Petroleum Open File Report POF 5-86

Petroleum Geology of the Lulu Lake Area, Southwestern Manitoba

By C. Martiniuk and M. Arbez

Manitoba
Energy and Mines
Petroleum

1986

Manitoba
Energy and Mines
Petroleum

Petroleum Open File Report POF 5-86

Petroleum Geology of the Lulu Lake Area, Southwestern Manitoba

By C. Martiniuk and M. Arbez

Winnipeg, 1986

Energy and Mines

Hon. Wilson D. Parasiuk
Minister

Charles S. Kang
Deputy Minister

Petroleum Branch
H. Clare Moster
Executive Director

TABLE OF CONTENTS

FIGURES

Page

TABLES

INTRODUCTION

General Introduction

The Lulu Lake study area lies entirely within the subcrop belt of the Lodgepole Formation as shown in Figure 1. It covers an area of approximately 560 sq. km (216 sq. mi.) and encompasses Townships 1 and 2; Ranges 20 - 22 WPM (Fig. 2).

Within the study area, the eroded Lodgepole strata are unconformably overlain by the "Red Beds" of the Lower Amaranth Formation of Jurassic age and conformably underlain by the black shales and siltstones of the Bakken Formation. Production is obtained from the Upper Whitewater Lake Member of the Lodgepole Formation.

The purpose of this study is to assess the Upper Whitewater Lake Member of the Lulu Lake Field and surrounding areas of southwest Manitoba. To accomplish this, the following information is presented:

- the stratigraphy of the Mississippian Lodgepole Formation.
- a summary of the history of exploration activity within the area of study.
- a description of the lithologies of the various members of the Lodgepole Formation determined through core and thin section examination.
- a discussion of the depositional environment of the members of the Lodgepole Formation.
- the reservoir characteristics and trapping mechanisms of the Upper Whitewater Lake Member with respect to stratigraphy.
- the reservoir engineering properties (porosity, permeability, water saturation, pay thickness) and oil-in-place values, obtained from well log and core data correlations.

The geological information and conclusions in this report are based on data available to June, 1986. Reservoir engineering properties were obtained and mapped based on data available to August, 1985. Cumulative production and remaining recoverable reserves estimates were updated to December 31, 1985.

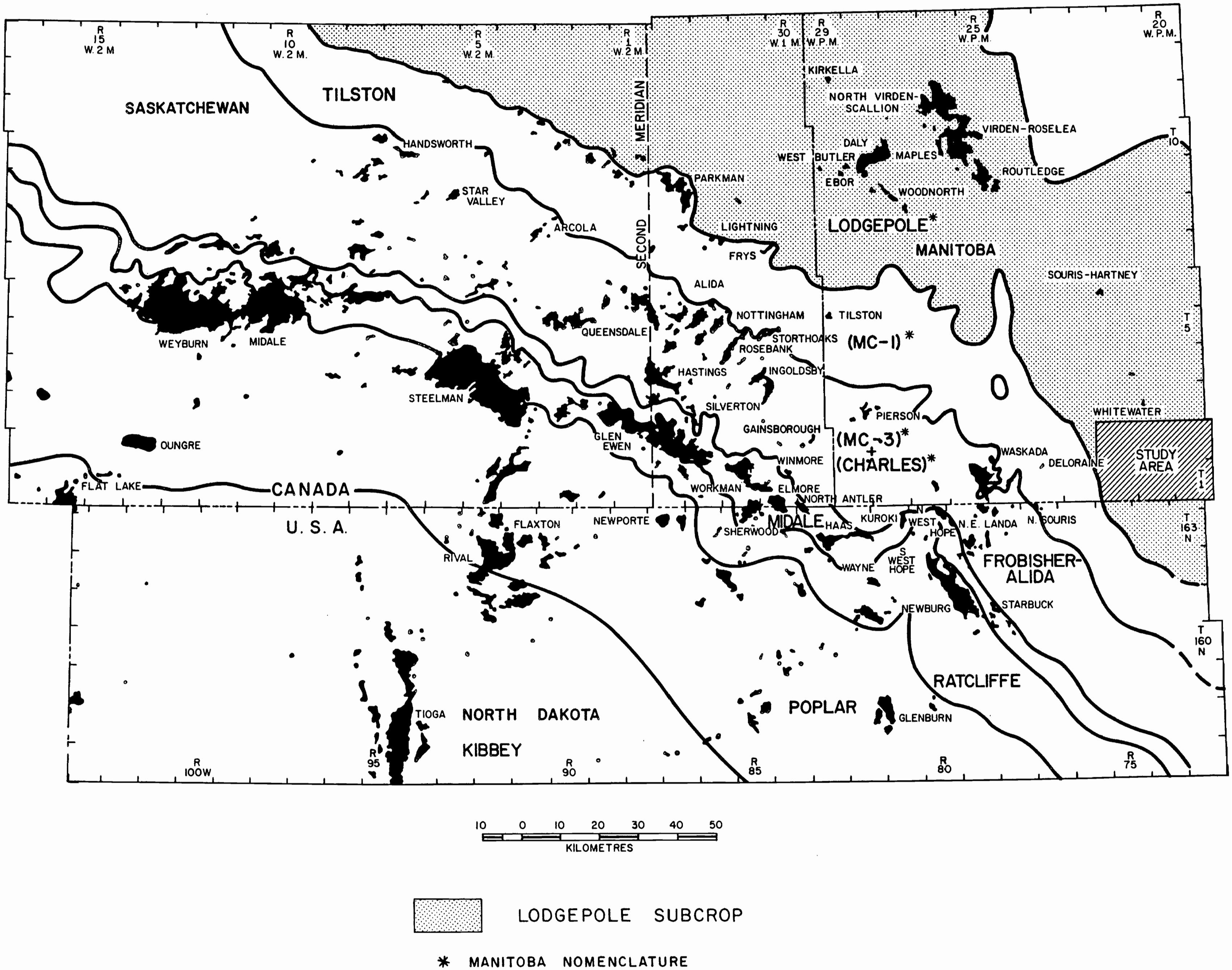


Figure 1: Map showing Mississippian Subcrop Belts and Location of Study Area

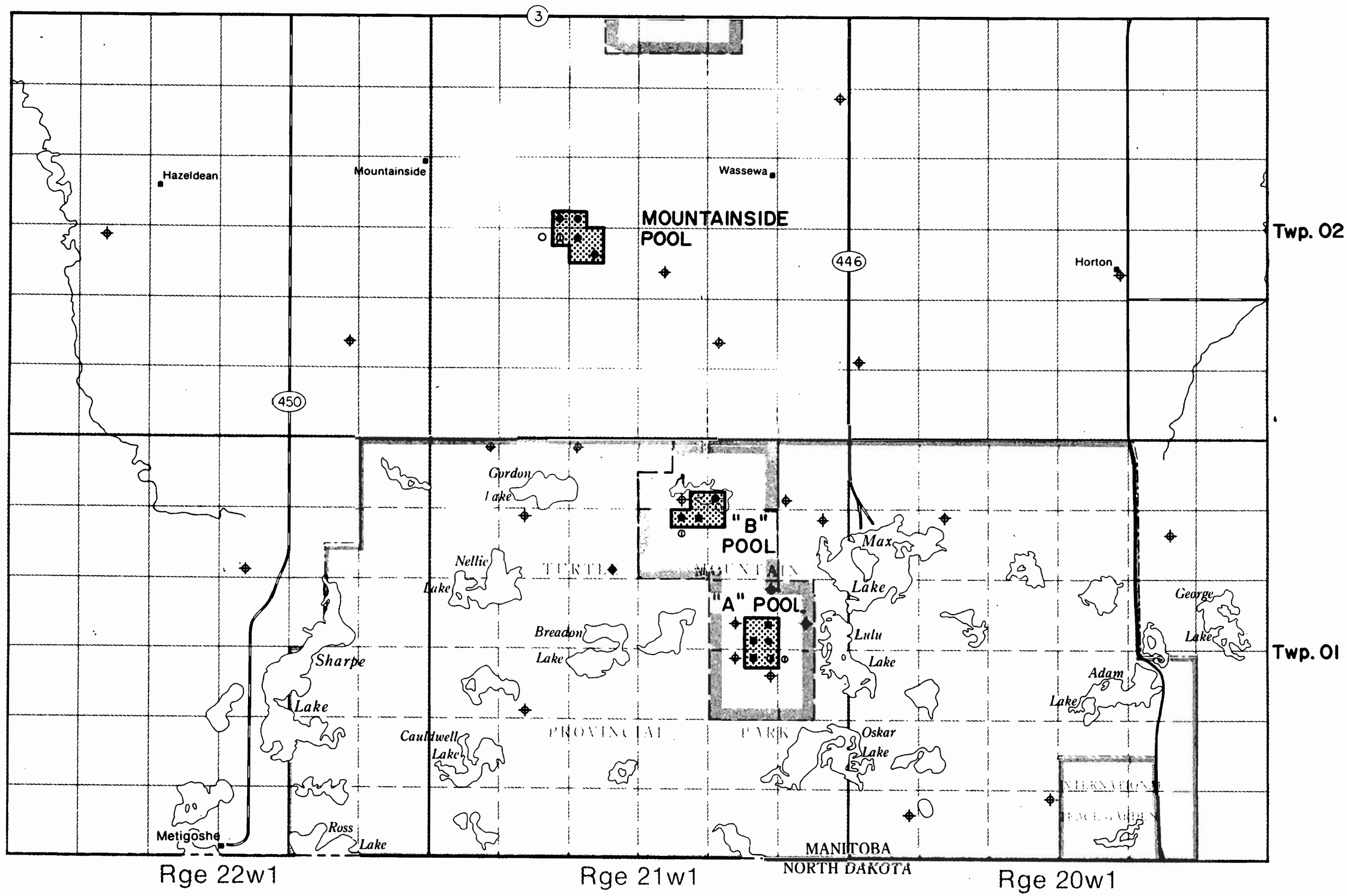


Figure 2: Plat Showing Pool Locations within the Study Area

Geological Setting

Southwestern Manitoba is located on the northeastern flank of the Williston Basin. Sedimentary rocks of Paleozoic and Mesozoic age occur in this region forming a basinward-thickening wedge to the southwest. A major angular unconformity separates the Paleozoic rocks from the Mesozoic sections and probably represents one or more periods of erosion occurring from late Mississippian to early Jurassic time. During that erosion, Paleozoic strata were tilted basinward which resulted in the progressive truncation of these strata toward the basin margin. In the Lulu Lake area, the porous reservoir beds of the Lodgepole Formation are truncated at the erosional surface (Fig. 3). A seal created by the overlying Lower Amaranth "Red Beds" provides a series of stratigraphic traps. This report deals with the producing reservoirs within the upper unit of the Whitewater Lake Member in the Lulu Lake area.

General Stratigraphy

Mississippian strata within the Lulu Lake study area dip regionally southwestward toward the centre of the Williston Basin at an average of 7.2 metres per kilometre (38 feet per mile). They are divided, in ascending order, into the Bakken Formation and the Lodgepole Formation of the Lower Mississippian Madison Group. The Mission Canyon and Charles Formations, which overlie the Lodgepole Formation, are both eroded within the study area.

Strata within the Mississippian represent a major marine transgressive-regressive cycle (McCabe, 1959). During the initial advancement of Mississippian seas the basal black shales and siltstones of the Bakken Formation were deposited over the eroded Devonian. Continued subsidence in the Williston Basin resulted in deposition of the limestones of the Lodgepole Formation. Several small-scale transgressive-regressive sequences of cyclical sedimentation were superimposed during (middle) Lodgepole time. These subcycles are represented in the Virden and Whitewater Lake Members of the Lodgepole Formation by a cyclic repetition of oolitic and/or crinoidal limestones.

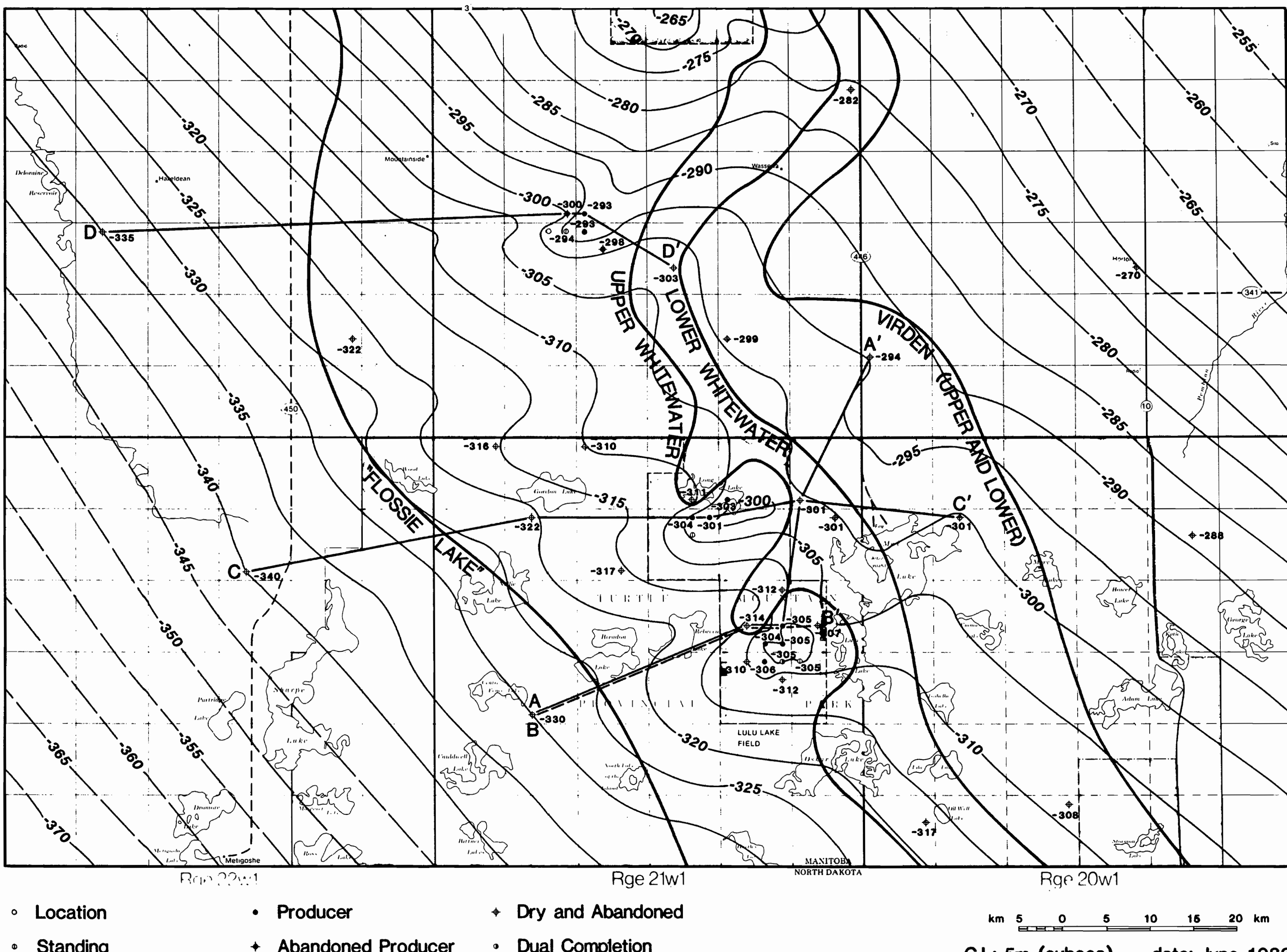


Figure 3: Structure Map - Top of the Mississippian Erosional Surface

Stratigraphic Nomenclature

The Lodgepole Formation constitutes the lowermost portion of the Madison Group of early Mississippian age. It is correlative with the Bottineau Interval of North Dakota and the Souris Valley Beds of southeastern Saskatchewan.

The stratigraphic terminology used in this report is that proposed by Stanton (1958) and McCabe (1963). Within the study area, the Lodgepole Formation is subdivided into four members (Fig. 4) and they are in ascending order: Scallion, Virden, Whitewater Lake and Flossie Lake.

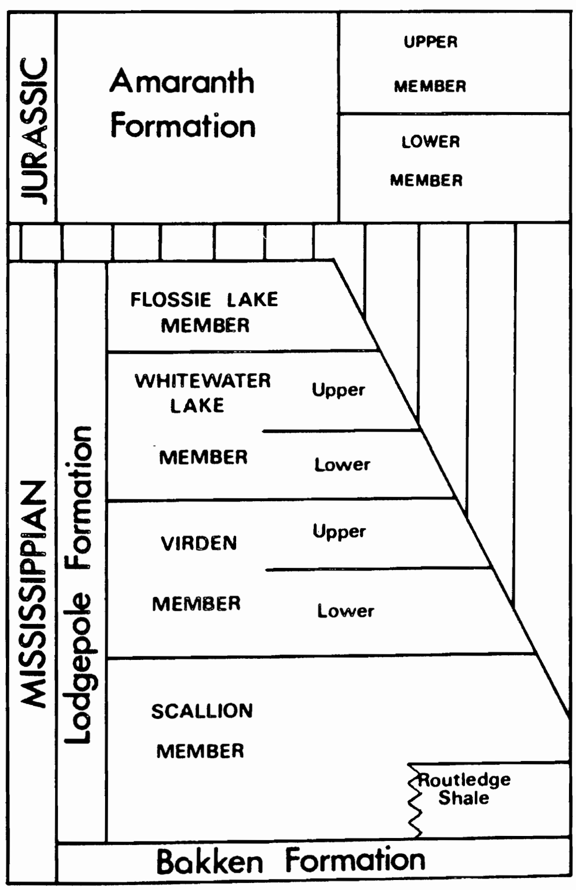


Figure 4: Stratigraphic Column
(after Young and Greggs, 1975)

The type log used for correlations of these members is given in Figure 5.

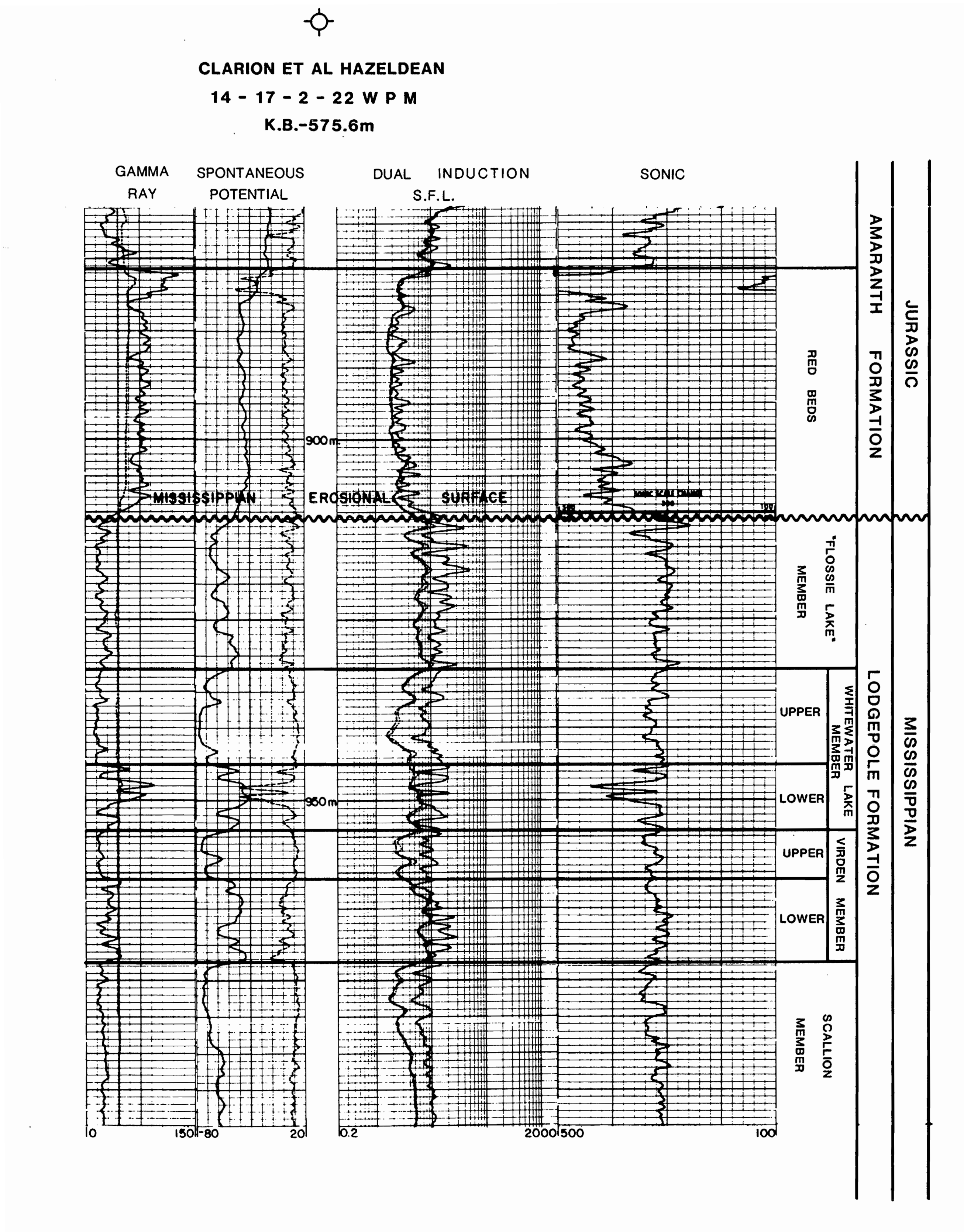


Figure 5: Type Log Showing Subdivisions of the Lodgepole Formation

The Scallion Member lies conformably on the Bakken Formation. It consists of white to medium grey, finely crystalline to chalky, cherty limestones. On the SP log it is characterized by a clean, negative response (Fig. 5).

Developed within the lower portion of the Scallion is a shale sequence that directly overlies the Bakken. This sequence is referred to as the Routledge Shale and is present locally within the eastern part of the Lulu Lake study area. It is a dark brown to black, slightly calcareous, silty shale. It is similar in log pattern and lithologic character to the underlying Bakken Formation and appears to be a facies variation of the lower Scallion.

Overlying the Scallion Member is the lower unit of the Virden Member. The Virden Member represents the lower of two cycles of deposition developed within the upper portion of the Lodgepole Formation. The Lower Virden Member consists of cyclically interbedded, light to buff oolitic limestone lentils and mottled grey to maroon argillaceous limestones.

These lentils have been defined and are easily correlated throughout the Virden Field to the north, but are less easily traced in the study area. For this reason, the Lower Virden Member is not subdivided in the Lulu Lake area. The Lower Virden Member is marked lithologically by an increase in argillaceous content relative to the underlying Scallion Member. On the SP log, this contact is picked at the shale break above the clean SP log response of the Scallion.

The Upper Virden Member consists primarily of clean crinoidal limestone and displays a uniform negative SP log character. The upper limit of the unit is marked by an abrupt contact with an overlying red to purple, calcareous shale to shaly limestone. This shale marks the base of the Lower Whitewater Lake Member and is often referred to in field terminology as the "Virden Shale".

The lower unit of the Whitewater Lake Member consists of interbedded oolitic limestone and grey to maroon calcareous shale or argillaceous limestone, similar in lithology and log response to the Lower Virden. It represents the basal portion of the second cycle of deposition developed within the upper Lodgepole Formation in the study area. The upper contact of the Lower Whitewater Lake Member is marked by a sharp decrease in argillaceous content.

The upper unit of the Whitewater Lake Member consists mainly of oolitic-bioclastic limestone and is the producing zone for the Lulu Lake Field. The upper limit of the unit is picked as the top of the blocky, clean SP log characteristic of the Upper Whitewater Lake Member. Lithologically, this contact is marked by the gradation from bioclastic limestone to an overlying argillaceous limestone.

The unit referred to as the unnamed Upper Lodgepole, or "Flossie Lake" Member, completes the Lodgepole sequence. It consists mainly of argillaceous limestones and bands of secondary anhydrite, and occurs only within a north-northwest trending subcrop belt along the western boundary of the study area (Fig. 3).

Shales and siltstones of the Jurassic Lower Amaranth "Red Beds" unconformably overlie the Flossie Lake.

EXPLORATION HISTORY

There are three designated pools within the Lulu Lake study area. These include: Lulu Lake Lodgepole WL A Pool ("A" Pool), Lulu Lake Lodgepole WL B Pool ("B" Pool) and Other Areas Lodgepole WL E Pool ("Mountainside" Pool).

The following description of exploration history is based on production data obtained to December 31, 1985.

Lulu Lake Field ("A" Pool)

The Lulu Lake "A" Pool was discovered in December of 1952. The discovery well, Fawn (formerly Royalite Triad) Lulu Lake Prov. 16-14-1-21 WPM, was completed in the Upper Whitewater Lake Member with 5.2 m (17') net pay (McCabe, 1963). Initial production for the first year averaged 5.2 m^3/day of 850 kg/m^3 (35^o API oil). In September of 1957 the well was abandoned as uneconomic. It was re-entered in August of 1965 and was completed as a dual oil well/salt water disposal well, and, at present, remains active. Production is from the Upper Whitewater Lake Member with salt water disposal in the Upper Virden Member. As of December 31, 1985, cumulative production from this well was 13 465.9 m^3 oil and 65 514.2 m^3 water.

Two years after the discovery of the "A" Pool, two development wells were drilled by Royalite Oil Co. Ltd. These were 15-14-1-21 WPM, drilled in December of 1954, and 2-23-1-21 WPM, drilled in January of 1955. Both were completed in the Upper Whitewater Lake Member. During the years 1958-1964 and 1967-1980 no wells were drilled in the Lulu Lake area. Three wells drilled during 1965-1966 were unsuccessful.

Activity resumed in 1982 when Andex Oil and Gas completed three development wells adjacent to the three producing Royalite/Fawn Wells. The first of these wells, 8-23-1-21 WPM, was completed in July in the Upper and Lower Whitewater Lake Members. The Lower Whitewater was subsequently plugged and production obtained only from the Upper unit. In December of the same year, Andex Oil and Gas completed the other two development wells, 13-13-1-21 WPM and 1-23-1-21 WPM, both in the Upper Whitewater Lake Member (Fig. 3). The well at 13-13-1-21 WPM was suspended and subsequently abandoned in 1985, with no production. The well at 1-23-1-21 WPM, remains as an active producer.

Recent Discoveries

(a) "Mountainside" Pool

Recent drilling in July of 1982 led to the discovery of the "Mountainside" Pool, ten kilometres northwest of the original Lulu Lake "A" Pool. The discovery well, Roxy-Clarion et al Mountainside 13-16-2-21 WPM, was completed as an Upper Whitewater Lake Member producer and, as of December 31, 1985, has produced 3 850.6 m^3 oil and 9 477.7 m^3 water.

From 1983 to 1984, three follow-up development wells were drilled by Roxy Petroleum and Andex Oil and Gas. Two of these, 11-16-2-21 WPM and 1-20-2-21 WPM, were abandoned after less than two years of production, due to poor economic recovery. The third, 4-21-2-21 WPM has been on production since March of 1983.

(b) Lulu Lake Field ("B" Pool)

Drilling in July of 1984 led to the discovery of a small Mississippian oil pool two and one-half kilometres northwest of the original Lulu Lake "A" Pool (Fig. 2). The discovery well, Andex-Roxy Lulu Lake Prov. 15-27-1-21 WPM, was drilled on a separate Mississippian paleotopographic high on the erosion surface. The well was completed in the Upper Whitewater Lake Member and produced 3 893.8 m^3 oil and 453.5 m^3 water as of December 31, 1985. This discovery well led to designation of the "B" Pool.

An offsetting development location in this "B" Pool, Andex Lulu Lake Prov. 16-27-1-21 WPM, was drilled and successfully put on production in August of 1984. Another offset well, Andex Lulu Lake Prov. 4-35-1-21 WPM, was drilled in November of 1984 and is an active producer.

Table 1 gives a complete summary of production for the entire study area.

TABLE 1

PRODUCTION DATA FOR THE UPPER WHITEWATER LAKE MEMBER, LULU LAKE STUDY AREA (Twps. 1 & 2; Rges 20-22 WPM)

POOL LOCATION	INITIAL ON-PRODUCTION DATE	AVERAGE DAILY PRODUCTION (1st yr. of production) (m^3/day)		AVG WATER-CUT 1st year of production (%)	CUMULATIVE PRODUCTION to Dec. 31st, 1985 (m^3)		AVG WATER-CUT 1985 Production (%)
		OIL	WATER		OIL	WATER	
"A" Pool							
15-14-01-21 WPM	Dec. 1954	6.7	1.6	19	11 064.3	68 396.4	99
16-14-01-21 WPM	Dec. 1952	5.2	5.2	50	13 465.9	65 514.2	93
01-23-01-21 WPM	Dec. 1982	1.0	1.5	60	1 111.6	1 395.7	59
02-23-01-21 WPM	Jan. 1955	5.2	2.4	32	10 286.3	40 160.7	95
08-23-01-21 WPM	July 1982	3.7	0.02	1	2 799.2	307.1	16
"B" Pool							
15-27-01-21 WPM	July 1984	6.55	0.31	4	3 893.8	453.5	12
16-27-01-21 WPM	Aug. 1984	7.60	0.5	6	2 284.5	519.3	15
04-35-01-21 WPM	Nov. 1984	2.00	0.00	0	2.0	0.0	---
"Mountainside" Pool							
11-16-02-21 WPM	Mar. 1984 abandoned - Nov. 1984	0.74	8.85	92	94.9	1 133.3	---
13-16-02-21 WPM	July 1982	1.29	0.83	39	3 850.6	9 477.7	71
01-20-02-21 WPM	Aug. 1983 abandoned - Nov. 1984	2.1	11.7	85	2.1	11.7	---
04-21-02-21 WPM	Mar. 1983	3.44	3.87	53	2 669.8	4 372.4	67

LITHOLOGY AND ENVIRONMENT OF DEPOSITION

Introduction

To determine the lithologic and textural features in the Lulu Lake study area, several cores were examined. Nine cores were selected and described according to Dunham's Classification of Limestones (Fig. 6), and Choquette and Pray's Classification of Carbonate Porosity Types (Fig. 7). Several thin sections from selected cored intervals were also examined.

A detailed description of each of these cored wells is given in the Appendix.

The stratigraphic cross-section A-A' in Figure 8 shows the overall stratigraphy of the various members of the Lodgepole Formation within the Lulu Lake Field.

Lithology

The following is a summary of the lithologies found in the Scallion, Upper and Lower Virden, and Upper and Lower Whitewater Lake Members. It should be noted that an in-depth petrologic and petrographic study of cores is beyond the scope of this report, so the descriptions of the various members of the Lodgepole Formation that appear here provide only a general outline of lithologies.

(a) Scallion Member

The Scallion Member is present throughout the study area. The few wells drilled deep enough to penetrate a complete section of the Scallion Member show a maximum thickness of 79.6 m (261 ft). The Scallion consists primarily of reddish to grey-pink, dense, horizontally laminated micritic limestone with interbeds of chalky, skeletal packstone-grainstone. Nodules of chert and fragments of brachiopods and crinoids have been noted throughout the Member.

Classification of limestones according to depositional texture					
Depositional texture recognizable					Depositional texture not recognizable
Original components not bound together during deposition				Original components bound together during deposition	
Contains mud (fine silt and clay size particles)			Lacks mud		
Mud-supported		Grain-supported			Crystalline carbonate (subdivide according to physical or diagenetic texture)
Less than 10 percent grains	More than 10 percent grains				
Mudstone	Wackestone	Packstone	Grainstone	Boundstone	

Figure 6: Dunham's Classification of Limestones (after Dunham, 1962)

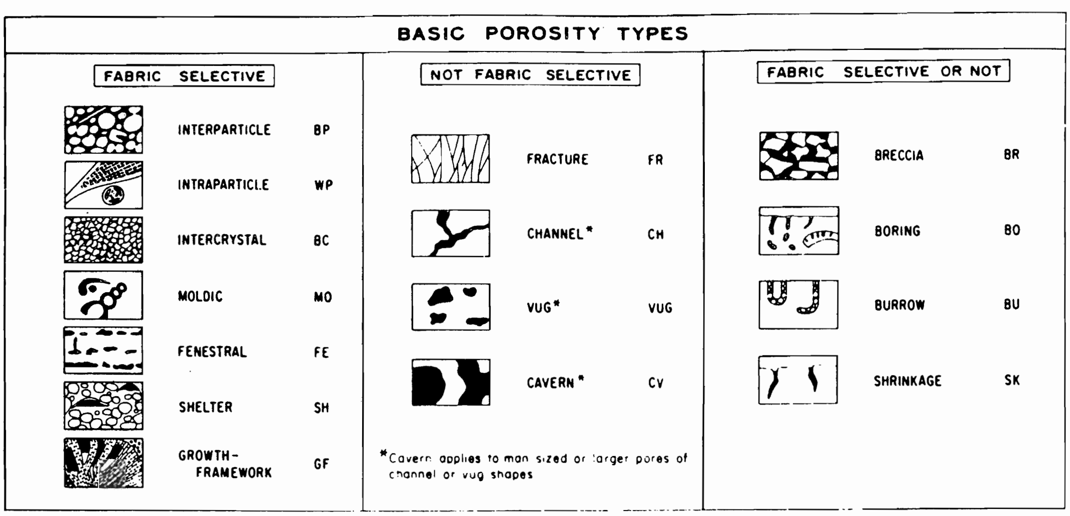


Figure 7: Classification of Porosity Types in Carbonate Rocks (after Choquette and Pray, 1970)

According to McCabe (1959) the general lithology of the Scallion reflects deposition in shallow to moderate water depths in an open marine shelf environment. The red-pink colour exhibited by the limestone is thought to be an indicator of free-circulation oxidizing conditions at the time of deposition.

(b) Virden Member

The Virden Member extends as far east as the western half of Township 1 and the west boundary of Township 2, Range 20 WPM where it has been truncated at the post-Mississippian-pre-Jurassic unconformity (Fig. 3). A general westward thinning of the Virden Member is observed in the area with depositional thickness ranging from 27.5 m (90 ft) in the east to 18.2 m (60 ft) in the west. The Virden Member has been divided into a clean, upper unit and an argillaceous, lower unit. The Lower unit consists of cyclically interbedded maroon, red, calcareous wackestone/mudstones and crinoidal wackestone/packstones.

The upper clean unit consists of light grey, buff or red, crinoidal/oolitic packstone/grainstones with some interbedding of light grey, calcareous mudstones. The grainstones, in thin section, appear to be a mixture of crinoid and pelloid grains. Brachiopod fragments are present throughout. Porosity is largely intergranular and ranges from fair to good. In places, evidence of porosity reduction is seen where grains are in contact with one another along sutured boundaries.

According to a study done by Young (1973), the two units of the Virden Member represent a cycle of deposition in a near shore, shallow water, shoal environment.

(c) Whitewater Lake Member

The Whitewater Lake Member extends only as far east as Townships 1 and 2, Range 20 WPM, where it has been truncated at the post-Mississippian-pre-Jurassic unconformity. Remaining thicknesses range from 4.5 m (15 ft) to 26 m (85 ft).

According to Zakus (1967) and Stanton (1958) the Whitewater Lake Member represents a cycle of deposition similar to that of the underlying Virden Member. The Whitewater Lake Member, like the Virden, has a clean upper unit and an argillaceous lower unit.

(i) Lower Whitewater Lake

The Lower Whitewater Lake Member consists of cyclically interbedded red, grey or green, horizontally laminated, bioclastic mudstone/wackestones, and buff or red, partly dolomitized (near the erosional surface), crinoidal/oolitic packstone/grainstones. The packstone/grainstones are stylolitic, show fair to poor porosites with horizontal/vertical fractures and are in places oil-stained. The Lower Whitewater Lake Member generally has a higher oolitic content than the Lower Virden Member.

The Lower Whitewater Lake Member is micritic in thin section. What appear as oolite grains in hand specimen, may be more accurately described as micritic pelloids in thin section. In places, these pelloidal grains have aggregated to form micrite "lumps". The grains are largely cemented by coarse grained sparry calcite. Matrix consists chiefly of fine grained calcite. Porosity is primarily secondary, moldic. Crinoid and brachiopod fragments are the major bioclastic constituents. Minor occurrences of finely crystalline anhydrite were also noted, indicating some secondary alteration.

(ii) Upper Whitewater Lake

In hand sample, the Upper Whitewater Lake Member consists of grey, stylolitic, in places oil-stained, bioclastic (crinoid and brachiopod), oolitic packstone/grainstones which display good intergranular and vuggy porosity. These packstone/grainstones are interbedded with grey or red, bioclastic wackestones. In general, the lithologies observed in core are comparable to those observed in the Upper Virden Member. However, in the 8-23-1-21 WPM well, brown, sucrosic, oil-stained dolomite displaying good intercrystalline porosity was noted in the uppermost 3.3 m of the Upper Whitewater Lake Member. This lithology was not present in any of the core of the Upper Virden Member.

In thin section, the bioclastic, oolitic packstone/grainstones consist mainly of concentrically laminated, hematite-stained oolite grains and fragments of crinoids and brachiopods. Minor amounts of lithoclasts are also present in the form of irregularly shaped micritic lumps. Intergranular material includes sparry calcite cement (acting as the main porosity inhibitor) and fine grained micrite. Based on limited core data, there appears to be little evidence of either dolomitization or anhydritization. Where fair to good porosity is developed, it is mainly of the secondary solution type. Minor evidence of original primary intergranular porosity, however, does exist.

The Whitewater Lake Member appears to represent a deposit formed in a coastal shoal environment as outlined in a study done by Zakus (1967) (Fig. 9). Conditions of sedimentation of this "cycle" are probably comparable to those which formed the underlying "cycle" of deposition of the Virden Member.

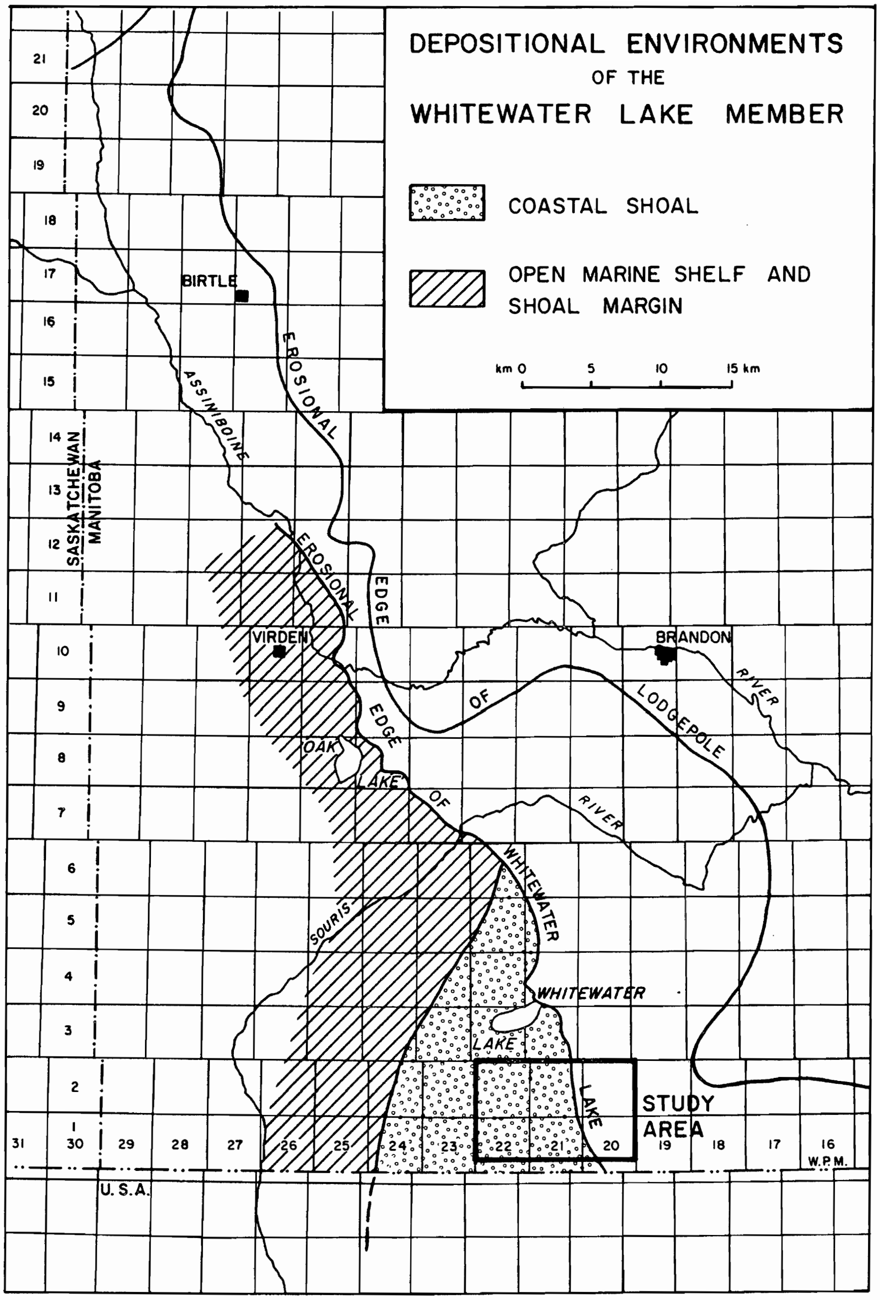


Figure 9: Environment of Deposition of the Whitewater Lake Member

STRUCTURE AND ISOPACH

Several maps and cross-sections were constructed from available well log data within the study area to evaluate the structure and erosional topography of the Upper Whitewater Lake Member. The following is a discussion of the structures and isopachs of the Lower Whitewater Lake Member, Upper Whitewater Lake Member and Jurassic Red Beds (listed in ascending order).

The structure map on top of the Lower Whitewater Lake (Fig. 10) defines the present-day structure within the study area. True present-day structure is represented by contours within the erosional limit of the Upper Whitewater Lake Member. Where the Lower Whitewater has been partially or completly eroded within the subcrop belt, broken contours are shown.

The true structure on the Lower Whitewater follows the southwest dip that exists in the area, and is, for the most part, fairly regular. Subtle "highs", however, are seen at the "Mountainside" and Lulu Lake Field pool localities. These correspond to "highs" viewed on the overlying Mississippian erosion surface. The presence of these local "highs" may be indicative of minor late or post Mississippian uplift.

To illustrate the depositional and erosional trends of the Whitewater Lake Member, an isopach map of the producing Upper Whitewater was constructed (Fig. 11). A general erosional thinning occurs toward the edge of the Upper Whitewater Lake subcrop belt. Preserved "thicks" occur as isolated pods at the "Mountainside" and Lulu Lake Field Pools along the erosional edge.

A true trend of deposition could not be delineated west of the Whitewater Lake subcrop belt due to sparse well data. As a result, only an extrapolated isopach thickness trend is represented outside of the subcrop belt (Fig. 11).

The map of the top of the Mississippian (Fig. 3) defines the structure on the erosion surface. Contours within the region of Upper Whitewater Lake subcrop represent structure on top of the Upper Whitewater Lake reservoir beds.

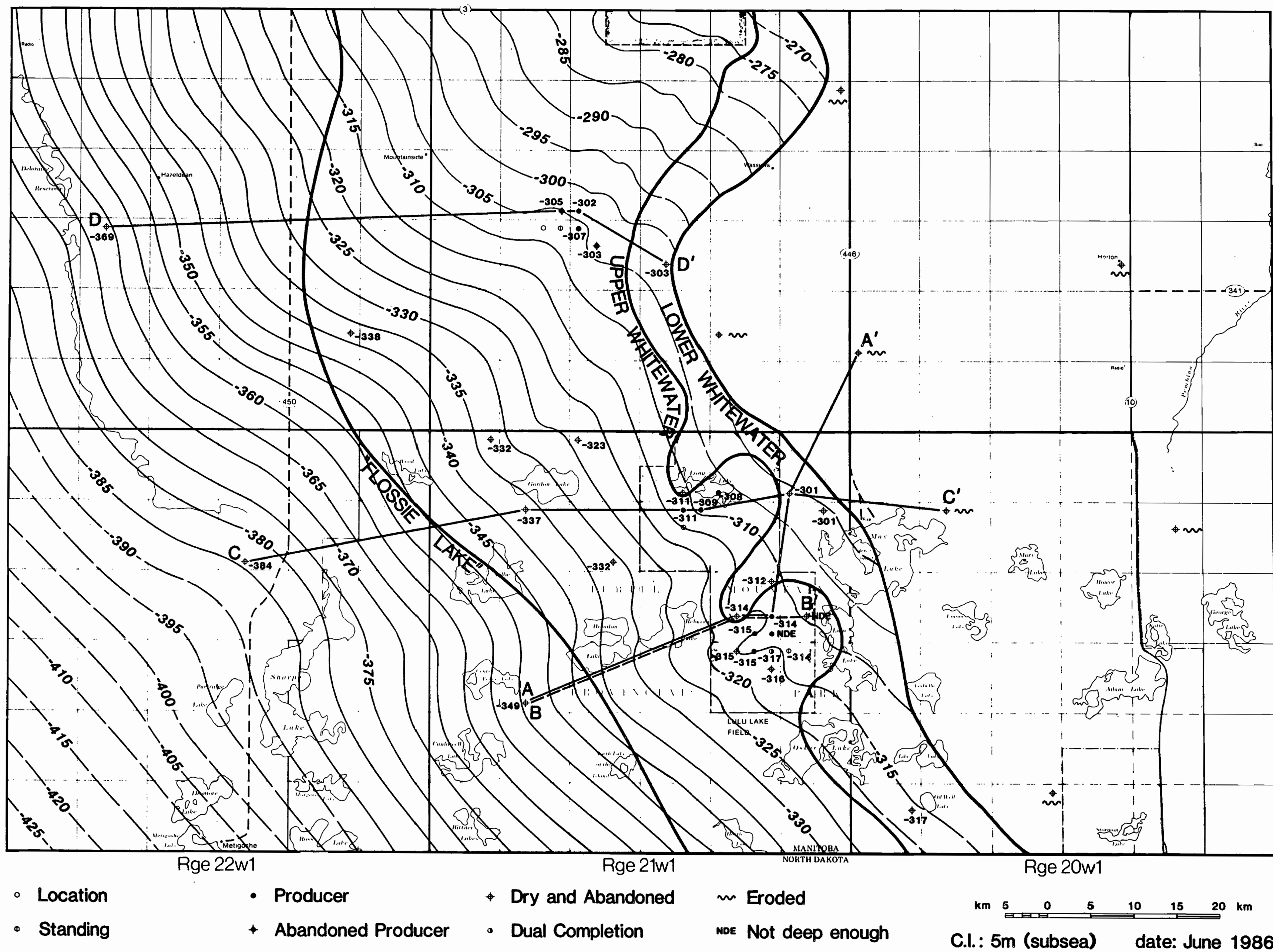


Figure 10: Structure Map - Top of the Lower Whitewater Lake Member

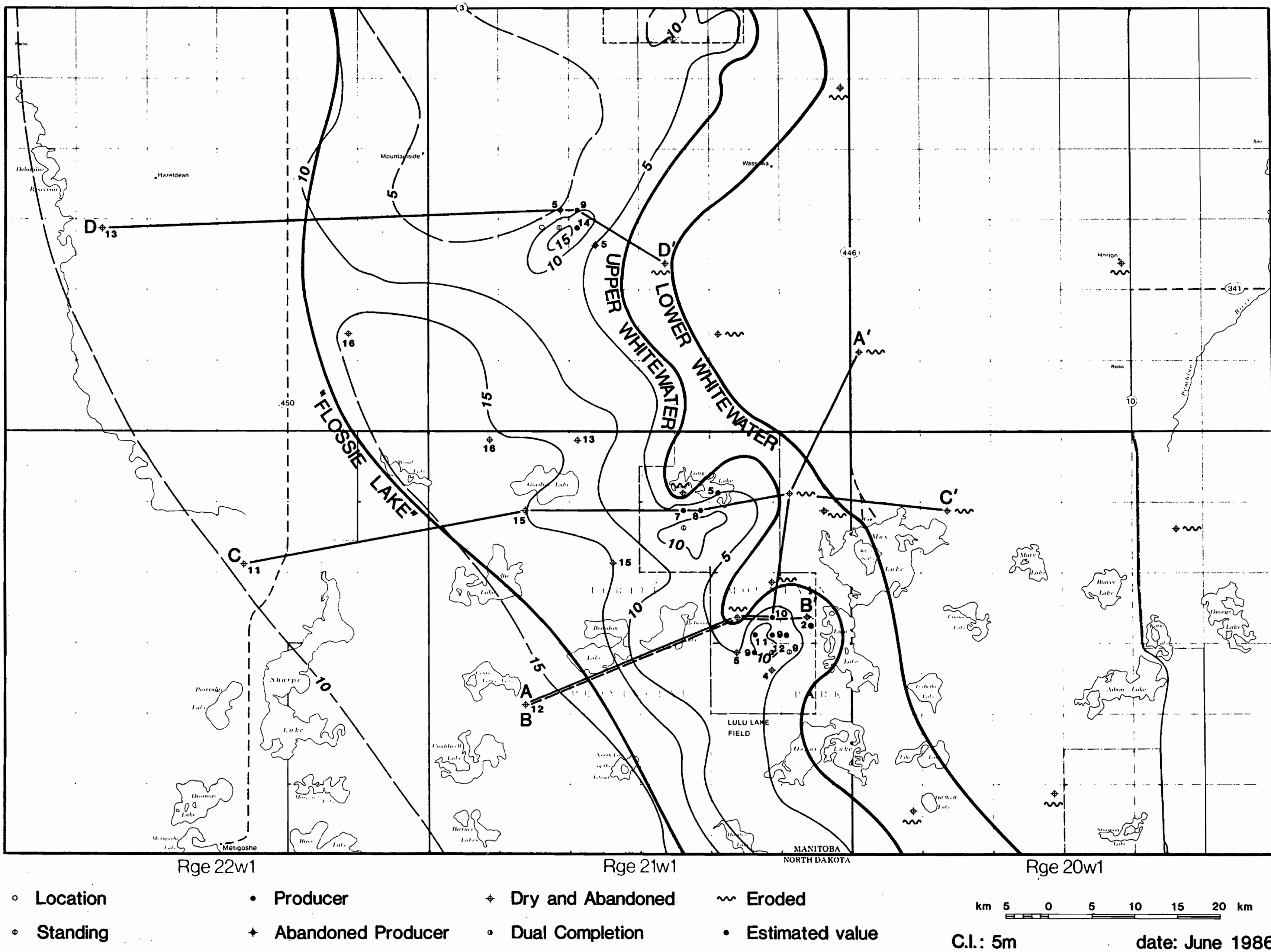


Figure 11: Isopach Map - Upper Whitewater Lake Member

Generally, the erosion surface is homoclinal, dipping regionally toward the southwest (Fig. 3). Several minor southwest-trending noses exist along the eastern flank of the Upper Whitewater Lake Member subcrop belt. These isolated "highs" are present at the "Mountainside" Pool and Lulu Lake "A" and "B" Pools, as mentioned earlier, and are coincident with thinning of the overlying Red Bed isopach. Evidence of closure is seen at the "A" and "B" Pools of the Lulu Lake Field.

A number of features were noted on the isopach map of the overlying Red Bed Formation (Fig. 12). The top of the Red Beds is believed to be an approximate time stratigraphic marker, and the Red Beds isopach is considered to be a direct reflection of underlying Mississippian erosional topography.

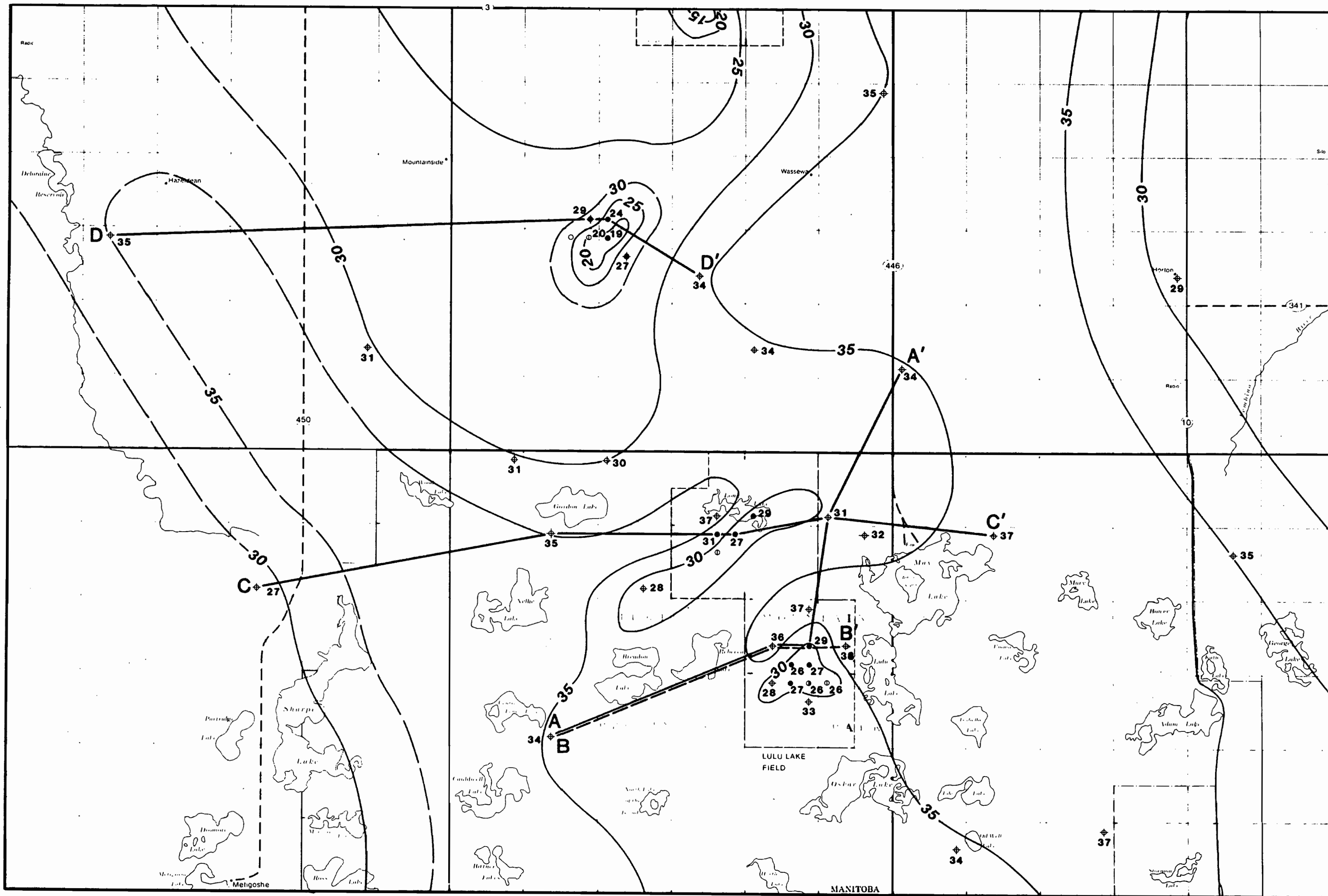
Several NE-SW-trending isolated Red Bed "thins" were noted near the erosion limit of the Upper Whitewater Lake subcrop belt. These are reflected on the underlying erosion surface as small isolated "highs" notably at the "A" and "B" Pools of the Lulu Lake Field and as a small southwest-dipping nose at the "Mountainside" Pool and are therefore paleotopographic rather than structural features. Red Bed "thicks", also trending NE-SW, were noted between the "A" and "B" Pools and north of the Field. These "thicks" correspond to underlying Mississippian erosional "lows".

The structure map of the top of the Red Beds (Fig. 13) is a subdued expression of the Mississippian erosion surface. The Red Bed surface is fairly regular, and follows the regional southwest dip present in the study area. "Highs" noted on the Mississippian at Lulu Lake and "Mountainside" Pools are mirrored slightly on the Red Bed surface. No evidence of closure, however, is seen on the Red Bed structure.

Trapping Mechanisms

Using the above discussion of structure and isopach, the following overall picture of hydrocarbon trapping mechanisms is proposed.

The area of study appears to be primarily stratigraphically



◦ Location
⊕ Standing
• Producer
✦ Abandoned Producer
⌖ Dry and Abandoned
◦ Dual Completion

km 5 0 5 10 15 20 km

C.I.: 5m

date: June 1986

Figure 12: Isopach Map - Lower Amaranth (Red Beds)

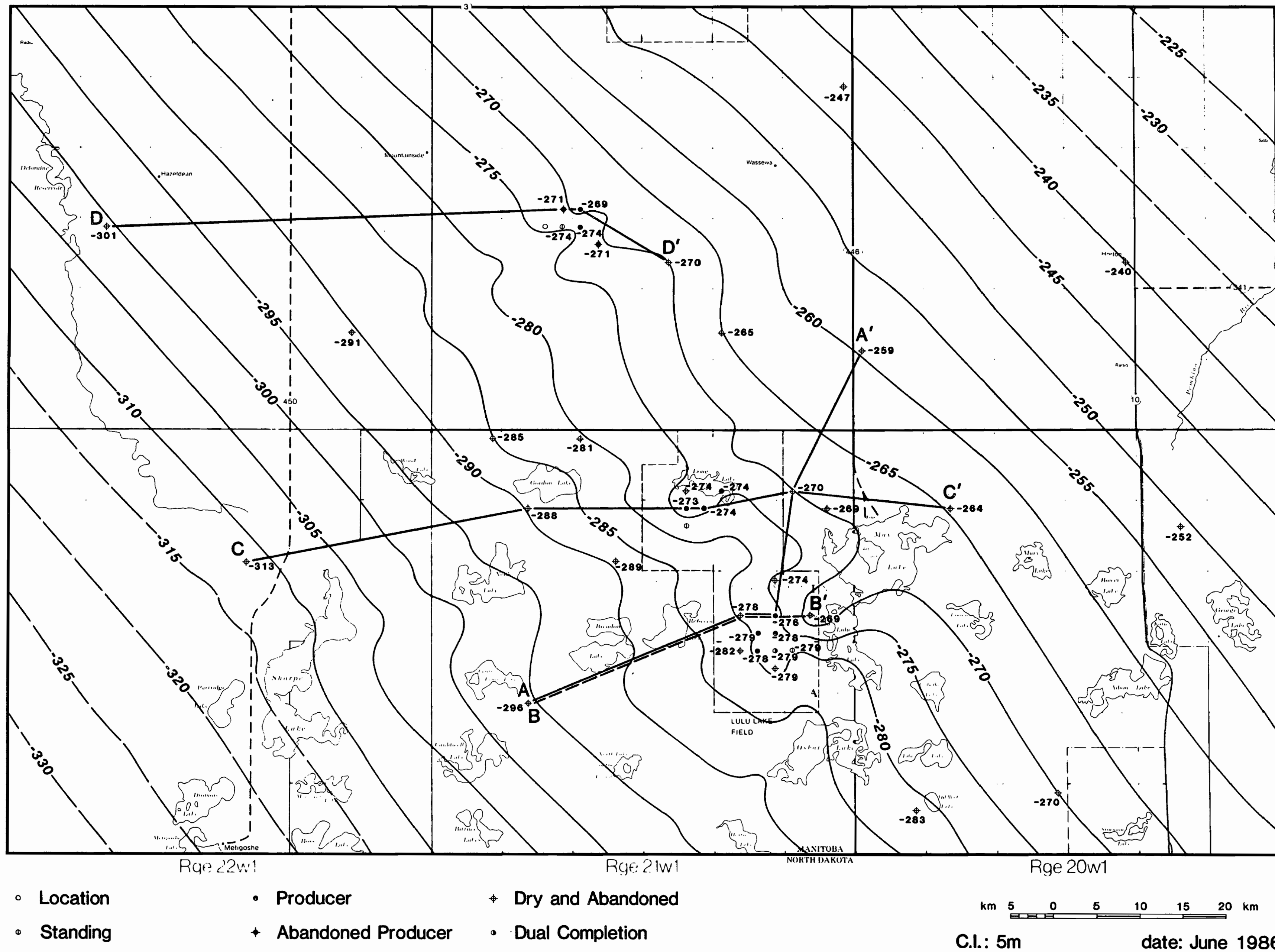


Figure 13: Structure Map - Top of the Lower Amaranth (Red Beds)

controlled. The "highs" observed on the Mississippian erosional surface within the producing areas are mainly paleotopographic in origin. Formation of these "erosional remnants" occurred during Mississippian erosion, whereupon Upper Whitewater Lake Member was preserved as "erosional highs". This is indicated by closures seen on the erosion surface corresponding with Upper Whitewater Lake isopach thickening. Following erosion, the Red Beds were deposited, infilling the "lows" and "highs" on the Mississippian surface. Isopach thinning of the Red Beds noted near the Upper Whitewater erosion limit outlines these isolated paleotopographic "highs".

It appears, however, that there may also have been some minor structure influence of these "highs". A late uplift is suggested by "highs" observed on the Lower Whitewater Lake structure reflected on up through the Mississippian to the erosion surface and also as subdued "highs" on the Red Bed surface. This later event may have served to further emphasize the Mississippian erosional topography, but it is possible that this "uplift" could have been due to differential compaction.

Production in the Lulu Lake Field and "Mountainside" Pool is obtained from the erosional "highs" occurring within the Upper Whitewater Lake subcrop belt. The traps occur within the updip limits of the reservoir beds of the Upper Whitewater Lake Member, where these beds have been truncated at the Mississippian erosion surface.

The stratigraphic cross-section B-B', C-C' and D-D' depict the distribution of the reservoir in the south "A" and the north "B" Pool of the Lulu Lake Field and the "Mountainside" Pool, shown in Figures 14 to 16, respectively. These sections illustrate the progressive eastward truncation of the Upper Whitewater Lake beds.

Due to the lack of an effective alteration zone at the unconformity surface, no effective impermeable Mississippian "cap rock" is present in these Pools. Thus, the shales and siltstones of the overlying "Red Beds" provide the required seal.

By correlating logs to core data, important reservoir properties such as porosity, permeability, pay thickness, water saturation and oil-in-place have been obtained for pools in the study area. The methodology used to obtain these reservoir properties, as well as their description and presentation in Figures 17 to 31 are discussed. As previously noted, all reservoir engineering properties were obtained and mapped on data available to August, 1985. Cumulative production and remaining recoverable reserves estimates were updated to December 31, 1985.

Methodology

(a) Derivation of Upper Whitewater Lake Porosities

Upper Whitewater Lake core porosities have been depth-shifted to match the sonic traces for a total of 13 wells in the study area (Fig. 17). Fractured and non-fractured data were both included in the crossplot in Figure 17.

A good correlation of sonic travel time to core porosity exists (correlation coefficient = 0.85). Recorded sonic travel times (Δt) range from 169 to 242 msec/m and plotted core porosities ($\emptyset$) range from 3 to 24%. The following correlation was obtained:

$$\emptyset_c = \frac{\Delta t - 166}{299}$$

where:

$\emptyset_c$ = core porosity in fractions

Δt = sonic travel time in msec/m.

The favourable correlation coefficient indicates that the Upper Whitewater Lake Member is lithologically similar throughout the area. The porosity-travel time equation (above) is justifiably used to obtain Upper Whitewater Lake porosities in the study area.

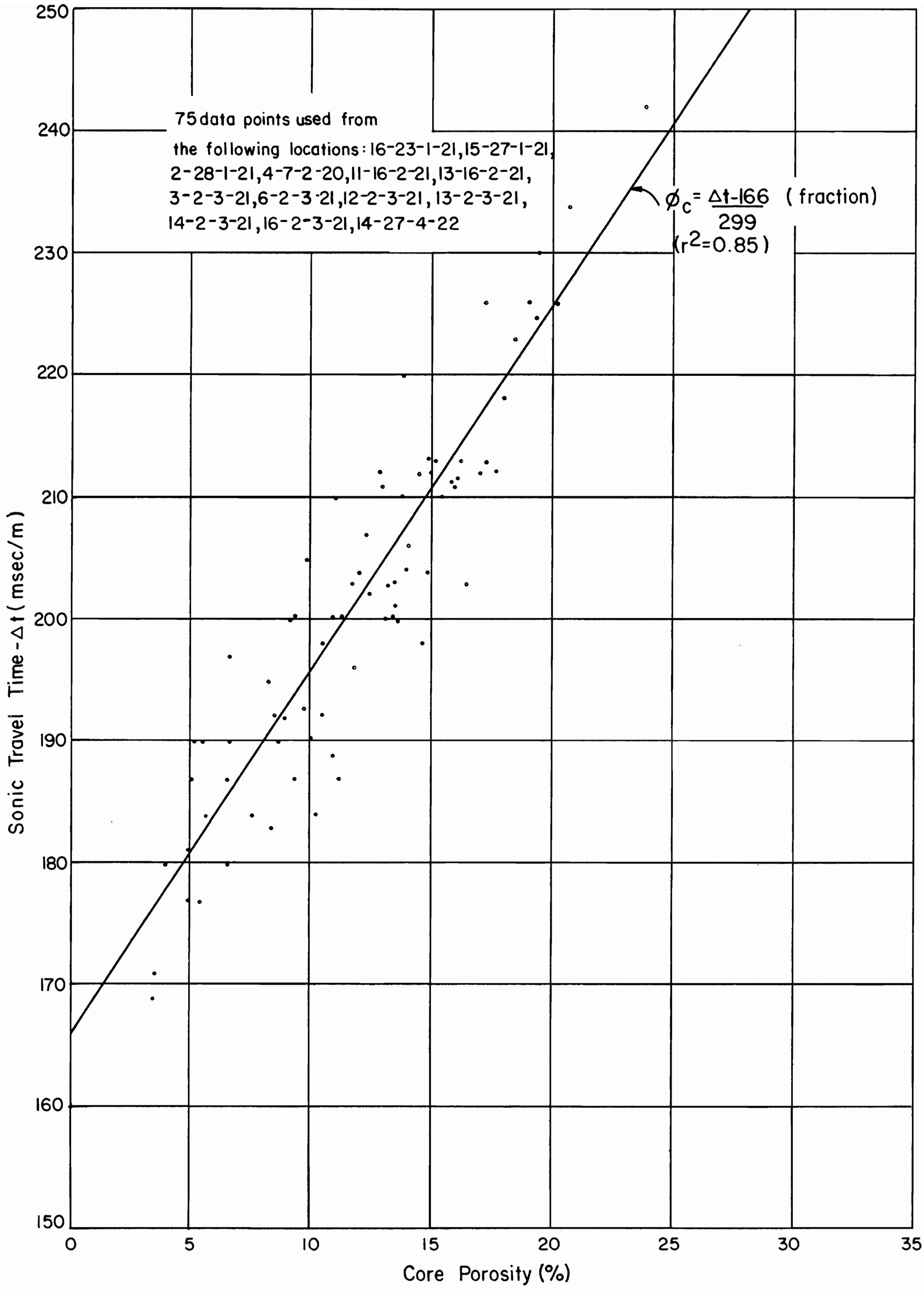


Figure 17: Sonic Travel Time Versus Core Porosity Plot for Lulu Lake, Mountainside, Whitewater Areas (Upper Whitewater Lake Member)

(b) Derivation of Upper Whitewater Lake Permeabilities and Definition of Permeability Cut-Off

A poor correlation between permeability and porosity is obtained when all available Upper Whitewater Lake core data are plotted (see Fig. 18). By omitting data from fractured samples, the correlation coefficient is dramatically improved, from 0.50 to 0.71 (Fig. 19). As expected, fracturing increases Upper Whitewater Lake permeability but does not affect Upper Whitewater Lake porosity.

Based on completion and production information from Mississippian wells in southwest Manitoba, carbonates with core permeabilities below 1 md are non-producible. This 1 md permeability cut-off has been applied to the study area. A permeability of 1 md corresponds to a core porosity of 7.5% and a sonic travel time of 188 msec/m. Those portions of the Upper Whitewater Lake Member which have a sonic travel time of less than 188 msec/m are excluded from average porosity, permeability, water saturation, net pay and oil-in-place calculations.

(c) Formation Water Resistivity

The Upper Whitewater Lake and Upper Virden Members are geologically similar within the study area. Logs show that there is bottom water in the Upper Whitewater Lake Member at a few locations in the area. The Upper Virden Member is wet throughout the area.

Where either or both members are wet, the formation water resistivity (Rw) is calculated from the following water saturation equation:

$$Sw^n = \frac{a\ Rw}{\text{Ø}^m Rt}$$

where:
a, m and n are unitless
Sw ranges from 0 to 1.0
Rw and Rt are in ohm-metres
Ø ranges from 0 to 1.0

with Sw=1.0, a=1 and m=n=2:

$$Rw = \text{Ø}^2 Rt$$

Fig. 18

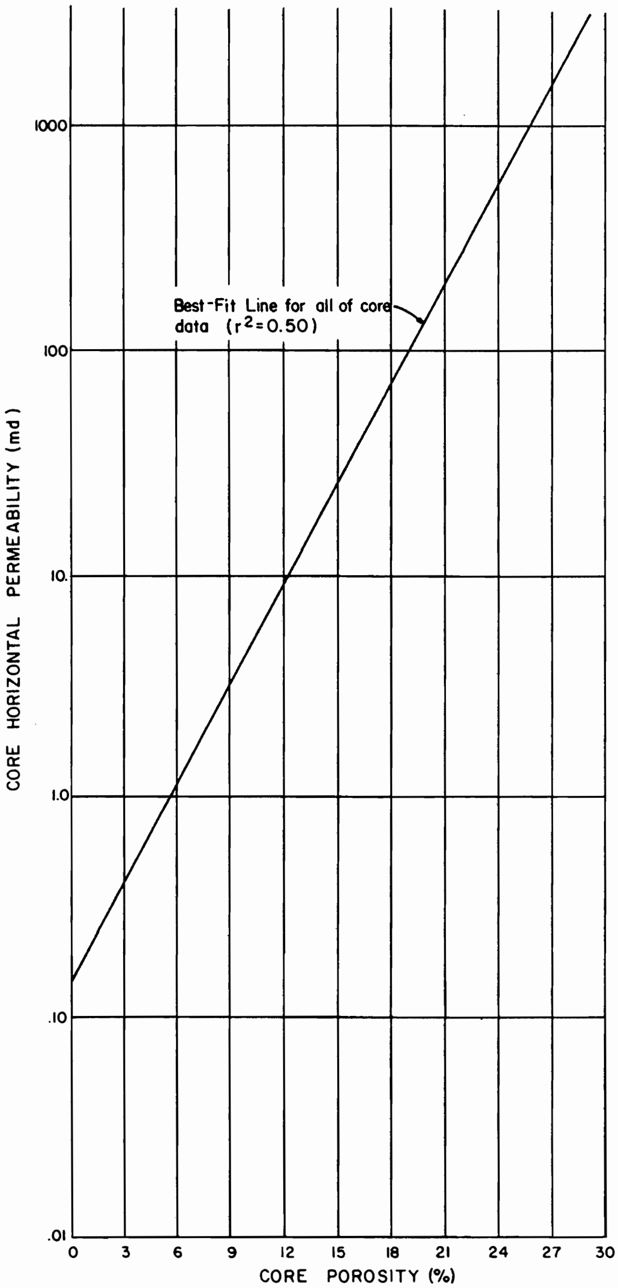


Fig. 19

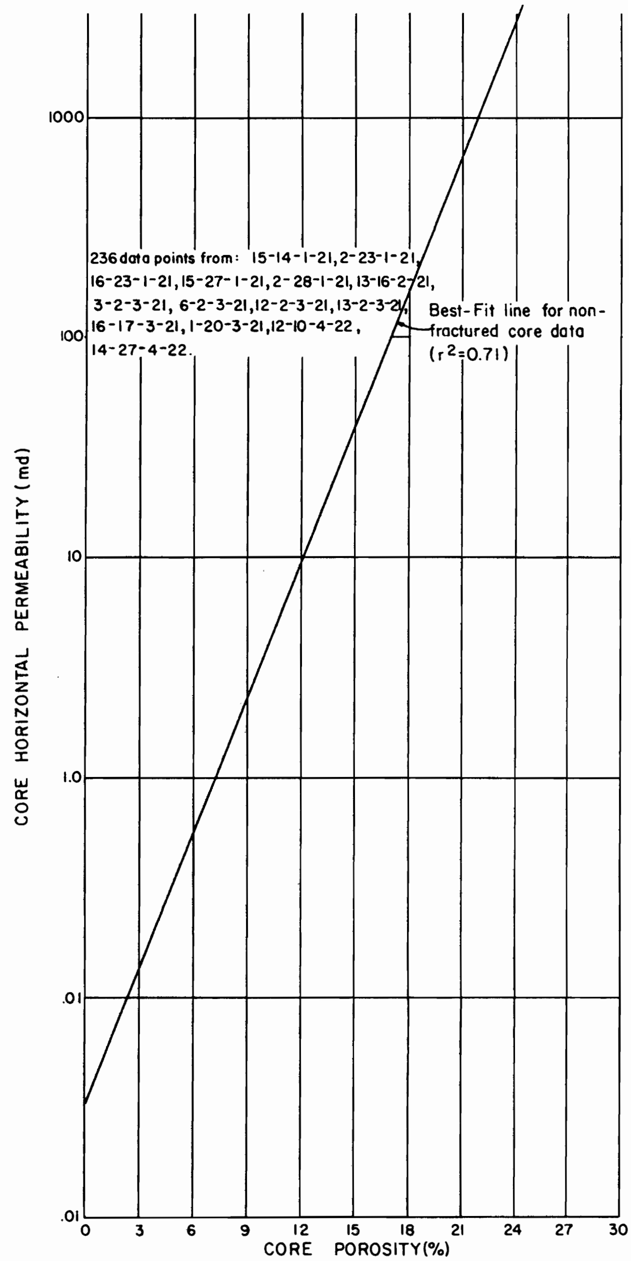


Figure 18: Core (Horizontal) - Permeability Versus Porosity Plot for Lulu Lake, Mountainside, Whitewater and South Regent Areas (Upper Whitewater Lake Member)

Figure 19: Core (Horizontal) - Permeability Versus Porosity Plot for Study Area (Fractured Samples Excluded), Upper Whitewater Lake Member

An Rw versus elevation (top of Upper Whitewater Lake) plot (Fig. 20) shows that Rw increases as the formation becomes structurally higher. Average Rw values in the area are 0.06 ohm-m.

In wells where the Upper Whitewater Lake and the Upper Virden Members are both wet, their respective Rw values are almost identical. It can therefore be assumed that Virden Member water resistivities match Upper Whitewater Lake Member water resistivities. The best fit line in Figure 20 (correlation coefficient = 0.79) is used to obtain Rw for the Upper Whitewater Lake and Upper Virden Members.

(d) Water Saturations - Lulu Lake Oil/Water Contact

For wells which have the necessary resistivity and sonic logs, water saturations are calculated with the Archie equation:

$$Sw^n = \frac{a\ Rw}{\emptyset^m Rt} \qquad \text{where } a=1,\ m=n=2,\ Rw \text{ from Figure 20}$$

A fairly good Sw versus elevation (top of Upper Whitewater Lake Member) correlation was obtained from new well data in the study area (Fig. 21). Some of the older wells in the area do not have the necessary logs to calculate Sw. For these wells, Sw estimates were made with the help of Figure 21.

Based on Sw calculations in the study area, an oil/water contact follows the 310 m subsea structure contour in the Upper Whitewater Lake Member.

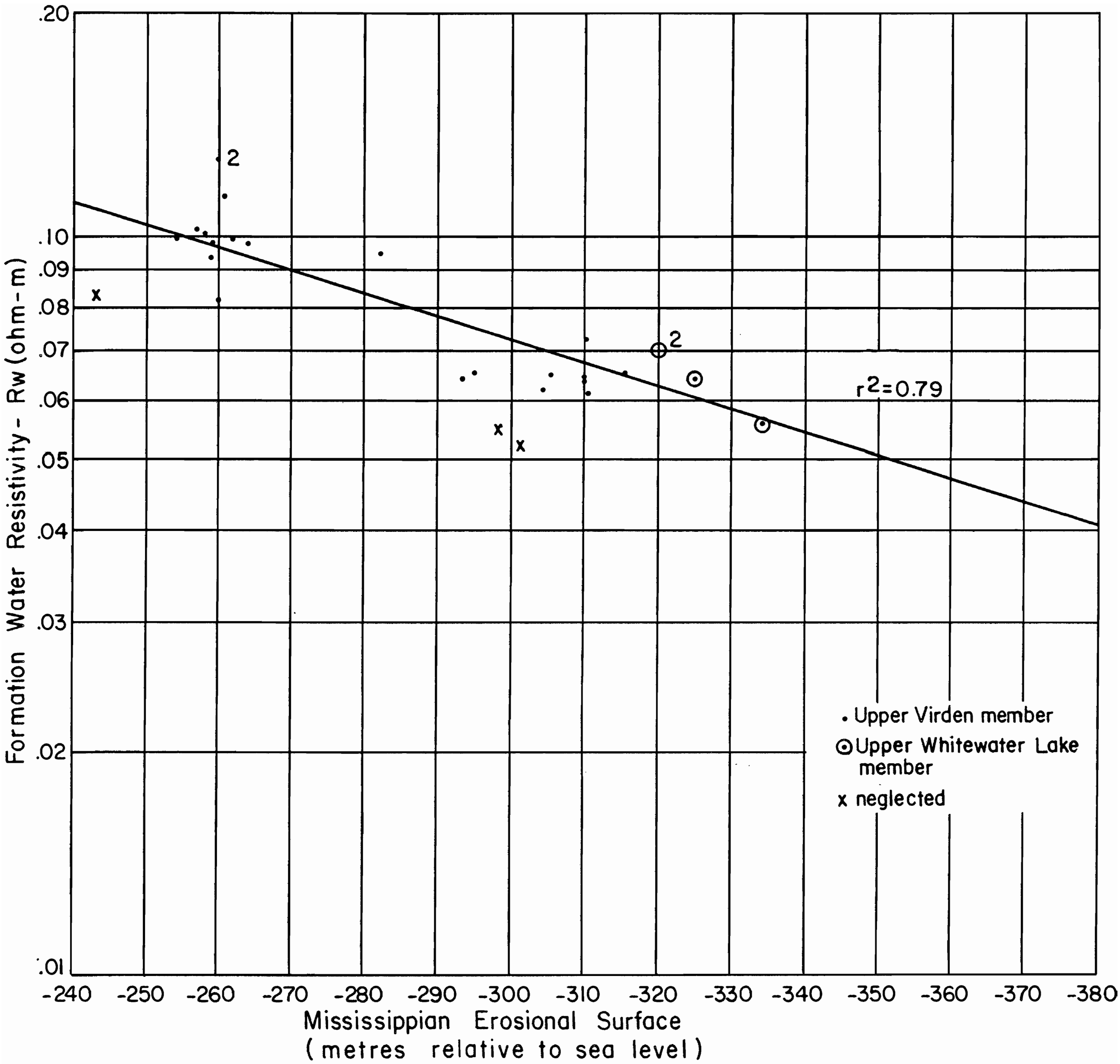


Figure 20: RW versus Elevation for Upper Whitewater Lake and Upper Virden Members in Study Area

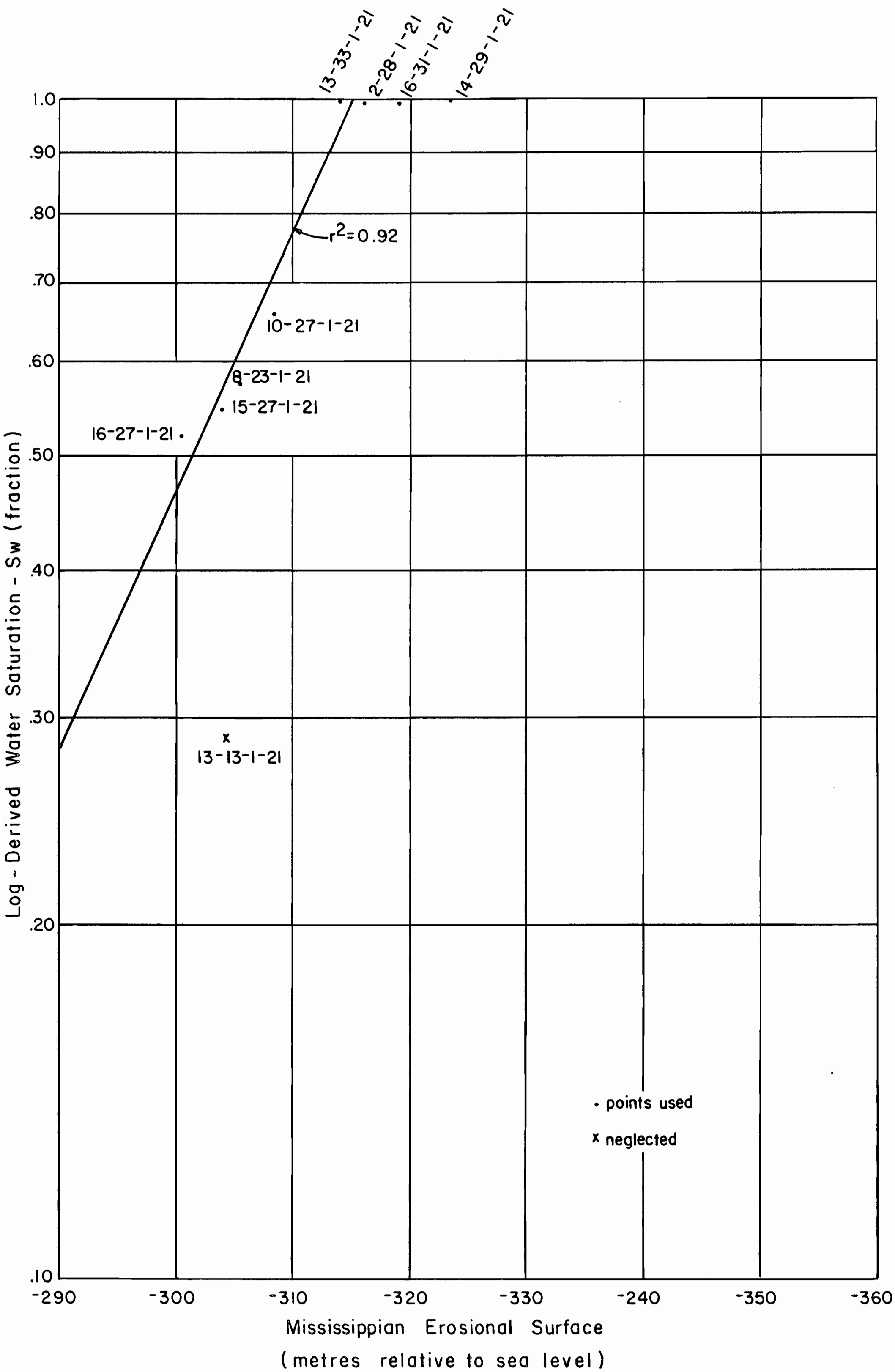


Figure 21: SW versus Elevation for Upper Whitewater Lake Member in Lulu Lake Area

DESCRIPTION

(a) Lulu Lake Field

i) Water Saturation (Fig. 22)

The average Upper Whitewater Lake Member water saturation for both the "A" and "B" Pools is 59%. As previously discussed, water saturations increase as the Upper Whitewater Lake Member becomes structurally lower (Figure 21). There is a sharp oil/water contact in the Upper Whitewater Lake Member at a depth of 310 m subsea. The Upper Whitewater Lake Member is wet at the north, west and south sides of the Field.

ii) Porosity (Fig. 23)

Porosity contours trend in a northwest-southeast direction in the southeast portion of the Lulu Lake Field. Upper Whitewater Lake ("A" Pool) porosities range from 12 to 16%. The highest porosities have developed in the central portion of the "A" Pool in 16-14-1-21 WPM. Porosities decrease away from this location.

Within the northwest portion of the "B" Pool, porosity contours trend east-west. The lowest average porosity at 15-27-1-21 WPM is 11%. Porosities increase to 16 or 17% away from this location.

iii) Permeability (Fig. 24)

Porosity and permeability trends coincide, as would be expected from the good permeability/porosity correlation in Figure 19.

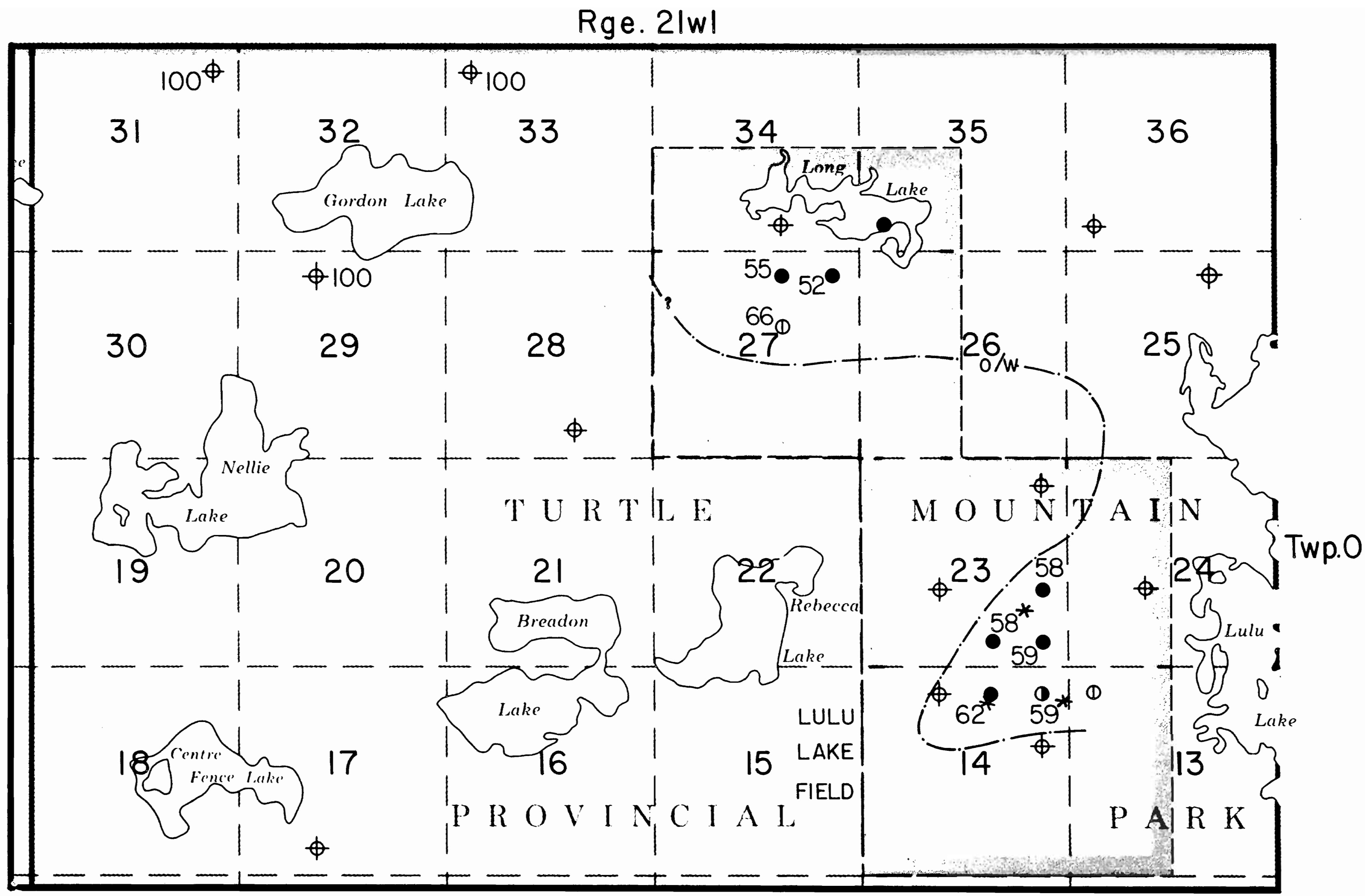


Figure 22: Water Saturations - Lulu Lake Area, Upper Whitewater Lake Member

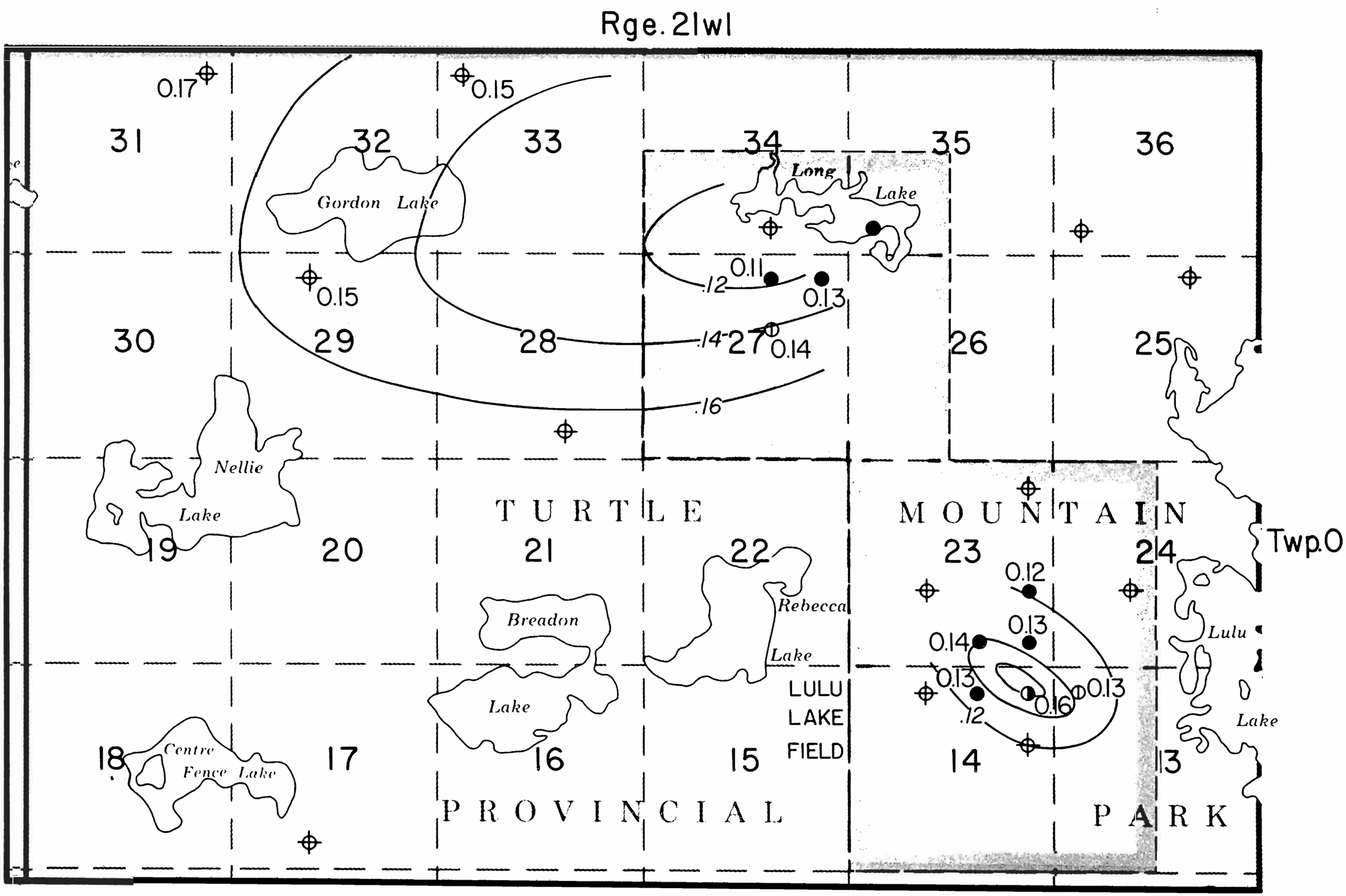


Figure 23: Porosity - Lulu Lake Area, Upper Whitewater Lake Member

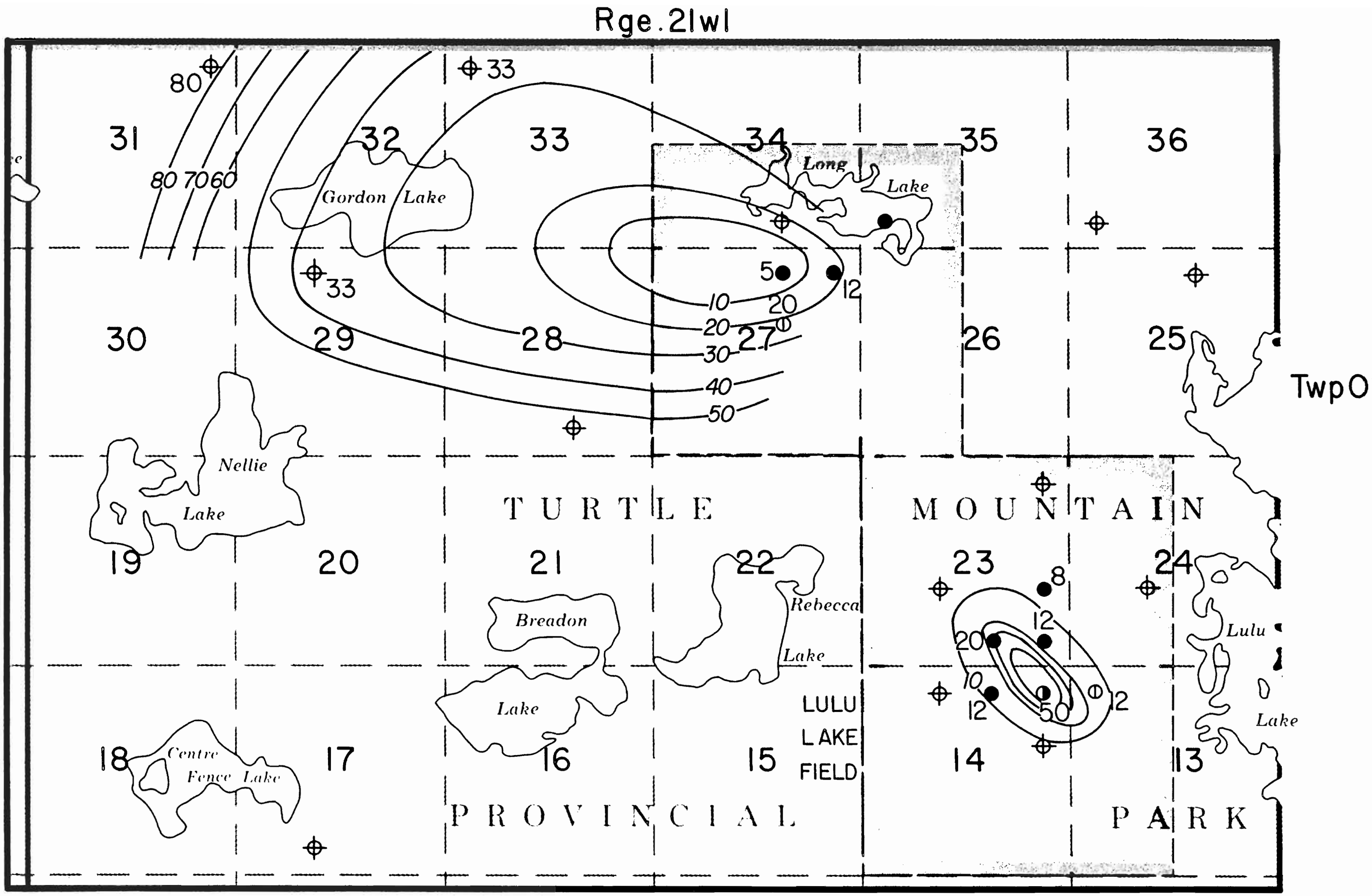


Figure 24: Permeability - Lulu Lake Area, Upper Whitewater Lake Member

iv) <u>Net Pay 'h'</u> (Fig. 25)

In the "A" Pool, net pay contours generally follow the water-oil contact. Wells 15-14-1-21 WPM, 16-14-1-21 WPM and 2-23-1-21 WPM exhibit the best net pays (greater than 3 m). Net pay decreases away from these three locations until it is zero at the water/oil contact.

In the northwest portion of the Field ("B" Pool), net pay is roughly 3 m at 16-27-1-21 WPM and decreases away from this location.

v) <u>Oil-In-Place</u> (Fig. 26)

As previously noted, the Upper Whitewater Lake Member is wet at the north, west and south ends of the "A" Pool. The Upper Whitewater Lake Member thins to the east. The portion of the "A" Pool with the most oil-in-place lies in a northwest-southeast segment between 2-23-1-21 WPM and 16-14-1-21 WPM wells. Oil-in-place decreases away from these two wells.

The greatest amount of oil-in-place in the "B" Pool is at 16-27-1-21 WPM. Hydrocarbon content decreases rapidly away from this producer.

The oil-in-place map indicates that there does not appear to be any future drilling potential in the immediate area. The original oil-in-place for the Lulu Lake Field ("A" and "B" Pools combined) is 422 665 m^3. The estimated recoverable reserves for the Field are 57 957 m^3 oil or 14% of the oil-in-place.

vi) <u>Reservoir Properties</u>

The following tables list some of the reservoir properties for the non-confidential wells in the Lulu Lake Field "A" and "B" Pools.

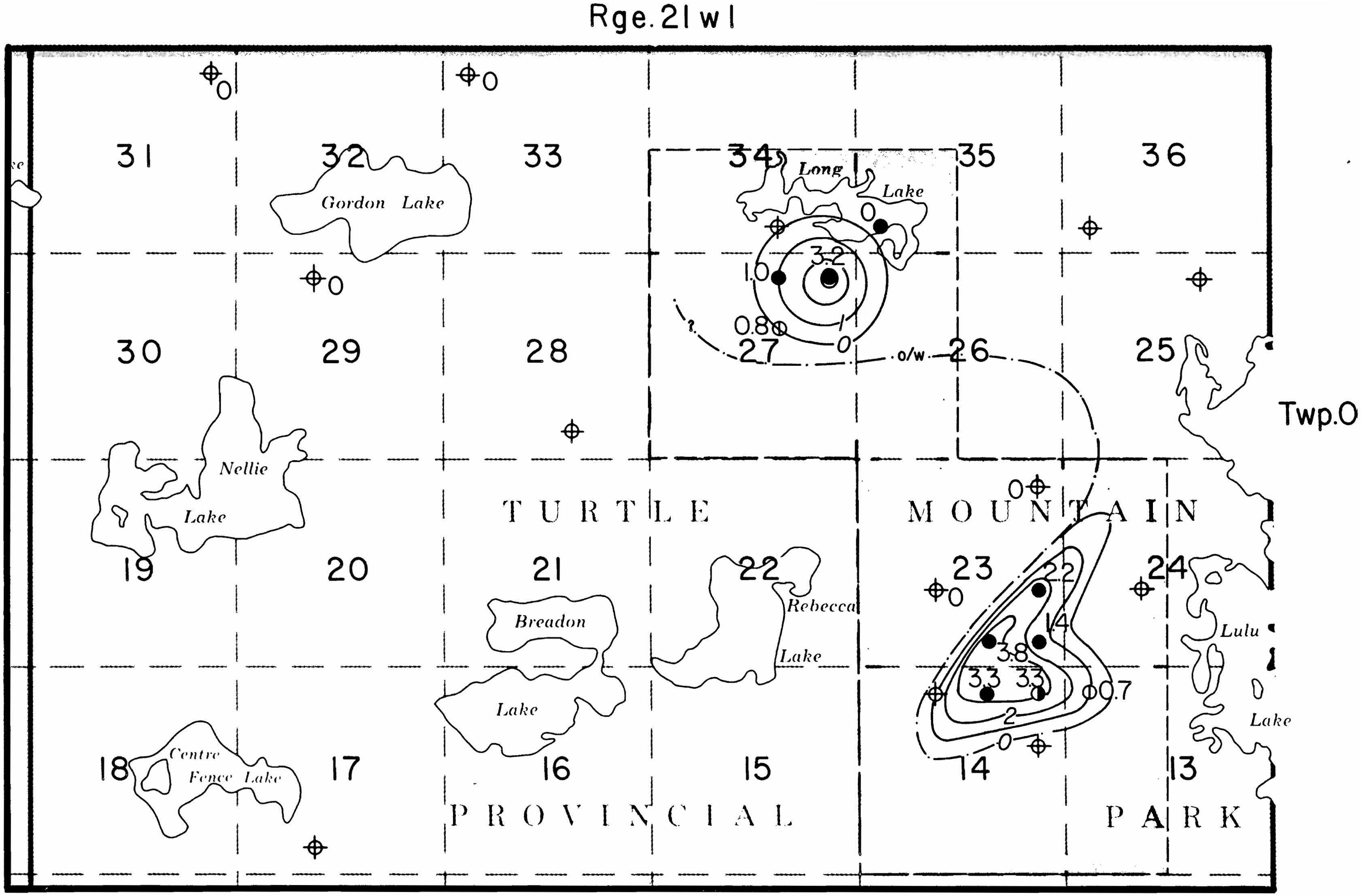


Figure 25: Net Pay - Lulu Lake Area, Upper Whitewater Lake Member

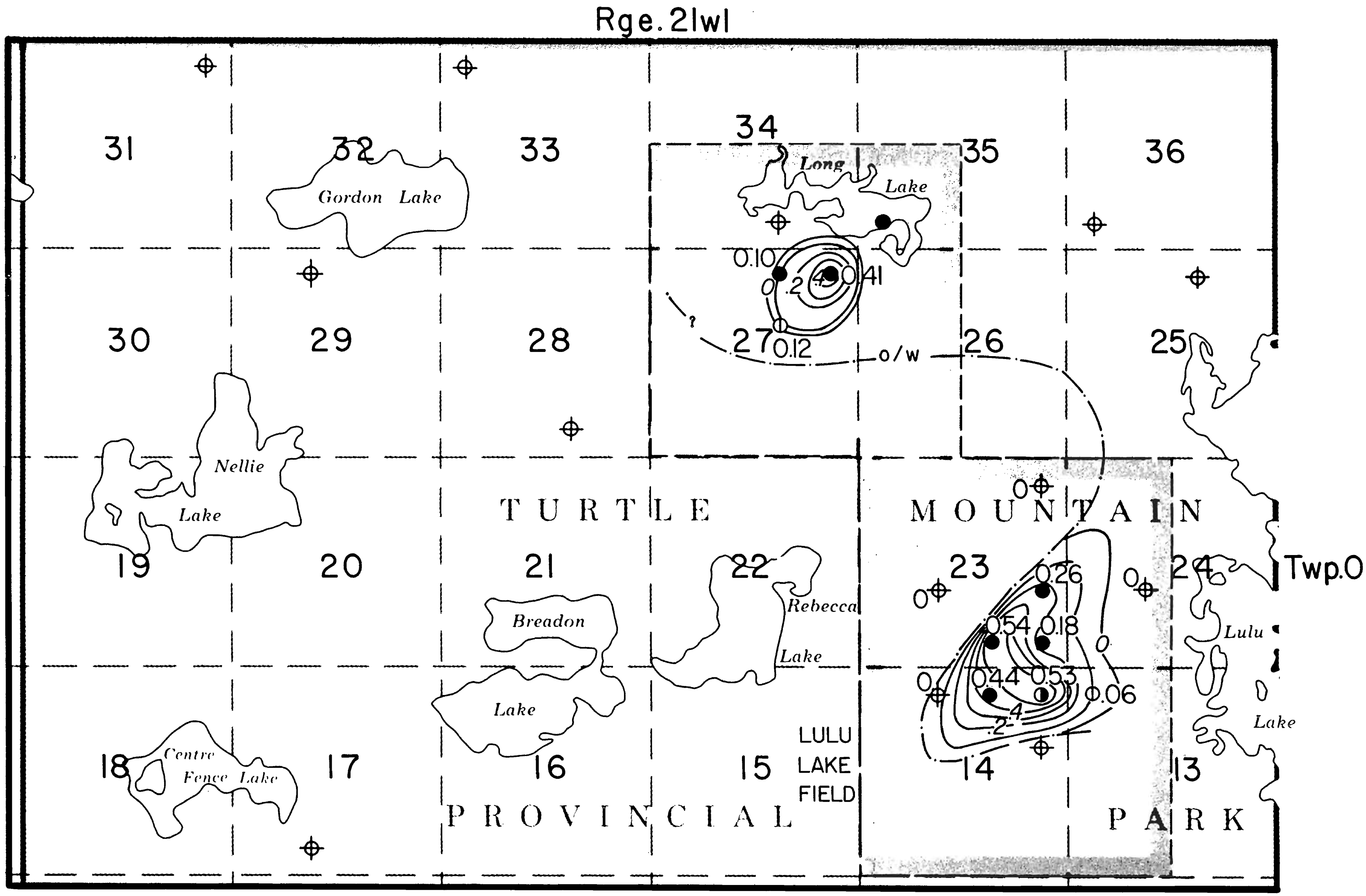


Figure 26: Oil-in-Place Per Unit Area - Lulu Lake Area, Upper Whitewater Lake Member

TABLE 2: Lulu Lake Field ("A" Pool) Reservoir Properties

I. General Information:

1.	Year of discovery		1952
2.	Number of Wells:	a) Capable of Oil Production	5
		b) Produced during 1985	5
		c) Service	1
		d) Active during 1985	5
		e) Previous Producers	0
3.	Spacing		16 ha
4.	Average Depth of Producing Zone		1 003 m KB
5.	Crude Oil Quality:	a) Density	847 kg/m^3
		b) Sulphur Content	9.48 g/kg
6.	Permeability (cut off 1.0 md)		20 md
7.	Initial Pressure (at datum 304 m.,ss)		Not Available
8.	Current Pressure (at datum 304 m.,ss)		Not Available
9.	Recovery Mechanism:		Water Drive

II. Reserves Information:

1.	Production Area (A)	151 ha
2.	Net Pay (h) (cutoffs; 0 = 7.5%, k = 1.0 md)	3.9 m
3.	Porosity (Ø)	14 %
4.	Connate Water Saturation (Sw)	59 %
5.	Shrinkage Factor (1/Boi)	0.93
6.	Original Oil in Place	314 463 m^3
7.	Recovery Factor	14 %
8.	Ultimate Recoverable Reserves	42 809 m^3
9.	Cumulative Production (to Dec. 31, 1985)	38 727 m^3
10.	Remaining Recoverable Reserves (Dec. 31, 1985)	4 082 m^3

TABLE 3: Lulu Lake Field ("B" Pool) Reservoir Properties

I. General Information:

1.	Year of discovery		1984
2.	Number of Wells:	a) Capable of Oil Production	3
		b) Produced during 1985	2
		c) Service	0
		d) Active during 1985	2
		e) Previous Producers	0
3.	Spacing		16 ha
4.	Average Depth of Producing Zone		1 007 m KB
5.	Crude Oil Quality:	a) Density	850 kg/m^3
		b) Sulphur Content	8.50 g/kg
6.	Permeability (cut off 1.0 md)		15 md
7.	Initial Pressure (at datum 304 m.,ss)		Not Available
8.	Current Pressure (at datum 304 m.,ss)		7 884 kPa
9.	Recovery Mechanism:		Water Drive

II. Reserves Information:

1.	Production Area (A)	67 ha
2.	Net Pay (h) (cutoffs; 0 = 7.5%, k = 1.0 md)	3.0 m
3.	Porosity (Ø)	13 %
4.	Connate Water Saturation (Sw)	56 %
5.	Shrinkage Factor (1/Boi)	0.94
6.	Original Oil in Place	108 202 m^3
7.	Recovery Factor	14 %
8.	Ultimate Recoverable Reserves	15 148 m^3
9.	Cumulative Production (to Dec. 31, 1985)	7 180 m^3
10.	Remaining Recoverable Reserves (Dec. 31, 1985)	7 968 m^3

(b) "Mountainside" Pool

i) Water Saturation (Fig. 27)

Upper Whitewater Lake Member water saturations increase from the southeast to the northwest (55% at 11-16-2-21 WPM to 82% at 1-20-2-21 WPM). The Upper Whitewater Lake Member drops off (structurally) to the west-southwest. The discrepancy between Sw and structure may be attributable to the lack of data in the area.

ii) Porosity (Fig. 28)

Porosity changes generally correlate with structural variations. Upper Whitewater Lake Member porosities decrease when the formation becomes structurally lower.

iii) Permeability (Fig. 29)

As expected, porosity and permeability trends match (i.e. decreasing permeability with decreasing porosity).

iv) Net Pay 'h' (Fig. 30)

The net pay thickness at 13-16-2-21 WPM is 3.2 m. Net pay thicknesses decrease away from this location. Net pay contours follow a northwest-southeast trend.

v) Oil-In-Place (Fig. 31)

Oil-in-place appears to be concentrated in the 13-16-2-21 WPM spacing unit and decreases rapidly away from this location. Oil-in-place contours trend in a northwest-southeast direction.

vi) Reservoir Properties

The following table lists some of the reservoir properties for the "Mountainside" Pool.

TABLE 4: "Mountainside" Pool Reservoir Properties

I. General Information:

1. Year of discovery		1982
2. Number of Wells:	a) Capable of Oil Production	3
	b) Produced during 1985	2
	c) Service	0
	d) Active during 1985	2
	e) Previous Producers	2
3. Spacing		16 ha
4. Average Depth of Producing Zone		895 m KB
5. Crude Oil Quality:	a) Density	860 kg/m^3
	b) Sulphur Content	10.30 g/kg
6. Permeability (cut off 1.0 md)		31 md
7. Initial Pressure		Not Available
Current Pressure		Not Available
9. Recovery Mechanism:		Water Drive

II. Reserves Information:

1. Production Area (A)	13 ha
2. Net Pay (h) (cutoffs; 0 = 7.5%, k = 1.0 md)	2.7 m
3. Porosity (Ø)	15 %
4. Connate Water Saturation (Sw)	63 %
5. Shrinkage Factor (1/Boi)	0.94
6. Original Oil in Place	157 795 m^3
7. Recovery Factor	5 %
8. Ultimate Recoverable Reserves	7 670 m^3
9. Cumulative Production (to Dec. 31, 1985)	6 520 m^3
10. Remaining Recoverable Reserves (Dec. 31, 1985)	1 150 m^3

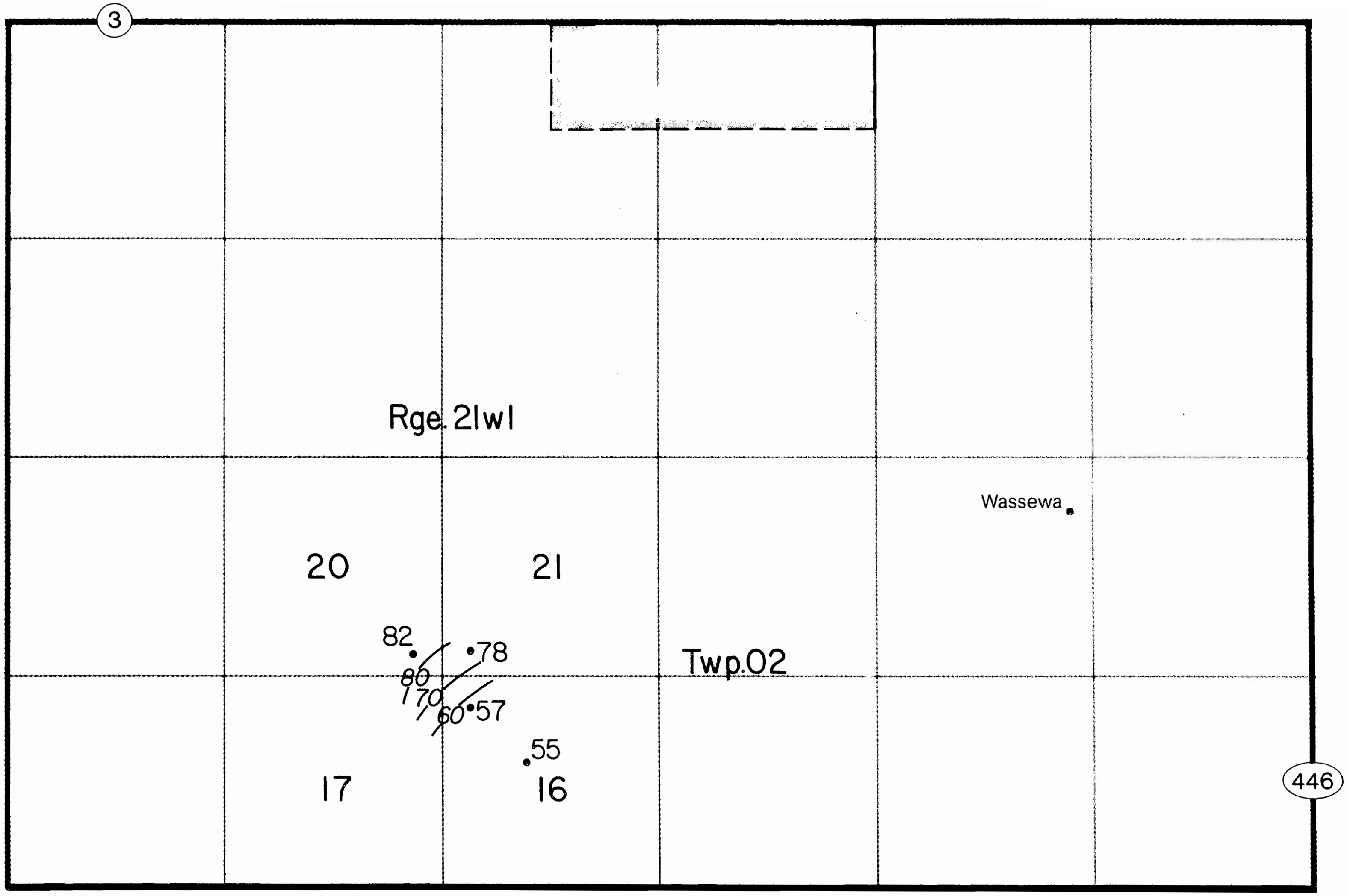


Figure 27: Water Saturations – Mountainside, Upper Whitewater Lake Member

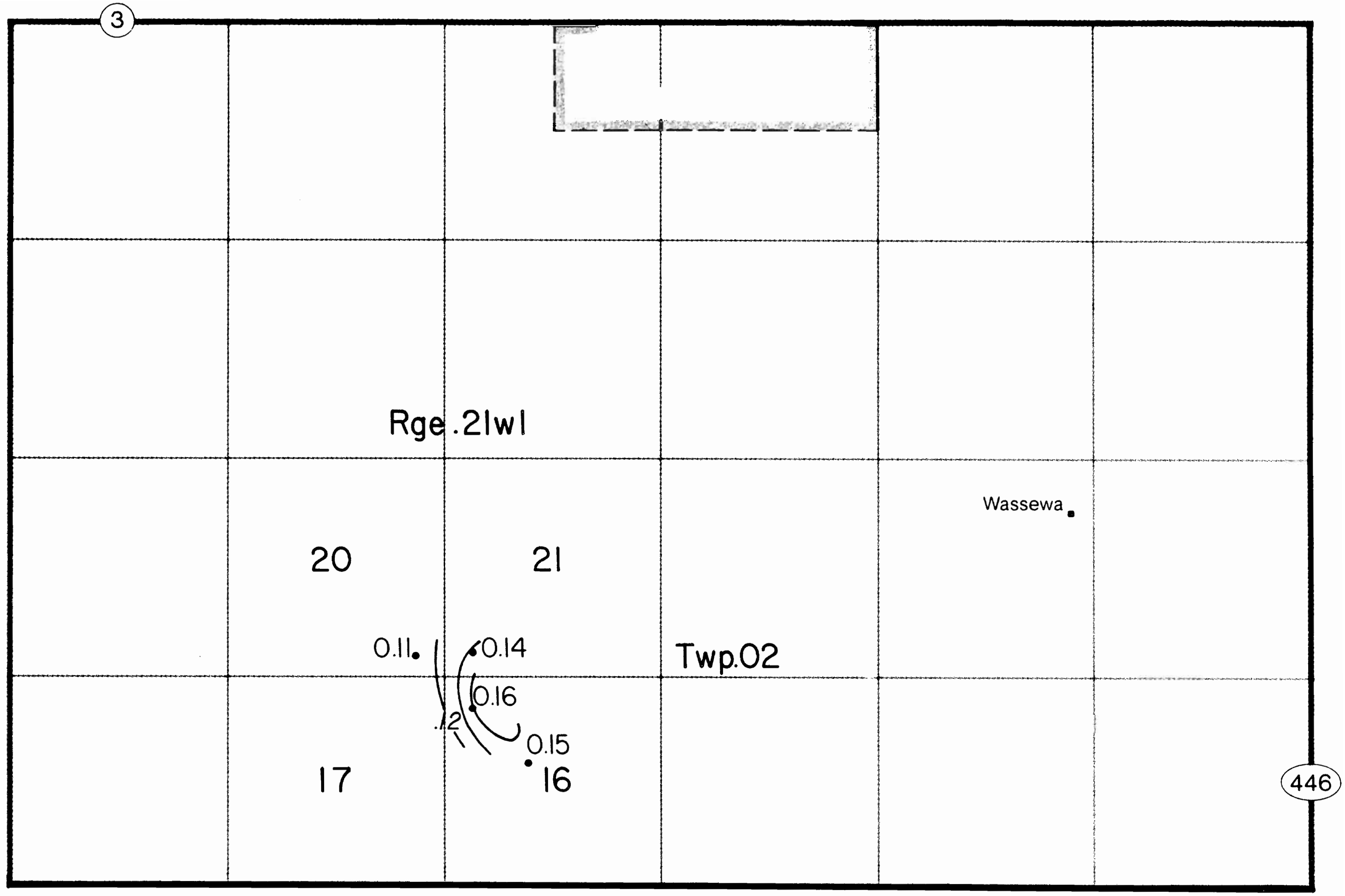


Figure 28: Porosity - Mountainside, Upper Whitewater Lake Member.

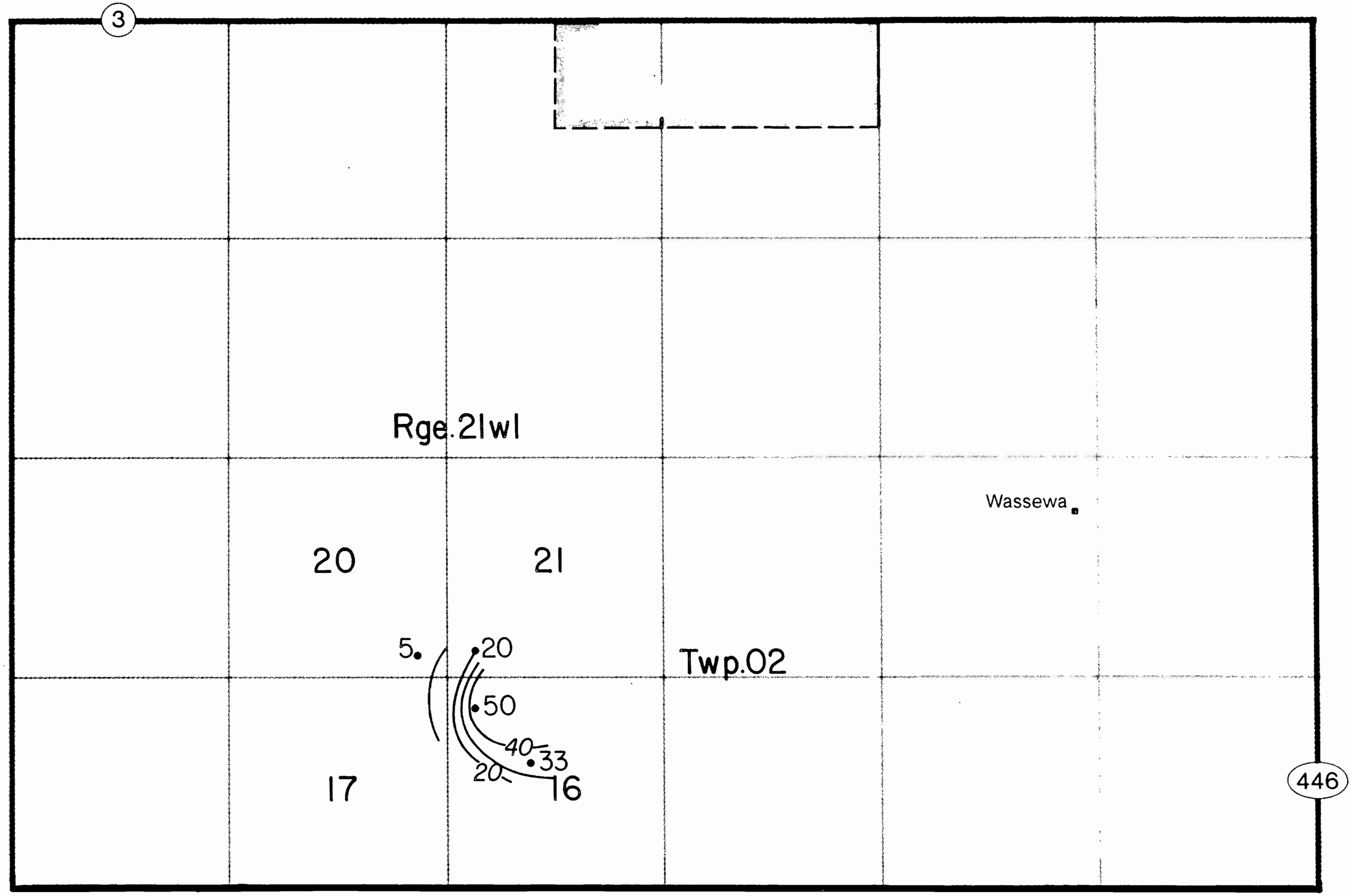


Figure 29: Permeability - Mountainside, Upper Whitewater Lake Member

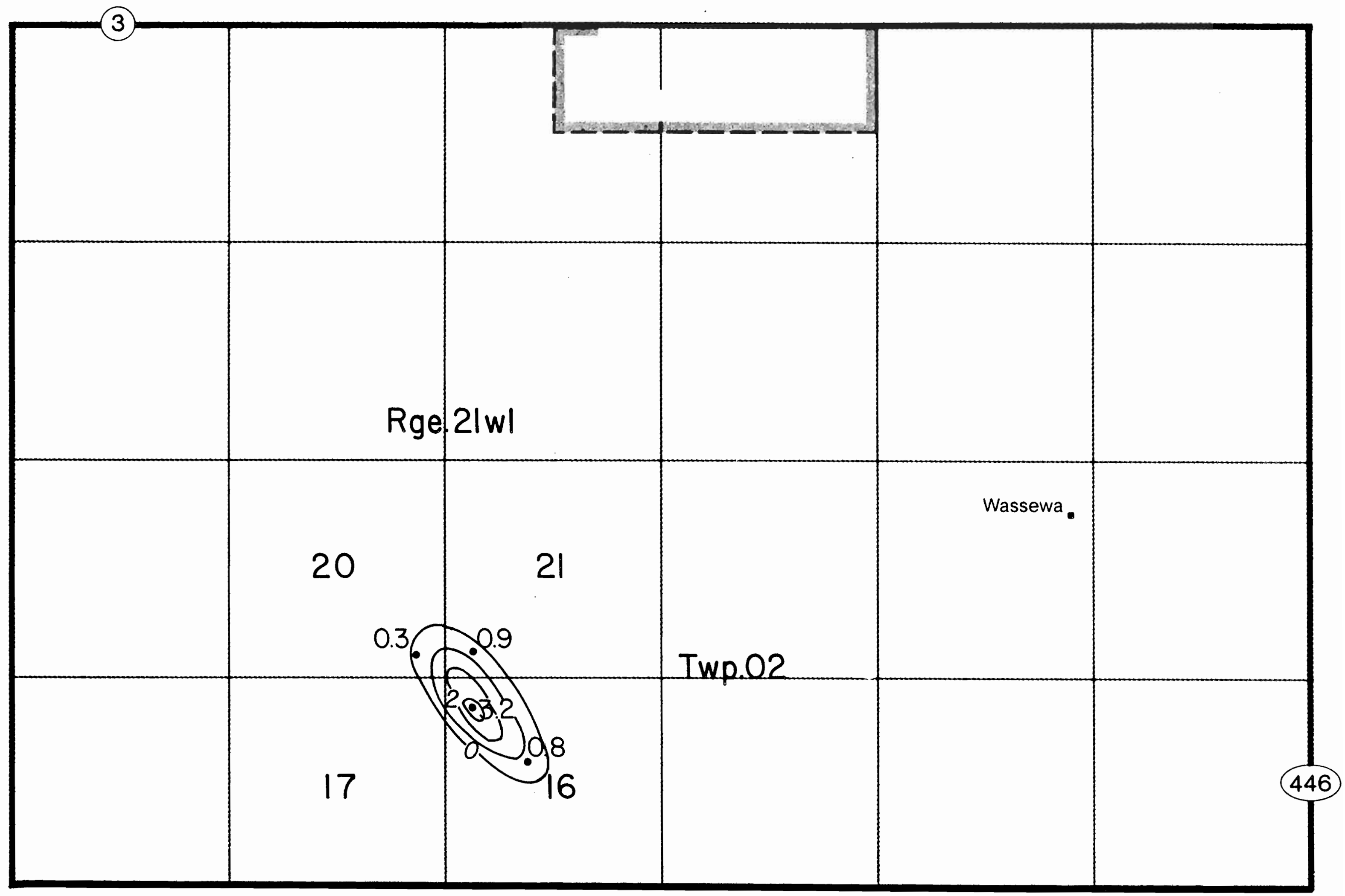


Figure 30: Net Pay - Mountainside, Upper Whitewater Lake Member

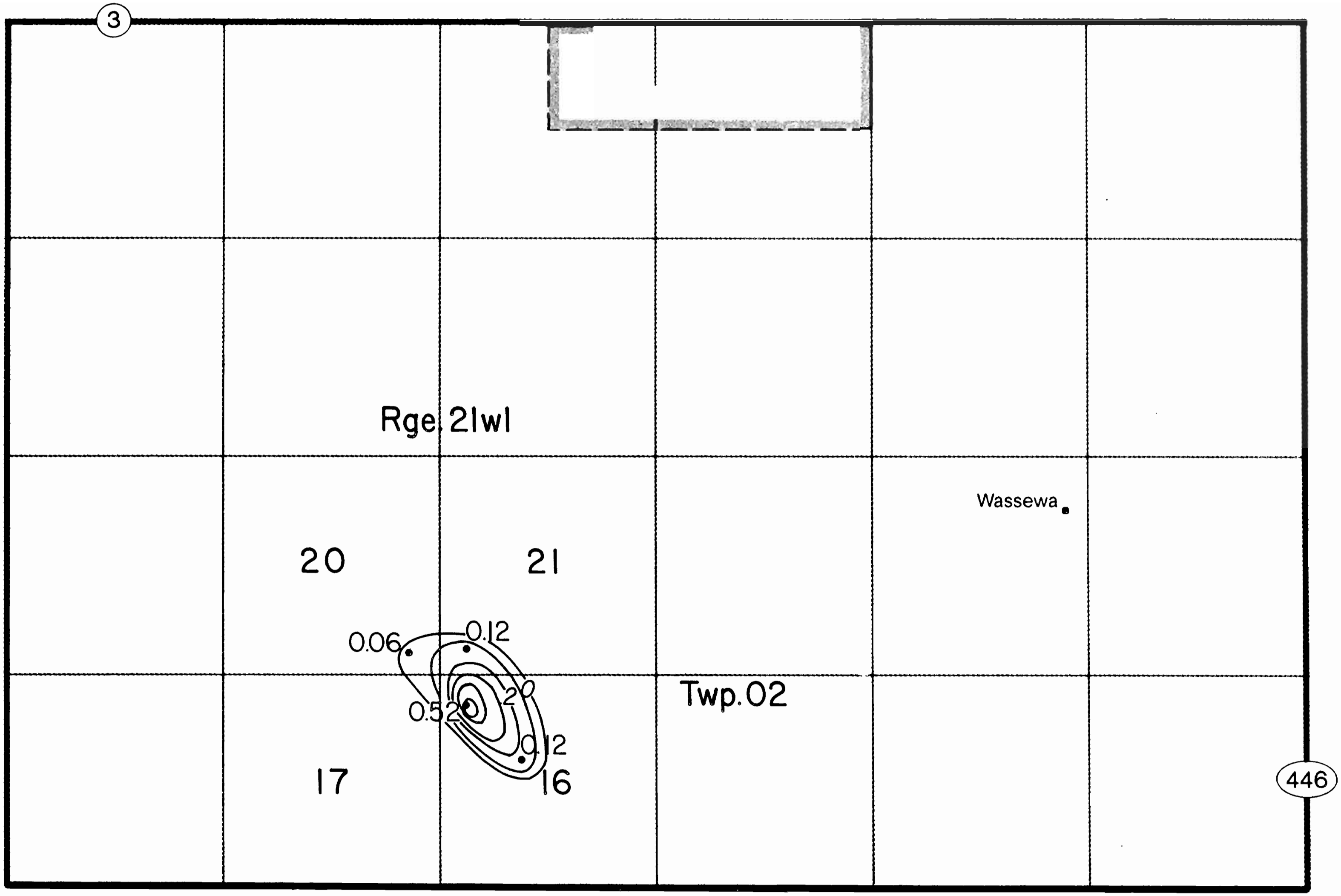


Figure 31: Oil-in-Place Per Unit Area - Mountainside, Upper Whitewater Lake Member

CONCLUSION

The Whitewater Lake Member of the Lulu Lake study area represents part of a complex transgressive-regressive cycle of deposition which occurred during Mississippian (Lodgepole Formation) time. It is divided stratigraphically into an upper clean unit and a lower argillaceous unit. The Member is believed to have been deposited in a coastal shoal environment and represents the uppermost part of a cycle of calcareous sedimentation similar to the underlying Virden Member.

Production in the area is obtained from the upper unit of the Whitewater Lake Member. Lithologically, it consists of oolitic packstone/grainstones with some interbedding of bioclastic wackestone. Porosity is chiefly due to secondary solution, although evidence of original primary intergranular porosity exists. The main inhibitor of porosity is in-filling by sparry calcite cement.

Hydrocarbon accumulation present in the porous beds of the Upper Whitewater Lake Member, occurs within erosional "highs" truncated at the Mississippian erosion surface. These "highs" may have had some minor internal Mississippian structural control. Shales and siltstones of the overlying "Red Beds" provide the required seal.

Using values derived from reservoir engineering calculations, average porosity for the Lulu Lake "A" Pool is 14%, and average permeability is 20 md. The average porosity for the Lulu Lake "B" Pool is 13%, and average permeability is 15 md. For the "Mountainside" Pool, porosities average 15% and permeabilities average 31 md. Estimated ultimate recoverable reserves for Lulu Lake "A" Pool, "B" Pool and "Mountainside" Pool are 42 809 m^3, 15 148 m^3 and 7 670 m^3 of oil, respectively. As of December 31, 1985, Lulu Lake "A" Pool had produced 38 727 m^3 of oil, Lulu Lake "B" Pool 7 180 m^3 and "Mountainside" Pool 6 520 m^3 oil.

Future Potential

Based on reservoir engineering and geologic data it appears that there is limited future development potential within the existing Pools in the study area. However, production may be obtained from other, as yet undiscovered isolated "highs" occurring along the eastern edge of the Upper Whitewater Lake subcrop belt. These "highs" on the Mississippian erosional surface are identified by underlying subdued "highs" within lower Mississippian marker beds and are also reflected by thinning of the overlying Red Beds. Consideration for future exploration of these erosional "highs" should be directed northward towards the Whitewater Field, near the erosion edge of the Upper Whitewater Lake subcrop trend.

REFERENCES

Barchyn, D.
1982: Geology and hydrocarbon potential of the Lower Amaranth Formation Waskada - Pierson Area, Southwestern Manitoba: Manitoba Mineral Resources Division, Geological Report GR82-6.

Choquette, P.W. and Pray, L.C.
1970: Geologic nomenclature and classification of porosity in sedimentary carbonates: Bulletin of the American Association of Petroleum Geologists, v. 54, p. 207-250.

Dunham, R.J.
1962: Classification of carbonate rocks according to depositional texture: Bulletin of the American Association of Petroleum Geologists, p. 108-121.

McCabe, H.R.
1959: Mississippian stratigraphy of Manitoba: Manitoba Mines Branch Publication 58-1.

McCabe, H.R.
1963: Mississippian oil fields of southwestern Manitoba: Manitoba Mines Branch Publication 60-5.

Pettijohn, F.J.
1975: Sedimentary rocks: New York, Harper and Row.

Stanton, M.S.
1958: Stratigraphy of the Lodgepole Formation, Virden-Whitewater area. Manitoba: in Goodman, A.J., ed., Jurassic and Carboniferous of western Canada: Bulletin of the American Association of Petroleum Geologists, John Andrew Allan Memorial Volume, p. 372 - 350.

Young, H.R.
1973: Petrology of the Virden Member of the Lodgepole Formation (Mississippian) in southwestern Manitoba: Unpub. Ph.D. thesis, Queen's University, Kingston, Ontario.

Young, H.R., and Greggs, R.G.
1975: Diagenesis in Lodgepole limestones, southwestern Manitoba: Bulletin of Canadian Petroleum Geologists, v. 23, p. 201-223.

Zakus, P.D.
1967: The sedimentary petrology and stratigraphy of the Mississippian Whitewater Lake Member of southwestern Manitoba: Unpub. M. Sc. Thesis, University of Manitoba, Winnipeg, Manitoba.

APPENDIX: SELECTED CORE DESCRIPTIONS

Amerada Turtle Mtn. Prov.
16-4-1-20 WPM

Mississippian - Lodgepole Formation

Upper Virden Member

3233 - 3243 feet (985.4 - 988.5 m)	Crinoidal oolitic Packstone: poor intercrystalline porosity, shell fragments, stylolitic.

Cities Service Turtle Mountain
14-29-1-20 WPM

Mississippian - Lodgepole Formation

Upper Virden Member

3225-3226 feet (983 - 983.3 m)	Dolomite: buff, brachipod and shell fragments replaced by anhydrite; chalky.
3226 - 3232 feet (983.3 - 985 m)	Bioclastic Packstone: light grey-buff, silicified crinoid fragments, intergranular and moldic porosity.
3232 - 3239.5 feet (985 - 987.4 m)	Mudstone: light grey, chert and silica replacement of shell fragments throughout, argillaceous, calcareous.
3239.5 - 3240 feet (987.4 - 987.6 m)	Bioclastic Packstone: moldic porosity.
3240 - 3240.8 feet (987.6 - 987.8 m)	Shale: rust/maroon mottled, chert-replaced fossil fragments and intraclasts of chert, calcareous.

Lower Virden Member [3243 feet (988.5 m) - E-log]

3240.8 - 3245.7 feet (987.8 - 989.3m)	Wackestone: maroon/red, shell fragments replaced by silica, hematitic throughout, interbedded with grey calcareous shale, grades basally into crinoidal wackestone/packstone, grey-red mudstone at base.
3245.7 - 3248.6 feet (989.3 - 990 m)	as above

3248.6 - 3251.7 feet (990 - 991 m)	as above
3251.7 - 3260 feet (991 - 933.6 m)	as above; mudstone stylolitic
3260 - 3261 feet (993.6 - 994 m)	Wackestone: red/maroon mottled; brachiopod fragments replaced with silica.
3261 - 3262 feet (994 - 994.3 m)	Packstone: grey-buff, fossil fragments replaced by grey anhydrite.
3262 - 3268.5 feet (994.3 - 996.2 m)	Wackestone/Mudstone: grey - buff, red near base, replacement of fossil fragments by anhydrite, hematitic throughout, nodules of white chert throughout.
3268.5 - 3269.7 (996.2 - 996.6 m)	Interbedded shale (red) and Bioclastic Wackestone.

Scallion Member [3272 feet (997.3 m) - E-log]

3269.7 - 3271.2 feet (996.6 - 997 m)	Bioclastic Grainstone: crinoid, brachiopod fragments, chert nodules.
3271.2 - 3271.8 feet (997 - 997.2 m)	Mudstone/shale: red, horizontally laminated.
3271.8 - 3279 feet (997.2 - 999.4 m)	Interbedded shale (red) and Bioclastic Packstone: 3 cm intraclasts, chalky, shell fragments.

Northern Nellie Lake
3-17-1-21 WPM

Jurassic - Lower Amaranth ("Red Beds") Formation

3280 - 3322 feet (999.7 - 1012.5 m)	Siltstone: reddish brown, argillaceous, few clasts of white anhydrite (increasing basally).

Mississippian - Lodgepole Formation

Flossie Lake Member [3364 feet (1025 m) - E-log]

3322 - 3325 feet (1012.5-1013.5 m)	Dolomite: grey.
3325 - 3340 feet (1013.5-1018.0 m)	Skeletal, pelletal Wackestone/Packstone: brachiopod shells, oil-stained stylolitic, red shale stringer at base.

Golden Eagle
6-23-1-21-WPM

Jurassic - Lower Amaranth ("Red Beds") Formation

3320 - 3328 feet (1012 - 1014.4 m)	Siltstone: reddish brown, argillaceous, anhydrite inclusions (increasing basally)

Mississippian - Lodgepole Formation

Lower Whitewater Lake Member [3327 feet (1014 m) - E-log]

3328 - 3330 feet (1014.4 - 1015 m)	Dolomite: cream, dense, bioclastic
3330 - 3334 feet (1015 - 1016.2 m)	Bioclastic Wackestone/Packstone: shell fragments, trace anhydrite, microstylolites, pinpoint vuggy porosity, oil-stained throughout.
3334 - 3335 feet (1016.2 - 1016.5 m)	Shale: red, fossiliferous, horizontally laminated, fractures.
3335 - 3362 feet (1016.5 - 1024.7 m)	Oolitic Packstone/Grainstone: red, fragmental, lithoclasts 1.5 mm - 4.0 mm, (1/20"-1") anhydrite infilling, secondary porosity.

Upper Virden Member [3362 feet (1024.7 m) - E-log]

3362 - 3370 feet (1024.7 - 1027 m)	Bioclastic, oolitic Packstone/Grainstone: lithoclastic, stylolitic, horizontal fracturing, increasing oolite content with depth.

Andex Lulu Lake Prov.
8-23-1-21 WPM

Mississippain - Lodgepole Formation

Upper Whitewater Lake Member

1012 - 1015.3 m	Dolomite: brown, sucrosic, good intercrystalline porosity, elongate lithoclasts (≪8 mm), oil-stained throughout.
1015.3 - 1016.6 m	Bioclastic Wackestone
1016.6 - 1019.5 m	Bioclastic Wackestone grading into Bioclastic Packstone/Grainstone: grey, horizontally fractured, vuggy, moldic porosity, some oil staining.

Lower Whitewater Lake Member (1018 m – E-log)

1019.5 – 1021.3 m	Shale (red) interbedded with skeletal Packstone: preserved sponge or coral present.
1021.3 – 1025.5 m	Oolitic, crinoidal Packstone/Grainstone: red, stylolitic, vertical fracturing in-filled with pyrite.
1025.5 – 1026.2 m	Interbedded Shale and skeletal Packstone: red, mottled.

Upper Virden Member (1027 m – E-log)

1026.2 – 1030 m	Crinoidal Packstone/Grainstone: large vuggy porosity, silica in-filling, oil-stained, grades into oolitic, crinoidal Grainstone: reddish chert replacement, interbedded with calcareous skeletal wackestone and red shale.

Andex Roxy Lulu Lake Prov.
15-27-1-21 WPM

Mississippain – Lodgepole Formation

Upper Whitewater Lake Member (1005.5 m – E-log)

1005 – 1010.5 m	Oolitic Packstone interbedded with fragmental Limestone: grey, tight streaks interbedded with bands of good intergranular porosity, oil-stained.
1010.5 – 1013 m	Bioclastic Packstone: crinoid and brachiopod fragments, good vuggy porosity.

Lower Whitewater Lake Member (1013 m – E-log)

1013 – 1013.8 m	Interbedded skeletal Wackestone and Shale (red): brachiopod and shell fragments.
1013.8 – 1015 m	Skeletal Packstone: moldic porosity, some vuggy porosity sporadic oil staining.
1015 – 1023 m	Interbedded Shale (red) and oolitic Packstone/Grainstone: horizontally laminated, bioturbated, crinoid, brachiopod and bryozoan fragments.

Royalite Turtle Mtn. Prov.
4-36-1-21 WPM

Mississippian - Lodgepole Formation

Lower Whitewater Lake Member

3279 - 3282.5 feet (999.4 - 1000.5 m)	Bioclastic Packstone: dolomite 3279' - 3280' (999.4 - 999.7 m), vertically and horizontally fractured, in-filled by anhydrite, poor porosity.
3282.5 - 3285.75 feet (1000.5 - 1001.5 m)	Shale: red, non-calcareous
3285.75 - 3286.75 feet (1001.5 - 1001.8 m)	Bioclastic pelletal Packstone: vuggy porosity near base, grades into red mudstone/shale near base.
3286.75 - 3298 feet (1001.8 - 1005.2 m)	Interbedded Shale (red) and Wackestone.
3298 - 3305 feet (1005.2 - 1007.4 m)	Oolitic Grainstone.
3305 - 3309.5 feet (1007.4 - 1008.7 m)	Interbedded Wackestone and lime Mudstone: horizontal laminations

Upper Virden Member [3308 feet (1008 m) - E-log]

3309.5 - 3313 feet (1008.7 - 1010 m)	Bioclastic Wackestone: more oolitic near base.
3313 - 3318 feet (1010 - 1011.3 m)	Oolitic Grainstone: chalk break at base of unit.
3318 - 3323.5 feet (1011.3 - 1013 m)	Skeletal Packstone: chalk break at base of unit (6").
3323.5 - 3328 feet (1013-1014.4 m)	Lime Mudstone.
3328 - 3339 feet (1014.4 - 1017.7 m)	Bioclastic, Oolitic Wackestone/Packstone.

Chevron Max Lake
4-7-2-20 WPM

Mississippian - Lodgepole Formation

Lower Virden Member

3110 - 3136 feet (948 - 956 m)	Mudstone: red/green interbedded, chert replaced fossil fragments, chert nodules.

(note: first 25 feet of core missing)

Scallion Member [3135 feet (955.5 m)- E-log]

3136 -3170 feet (956 - 966.2 m)	Argillaceous Limestone: reddish, grey-pink, abundant white gypsum or anhydrite?, fossiliferous, thinly bedded with skeletal packstone.
3170 - 3196 feet (966.2 - 974.1 m)	Mudstone: dense, anhydrite lamination

Roxy et al Mountainside
13-16-2-21 WPM

Mississippian - Lodgepole Formation

Upper Whitewater Lake Member

894 - 894.8 m	Anhydrite: grey/blue.
894.8-895.3 m	Bioclastic Packstone.
895.3 - 896 m	Lime Mudstone.
896 - 906.0 m	Bioclastic Packstone/Grainstone: shell fragments partially silica-replaced, some stylolites, interbedded oil-stained beds, becoming more oil-stained towards base, good vuggy and intergranular porosity near base.

Lower Whitewater Lake Member (907 m - E-log)

906 - 906.3 m	Mudstone/Wackestone: grey, brachiopod fragments.
906.3 - 912 m	Oolitic Packstone: hematitic, laminated, stylolitic, fair vuggy porosity, some shell fragments.

Clarion et al Hazeldean
14-17-2-22 WPM

Mississippian - Lodgepole Formation

Lower Whitewater Lake Member

951 - 951.5 m	Oolitic Grainstone: dolomitic, buff-tan, some intergranular porosity.
951.5 - 953 m	Interbedded Shale: red/green, chert fragment (1 cm), horizontally laminated, abundant shell fragments.

Upper Virden Member (954.3 m - E-log)

953 - 956.6 m	Bioclastic oolitic Packstone: pelletal, some ooids, thin band of chalk near top of unit, interbed of green/red calcareous shale (953.3 - 953.5 m).
956.6 - 958 m	Interbedded Shale: red/green; calcareous, iron-stained, thin concentrated bioclastic units throughout.
958 - 959.9 m	Wackestone grading to Packstone: argillaceous thin horizontal (2 mm) bands of chalk, white chert nodules (1 cm), some horizontal fracturing, grey-white anhydrite (959.5 - 959.8 m) band.

Lower Virden Member (963 m - E-log)

960.2 - 961.2 m	Bedded Mudstone: red/green, abundant white chert hematitic, abundant silicified shell fragments, dark green shale with chert fragments in upper portion of unit.
961.2 - 961.7 m	Bioclastic Packstone/Grainstone: thin chalk band in middle of unit.
961.7 - 964 m	Shale: red/green, bioclastic grainstone interbedding (green), abundant shell fragments, abundant chert, thin laminae (plant debris), irregular chalk clasts.