environment for rock sequences of the Lower Amaranth Formation in southern Manitoba.

CURRENT INTERPRETATIONS

Three basic lithofacies have been recognized in the Lower Amaranth Formation in the study area:

a) sandstone facies - locally developed within the siltstone facies - lower sandy unit
b) siltstone facies with minor mudstone - lower sandy unit
c) mudstone facies with minor siltstone - upper shaly unit

a) Sandstone Facies: (Subtidal Deposits)

The basic sedimentary characteristics of this lithofacies are: 1) development of up to 4 sandstone subunits in a fining upward sequence, 2) sandstone grains are mostly subrounded to rounded and rarely subangular and range in size generally from fine to very fine and locally from coarse to medium, 3) crossbedding, 4) thickness variations, 5) sandstones are discontinuous and occur at different stratigraphic positions, 6) abundance of subrounded to rounded noncemented 'frosted' medium to coarse quartz grains, 7) abundance of anhydrite nodules and/or blebs, and 8) local occurrence of siltstone interclasts and/or lenses.

In this facies fining upward sequences have been observed in the drill core. Coarse grained sandstones occur at the base and are overlain by thin beds of fine grained sandstones that in turn are overlain by the siltstone facies. This fining upward sequence is repeated to a maximum of four times in four individual cycles as observed in 4-1-29 WPM and 8-10-29 WPM wells (Figures 6, 13). The above characteristics are similar to those noted by Hansen (1987) and could be the products of deposition in tidal channels in the subtidal environment.

Progradation of tidal flats tends to produce a fining upward sequence that reflects a transition from low tide level sand flats, upward into high tide level mud flats, and eventually into supratidal flats. This sequence may be cut at any level by erosive-based tidal channel sequences (Reineck, 1967). The abrupt presence or absence of the tidal-channel coarse grained sandstone facies of the lower sandy unit could be explained by this process.

b) Siltstone Facies: (Intertidal Deposits)

This facies consists of brownish-red, interlaminated siltstones with very thin beds of mudstones in its upper part, and very fine-to fine-grained sandstones in the lower part. Lenticular bedding is common. Locally developed siltstone and mudstone interclasts are also noted in the sequence. Thin shale laminae occur in the upper part of the unit. Frosted, noncemented, medium- to coarse-quartz grains are common in the lower part. Anhydrite nodules and blebs occur throughout the sequence.

The characteristics described above are similar to those noted by Hansen (1987) and could suggest an intertidal environment for this facies with several cyclic (intermittent) breaks that resulted in local channel-fill deposits of the sandstone facies in the form of individual subunits. A transitional sequence of this facies, depending upon its sand/silt ratio, will be deposited anywhere from upper subtidal to lower intertidal flats (Hansen, 1987).

c) Mudstone Facies: (Supratidal Deposits)

The upper shaly unit is a mud dominated sequence. This facies comprises reddish-brown mudstones and shales with local bands of shaly siltstones and very fine grained silty, shaly sandstones in the lower portion of the sequence. The upper part is homogeneous, massive and thick bedded as compared to the lower part where parallel-laminations and wavy bedding are noted. Scattered anhydrite blebs and siltstone lenses and interclasts occur in the lower portion of the sequence. Locally preserved mud cracks are also reported in this facies (Hansen, 1987).

These sedimentary characteristics are similar to those reported by Hansen (1987) and indicate that this facies is the product of deposition under weak, low energy, very shallow water conditions common in the supratidal zone of a tidal flat environment.

At places the contact between the siltstone facies of the lower sandy unit and the mudstone facies of the upper shaly unit is gradational. Rocks that are composed of silt and mud in highly variable percentages, become a transitional sequence that has wavy- to lenticular-bedding. This transitional sequence suggests depositional conditions that could range from upper intertidal to lower supratidal before supratidal depositional condition prevailed.

In summary, the "lower sandy unit" was apparently deposited under conditions ranging from subtidal (channel-fill sandstone facies) to intertidal flats (siltstone facies), whereas the "upper shaly unit" was deposited in supratidal mud flat condition.

The sedimentary characteristics observed in these lithofacies of the Lower Amaranth Formation are similar to those described, and interpreted by previous workers to be deposited in a tidal flat environment. The distribution of the sandstone facies is also supported by deposition in tidal channels under the subtidal conditions. Therefore it is suggested that the Lower Amaranth Formation in the Coulter-Pierson area was deposited in a tidal flat environment (Figure 14).

TRAPPING MECHANISM

Oil production in Manitoba is confined to the northeastern flank of the Williston Basin mainly as a result of the post-Mississippian pre- Mesozoic unconformity. Mississippian beds currently produce about 73 percent of Manitoba oil from a series of stratigraphic units where porous cyclic carbonates are truncated by pre-Mesozoic erosion and sealed by rocks of the (Lower) Amaranth Formation. The remaining 23 percent is obtained from discontinuously developed sandstone facies in the lower portion of the Lower Amaranth Formation in the Waskada and Coulter-Pierson areas.

The accumulation of oil in southwestern Manitoba is generally controlled by a combination of complex stratigraphy, facies distribution and diagenesis. The accumulations in the Daly, Virden and Waskada fields are also partly attributed to structure possibly resulting from multi-stage dissolution of the underlying Devonian Prairie Evaporite (salt) Formation and the subsequent collapse of overlying strata (McCabe, 1959; Rogers, 1986; Barchyn, 1982; Hansen, 1987).

Paleotopography of the Mississippian erosional surface (Figure 7, in pocket) controls the distribution and thickness variation of the Lower Amaranth Formation in the study area. Thickness of the formation is positively correlated with the thickness of the lower sandy unit within which the reservoir facies (sandstone) is developed. In paleotopographically high areas (Twp. 3, Rge. 28-29), where thickness of the Lower Amaranth Formation averages about 27 m, the lower sandy unit is thin (average 9 m) and includes no reservoir facies. Conversely, reservoir facies are developed in areas (Twp. 1-2, Rge. 27-29) where the lower sandy unit thickens (12-20 m) along with a thick Lower Amaranth sequence (34-40 m). Based on these observations, it is postulated that the paleotopography of the Mississippian erosional surface controls the distribution of the reservoir facies within which oil accumulations occur depending upon development of favourable reservoir characteristics and parameters.

In the study area, the trapping mechanism for Lower Amaranth oil is mainly stratigraphic with no known evidence of any structural trap (control). The accumulation is primarily controlled by facies distribution within the lower sandy unit, i.e. porous sandstone facies pinching out against tight siltstone facies.

Underlying the Lower Amaranth sediments are Mississippian carbonates truncated by the post-Mississippian pre-Mesozoic (Pre Lower Amaranth) unconformity. The uppermost part of the Mississippian sequence is commonly characterized by a dense zone, composed of anhydrite and anhydritic dolomite, which is identified as an "altered zone". This zone is extremely variable in thickness (cross-sections A-A' to I-I', Figures 15-24, in pocket). It is generally assumed that the altered zone is formed by anhydritization and dolomitization of porous limestone through diagenesis (McCabe, 1959; Barchyn, 1982; Hansen, 1987). The magnesium sulphate-rich formation water associated with the Amaranth evaporites and red beds percolated downward into the porous Mississippian carbonates and altered that primary rocks (McCabe, 1959). In areas where the altered zone is thin or absent, McCabe (1959) postulated that the Mississippian primary carbonates were possibly not porous at the unconformity during Lower Amaranth time. This prevented any downward percolation of magnesium rich water resulting in no (or minimum) alteration of the Mississippian carbonates. The thickness of the Mississippian porous carbonates exposed at the unconformity (at that time) has, therefore, controlled the thickness of the altered zone, though, for the most part, the thickness is highly unpredictable (Hansen, 1987).

Where it is present, the altered zone forms an effective seal for entrapment of hydrocarbon in the Mississippian carbonates. It is postulated that the oil trapped in the Lower Amaranth Formation is Mississippian oil that migrated upward into the Lower Amaranth reservoir facies in areas where the effective seal (altered zone) is lacking (thin or absent) and/or where the Lower Amaranth rocks, immediately overlying unconformity, are permeable due to possible fractures (Barchyn, 1982; Hansen, 1987). Oil is thus accumulated within the porous sandstone facies and is trapped by the overlying impermeable siltstone/mudstone facies and laterally by the pinchout of porosity and permeability within the sequence of the lower sandy unit (Figures 6, 13). The impermeable siltstones and mudstones prevent further vertical and updip migration. Consequently, the lower sandy unit acts as both a reservoir and a seal in most cases.

In conclusion the Lower Amaranth oil in the Coulter-Pierson area has been trapped due to following conditions:

- migration of hydrocarbon from the underlying Mississippian carbonates to the sandstone facies of the Lower Amaranth Formation where the altered zone in the carbonates is either absent or has become an ineffective seal; and
- porosity and permeability variations within the lower sandy unit due to lithofacies variations from reservoir sandstone facies to non-reservoir tight siltstone facies.

RESERVOIR FACIES

The main reservoir rocks of the Lower Amaranth Formation in the study area are generally fine and locally medium- to coarse-grained quartzose sandstone present in the form of several individual subunits separated by impermeable siltstones in the lower sandy unit (Figures 6 and 13).

Oil is trapped within these porous sandstone subunits and production is obtained from where the reservoir characteristics and properties are favourable (cross-sections E-E' to I-I'; Figures 19-24, in pocket).

It must be noted that the subunits developed within each cycle, are not always composed of pure sandstone (generally quartzose). Rather the facies change from sandstone within the pools to siltstone and/or silty mudstone outside the pool boundaries in accordance with the pevailing environment that had existed in the area at the time of deposition.

Figure 12 (in pocket) is an isopach map of the composite net pay of the potential reservoir sandstone present in each established pool. In constructing this map cutoffs of 8 per cent porosity and one millidarcy permeability (from core analysis) have been assumed. In general this map outlines the pool boundaries and possible extension of the oil-bearing reservoir.

RESERVOIR CHARACTERISITCS

The reservoir sandstone facies in the Lower Amaranth Formation is variable in nature. Porosity is generally scattered and its development is erratic resulting in differing reservoir characteristics in each designated pool. In the study area reservoir beds are heterogeneous and complex in terms of reservoir parameters. Arbez (1990) provides a detailed method for obtaining effective and total porosities and water saturations of the reservoir beds in the Lower Amaranth Formation. Though Arbez's method is based on data from the South Pierson Lower Amaranth pools, the same approach may be applied elsewhere in the area to roughly estimate reservoir parameters.

POROSITY IN THE STUDY AREA

Porosity in the sandstones and siltstones is generally intergranular modified by authigenic minerals (anhydrites in most cases). Abundant anhydrites occur throughout the sequence including the reservoir sandstone facies. Secondary anhydrites have occluded the pre-existing porosity. Some of the cleanest sandstones (under the microscope and by gamma ray log response) show lower permeabilities due to anhydritic infilling pore space. Sandstones with nonspherical and subrounded to subangular grains tend to have higher visible porosities than sandstones composed of spherical and well rounded grains. Porosity varies erratically from 7 to 25 percent (core analysis) from well to well. With variantions in porosity comes considerable variations in permeability (Table 3).

Coulter Field

The reservoir rock in the Coulter Field is characterized by a silty, very fine- to fine-grained, and rare medium-to-coarse grained, quartzose sandstone facies with porosities ranging from 7 to 19 percent and permeabilities from 0.5 to 4.0 millidarcies. The reservoir grains are poorly sorted and authigenic anhydrite have occluded the intergranular pores thus reducing the porosities and permeabilities. Interlaminated siltstone lenses are also noted. Consequently, the reservoir porosity is unevenly distributed. The net pay in this field ranges from 2.0 to 3.5 m (Figure 12, in pocket).

South Pierson Field

The reservoir rocks in the South Pierson Field are generally composed of well-sorted, fine to medium to coarse grained sandstones with clay and anhydrite free matrix resulting in the development of better porosities and permeabilities than those present in the Coulter Field. The textural variation is attributed to localized high energy environment during channel-fill and channel-creek conditions. In the A Pool, the porosities are comparatively erratic, irregular and scattered and permeabilities are comparatively low. In the B, C, D and E Pools, good to excellent porosities are noted. Porosities range from 12 to 25 per cent and permeabilities from 2 to 19 millidarcies.

Average porosity and permeability values obtained from core analysis on 11 selected wells in the South Pierson Field are tabulated in Table 4. The net pay ranges from 2.5 to 4.5 m in the "A" pool and from 3.0 to 7.0 m in the "B" pool (Figure 12, in pocket). Arbez (1990) provides a detailed reservoir evaluation of the major pools in this field.

COMPLETION AND RELATED PROBLEMS

The Lower Amaranth wells are typically perforated over wide intervals covering the main reservoirs i.e. the "main" sand and also the "A" and "B" sands depending upon their reservoir characteristics. The "lower" sand interval is usually found wet and therefore not perforated (cross-sections E-E' to I-I', Figures 19-24, in pocket). Due to low matrix permeabilities, hydraulic fracturing is usually required to permit production at economic rates.

Improperly designed fracture treatments generally result in development of excessive fracture height that can extend into the underlying Mississippian carbonates, particularly where the altered zone is absent or thin. Where Mississippian rocks are wet, this results in excessive levels of water production. Consequently, wells such as 4 and 10 of section 21-2-29WPM, which have favourable reservoir properties, are nonproducing. Considerable engineering analysis has been directed in solving this completion problem. Kooyman et al. (1989) have proposed several refinements of the completion program to enhance the chance of success. Wells completed in the South Pierson Lower Amaranth B Pool, subsequent to this analysis, suggest some improvement in completion effectiveness. Refinement of completion programs is continuing.

Unless the completion job is further improved by applying more (and new) sophisticated techniques to limit the fracture height to the reservoir, the productivity (due to high water cut) will continue to decline. Arbez (1990) gives a detailed engineering account of production decline for the South Pierson Field and the same approach could be applied to areas where Lower Amaranth Formation becomes potential and viable for hydrocarbon exploration.

TABLE 3
SELECTED WELLS FOR LOWER AMARANTH CORE EXAMINATION

Pool	Location WPM	Core Inteval (m)	Net Pay (m)	Av. from Core An Ø	Av. from Core An K	Perforated Interval (m)	Date On Production	Date Abandoned	Total Production Dec. 31, 1989 (m³) Oil	Total Production Dec. 31, 1989 (m³) Water
Coulter										
"A" Pool										
11 29A	11-21-1-27	0949.0 - 0967.0	3.5	N/A	N/A	945-963	12/82		1340	31 000
	05-22-1-27	0948.0 - 0966.0	0	16?	2.7	-	D&A	6/84		
	01-30-1-27	0955.0 - 0973.0	3.0	N/A	N/A	963 - 965.5	3/83		1287	231
South Pierson										
"A" Pool										
12 29A	02-30-2-28	0966.0 - 1005.25	4.5	13.3	2.3	978 - 980.0	1/83	11/83	11	432
						982 - 990.5				
	09-24-2-29	0974.0 - 1010.00	3.0	14.6	3.25	981 - 984	3/82		6407	39740
						986 - 991				
	14-24-2-29	0982.5 - 1000.75	2.5	11.8	2.0	985 - 994	3/84	9/86	347	897
"B" Pool										
12 29B	14-04-2-29	1020.0 - 1038.0	3.8	14.7	4.0	1028.5 - 1032.0	7/88		2887	1218
	16-08-2-29	1017.0 - 1035.0	5.5	15.7	3.8	1018 - 1020	12/85		6129	1393
						1024 - 1029				
	16-09-2-29	1010.0 - 1028.0	4.0	16.0	4.4	1018.5 - 1022.7	10/87		6267	871
	08-10-2-29	1010.0 - 1028.0	5.0	18.0	5.8	1016 - 1022	12/87		2326	19250
	10-15-2-29	1003.0 - 1021.0	0	12.0	0.6	-				
	10-21-2-29	1003.0 - 1021.0	6.0	14.4	3.0	1005 - 1008	3/87		0	62
						1010 - 1014				
"C" Pool										
12 29C	06-19-2-29	1022.0 - 1040.0	5.5	17.5	29.0	1021 - 1031	6/87		3331	39
"E" Pool										
12 29E	06-07-2-29	1025.0 - 1043.0	4.8	15.0	5.0	1029.5 - 1032.5	12/86		41	700
						1036.0 - 1037.0				
Other Areas										
99 29D	15-26-1-28	0972.5 - 0990.5	4.0	N/A	N/A	973 - 974	7/83	10/85	58	1060
						979.5 - 981.0				
	05-34-1-28	0980.0 - 0998.0	2.5	14.0	4.0	986.0 - 990.0	12/83	10/84	82	2443

CONCLUSIONS

1. The Lower Amaranth Formation in southwestern Manitoba represents the first preserved sediments of the Mesozoic era. The paleotopography of the Mississippian erosional surface in the Coulter-Pierson area has affected the distribution and thickness variation of the Lower Amaranth Formation and of the reservoir facies. Subparallel elongated belts of thick Lower Amaranth sequence are generally coincident with paleotopographic lows.
2. The Lower Amaranth sediments in Manitoba were deposited along the northeastern flank of the Williston Basin in the restricted Amaranth sub-basin under a low energy, tidal flat environment . The deposition remained associated with periodic inundation of the tidal flat and subsequent exposure of sediments.
3. The Lower Amaranth Formation is separated from the underlying Mississippian strata by a marked angular unconformity and is overlain by a thick sequence of evaporites of the Upper Amaranth Formation. The upper and lower contacts of the Lower Amaranth Formation are sharp and easily identified in drill cores and mechanical logs. Based on distinct log characteristics (response) and lithology, the Lower Amaranth sequence can be readily subdivided into two units: (i) an upper shaly unit; and (ii) a lower sandy unit.
4. In the study area, three generalized lithofacies are recognized in drill cores of the Lower Amaranth Formation. Features of these lithofacies are presented in Table 4.
5. The channel fill deposits of the sandstone facies are the primary reservoir rocks for the Lower Amaranth oil. It is believed that the Lower Amaranth oil is actually Mississippian oil that migrated upward in areas where an effective seal ("altered zone") is lacking (thin or absent) and/or where the Lower Amaranth rocks that immediately overlie the unconformity are permeable due to possible fractures.
6. In the study area, the trapping mechanism is stratigraphic in nature with no known evidence of any structural traps. Oil is trapped within the porous sandstone subunits by porosity-permeability pinch-out due to lateral and vertical variations in lithofacies. Reservoir qualities and characteristics are heterogeneous and are controlled by, depositional environments, compaction and anhydritization through diagenetic processes.
7. Porosities are generally intergranular and vary from a minimum of 7 to a maximum of 25 percent. In most cases, porosities are occluded by secondary anhydrites thus considerably reducing the porosities from well to well. With variations in porosities comes considerable variations in permeabilities. Perforation and completion intervals are usually extensive covering all potential to sub-potential sandstone subunits (generally from 'main' sand to 'B' sand) depending upon their reservoir characteristics and qualities.

TABLE 4
LOWER AMARANTH LITHOFACIES FEATURES

i) Upper shaly unit	Supratidal Facies:	mudstones: reddish brown, massive, interlaminated with siltstone and rare silty sandstone stringers.
ii) Lower sandy unit	Intertidal Facies:	siltstones: reddish brown, with mudstone stringers and very fine grained sandstone lenses,
	Subtidal Facies:	sandstones: coarse to medium to fine grained in several repeated cycles in fining upward sequences.

The sandstone facies is further subdivided into two main sequences.

a) a coarse (subtidal channel-fill) sequence deposited locally, and composed of coarse- to medium-grained sandstones at the base overlain by fine- to very fine-grained sandstone in turn overlain by siltstone in each individual cycle; and

b) a more dominant (intertidal) sequence composed of fine- to very fine-grained sandstone at the base that fines upward to lenticular and wavy bedded siltstones.

RECOMMENDATIONS

For prospect generation and future exploration for the Lower Amaranth oil in other areas of the Manitoba portion of the Williston Basin, it must be remembered that sandstone deposition is a dynamic process and that the reservoir qualities change spatially due to a number of phenomena such as progradation, transgression or regression, subsidence, burial, compaction, cementation and alteration through diagenetic processes. These factors, occurring either separately or in combination, will affect the reservoir characteristics of the sandstone facies. The result is the commonly occurring variations in reservoir quality within the same producing intervals of any given area. It is the magnitude of these variations in reservoir quality that is difficult to predict, and as such makes the process of prospect generation and evaluation subtle and complex.

For any given area the following factors should be taken into consideration when exploring for Lower Amaranth oil.

1. evidence of paleotopographically low areas on the Mississippian erosional surface;
2. occurrence of a thick (in excess of 30 m) Lower Amaranth sequence;
3. evidence of a subtidal environment that would result in deposition of channel-fill and/or channel creek sediments of sandstone dominated facies;
4. presence of either a thin, or absence of the, "altered zone" that would allow Mississippian oil to move upward into the Lower Amaranth reservoir; and
5. localized areas where evidence suggests multistage Devonian salt solution and subsequent collapse of the Lower Amaranth Formation resutling in its localized thickening.

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APPENDIX I

CORE DESCRIPTION

APPENDIX I: CORE DESCRIPTIONS

COULTER A POOL (11 29A)
NEWSCOPE* COULTER 11-21-1-27 WPM
Cored Interval: 949.0 - 967.0 m Recovery: 18 m

Interval (m)		Thickness (m)	Description
949.0	953.0	4.0	Siltstone: dark brown, shaly, grades to silty mudstone, anhydrite blebs, subangular to subrounded medium quartz grains near the base, scattered pin point intergranular porosity throughout.
			"B" Sand: 953.0 - 954.3 (1.3 m)
953.0	954.3	1.3	Sandstone: dark brown to brown to tan, very fine grained, well sorted, massive, anhydrite big blebs at the top, argillaceous matrix, tight.
954.3	955.36	1.06	Siltstone: dark brown, very thin bedded, sandy, grading to very fine grained sandstone, banded, shaly matrix, anhydrite blebs, fair intergranular porosity throughout the interval.
			"A" Sand: 955.36 - 956.36 (1.0 m)
955.36	956.36	1.0	Sandstone: light tan to light grey, very fine- to fine-grained, some medium- to coarse-subrounded noncemented quartz grains, non-calcareous matrix, pin point intergranular porosity.
956.36	957.0	0.64	Siltstone: dark to medium brown, shaly, anhydrite blebs, sandy at the base, grading to very fine grained sandstone, scattered pin point porosity.
			"Main" Sand: 957.0 - 959.8 (2.8 m)
957.0	958.0	1.0	Sandstone: medium brown to tan to brown grey, very fine grained, 5 per cent fine- to medium- noncemented quartz grains throughout, ill sorted, anhydrite blebs throughout, fair intergranular porosity, **patchy oil staining**.
958.0	959.8	1.8	Sandstone: light grey to buff, very fine to fine to medium (10%) grained, transparent subrounded medium noncemented quartz grains throughout, anhydrite blebs, pin point intergranular porosity, **patchy oil staining**.
959.8	961.15	1.35	Siltstone: dark brown to dark red brown, massive, matrix partly shaly and sandy, anhydrite blebs, tight.
961.15	962.8	1.65	Sandstone: dark to medium brown, very fine to fine to medium (10%) grained, medium grains are transparent subrounded quartz, scattered anhydrite blebs, pin point intergranular porosity.
962.8	964.75	1.95	Siltstone: dark brown, massive, shaly, sandy at the base, grading to very fine grained sandstone, tight.
			"Lower" Sand: 964.75 - 967.0 (2.25 m)
964.75	967.0	2.25	Sandstone: dark brown to dark tan, very fine grained, partly fine grained, interbedded with sandy siltstone, massive, no visible porosity in this interval.

* Present name of well is Mann Oil Coulter 11-21-1-27WPM.

VOYAGER BLACKROCK COULTER PROV. 5-22-1-27 WPM

Cored Interval: 948.0 - 966.0 m Recovery: 18 m

Interval (m)		Thickness (m)	Description
948.0	948.57	0.57	Siltstone: dark brown, sandy, some transparent fine noncemented quartz grains, partly shaly.
948.57	949.36	0.79	Siltstone: grey to medium grey, sandy, grading to very fine grained sandstone.
949.36	950.9	0.54	Siltstone: dark brown as above.
950.9	952.0	1.1	Sandstone: medium brown grey, very fine grained, silty and banded with dark brown siltstone, no visible porosity.
952.0	953.65	1.65	Siltstone: dark brown, partly shaly, interbedded with very fine grained sandstone beds of 1" thick, tight.
			"B" Sand*: 953.65 - 955.0 (1.35 m)
953.65	955.0	1.35	Sandstone: grey to medium grey, very very fine grained, grading to sandy siltstone, tight.
955.0	956.0	1.0	Siltstone: dark brown, partly sandy, shaly, scattered anhydrite blebs, tight.
			"A" Sand: 956.0 - 957.0 (1.0 m)
956.0	957.0	1.0	Sandstone: medium brown to brown grey, very fine- to fine-grained, transparent medium 5-10 per cent noncemented quartz grains, spordic intergranular porosity.
957.0	957.8	0.8	Siltstone: grey brown, partly sandy grading to very fine grained sandstone, tight.
			"Main" Sand: 957.8 - 960.0 (2.2 m)
957.8	959.5	1.7	Sandstone: medium brown to medium grey brown, very fine- to fine-grained, well-sorted, anhydrite blebs throughout, no visible porosity.
959.5	960.0	0.5	Sandstone: light tan to light grey, very fine grained, partly fine- to medium-grained, no visible porosity.
960.0	962.0	2.0	Siltstone: dark brown to dark red brown, shaly matrix partly sandy near base, tight.
962.0	962.7	0.7	Sandstone: grey to brown grey, very fine grained, massive, silty, few anhydrite blebs, no visible porosity.
962.7	963.1	0.4	Siltstone: dark brown to brick red brown, sandy in parts.
963.1	963.4	0.3	Sandstone: grey with dark brown bands, very fine- to fine-grained, massive, no visible porosity.
963.4	965.2	1.8	Siltstone: dark to medium brown, grading locally to very fine grained sandstone, anhydrite blebs, shaly, tight.
			"Lower" Sand: 965.2 - 967.2 (2.0 m)**
965.2	966.0	0.8	Sandstone: dark brown, very fine grained, partly silty, anhydrite blebs, no visible porosity.
966.0	967.2	1.2	Not cored.

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* Sandstone response not identifiable in logs (G.R. Sonic, IES).

** Logs (GR, Sonic, IES) do not show usual sandstone response for the "Lower" sand interval in this well.

NEWSCOPE COULTER 1-30-1-27 WPM

Cored Interval: 955.0 - 973.0 m **Recovery: 18.0 m**

Interval (m)		Thickness (m)	Description
955.0	957.2	2.2	Siltstone: medium brown, grains well-sorted, well cemented, massive and hard, scattered anhydrite blebs, tight.
957.2	958.8	1.6	Siltstone: as above, partly sandy, 10-15 per cent transparent fine non-cemented quartz grains, scattered fair intergranular porosity.
			"B" Sand: 958.8 - 959.65 (0.85 m)
958.8	959.65	0.85	Sandstone: medium brown, very fine grained, partly silty, well sorted, scattered poor to fair intergranular porosity.
959.65	961.40	1.75	Siltstone: dark to medium brown, massive, hard, 5 per cent transparent fine noncemented quartz grains, banded (dark brown with medium brown), tight.
			"A" Sand: 961.4 - 962.2 (0.8 m)
961.40	962.20	0.8	Sandstone: medium brown, very fine grained, slightly calcareous matrix, well-sorted, sucrosic texture, massive, no visible porosity.
962.20	962.60	0.4	Sandstone: grey, very fine grained, silty, hard, crossbedded, tight.
962.60	963.0	0.4	Siltstone: medium grey to grey, very sandy, grading to very fine grained sandstone, crossbedded, tight.
			"Main" Sand: 963.0 - 966.1 (3.10 m)
963.0	964.35	1.35	Sandstone: light brown to light grey, very fine- to fine-grained, some transparent fine noncemented quartz grains, few scattered small anhydrite blebs, good intergranular porosity, **patchy to uniform oil staining**.
964.35	965.0	0.65	Sandstone: medium to light grey, fine grained, abundant transparent fine- to medium- noncemented quartz grains, some scattered anhydrite blebs, non-calcareous, poor intergranular porosity, **patchy to uniform oil staining**.
965.0	966.10	1.10	Sandstone: medium grey, salt and pepper, very fine grained, partly fine grained, massive, dense, hard, non-calcareous, scattered white anhydrite blebs, poor intergranular porosity, bottom 0.5m tight.
966.10	967.35	1.25	Mudstone: dark brown, hard, dense, massive, silty in parts.
967.35	968.10	0.75	Siltstone: dark to medium brown, well sorted, sandy in parts, transparent very fine noncemented quartz grains, banded.
968.10	969.15	1.05	Siltstone: medium brown, well sorted, anhydrite blebs, sandy in parts.
969.15	970.15	1.0	Siltstone: dark to medium brown, well sorted, hard and dense, few anhydrite blebs, banded.
970.15	971.15	1.0	Siltstone: medium brown, calcareous cement, sandy in parts, some scattered transparent fine noncemented quartz grains, thin clay partings.
971.15	973.0	1.85	Siltstone: medium brown, calcareous cement, well sorted, appears to have sucrosic texture, argillaceous in parts.

SOUTH PIERSON A POOL (12 29A)
LYLETON ET AL SOUTH PIERSON 2-30-2-28 WPM
Cored Interval: 966.0 - 1 005.25 m Recovery: 39.25 m

Interval (m)		Thickness (m)	Description
966.0	968.1	2.1	Mudstone: dark brown to brick red, silty, siltstone lenses at places.
968.1	968.4	0.3	Siltstone: dark brown, trace anhydrite blebs, partly shaly.
968.4	969.4	1.0	Mudstone: as above, very silty, grades to siltstone.
969.4	970.0	0.6	Siltstone: dark brown, massive, sandy in parts.
970.0	971.0	1.0	Sandstone: dark brown, very fine grained, silty, grades from silty sandstone to sandy siltstone, anhydrite blebs throughout.
971.0	974.0	3.0	Siltstone: dark brown to dark red brown, partly shaly, scattered anhydrite blebs.
974.0	975.0	1.0	Mudstone: as above, silty.
975.0	976.0	1.0	Siltstone: dark brown, banded, shaly and shale partings.
976.0	978.5	2.5	Siltstone: medium brown, sandy, grades to very fine grained sandstone, white to light grey fine grained sandstone lenses throughout, anhydrite blebs, trace intergranular porosity.
			"B" Sand: 978.5 - 979.5 (1.0 m)
978.5	979.5	1.0	Sandstone: medium brown, very fine- to fine-grained, transparent medium noncemented quartz grains (5-10%), sucrosic texture, small anhydrite blebs, fair to good intergranular porosity, trace hair line fractured porosity, **patchy oil staining**.
979.5	981.5	2.0	Siltstone: medium brown, partly sandy, anhydrite blebs throughout.
			"A" Sand: 981.5 - 982.0 (0.5 m)
981.5	982.0	0.5	Sandstone: brown, very fine- to fine-grained, anhydrite blebs, no visible porosity.
982.0	983.0	1.0	Siltstone: as above.
983.0	983.5	0.5	Sandstone: medium brown, fine grained, partly medium- to coarse-grained, white fine grained sandstone lenses, anhydrite blebs common.
983.5	984.0	0.5	Siltstone: as above
			"Main" Sand: 984.0 - 986.0 (2.0 m)
984.0	986.0	2.0	Sandstone: medium brown to medium grey brown to tan, fine- to medium-grained, partly very fine grained, well sorted, non-calcareous, good to excellent intergranular porosity, **patchy to uniform oil staining**.
986.0	987.25	1.25	Siltstone: dark grey, brown, partly sandy, fair intergranular porosity, **patchy oil staining**.
987.25	987.75	0.5	Siltstone: dark grey brown, anhydrite blebs, sandy, trace intergranular porosity.
987.75	988.35	0.6	Sandstone: medium brown, very fine- to fine-grained, partly medium grained, thin bedded, crossbedded, partly silty, poor to fair intergranular porosity.
988.35	989.0	0.65	Siltstone: dark to medium brown, anhydrite blebs, sandy, trace pin point porosity.
989.0	991.1	2.1	Sandstone: medium brown to tan, very fine grained, silty, grades to sandy siltstone, poor intergranular porosity.

"Lower" Sand*: 991.1 - 994.0 (2.9 m)

991.1	993.6	2.5	Sandstone: tan to medium brown, very fine grained, anhydrite blebs, 10 cm grey, fine grained sandstone near base, no visible porosity.
993.6	994.0	0.4	Sandstone: dark brown, very fine- to fine-grained, abundant anhydrite blebs, contact with Mississippian carbonate very sharp.
Mississippian Top: 994.0			
994.0	995.0	1.0	Dolomite: buff to buff white, very anhydritic, large anhydrite blebs in dolomite matrix.
995.0	1 005.25	10.25	Dolomite/Limestone: buff to light grey, finely crystalline, large vugs, good to excellent vuggy and intercrystalline porosity; **patchy to uniform oil staining**.

* Logs (GR. Sonic, IES) indicate only 1.7 m of sandstone response from 991.0 to 992.7 m (Figures 19 and 20), whereas the drill core reveals 2.9 m of sandstone facies.

LYLETON ET AL SOUTH PIERSON 9-24-2-29 WPM

Cored Interval: 974.0 - 1 010.0 m Recovery: 36 m

Interval (m)		Thickness (m)	Description
974.0	975.75	1.75	Siltstone: dark brown, sandy, interbedded with sandstone: dark brown, very fine- to fine-grained, silty, tight.
975.75	976.55	0.8	Siltstone: dark to medium brown, massive, anhydrite blebs, partly shaly, trace intergranular porosity.
976.55	977.5	0.95	Siltstone: as above, sandy, grading to very fine grained sandstone, poor to fair intergranular porosity.
977.5	979.0	1.5	Siltstone: dark to medium brown, partly shaly, anhydrite blebs.
979.0	980.25	1.25	Siltstone: medium brown, partly shaly, anhydrite blebs, sandy, grading in parts to very fine grained sandstone, poor pin point porosity.
980.25	980.75	0.5	Siltstone: as above, grading to very fine grained sandstone, tight.
980.75	982.0	1.25	Sandstone: silty, medium brown, very fine grained, white sandstone lenses, poor to fair intergranular porosity.
			"B" Sand: 982.0 - 983.0 (1.0)
982.0	983.0	1.0	Sandstone: silty as above: bands of medium grained sandstone with good intergranular porosity.
983.0	984.0	1.0	Siltstone: dark brown to brick red brown, shaly matrix, pin point intergranular porosity.
984.0	985.0	1.0	Sandstone: grey to medium grey, very fine- to fine-grained, some medium grains of noncemented transparent quartz, anhydrite blebs, silty, grades in part to sandy siltstone, tight.
			"A" Sand: 985.0 - 986.0 (1.0 m)
985.0	986.0	1.0	Sandstone: light grey to tan, fine grained, anhydrite blebs, poor intergranular porosity, trace hairline fractured porosity.
986.0	987.0	1.0	Siltstone: dark brown to dark grey brown, sandy, white very fine grained sandstone lenses throughout, thin bedded, poor to fair intergranular porosity in sandstone lenses.
			"Main" Sand: 987.0 - 989.8 (2.8 m)
987.0	988.0	1.0	Sandstone: light grey to brown grey, very fine- to fine-grained, some buff siltstone lenses, fair intergranular porosity, **good uniform staining**.
988.0	989.8	1.8	Sandstone: light to medium brown grey, fine grained, poorly cemented, subangular to subrounded ill-sorted grains, good intergranular porosity, **good uniform oil staining**.
989.8	990.0	0.2	Siltstone: medium brown to grey brown, partly sandy, pin point intergranular porosity.
990.0	991.0	1.0	Siltstone: dark brown to medium brown, banded, partly shaly and sandy, small anhydrite blebs, trace intergranular porosity.
991.0	992.0	1.0	Siltstone: dark brown, sandy, grading to very fine grained sandstone, tight.
992.0	993.0	1.0	Siltstone: dark to medium brown, massive, anhydrite blebs, sandy.
993.0	994.0	1.0	Siltstone: medium brown, very sandy, grading to very fine grained sandstone, tight.
994.0	995.0	1.0	Siltstone: dark to medium brown, scattered anhydrite blebs, trace pin point porosity.
			"Lower" Sand: 995.0-977.35 (2.35 m)
995.0	977.35	2.35	Sandstone: medium brown, very fine- to fine-grained, silty in parts, 5-10 per cent transparent medium noncemented quartz grains, anhydrite blebs throughout, well cemented, non-calcareous, tight.

Mississippian top: 997.35

997.35	1 000.0	2.65	Dolomite: buff white to light grey, very anhydritic with large anhydrite blebs in dolomite matrix, massive, hard, dense.
1 000.0	1 010.0	10.0	Dolomite/Limestone: buff to light grey, fine- to medium-crystalline, abundant vugs, good to excellent vuggy and intercrystalline porosity.

LYLETON ET AL SOUTH PIERSON 14-24-2-29 WPM

Cored Interval: 982.5 - 1 000.75 m Recovery: 18.25 m

(Core depth adjusted to log depth)

Interval (m)		Thickness (m)	Description
982.5	983.0	0.5	Siltstone: brick red to dark brown, very sandy, grading to very fine grained sandstone, well sorted, well cemented, argillaceous, noncalcareous, small anhydrite blebs throughout.
983.0	983.4	0.4	Sandstone: light grey, very fine- to fine-grained, well cemented, well sorted, noncalcareous, tight.
			"B" Sand: 983.4 - 985.5 (2.1 m)
983.4	984.4	1.0	Sandstone: dark brown to dark tan to tan, partly light brown, very fine- to fine-grained, well sorted, anhydrite blebs, bands of silty mudstone, no visible porosity.
984.4	985.5	1.1	Sandstone: medium brown, fine grained, partly medium grained, subangular to subrounded, gives sucrosic texture under 3 x 15 power, scattered anhydrite blebs, poor to fair intergranular porosity, **patchy oil staining**.
985.5	986.0	0.5	Mudstone: dark brown to dark red brown, silty, grades to shaly siltstone.
986.0	987.5	1.5	Siltstone: grey to tan, sandy, grades to silty very fine grained sandstone, well-sorted quartz grains, banded, thin bands of dark brown siltstone interbedded with grey siltstone, fair intergranular porosity, **patchy oil staining**.
			"A" Sand: 987.5 - 988.0 (0.5 m)
987.5	988.0	0.5	Sandstone: light grey to white grey, medium- to coarse-grained, ill sorted, subangular to subrounded, bottom 15 cm grity, partly siliceous cement, no visible porosity.
988.0	989.0	1.0	Mudstone: dark brown to brick red brown, very silty, interbedded with thin bands of siltstone as above.
989.0	990.0	1.0	Siltstone: dark brown, well sorted, argillaceous, partly sandy.
			"Main" Sand: 990.0 - 992.2 (2.2 m)
990.0	992.2	2.2	Sandstone: dark brown to tan, very fine- to fine-grained, partly medium grained, ill sorted, scattered anhydrite blebs at base, good intergranular and vuggy porosity, **patchy to uniform oil staining**.
992.2	993.7	1.5	Siltstone: dark to medium brown, sandy, grades in parts to very fine grained sandstone, scattered anhydrite blebs, poor to fair intergranular porosity, **patchy oil staining**.
993.7	994.7	1.0	Siltstone: dark brown to tan, very sandy, grades to very very fine grained sandstone, abundant anhydrite blebs, fair intergranular porosity, **patchy oil staining**.
994.7	995.4	0.7	Mudstone: dark red brown to dark brown, silty, grading in parts to shaly siltstone, banded, anhydrite blebs throughout.
995.4	997.4	2.0	Siltstone: dark brown, anhydrite blebs throughout, sandy in parts with very fine grained sandstone lenses, crossbedded, tight.
			"Lower" Sand: 997.4 - 999.7 (2.3 m)
997.4	998.2	0.8	Sandstone: medium brown, very fine grained, well sorted, massive, crossbedded, shaly matrix, anhydrite blebs, tight.
998.2	998.8	0.6	Siltstone: as above, sandy.
998.8	999.7	0.9	Sandstone: brick red, fine grained, medium grained at the base, mainly as above.
999.7	1 000.75	1.05	Siltstone: dark brown, sandy, grades to very fine- to fine-grained sandstone, 5-10 per cent rounded coarse noncemented grains of transparent quartz, clayey cement, noncalcareous, anhydrite blebs throughout, tight.

SOUTH PIERSON B POOL (12 29B)
HOME SCURRY S. PIERSON 14-4-2-29 WPM*
Cored interval: 1 020.0 - 1038.0 m Recovery: 14.1 m

Interval (m)		Thickness (m)	Description
1 020.0	1 022.20	2.20	Siltstone: dark brown, shaly, grading to silty mudstone, scattered anhydrite blebs.
1 022.2	1 025.5	3.3	Siltstone: dark brown, some fine- to medium-grains of frosted quartz, anhydrite blebs, poor intergranular porosity in the middle of the interval.
			"A" Sand: 1 025.5 - 1 026.15 (0.65 m)
1 025.5	1 026.15	0.65	Sandstone: light grey, very fine grained, silty, grading to sandy siltstone, scattered poor intergranular porosity.
1 026.15	1 027.5	1.35	Siltstone: medium brown, banded with dark brown, scattered anhydrite blebs, tight.
1 027.5	1 028.0	0.5	Siltstone: tan to medium brown, banded, some fine grains of frosted quartz, no visible porosity.
			"Main" Sand: 1 028.0 - 1 031.3 (3.3 m)
1 028.0	1 029.0	1.0	Sandstone: greenish grey to light tan, very fine grained, crossbedded, partly silty, some fine grained lenses of frosted quartz, pinkish brown nodular anhydrite, fair intergranular porosity.
1 029.0	1 030.2	1.2	Sandstone: light grey to grey brown, very fine- to fine-grained, medium grained frosted quartz in lenticular form, scattered anhydrite blebs, green shale partings, crossbedded, good intergranular porosity, **patchy oil staining**.
1 030.2	1 031.3	1.1	Sandstone: light grey, fine- to medium-grained, abundant medium grains of frosted quartz, pink felspar lenses at the base, good intergranular porosity, **patchy oil staining**.
1 031.3	1 032.64	1.34	Siltstone: grey to medium grey to medium brown, banded, sandy in parts, massive, hard.
1 032.64	1 034.10	1.46	Siltstone: dark brown, banded, massive anhydrite blebs throughout.
1 034.10	1 038.0	3.9	Core not recovered.

* 'B' sand not developed.

HOME ET AL SOUTH PIERSON 16-8-2-29 WPM

Cored Interval: **1 017 - 1 035.0 m** **Recovery:** **18 m**

Interval (m)		Thickness (m)	Description
1 017	1 018	1.0	Siltstone: dark to medium brown, well sorted, hard, dense.
1 018	1 019.2	1.2	Siltstone: sandy, grey to medium grey, banded with brown siltstone, well sorted, clayey matrix, trace intergranular porosity.
			"B" Sand: 1 019.2 - 1 020.0 (0.8 m)
1 019.2	1 020.0	0.8	Sandstone: silty, grey to medium grey, banded with brown sandstone, very fine grained, anhydrite blebs, fair intergranular porosity, **patchy oil staining**.
1 020.0	1 021.7	1.7	Siltstone: light to grey brown, well-sorted grains, green grey shale partings, tight.
			"A" Sand: 1 021.7 - 1 022.4 (0.7 m)
1 021.7	1 022.4	0.7	Sandstone: grey to grey brown, fine- to medium-grained, ill sorted, subangular to subrounded to rounded noncemented medium quartz grains, matrix slightly calcareous, no visible porosity.
1 022.4	1 024.95	2.55	Siltstone: medium brown, banded with dark brown, massive, trace intergranular porosity.
			"Main" Sand:1 024.95 - 1 028.9 (3.95 m)
1 024.95	1 025.3	0.35	Sandstone: light grey to light brown, very fine- to fine-grained, silty, 10-20 per cent subrounded to rounded medium grains of noncemented transparent quartz, good intergranular porosity, **patchy oil staining**.
1 025.3	1 025.8	0.5	Sandstone: light grey to light brown, very fine grained, well sorted, silty, good intergranular porosity, **uniform oil staining**.
1 025.8	1 028.9	3.1	Sandstone: light brown to light grey, very fine- to fine-grained, pink quartzose medium grained sandstone lenses throughout the interval, very slightly calcareous matrix, some brown siltstone lenses, anhydrite blebs, massive, good intergranular porosity, **patchy staining**
1 028.9	1 029.75	0.85	Mudstone/Siltstone: dark brown mudstone banded with grey to brown siltstone, white anhydrite blebs, fine grained sandstone lenses.
1 029.75	1 032.0	2.25	Siltstone: medium brown banded with dark brown, dense, well sorted, sandy, 5-20 per cent fine grains of noncemented transparent quartz.
1 032.0	1 034.0	2.0	Siltstone*: light to medium brown, scattered dark brown siltstone lenses, massive, hard.
1 034.0	1 035.0	1.0	Siltstone*: as above, sandy in parts.

* Logs (GR. sonic, IES) response suggests (Lower Sand) sandstone. Please note the SP and GR response from 1 032 to 1 035 log depth. Core of this interval is all siltstone like the one described above from 1 029.75 to 1 032. Why then sandstone like response?

HOME SCURRY SOUTH PIERSON 16-9-2-29 WPM*

Cored interval: 1 010 - 1 028 m Recovery: 18 m

Interval (m)		Thickness (m)	Description
1 010.0	1 011.4	1.4	Siltstone: dark to medium brown, shaly, grading in part to silty mudstone, some brown to white anhydrite blebs, tight.
1 011.4	1 013.1	1.7	Siltstone: medium brown, well sorted, sandy in parts, very fine grained sandstone lenses, abundant white anhydrite blebs, tight.
1 013.1	1 014.0	0.9	Siltstone: medium to light brown, light brown sandy siltstone lenses, anhydrite blebs throughout, tight.
1 014.0	1 015.0	1.0	Sandy Siltstone: medium brown, some fine transparent quartz grains, ill sorted, scattered anhydrite blebs, tight.
1 015.0	1 015.5	0.5	Mudstone: dark brown, silty, hard, massive, anhydrite blebs.
1 015.5	1 018.25	2.75	Siltstone: medium brown, sandy, grading to very fine grained sandstone, fine- to medium-grains of noncemented transparent quartz, scattered anhydrite blebs, tight, no visible porosity.
1 018.25	1 019.0	0.75	Siltstone: medium to light brown, bands of anhydrite large blebs, sandy near the base, fining upward sequence, tight.
			"Main" Sand: 1 019.0 - 1 022.25 (3.25 m)
1 019.0	1 020.0	1.0	Sandstone: light brown to tan to light grey, very fine grained, slightly calcareous matrix, silty in parts, good intergranular porosity, **patchy to uniform oil staining**.
1 020.0	1 021.0	1.0	Sandstone: light brown to light grey, very fine- to fine-grained, bioturbated, some anhydrite blebs of various sizes, fair to good intergranular porosity, **uniform oil staining**.
1 021.0	1 022.25	1.25	Sandstone: as above, grain size becomes from very fine- to fine to medium grained, abundant medium grains of transparent to pink quartz, fining upward sequence, tight.
1 022.25	1 023.0	0.75	Siltstone: medium to light brown, dense, partly sandy, scattered anhydrite blebs, tight.
1 023.0	1 024.0	1.0	Siltstone: dark brown, massive, hard, very small size of numerous white anhydrite blebs, tight.
1 024.0	1 026.6	2.6	Siltstone: dark brown, hard, banded, bands of anhydrite blebs in cyclic order, bioturbated, tight.
			"Lower" Sand: 1 026.6 - 1 027.5 (0.9 m)**
1 026.6	1 027.5	0.9	Siltstone: dark brown, sandy, fine grains of transparent quartz, massive, dense, bioturbated, tight.
1 027.5	1 028.0	0.5	Siltstone: as above, not sandy, abundant anhydrite blebs.

* 'A' and 'B' Sands not developed.

** 'Lower' Sand interval is composed of sandy siltstone, whereas logs (GR, SP, IES) indicate sandstone response.

HOME SCURRY SOUTH PIERSON 8-10-2-29 WPM

Cored interval: 1 010.0 - 1028.0 m Recovery: 15.8 m

Interval (m)		Thickness (m)	Description
1 010.0	1 012.0	2.0	Siltstone: medium brown banded with dark brown, elongated to subrounded anhydrite blebs throughout, hard, laminated, trace of crossbedding, frosted quartz grains in 1 011.10 1011.45 interval, tight.
1 012.0	1 012.20	0.20	Siltstone: light brown to tan, partly sandy.
1 012.20	1 014.70	2.5	Siltstone*: medium to dark brown, massive, hard, anhydrite blebs throughout, tight.
			"A" Sand: 1 014.70 - 1 015.35 (0.65 m)
1 014.70	1 015.35	0.65	Sandstone: light grey to light brown, very fine grained, some fine- to medium-grains of frosted quartz, scattered few anhydrite blebs, no visible porosity.
1 015.35	1 017.0	1.65	Siltstone: dark brown, laminated, some fine grains of frosted quartz, anhydrite blebs common, tight.
			"Main" Sand: 1 017.0 - 1 021.40 (4.4 m)
1 017.0	1 017.30	0.3	Sandstone: greenish grey, banded with brick red brown and light brown, very fine grained, some fine grains of frosted quartz, laminated, no visible porosity.
1 017.30	1 018.05	0.75	Sandstone: greenish grey, very fine- to fine-grained, pink brown anhydrite nodules, some white fine grained sandstone interclasts, hairline fractures, good intergranular and fractured? porosity, **patchy to uniform oil staining**.
1 018.05	1 019.30	1.25	Sandstone: light greenish grey to tan in lenticular form, very fine- to fine-grained, very thin bands of medium grains of frosted quartz, fine grained pink felspar lenses, trace to poor intergranular porosity, **patchy to uniform oil staining**.
1 019.30	1 020.40	1.10	Sandstone: light greenish grey to light brown to tan, fine- to medium-grained, partly coarse grained, medium- and coarse-grains of frosted quartz, silica cement, few lenses of medium grained pink felspar, good intergranular porosity, **patchy to uniform oil staining**.
1 020.40	1 021.40	1.0	Sandstone: greenish grey mingled with medium brown in form of lenses (interfingered pattern), very fine grained, thin bedded, no visible porosity.
1 021.40	1 021.90	0.5	Siltstone: greenish grey with brown patches, (brown interclasts?), massive, hard, tight.
1 021.90	1 022.90	1.0	Core not recovered.
1 022.90	1 024.0	1.1	Siltstone: dark brown, shaly partings, shaly matrix, grading to silty mudstone, white anhydrite blebs throughout.
			"Lower" Sand: 1 024.0 - 1 026.8 (2.8 m)
1 024.0	1 025.10	1.10	Sandstone: light brown to pink brown to medium brown, banded, very fine to fine to medium grained, (frosted quartz and pink felspar are usually medium grained), fining upward sequence, trace anhydrite blebs, good intergranular porosity, **patchy oil staining**.
1 025.10	1 026.80	1.70	Sandstone: light grey to light brown, banded, lentricular, fine- to medium-grained, fine grained thin bands interbeds with medium grained thin bands (medium grains are of frosted quartz) excellent intergranular porosity, **patchy oil staining**.
1 026.8	1 028.0	1.2	Core not recovered.

* "B' Sand not developed (Figures 13, 21, and 22).

HOME SCURRY SOUTH PIERSON 10-15-2-29 WPM*

Cored Interval: 1 003.0 - 1 021.0 m Recovery: 18 m

Interval (m)		Thickness (m)	Description
1 003.0	1 005.0	2.0	Mudstone: brick red to dark red brown, silty, banded, massive.
1 005.0	1 006.0	1.0	Siltstone: brick red, shaly bands, medium grained quartz at the base, sandy, grades to silty sandstone, tight.
1 006.0	1 008.5	2.5	Siltstone: as above, light grey fine grained sandstone lenses, some anhydrite blebs.
1 008.5	1 010.2	1.7	Mudstone: brick red to dark brown, silty in parts.
			"Main" Sand: 1 010.2 - 1 013.0 (2.8 m)
1 010.2	1 011.0	0.8	Sandstone: brown to medium brown, very fine- to fine-grained, medium grained in parts, hard, massive, no visible porosity.
1 011.0	1 013.0	2.0	Sandstone: tan to tan grey to brown, very fine to fine to medium grained, white medium grained quartz are embedded along with fine grained sandstone, ill sorted, subangular to subrounded, scattered anhydrite blebs throughout, no visible porosity.
1 013.0	1 015.0	2.0	Siltstone: dark brown, shaly, grades to silty mudstone, banded.
1 015.0	1 017.0	2.0	Siltstone: brick red, shaly, grades to silty mudstone.
			"Lower" Sand: 1 017.0 - 1 018.2 (1.2 m)
1 017.0	1 018.2	1.2	Sandstone: dark brown, very fine grained, silty, grades to sandy siltstone, scattered medium grained frosted quartz in matrix, no visible porosity.
1 018.2	1 019.5	1.3	Siltstone: dark brown, sandy, anhydrite blebs throughout, tight.
1 019.5	1 020.0	0.5	Mudstone: dark brown, silty, grey clay blebs.
Mississippian Top: 1 020			
1 020.0	1 021.0	1.0	Dolomite: very anhydritic grades to dolomitic anhydrite: light grey to white grey, massive.

* 'A' and 'B' Sands are not developed.

HOME SCURRY SOUTH PIERSON 10-21-2-29 WPM

Cored Interval: 1 003.0 - 1021.0 m Recovery: 18 m

Interval (m)		Thickness (m)	Description
1 003.0	1 004.0	1.0	Mudstone: dark brown, silty, grading to shaly siltstone.
1 004.0	1 005.62	1.62	Siltstone: dark brown, banded with light grey brown, laminated and bioturbated, white anhydrite nodules and blebs, pin point intergranular porosity.
			"B" Sand: 1 005.62 - 1 006.62 (1.0 m)
1 005.62	1 006.62	1.0	Siltstone: medium brown, light brown lenses, partly sandy, cross bedded, some hair line fractures, matrix dense, possible fractured porosity (perfed interval: 1 005 - 1 008).
1 006.62	1 008.35	1.73	Siltstone: dark brown, banded, crossbedded and laminated, dense, hard, anhydrite blebs throughout, tight.
			"A" Sand: 1 008.35 - 1 008.85 (0.5 m)
1 008.35	1 008.85	0.5	Sandstone: medium brown, very fine grained, partly silty, trace intergranular porosity.
1 008.85	1 010.0	1.15	Siltstone: medium brown with dark brown patches, anhydrite blebs, sandy, grading to very fine grained sandstone, poor to fair intergranular porosity.
1 010.0	1 010.25	0.25	Sandstone: green grey, banded with dark brown lenses, very fine grained, very silty, poor intergranular porosity.
			"Main" Sand 1 010.25 - 1 013.0 (2.75 m)
1 010.25	1 011.20	0.95	Sandstone: light greenish grey to grey brown, very fine- to fine-grained, some frosted quartz grains, scattered brown nodular anhydrite, fair intergranular porosity, **uniform oil staining**.
1 011.20	1 011.70	0.5	Sandstone: light greenish grey to light brown, fine- to medium-grained, abundant medium grains of frosted pink quartz, medium grained pink sandstone banded with light grey fine grained sandstone, few scattered anhydrite blebs, good to excellent intergranular porosity, **uniform to patchy oil staining**.
1 011.70	1 012.35	0.65	Sandstone: light grey to light brown grey, fine- to medium-grained, medium grains are of frosted quartz, hard, crossbedded, trace of bioturbation, few scattered anhydrite blebs, fair intergranular porosity.
1 012.35	1 013.0	0.65	Sandstone: light to medium brown, very fine grained, laminated and crossbedded, anhydrite blebs throughout, poor to fair intergranular porosity.
1 013.0	1 013.70	0.70	Siltstone: light to medium brown, banded with dark brown, some light brown very fine grained sandstone lenses, abundant anhydrite blebs in dark brown siltstone, trace pin point porosity.
1 013.70	1 016.75	3.05	Siltstone: dark brown, banded with medium brown, crossbedded, bioturbated, white anhydrite blebs throughout in banded form, hard, tight.
			"Lower" Sand: 1 016.75 - 1 018.0 (1.25 m)
1 016.75	1 018.0	1.25	Sandstone: medium brown, very fine grained, with some fine grains of frosted quartz, partly silty, anhydrite blebs throughout, tight.
1 018.0	1 019.35	1.35	Siltstone: medium brown siltstone interclasts with dark brown siltstone, bioturbated, partly sandy, bands of anhydrite blebs, tight.
Mississippian top: 1 019.35			
1 019.35	1 020.0	0.65	Anhydrite: white, small and large blebs in a silty and dolomitic matrix, "anhydrite conglomerate" 'Charles Formation'.
1 020.0	1 021.0	1.0	Dolomite: white to light grey, very finely crystalline, abundant large anhydrite blebs, tight.

SOUTH PIERSON LOWER AMARANTH C POOL (12 29C)
HOME SCURRY SOUTH PIERSON 6-19-2-29 WPM
Cored Interval: 1 022.0 - 1 040.0 m Recovery: 18.0 m

Interval (m)		Thickness (m)	Description
			"B" Sand: 1 022.0 - 1 023.4 (1.4 m)
1 022.0	1 023.4	1.4	Sandstone: light brown to tan to light brown grey, very fine grained, well sorted, some fine grained white to transparent quartzose sandstone lenses, scattered few very small anhydrite blebs, matrix slightly calcareous, fair to good intergranular porosity, **uniform oil staining**.
1 023.4	1 024.02	0.62	Siltstone: dark brown banded with medium brown, massive, hard, matrix slightly calcareous and argillaceous, scattered anhydrite blebs, trace intergranular porosity.
1 024.02	1 024.26	0.24	Siltstone: medium to light brown, sandy, grades to very fine grained sandstone, poor intergranular porosity.
1 024.26	1 025.80	1.54	Siltstone: dark brown banded with medium brown as above.
			"A" Sand: 1 025.8 - 1 026.7 (0.9 m)
1 025.8	1 026.7	0.9	Sandstone: light brown to grey brown, very fine grained, well sorted, partly silty, slightly calcareous, scattered anhydrite blebs, fair to good intergranular porosity, **patchy oil staining**.
1 026.7	1 027.7	1.0	Siltstone to mudstone: dark brown banded with red brown, scattered anhydrite blebs, hard, massive.
			"Main" Sand: 1 027.7 - 1 030.8 (3.1 m)
1 027.7	1 028.2	0.5	Sandstone: light grey to medium grey, very fine- to fine-grained, cross-bedded, silty, poor intergranular porosity, **patchy oil staining**
1 028.2	1 029.5	1.3	Sandstone: light grey to light tan, fine- to medium-grained, pink and white sub rounded to rounded quartz grains, some anhydrite blebs, good intergranular porosity, **patchy to uniform oil staining**.
1 029.5	1 030.8	1.3	Sandstone: light grey, very fine grained, well sorted, matrix slightly calcareous, silty at the base, anhydrite blebs, good intergranular porosity, **uniform oil staining**.
1 030.8	1 031.20	0.4	Siltstone: brown to brown grey, banded with dark brown, partly sandy (sandy siltstone), numerous anhydrite blebs, trace to poor intergranular porosity.
1 031.20 -1 034.75		3.55	Siltstone: medium brown banded with dark brown, massive, hard, dense matrix, slightly calcareous, white anhydrite blebs throughout.
1 034.75	1 036.23	1.48	Siltstone: medium brown throughout, partly sandy, white anhydrite blebs, hard, dense.
1 036.23	1 037.00	0.77	Siltstone: medium to light brown, very well sorted, noncalcareous, sandy at the base, grading to very fine grained sandstone, occasional anhydrite blebs.

			"Lower" Sand*: 1037.0 - 1038..8 (1.8 m)
1 037.00	1 038.80	1.8	Siltstone: sandy, medium brown, well sorted, calcareous matrix, some brown to white anhydrite blebs, fine rounded grains (5%) of white quartz.
1 038.80	1 039.32	0.52	Sandstone: light grey to light grey brown, very fine to fine to medium grained, (medium grained near contact with the Mississippian carbonate), numerous white anhydrite blebs, calcareous cement, medium grained sandstone lenses in the very fine grained sand body, dense, tight, contact with Mississippian anhydrite very sharp.
Mississippian top: 1 039.32 m			
1 039.32	1 040.0	0.68	Anhydrite: light brown to white, with some anhydritic dolomite.

* Logs (GR, SP, IES) indicate the interval is of sandstone whereas drill core is composed of sandy siltstone (Figures 21 and 22).

SOUTH PIERSON LOWER AMARANTH E POOL (12 29E)
HOME SCURRY SOUTH PIERSON 6-7-2-29 WPM
Cored Interval: 1 025.0 - 1 043.0 m Recovery: 18.0 m

Interval (m)		Thickness (m)	Description
1 025.0	1 025.5	0.5	Mudstone: red brown, very silty, grading to siltstone, anhydrite blebs.
1 025.5	1 026.0	0.5	Siltstone: red brown, clayey, massive, banded.
1 026.0	1 027.0	1.0	Mudstone: red brown, silty bands.
1 027.0	1 028.0	1.0	Siltstone: as above, partly sandy.
1 028.0	1 029.5	1.5	Siltstone: grey to brown grey, noncalcareous, clayey cement, partly sandy, trace pin point porosity, **patchy oil staining**.
			"B" Sand: 1 029.5 - 1 031.5 (2.0 m)
1 029.5	1 030	0.5	Sandstone: grey, brown, very fine grained, partly silty at places, sandy siltstone lenses, pin point porosity, **patchy oil staining**.
1 030	1 030.5	0.5	Siltstone: brown, very shaly, grading to silty mudstone.
1 030.5	1 031.5	1.0	Sandstone: light grey to grey, very fine grained, quartz grains subangular to subrounded, partly sucrosic, slightly calcareous cement, at the base grain size becomes fine- to medium-grained, fining upward sequence, fair intergranular porosity, **patchy oil staining**.
1 031.5	1 032.5	1.0	Mudstone: red brown, silty, grades to shaly siltstone.
1 032.5	1 033.75	1.25	Siltstone: red brown to grey brown, sandy, grading in part to very fine grained sandstone, shaly in parts, slightly calcareous matrix, tight.
			"A" Sand: 1 033.75 - 1 035.0 (1.25 m)
1 033.75	1 035.0	1.25	Sandstone: brown to grey brown to grey, very fine- to fine-grained, well cemented, noncalcareous, subrounded to rounded, no visible porosity.
1 035.0	1 036.0	1.0	Mudstone: red to dark brown red, very silty, grading to shaly siltstone
1 036.0	1 037.0	1.0	Siltstone: brick red, banded with grey, at the base becoming sandy, fining upward sequence.
			"Main" Sand: 1 037.0 - 1 039.8 (2.8 m)
1 037.0	1 039.8	2.8	Sandstone: grey to light brown grey, very fine grained, fine grained in parts, matrix slightly calcareous, medium grained at the base, fining upward sequence, subangular to subrounded quartzose sandstone, fair to good intergranular porosity, porosity greater at the base, **good uniform oil staining**.
1 039.8	1 041.0	1.2	Siltstone: brown with red patches, partly sandy, grades to very fine grained sandstone, tight.
1 041.0	1 041.5	0.5	Sandy Siltstone: brown to brown grey, red patches, very fine grained sandstone lenses, partly argillaceous, tight.
1 041.5	1 043.0	1.5	Siltstone: brown to dark brown, banded with brick red mudstone, very fine grained sandstone bands, scattered anhydrite blebs at the base, tight.

OTHER AREA POOL (99 29D)
AMERAN ET AL LYLETON PROV. 15-26-1-28 WPM
Cored Interval: 972.5 - 990.5 m Recovery: 18 m

Interval (m)		Thickness (m)	Description
972.5	973.0	0.5	Siltstone: dark brown to dark tan, sandy, grades to very fine grained sandstone, top 10 cm silty mudstone.
973.0	973.75	0.75	Mudstone: dark brown, red to dull red, partly silty.
			"B" Sand: 973.75 - 974.35 (0.6 m)
973.75	974.35	0.6	Sandstone: medium grey brown to brown grey, very fine grained, 5-10 per cent medium grains of transparent quartz, anhydrite blebs, pin point intergranular porosity.
974.35	975.5	1.15	Siltstone: dark brown, shaly, grades to silty mudstone, anhydrite blebs throughout.
975.5	976.0	0.5	Mudstone: dark brown, massive, silty in parts, anhydrite blebs.
976.0	976.3	0.3	Siltstone: dark brown, sandy, grades to very fine grained sandstone with 5 per cent transparent fine- to medium-quartz grains.
			"A" Sand: 976.3 - 977.0 (0.7 m)
976.3	977.0	0.7	Sandstone: light to medium grey, partly brown, very fine- to fine-grained, 5 per cent medium grains of transparent quartz, slightly calcareous cement, poor to fair intergranular porosity.
977.0	978.15	1.15	Siltstone: dark brown to dark red brown, sandy, partly grades to very fine grained sandstone, thin bands of silty mudstone, anhydrite blebs throughout.
			"Main" Sand: 978.15 - 980.15 (2.0 m)
978.15	980.15	2.0	Sandstone: light to medium grey, very fine- to fine-grained, partly medium grained (transparent quartz), crossbedded, scattered anhydrite blebs, poor to fair intergranular and vuggy porosity, **patchy oil staining**.
980.15	981.05	0.9	Siltstone: light to medium grey, sandy, grading to very fine grained sandstone as above, scattered poor to fair intergranular porosity.
981.05	982.0	0.95	Siltstone: dark brown, shaly, anhydrite blebs throughout, trace pin point porosity.
982.0	983.0	1.0	Sandstone: tan to grey, very fine- to fine-grained, 5 per cent medium grained, anhydrite blebs, slightly calcareous, no visible porosity.
983.0	985.0	2.0	Siltstone: dark red brown to dark brown, shaly in parts, anhydrite blebs throughout.
			"Lower" Sand*: 985.0 - 989.0 (4.0 m)
985.0	986.4	1.4	Sandstone: grey to medium brown, very fine grained, very silty, grades to sandy siltstone, tight.
986.4	987.0	0.6	Sandstone: medium brown to medium grey brown, very fine grained, silty in parts, tight.
987.0	988.0	1.0	Sandstone: medium brown, very fine- to fine-grained, 10 per cent fine black chert grains, anhydrite blebs throughout, tight.
988.0	988.5	0.5	Silty Sandstone: medium brown, very fine grained, partly shaly, tight.

* Logs (GR, Sonic, IES) indicate only 1.5 m of sandstone response from 987.0 to 988.5 m (Figures 21 and 22), whereas the drill core is composed of sandstone throughout the interval from 985.0 to 989.0.

988.5	989.0	0.5	Sandstone: medium brown, very fine- to fine-grained, anhydrite blebs throughout, scattered transparent medium quartz grains, tight, contact with Mississippian rock sharp.

Mississippian Top 989.0 m

989.0	990.5	1.5	Anhydrite: white to light grey, big anhydrite blebs in dolomite matrix, crypto crystalline.

RIDEAU PIPESTONE LYLETON PROV. 5-34-1-28 WPM

Cored Interval: **980 - 998.0 m** **Recovery: 18 m**

Interval (m)		Thickness (m)	Description
980	981.0	1.0	Siltstone: medium brown, sandy, grades to very fine grained sandstone, anhydrite blebs throughout, pin point intergranular porosity.
981.0	981.75	0.75	Sandstone: medium brown, very fine grained, partly silty, some transparent fine- to medium- quartz grains, no visible porosity.
981.75	982.25	0.5	Siltstone: as above
			"B" Sand: 982.25 - 983.0 (0.75 m)
982.25	983.0	0.75	Sandstone: medium brown, very fine- to fine-grained, well sorted, white sandstone lenses, poor intergranular porosity.
983.0	984.0	1.0	Sandy Siltstone: medium brown, grades to very fine grained sandstone, scattered intergranular porosity.
984.0	985.0	1.0	Siltstone: as above, medium brown banded with dark brown.
			"A" Sand: 985.0 - 986.0 (1.0 m)
985.0	986.0	1.0	Sandstone: silty, medium brown, very very fine- to fine-grained, anhydrite blebs, pin point intergranular porosity.
986.0	987.0	1.0	Siltstone: medium brown, sandy, poor to fair intergranular porosity.
			"Main" Sand 987.0 - 989.0 (2 m)
987.0	988.5	1.5	Sandstone: light to medium brown to medium grey brown, very fine- to medium-grained, abundant white and transparent medium quartz grains, fining upward sequence, fair to good intergranular porosity, **uniform oil staining**.
988.5	989.0	0.5	Sandstone: light brown, very fine grained, silty, grades to sandy siltstone, tight.
989.0	990.7	1.7	Siltstone: dark to medium brown, anhydrite blebs throughout, tight.
990.7	991.25	0.55	Sandstone: light to medium grey, very fine grained, anhydrite blebs throughout, very silty, grades to sandy siltstone.
991.25	995.0	3.75	Siltstone: dark brown, dense, grey shale partings, scattered anhydrite blebs, trace pin point porosity.
			"Lower" Sand*: 995.0 - 997.45 (2.45 m)
995.0	997.0	2.0	Sandstone: silty, medium brown, very fine- to fine-grained, dense, no visible porosity.
997.0	997.45	0.45	Sandstone: medium brown, very fine to fine to medium grained, fining upward sequence, abundant anhydrite blebs, very calcareous due to near contact with Mississippian rock.
Mississippian Top: 997.45			
997.45	998.0	0.55	Dolomite/Anhydrite: off white to grey white, limy, crypto crystalline.

* Logs (GR, sonic, IES) indicate only 1.8 m of sandstone from 995.0 to 996.8 (Figure 24), wheres the drill core contains 2.45 m of sandstone.

APPENDIX II

WELL DATA

APPENDIX II

WELL DATA FOR LOWER AMARANTH FORMATION
COULTER-PIERSON AREA
(Twp. 1-3, Rge. 27-29 WPM)
All Values in Metre

Location (WPM)	K.B.	Top Lr. Am.	Top Sandy Unit	Top Miss.	Total Sand	Cored Interval	Perfed Interval
04-01-1-27	455.0	929.0	950.0	969.5	5.0		
03-02-1-27	453.0	932.7	958.6	974.8	5.2		
01-03-1-27	456.0	947.3	976.0	993.6	5.2		
16-07-1-27	457.4	952.4	976.0	987.0	2.5		
05-09-1-27	457.0	949.0	969.0	987.0	5.5	969.0 - 987.0	
10-09-1-27	457.0	946.0	963.0	976.6	4.6		
11-09-1-27	456.0	945.0	?	979.6	5.2?	987.8 - 1 004.6	
12-09-1-27	460.0	948.5	968.3	984.5	5.5	972.3 - 998.8	
13-10-1-27	457.0	944.0	966.0	980.5	4.8	936.0 - 981.0	966.0 - 973.0
							976.0 - 978.0
13-15-1-27	458.0	939.0	962.0	977.5	5.0	1 043.0 - 1 061.0	1 036.0 - 1 053.0
05-16-1-27	457.0	944.0	964.0	980.0	4.5	965.0 - 983.0	
13-16-1-27	457.0	944.0	965.0	980.0	4.0	959.0 - 977.0	969.5 - 972.5
16-16-1-27	456.0	937.6	956.0	973.8	4.5	971.0 - 979.6	
05-17-1-27	459.0	952.0	972.0	990.0	6.0	968.0 - 986.0	977.0 - 979.0
07-18-1-27	460.0	952.0	972.0	986.0	6.0	970.0 - 988.0	977.5 - 980.5
05-20-1-27	454.4	938.8	961.6	973.8	4.6		
09-20-1-27	454.0	935.0	955.0	972.0	4.0	949.0 - 985.0	959.0 - 965.0
11-20-1-27	458.0	940.0	959.0	975.0	4.0	955.0 - 973.0	964.0 - 970.0
01-21-1-27	457.5	937.3	957.0	973.8	?		
05-21-1-27	457.0	940.0	963.0	976.0	1.5	953.0 - 971.0	964.0 - 969.0
07-21-1-27	454.7	934.2	956.5	968.7	3.0	962.8 - 990.0	972.0 - 975.0
08-21-1-27	455.7	933.3	955.8	970.0	3.0		
11-21-1-27	454.0	933.0	956.0	969.0	5.5	949.0 - 985.0	945.0 - 963.0
05-22-1-27	454.0	933.0	956.0	971.0	4.0	948.0 - 966.0	956.0 - 960.0
12-22-1-27	452.6	929.3	952.0	966.5	5.5	964.0 - 975.0	
A12-22-1-27	455.0	931.0	953.0	968.0	4.0	948.0 - 970.0	955.0 - 958.0
02-27-1-27	456.0	920.5	942.0	953.7	4.5		
16-28-1-27	456.3	928.0	950.0	964.0	3.0	952.5 - 956.5	
03-29-1-27	457.0	936.0	958.5	972.0	4.0	936.0 - 970.0	960.0 - 963.0
							947.0 - 951.0
01-30-1-27	457.0	940.0	961.5	975.0	4.5	955.0 - 973.0	963.0 - 965.5
09-30-1-27	458.0	937.0	957.0	971.5	4.0	950.0 - 976.0	957.5 - 967.0

APPENDIX II (continued)

Location (WPM)	K.B.	Top Lr. Am.	Top Sandy Unit	Top Miss.	Total Sand	Cored Interval	Perfed Interval
01-03-1-28	458.0	977.0	994.0	1 020.0	7.3		
03-04-1-28	462.4	997.0	1 013.0	1 038.0	11.0		
11-13-1-28	451.4	948.5	969.0	984.0	4.2		
05-14-1-28	455.0	969.0	993.0	1 007.0	4.9		
14-15-1-28	461.0	973.0	982.0	1 013.0	10.0		
16-15-1-28	460.0	972.5	992.0	1 012.0	5.0?		
01-16-1-28	461.0	974.0	994.0	1 012.0	8.5		
05-17-1-28	463.0	995.0	1 013.0	1 031.0	6.7		
12-17-1-28	463.0	994.0	1 012.0	1 032.0	6.5		
12-23-1-28	457.0	958.0	980.5	998.0	5.0		
13-26-1-28	460.0	956.5	980.0	993.0	4.0		982.0 - 984.0
15-26-1-28	459.0	952.0	973.0	990.0	5.0	972.5 - 990.5	974.0 - 981.0
09-27-1-28	460.0	959.0	985.0	995.0	2.0		
14-27-1-28	461.0	965.0	990.0	1 003.0	3.5	980.0 - 998.0	
15-29-1-28	462.0	976.0	1 002.0	1 013.0	3.0		
03-33-1-28	465.0	970.0	995.0	1 006.0	3.0		
07-33-1-28	465.0	967.0	993.0	1 005.0	5.0		
13-33-1-28	463.0	962.0	985.5	1 002.0	3.0		
05-34-1-28	462.0	962.0	985.0	998.0	4.0	980.0 - 998.0	986.0 - 990.0
15-35-1-28	458.0	948.0	972.5	984.0	3.0	964.0 - 982.0	957.0 - 960.0
							972.0 - 974.7
15-05-1-29	479.0	1 038.0	1 054.6	1 074.0	9.0	1 068.0 - 1 074.0	
08-15-1-29	469.0	1 018.6	1 043.6	1 055.5	6.0		
11-18-1-29	480.0	1 046.0	1 063.0	1 086.0	8.0		
05-34-1-29	484.6	1 007.4	1 022.0	1 044.5	9.0		
05-05-2-27	457.0	929.0	954.0	962.0	1.5		
08-05-2-27	454.0	922.0	940.0	954.0	5.4		
07-06-2-27	458.0	933.0	957.0	965.0	2.0		
08-06-2-27	458.0	932.0	956.0	966.0	2.0	951.0 - 969.0	
09-06-2-27	459.0	932.0	956.0	966.0	2.0		
10-06-2-27	459.0	931.7	957.0	966.5	3.0		
09-10-2-27	457.0	916.0	940.0	952.0	2.0	925.0 - 936.0	
03-14-2-27	455.4	904.6	928.0	939.0	2.0	923.5 - 932.7	
09-15-2-27	453.5	901.0	925.4	934.0	?		
02-18-2-27	457.8	928.7	952.2	963.2	2.4	953.4 - 978.1	
01-19-2-27	442.3	905.6	930.6	937.0	2.0		
15-24-2-27	453.0	883.0	907.0	920.0	1.5	920.0 - 938.0	

APPENDIX II (continued)

Location (WPM)	K.B.	Top Lr. Am.	Top Sandy Unit	Top Miss.	Total Sand	Cored Interval	Perfed Interval
15-27-2-27	452.3	892.4	916.2	923.0	1.5		
13-30-2-27	457.0	918.0	942.0	953.7	2.4		
14-05-2-28	466.0	967.0	995.0	1 007.0	5.0	989.0 - 1 004.0	991.0 - 998.0
15-05-2-28	463.6	963.2	990.6	1 004.0	3.0		
01-09-2-28	466.0	960.0	982.5	996.0	4.5	973.0 - 1 010.0	990.0 - 994.0
16-09-2-28	461.5	952.2	977.2	989.7	3.4		
01-11-2-28	456.3	938.2	963.2	975.0	2.4		
12-19-2-28	466.4	958.0	?	NP	?		976.0 - 990.0
14-20-2-28	465.0	951.0	976.3	987.6	3.3		
01-22-2-28	459.0	937.6	960.7	974.2	?	962.0 - 980.0	
12-27-2-28	464.0	937.0	963.0	971.0	4.0	959.0 - 977.0	959.0 - 966.5
15-27-2-28	461.7	934.0	959.0	969.6	6.0		
10-28-2-28	465.4	941.2	965.6	975.4	2.1		
04-29-2-28	464.0	949.0	975.0	986.0	3.0		
16-29-2-28	467.6	947.0	972.3	983.0	3.3		
02-30-2-28	467.4	957.0	984.0	994.0	2.0	984.0 - 1 005.0	978.0 - 990.5
05-30-2-28	467.0	955.0	980.0	990.0	2.0		
11-30-2-28	467.0	954.0	980.0	990.0	2.0		
12-30-2-28	468.0	955.0	978.0	992.0	2.0		979.0 - 986.0
04-34-2-28	464.2	934.0	958.0	970.0	2.4		
06-34-2-28	464.0	931.0	956.0	966.0	2.0		
07-34-2-28	463.0	929.0	953.0	964.0	1.5		
04-01-2-29	470.0	992.2	1 012.0	1 031.5	9.5	1 010.0 - 1 028.0	1 016.0 - 1 025.0
06-04-2-29	475.0	1 005.0	1 026.0	1 043.5	5.0	1 020.0 - 1 038.0	1 028.5 - 1 036.0
14-04-2-29	477.0	1 001.5	1 025.5	1 039.0	5.0	1 020.0 - 1 038.0	1 028.5 - 1 032.0
16-05-2-29	479.0	1 002.0	1 023.5	1 038.0	8.5	1 019.0 - 1 037.0	1 029.0 - 1 034.0
06-07-2-29	482.0	1 009.0	1 030.5	1 047.5	4.8	1 025.5 - 1 043.5	1 030.0 - 1 033.0
							1 036.0 - 1 039.0
08-08-2-29	479.0	1 003.0	1 023.0	1 043.0	4.0	1 020.0 - 1 038.0	1 031.0 - 1 033.5
11-08-2-29	481.0	1 005.0	1 025.0	1 043.0	6.0		
16-08-2-29	478.0	998.0	1 018.0	1 036.0	6.0	1 017.0 - 1 035.0	1 018.0 - 1 029.0
04-09-2-29	476.0	1 000.0	1 020.0	1 038.0	6.5	1 019.0 - 1 033.0	
08-09-2-29	473.5	995.0	1 016.5	1 032.0	5.5	1 010.5 - 1 028.5	1 033.5 - 1 035.0
12-09-2-29	477.0	996.0	1 020.0	1 033.5	6.0	1 020.0 - 1 038.0	1 022.5 - 1 025.5
14-09-2-29	478.0	996.0	1 017.5	1 034.0	5.0	1 022.0 - 1 058.0	1 022.5 - 1 027.0
16-09-2-29	474.0	992.0	1 014.0	1 030.0	6.5	1 010.0 - 1 028.0	1 018.5 - 1 022.7
06-10-2-29	473.0	994.0	1 014.0	1 032.0	4.0	1 010.0 - 1 028.0	1 019.5 - 1 023.0

APPENDIX II (continued)

Location (WPM)	K.B.	Top Lr. Am.	Top Sandy Unit	Top Miss.	Total Sand	Cored Interval	Perfed Interval
08-10-2-29	472.0	991.5	1 012.0	1 029.0	5.0	1 010.0 - 1 028.0	1 016.0 - 1 022.0
14-10-2-29	475.0	993.5	1 014.0	1 029.0	4.0	1 010.0 - 1 037.0	
16-10-2-29	471.0	989.0	1 007.0	1 025.0	7.0	1 008.0 - 1 026.0	1 009.5 - 1 017.0
16-11-2-29	469.0	982.0	1 006.5	1 020.0	5.0	994.0 - 1 030.0	1 003.0 - 1 013.0
04-15-2-29	475.0	990.0	1 009.0	1 024.0	6.5	1 010.5 - 1 028.5	1 010.0 - 1 019.0
10-15-2-29	473.0	984.0	1 005.0	1 020.0	4.5	1 003.0 - 1 021.0	
08-16-2-29	474.0	991.0	1 012.0	1 028.0	6.0	1 010.0 - 1 028.0	
06-17-2-29	480.5	1 000.0	1 021.0	1 037.5	3.5	1 017.0 - 1 035.0	1 026.0 - 1 029.5
06-19-2-29	483.0	1 002.0	1 021.5	1 040.0	6.0	1 022.0 - 1 040.0	1 021.0 - 1 034.0
04-21-2-29	481.0	992.0	1 013.0	1 028.0	7.0	1 010.0 - 1 028.0	1 012.0 - 1 017.0
10-21-2-29	477.0	984.0	1 003.5	1 020.0	7.0	1 003.0 - 1 021.0	1 005.0 - 1 014.0
03-24-2-29	467.0	971.0	994.0	1 006.5	5.0		
08-24-2-29	466.0	962.0	982.0	1 000.0	4.5	980.0 - 998.0	983.5 - 991.0
09-24-2-29	466.0	961.0	973.0	998.0	7.5	974.0 - 1 010.0	981.0 - 991.0
14-24-2-29	470.0	963.0	982.5	1 001.0	5.5	982.5 - 1 017.0	985.5 - 994.0
07-25-2-29	469.0	957.0	978.0	995.0	7.5	990.5 - 1 008.0	
08-25-2-29	467.0	955.0	976.0	992.0	8.0		
09-25-2-29	466.0	954.0	978.0	990.0	4.5		
10-25-2-29	468.0	957.4	981.5	994.5	3.0		
11-25-2-29	470.0	957.0	982.0	993.0	3.0		
16-25-2-29	469.0	953.5	975.0	990.5	7.0		
12-26-2-29	471.0	967.0	988.0	1 002.0	7.0	984.0 - 1 002.0	
06-28-2-29	479.0	981.0	1 002.0	1 017.5	8.0		
02-29-2-29	481.0	996.0	1 015.0	1 026.0	3.0		
13-32-2-29	481.0	984.0	1 010.0	1 021.0	3.0		
15-32-2-29	482.0	978.4	1 007.6	1 017.4	2.1		
12-33-2-29	480.0	983.0	1 009.0	1 020.0	2.5		
14-33-2-29	478.4	978.0	1 003.0	1 013.0	3.5		
04-36-2-29	469.0	956.5	982.5	993.0	2.5		
05-36-2-29	468.8	954.3	974.1	990.6	3.6		
10-01-3-27	458.0	881.0	905.0	912.0	1.5		
14-04-3-27	453.0	894.6	919.0	926.6	1.5	920.0 - 929.0	
12-12-3-27	457.0	879.0	901.0	907.0	2.0	890.0 - 918.0	
04-17-3-27	465.0	901.6	926.6	936.6	2.7	928.0 - 952.0	
04-01-3-28	463.0	928.0	953.0	964.0	2.5		
14-06-3-28	472.0	950.0	975.0	984.0	3.0		
05-07-3-28	472.0	955.5	972.5	981.0	2.5		

APPENDIX II (continued)

Location (WPM)	K.B.	Top Lr. Am.	Top Sandy Unit	Top Miss.	Total Sand	Cored Interval	Perfed Interval
06-07-3-28	472.0	951.0	971.5	983.0	3.5		
07-07-3-28	472.0	948.0	974.0	983.0	2.0		
08-07-3-28	471.2	945.0	970.2	979.0	1.8		
10-07-3-28	472.0	945.0	968.0	976.0	1.5		
11-07-3-28	473.0	945.0	971.0	977.0	2.0		
12-07-3-28	472.0	953.0	974.0	981.0	2.0		
13-07-3-28	472.0	951.0	970.0	976.0	2.0		
14-07-3-28	471.0	948.0	969.0	975.0	2.0		
15-07-3-28	470.0	943.4	968.0	974.8	1.8		
16-07-3-28	472.0	945.0	968.0	981.0	2.0		
13-08-3-28	472.0	941.5	962.0	977.0	2.0		
12-10-3-28	468.5	932.6	958.0	968.6	2.4		
09-12-3-28	461.0	912.0	937.0	947.0	2.0		
02-14-3-28	466.0	921.7	946.0	957.0	1.8	947.3 - 972.0	
13-15-3-28	468.0	927.0	951.0	962.0	2.0		
04-16-3-28	470.3	935.7	961.3	972.3	3.0		
10-16-3-28	471.0	930.8	955.8	965.0	1.8		
14-16-3-28	471.0	932.7	959.0	971.0	1.8		
16-16-3-28	467.0	928.0	953.0	965.0	3.0		
05-17-3-28	469.7	939.4	960.7	975.9	2.4		
13-17-3-28	473.0	944.3	965.0	977.2	1.8		
14-17-3-28	472.7	942.7	962.7	975.4	3.0		
01-18-3-28	471.0	941.8	967.0	977.8	1.8		
02-18-3-28	472.0	949.0	967.0	975.0	2.0		
03-18-3-28	472.0	950.0	969.0	977.0	2.0		
06-18-3-28	472.0	943.0	969.0	977.0	1.5		
07-18-3-28	473.0	949.0	969.0	976.5	2.0		
08-18-3-28	472.0	949.0	968.0	979.0	2.0		
09-18-3-28	470.6	945.8	964.7	976.9	2.0		
10-18-3-28	474.0	942.0	967.0	979.0	2.0		
11-18-3-28	474.0	946.0	971.5	981.5	2.0		
12-18-3-28	473.0	943.3	968.6	978.2	1.8		
13-18-3-28	474.3	943.3	968.6	978.2	2.0		
15-18-3-28	473.0	941.2	966.8	977.8	1.8		
16-18-3-28	473.0	941.0	966.0	978.0	2.0		
01-19-3-28	473.0	939.0	964.5	972.0	1.5		
02-19-3-28	472.4	940.3	966.8	976.9	1.8		

APPENDIX II (continued)

Location (WPM)	K.B.	Top Lr. Am.	Top Sandy Unit	Top Miss.	Total Sand	Cored Interval	Perfed Interval
03-19-3-28	474.0	942.0	967.5	974.0	1.5		
04-19-3-28	473.6	943.0	968.3	977.5	2.0		
06-19-3-28	474.0	941.8	966.8	975.4	1.8		
07-19-3-28	473.0	940.0	966.0	977.0	2.0		
08-19-3-28	473.0	937.0	962.5	973.0	2.0		
10-19-3-28	473.7	938.7	963.7	969.8	1.8		
11-19-3-28	473.0	942.0	967.0	975.0	2.0		
12-19-3-28	474.8	941.8	967.7	979.6	1.5		
01-20-3-28	471.0	941.0	961.0	973.0	1.5		
03-20-3-28	473.4	937.5	962.5	973.8	1.8		
04-20-3-28	472.4	937.8	962.3	970.5	1.8		
05-20-3-28	475.0	940.0	965.0	976.0	2.0		
01-21-3-28	470.0	928.5	954.0	966.0	2.0		
02-21-3-28	470.0	928.0	953.4	965.9	2.0		
03-21-3-28	470.0	930.0	950.0	964.0	2.0		
04-21-3-28	470.0	936.3	951.0	968.6	2.4		
10-21-3-28	469.0	926.9	952.8	964.0	1.5		
02-22-3-28	471.2	926.0	952.2	964.4	1.2		
03-22-3-28	469.0	925.0	950.0	961.0	2.0		
04-22-3-28	469.0	927.2	952.2	963.8	1.8	951.0 - 987.0	
04-25-3-28	465.0	906.0	930.0	937.0	1.5		
08-25-3-28	464.0	898.0	922.0	927.0	1.5	915.0 - 951.0	
04-26-3-28	470.0	915.7	941.0	949.0	2.0		
08-26-3-28	465.0	904.5	924.0	933.5	1.5	926.0 - 962.0	
02-27-3-28	467.2	918.0	938.8	953.1	1.8		
04-29-3-28	473.4	935.2	960.1	969.8	2.1	961.6 - 967.7	
04-30-3-28	475.5	938.7	964.4	974.4	1.5		
12-01-3-29	473.0	960.0	985.5	994.0	2.0		
13-01-3-29	474.0	958.0	984.0	993.0	2.0		
14-01-3-29	473.0	957.0	982.0	992.0	2.0		
12-02-3-29	476.4	967.7	993.6	1 003.4	3.0	997.6 - 1 027.5	
13-02-3-29	476.1	966.8	992.4	1 001.0	2.4	993.6 - 998.2	
01-03-3-29	476.5	974.0	995.0	1 010.0	3.0		
06-03-3-29	479.7	977.2	1 002.8	1 013.2	2.4		
02-04-3-29	482.2	984.5	1 010.1	1 020.4	1.8		
01-08-3-29	484.0	984.5	1 010.1	1 021.0	3.0	1 009.5 - 1 034.8	
13-08-3-29	488.6	987.8	1 010.1	1 015.0	1.8		

APPENDIX II (continued)

Location (WPM)	K.B.	Top Lr. Am.	Top Sandy Unit	Top Miss.	Total Sand	Cored Interval	Perfed Interval
08-10-3-29	478.5	967.4	992.4	998.2	3.0		
09-10-3-29	478.0	966.8	992.8	998.2	2.4		
02-11-3-29	476.0	963.2	988.8	998.0	2.4	991.5 - 1 004.0	
03-11-3-29	475.2	963.2	989.0	995.5	2.4		
04-11-3-29	476.7	966.2	992.4	999.1	2.4		
05-11-3-29	477.6	967.4	992.4	998.5	2.4		
06-11-3-29	474.3	960.7	985.7	990.0	2.4		
07-11-3-29	474.3	958.5	984.5	991.0	2.4		
08-11-3-29	473.0	957.0	981.5	993.6	3.0		
10-11-3-29	475.2	959.5	985.7	993.0	1.8		
11-11-3-29	475.2	962.0	987.6	994.0	2.1		
02-12-3-29	472.0	952.0	977.0	987.0	3.0		
04-12-3-29	475.0	958.0	983.0	992.0	3.0		
05-12-3-29	474.3	956.2	980.5	991.2	3.3	988.0 - 994.3	
10-12-3-29	475.0	952.0	975.0	988.0	2.0	972.0 - 1 005.0	
12-12-3-29	473.4	955.5	980.8	991.8	3.0	987.5 - 1 007.4	
02-13-3-29	473.4	951.0	976.0	987.6	3.0		
04-13-3-29	474.0	954.0	978.0	991.0	2.5		
07-13-3-29	474.0	949.7	975.4	986.0	3.0		
10-13-3-29	474.0	947.3	973.0	984.5	3.0		
12-13-3-29	474.0	952.2	977.8	988.2	2.8		
14-13-3-29	475.8	950.4	976.0	987.5	3.0		
15-13-3-29	477.3	947.3	972.3	983.9	3.0		
16-13-3-29	474.6	944.9	969.8	982.6	2.8		
07-14-3-29	475.4	955.0	979.0	993.0	2.0		
05-15-3-29	481.0	969.9	995.2	1 005.0	2.4	1 000.4 - 1 034.4	
12-15-3-29	480.6	970.5	996.7	1 007.4	2.1		
03-16-3-29	482.5	974.2	996.1	1 005.8	1.5		
06-16-3-29	484.0	972.0	993.0	1 003.0	1.8		
07-16-3-29	482.2	972.3	995.5	1 004.3	2.1		
08-16-3-29	480.0	967.7	993.0	1 000.0	2.4		
09-16-3-29	482.2	970.8	991.5	1 004.0	2.4		
10-16-3-29	481.0	969.0	994.0	1 002.0	3.0		
11-16-3-29	483.0	970.0	993.0	1 001.0	2.0		
12-16-3-29	486.0	973.0	998.0	1 003.0	3.0		
13-16-3-29	486.0	972.0	992.0	1 003.0	2.0		
16-16-3-29	481.2	969.2	994.9	1 001.6	3.0		

APPENDIX II (continued)

Location (WPM)	K.B.	Top Lr. Am.	Top Sandy Unit	Top Miss.	Total Sand	Cored Interval	Perfed Interval
06-17-3-29	488.0	976.0	997.0	1 002.0	1.0		
11-17-3-29	489.0	976.0	1 002.0	1 005.0	2.0		
13-17-3-29	489.0	977.0	1 002.0	1 006.5	2.0		
16-17-3-29	485.0	971.0	997.0	1 002.0	2.0		
06-18-3-29	492.0	986.0	1 012.0	1 017.0	2.5		
07-20-3-29	488.6	974.4	998.0	1 002.8	2.4		
08-21-3-29	482.2	967.7	990.0	996.0	3.0		
11-21-3-29	484.0	968.0	993.0	1 002.0	3.0		
14-21-3-29	484.0	965.0	991.0	997.0	2.0		
03-22-3-29	480.0	964.0	990.0	998.0	3.0		
10-23-3-29	478.5	949.7	972.9	986.3	3.0		
01-24-3-29	474.0	943.0	968.0	977.0	3.0		
02-24-3-29	474.9	947.0	972.3	982.7	3.0		
04-24-3-29	475.2	950.0	975.3	986.3	2.4		
06-24-3-29	475.2	946.4	972.3	985.1	1.8		
08-24-3-29	475.2	944.8	970.8	982.7	2.4		
10-24-3-29	475.2	945.2	970.5	978.1	2.4		
08-26-3-29	477.6	943.0	968.6	979.6	3.0		
04-27-3-29	484.0	966.2	990.6	999.7	3.0		
12-29-3-29	493.2	978.7	1 005.8	1 016.8	1.8		
13-31-3-29	498.3	978.4	1 004.3	1 013.7	3.0		