CHAPTER 4 – WOODBEND GROUP

RESERVOIRS

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INTRODUCTION

The stratigraphy and the geological history of the Woodbend Gp (Fig. 4.1) are described in the Introduction to this Atlas. It is therein noted that the Woodbend Gp consists principally of carbonates and shales, with the carbonates, typically of organic origin, forming the reservoir facies whereas, the shales, generally basinal infill, are primary source rocks. Evaporites are locally interbedded with the carbonates (Klovan, 1964; Mountjoy, 1980; Stoakes, 1980; Stoakes and Wendte, 1987).

There are three principal reservoir units within the Woodbend Gp: 1) the Leduc Fm 2) Grossmont Fm and 3) Camrose Mbr of the Ireton Fm (Fig. 4.1). Economically the Leduc Fm is the most significant of the three units with initial recoverable reserves

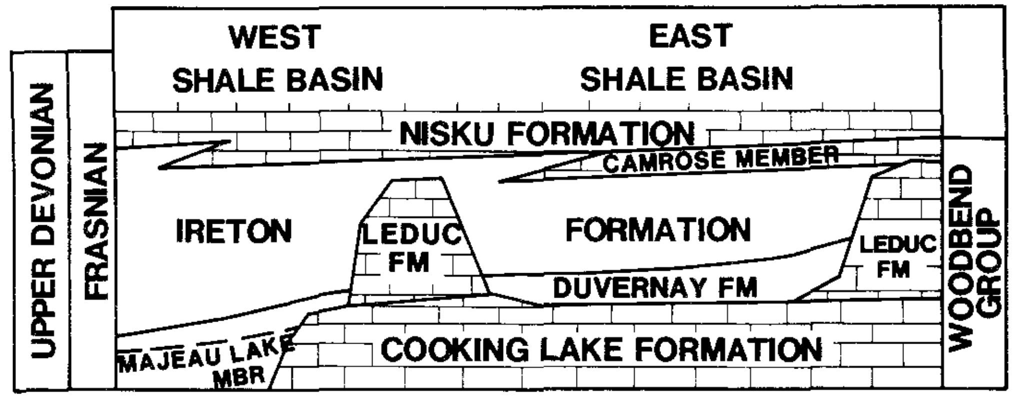

Figure 4.1. Stratigraphy of the Woodbend Gp of central Alberta (Stoakes, 1980).

estimated to be 490 x 10^6 m^3 of oil and 240 x 10^9 m^3 of gas. All of the example seismic lines incorporated into this chapter cross Leduc Fm reservoirs.

The Leduc Fm developed as fringing reef complexes, linear chains of reefs, isolated atolls and isolated pinnacles (Fig. 4.2). In the subsurface of central Alberta these build-ups overlie a regional platform facies, the Cooking Lake Fm, whereas in the Sturgeon Lake area, they rest on the Beaverhill Lake Gp. The Leduc Fm in central Alberta is typically encased and sealed by impermeable shales of the Duvernay and Ireton formations. In contrast the reefs to the northeast are capped by and in communication with Grossmont Fm carbonates. As a result of differential compaction of reef and off-reef facies, overlying strata typically drape across Leduc Fm build-ups. Drape is a function of the height of the reef, the thickness of the overlying sedimentary section and the relative compactibilities of the reef and off-reef facies.

Leduc Fm reservoirs generally develop within the up-dip edges of both the fringing reef complexes and the larger atolls and throughout the smaller atolls and the pinnacles. Whether these are stratigraphic traps or a combination stratigraphic and structural trap is arguable. Indeed isolated reefs (pinnacles and atolls) are encased in impermeable shale seals and could form traps regardless of the sense of regional dip. In contrast, reservoirs within the fringing reef complexes are generally confined to the up-dip edges of these build-ups and hence have a structural component. Within both the isolated and fringing reef reservoir examples, the distribution of hydrocarbons is influenced by post-depositional structure (due to both differential compaction and basin subsidence) however, the authors prefer to classify the pinnacles and atolls as stratigraphic traps and the fringing reefs generally as combination structural and stratigraphic traps.

The seven Leduc Fm reservoirs analyzed in this chapter are geographically and morphologically diverse. Included are reservoirs within fringing reef complexes (Penhold), atolls (Redwater, Obed, Sturgeon Lake, Leduc-Woodbend), pinnacles (Rich, Leduc-Woodbend) and reefs (Sturgeon Lake, Morinville/St. Albert-Big Lake). These build-ups are distributed throughout southcentral and westcentral Alberta. Sediments of the Alberta basin dip to the southwest and consequently, post-reef strata in the examples range from a minimum thickness of 950 m at Redwater to a maximum thickness of 4000 m at Obed. As expected, both the depth of burial and the lithology of the encompassing shales profoundly affect the morphology of the reef and the adjacent sedimentary section, specifically with respect to the magnitude of differential compaction and the resultant drape.

The Leduc Fm examples are morphologically diverse and consequently their seismic signatures are diverse. Time-structural drape, velocity pull-up and the contrast between the seismic images of the reef and the off-reef shales are characteristically associated with the seismic signatures of the Leduc Fm. In the suite of the Leduc Fm reef examples it will be shown that the Wabamun event drapes by as little as 5 ms (Rich Field) and by as much as 20 ms (Penhold Field); the Beaverhill Lake event is pulled up by as little as 10 ms (Morinville/St. Albert-Big Lake) and by as much as 40 ms (Leduc-Woodbend) and that the seismic images of the Leduc Fm and the Ireton Fm contrast sharply on some of the examples (Leduc-Woodbend) but are difficult to differentiate elsewhere (Morinville/St. Albert-Big Lake). These data are more thoroughly discussed within the interpretations of the specific examples.

PENHOLD FIELD

INTRODUCTION

Penhold field is located in the southern part of the east Ireton shale basin, along the western margin of the Bashaw complex, a northern extension of the southern Alberta shelf (Fig. 4.2). The field is divided into 14 assigned and unassigned pools (Table 4.1), six of which are in the Penhold field area (Fig. 4.3, Tables 4.1 and 4.2). Two of these six pools, D-3A and D-2A are Devonian reservoirs (Leduc Fm and Nisku Fm respectively). The other four, the Lower

ACKNOWLEDGEMENTS

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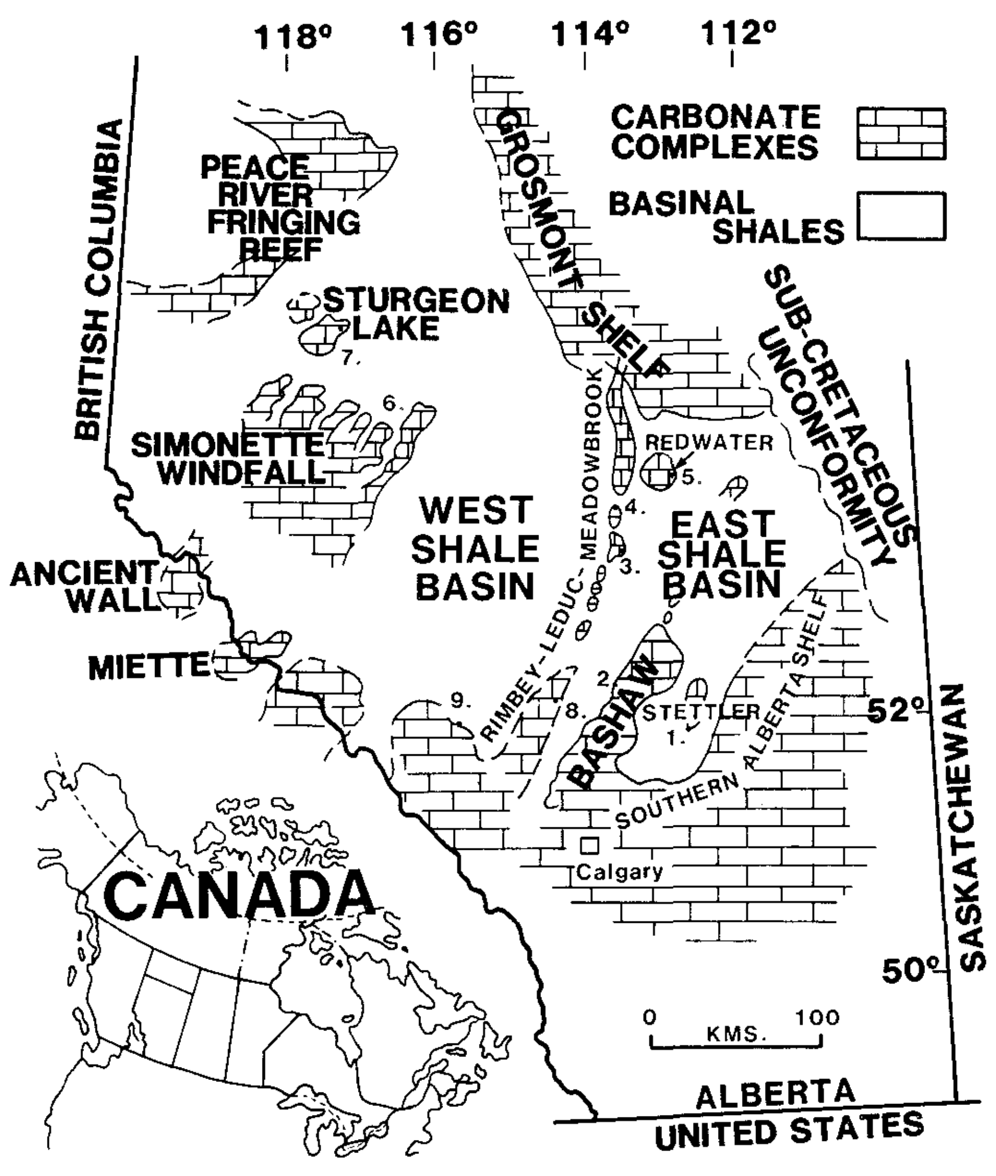

1. Rich
2. Penhold
3. Leduc Woodbend
4. Morinville
5. Redwater
6. Obed
7. South Sturgeon
8. Lanaway/Garrington
9. Ricinus

Figure 4.2. Distribution of the Woodbend Gp carbonate complexes (modified after Stoakes, 1980).

Mannville A, Lower Mannville B, Viking C and Viking D are Cretaceous reservoirs. The Leduc Fm, Nisku Fm and Viking Fm pools are more or less situated above the western margin of the Bashaw complex, whereas the Ellerslie Fm pools (Lower Mannville) are basinward (Fig. 4.3). All of these reservoirs are strongly influenced by the differential compaction of reef and off-reef sediment. For example, the Leduc Fm, Nisku Fm and Viking Fm pools are structurally closed across the reef rim whereas the fluvial sandstones of the Ellerslie Fm were preferentially deposited immediately to the west (basinward). Apparently, relief along the Pre-Cretaceous unconformity, during Lower Mannville time, reflected drape along underlying strata. This concept is illustrated in Figure 4.4.

Table 4.1. Production data for the six assigned pools in the Penhold study area

FIELD	POOL	PRODUCING ZONE	NUMBER OF WELLS	CUMULATIVE PRODUCTION Oil (m^3)	Gas (E^3 m^3)	Water (m^3)
Penhold	D-3A	Leduc	1	3,383.7	2,173.5	1,761.1
Penhold	D-2A	Nisku	3	10,079.3	4,211.0	3,798.0
Penhold	Lower Mannville A	Ellerslie	3	52,596.5	49,811.3	42.6
Penhold	Lower Mannville B	Ellerslie	3	56.3	347,438.4	1,255.6
Penhold	Viking C	Viking	1	20.1	4.6	62.9
Penhold	Viking D	Viking	1	365.9	64.6	0.0

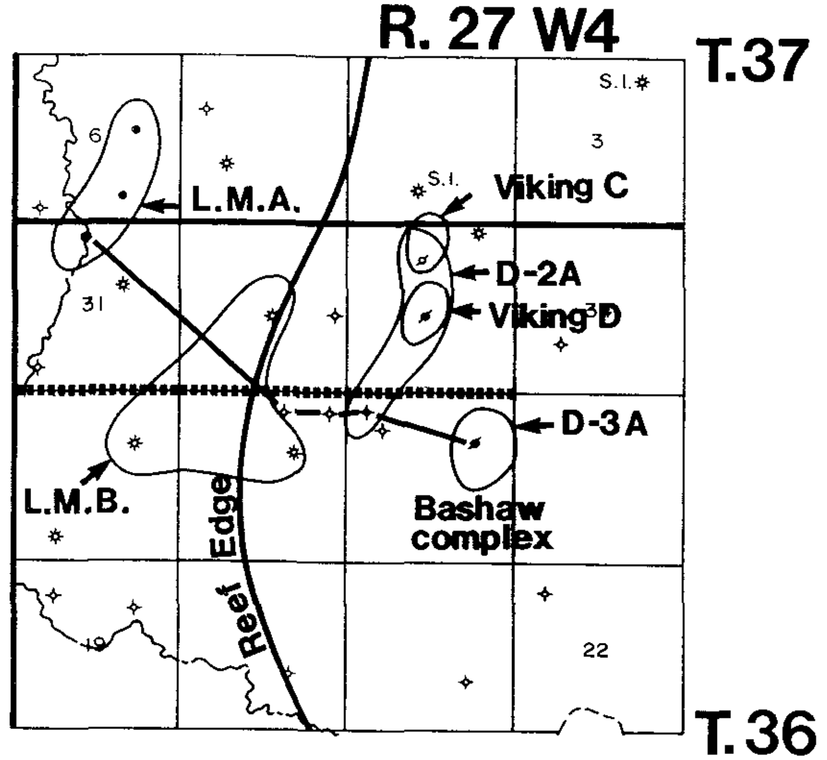

Figure 4.3. Penhold study area. Pool outlines, the four wells incorporated into the geological cross-section and the approximate location of the seismic line are shown (L.M.A. - Lower Mannville A pool; L.M.B. - Lower Mannville B pool).

Table 4.2. Production data for the Penhold area

WELL	FIELD	POOL	PRODUCING ZONE	PRODUCTION DATE	CUMULATIVE PRODUCTION Oil (m3)	Gas (E3 m3)	Water (m3)
9-28-36-27W4	Penhold	D-3A	Leduc	11/68	3,383.7	2,173.5	1,761.1
13-28-36-27W4	Penhold	D-2A	Nisku	07/61	7,321.0	3,640.1	6.4
10-29-36-27W4	Penhold	Lower Mannville B	Ellerslie	02/78	0.0	180,606.7	723.7
10-30-36-27W4	Penhold	Lower Mannville B	Ellerslie	11/73	56.3	139,585.2	420.1
14-31-36-27W4	Penhold	Lower Mannville A	Ellerslie	04/60	30,626.8	23,534.5	0.8
7-32-36-27W4	Penhold	Lower Mannville B	Ellerslie	09/83	0.0	27,246.5	111.8
6-33-36-27W4	Penhold	D-2A	Nisku	01/83	2,377.9	505.7	3,547.9
6-33-36-27W4	Penhold	Viking D	Viking	09/84	365.9	64.6	0.0
14-33-36-27W4	Penhold	D-2A	Nisku	04/83	380.4	65.2	243.7
14-33-36-27W4	Penhold	Viking C	Viking	02/84	20.1	4.6	62.9
2-6-37-27W4	Penhold	Lower Mannville A	Ellerslie	03/74	19,830.3	22,604.6	9.1
10-6-37-27W4	Penhold	Lower Mannville A	Ellerslie	02/83	2,139.4	3,672.2	32.7

The Leduc Fm in the Penhold field area (Fig. 4.5) is herein differentiated into full reef and basinal carbonate. The full reef towers some 250 m above the platform facies and is easily distinguished from off-reef shales on the basis of seismic image, velocity pull-up and drape. In contrast, without well control the basinal carbonates could be misinterpreted as either Duvernay Fm or lower Ireton Fm shales.

Penhold field was selected as an example Woodbend Gp reservoir for two reasons:

1) The Leduc Fm, D-3A pool illustrates that reservoirs within the fringing reef complexes are not restricted to the main up-dip edges; and

2) The D-3A, D-2A, Lower Mannville and Viking pools illustrate that structural and/or stratigraphic traps can form within Leduc Fm and/or post-Leduc Fm strata as a result of differential compaction of reef and off-reef sediments.

GEOLOGICAL CROSS-SECTION

The locations of the four wells incorporated into the geological cross-section (Fig. 4.5) and the example seismic line (Fig. 4.6) are superimposed, in Figure 4.3. Three of these wells are within 200 m of the seismic line, whereas the fourth (14-31), lies about one kilometre to the north. Such extrapolation is necessary for interpretative and illustrative purposes as this well is the deepest test in the study area. Note that none of these wells penetrated the Cooking Lake Fm and that the depth and slope of this formation (Fig. 4.5) is estimated from seismic and regional well-log control.

Three of the wells on the geological cross-section were drilled either into or above the Bashaw complex, herein referred to as full reef. This complex is typical of Leduc Fm build-ups in the east

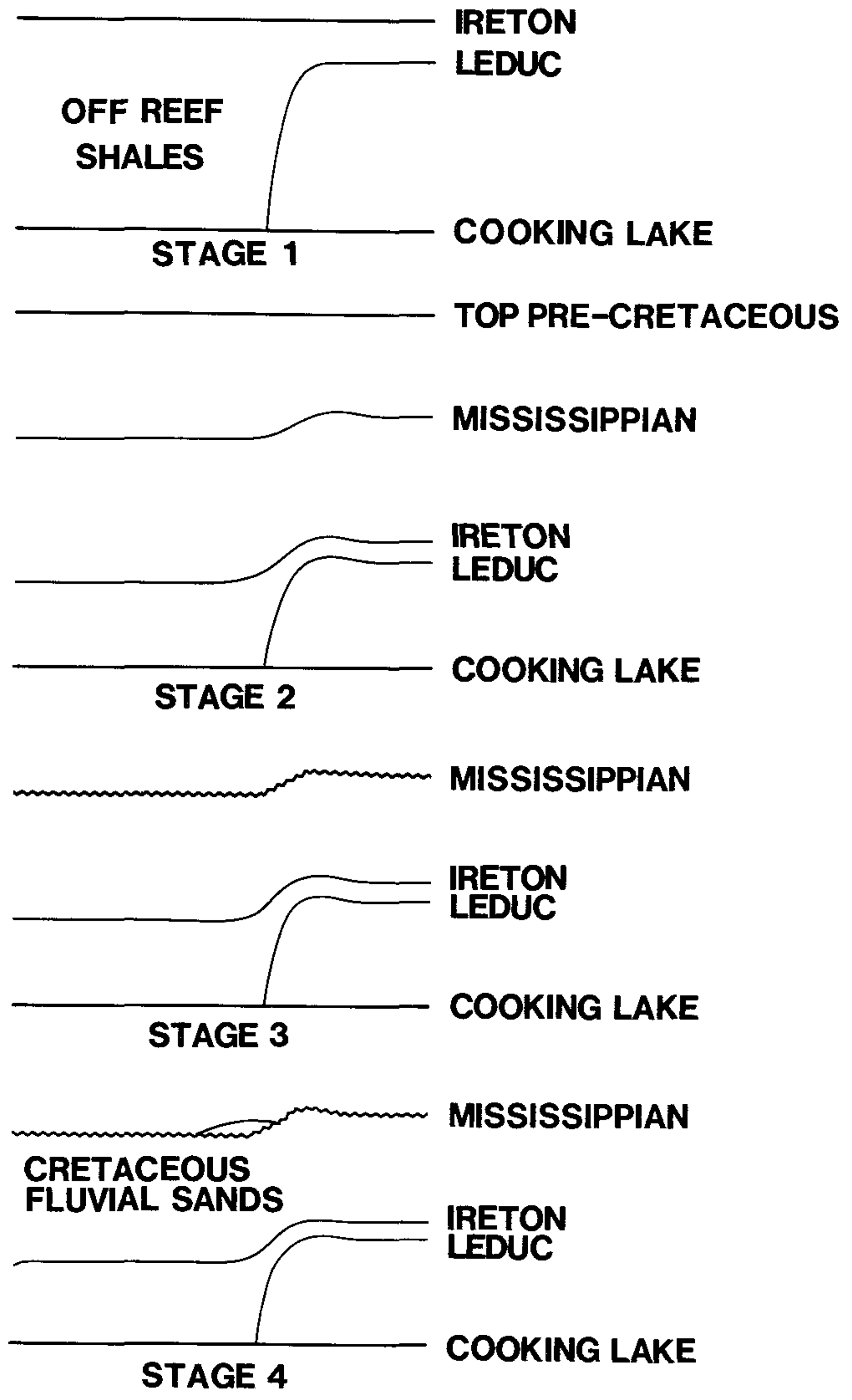

Figure 4.4. Structure at the Mississippian level, due to differential compaction, has influenced both erosion during the pre-Cretaceous and sedimentation during the early Cretaceous.

Ireton shale basin, standing some 250 m above the Cooking Lake Fm, resting directly on this platform facies and exhibiting a raised rim (Fig. 4.5). In contrast the Leduc Fm penetrated by the 14-31 well and herein referred to as basinal carbonate is atypical. These sediments, are relatively thin (about 60 m) and overlie some 45 m of Duvernay Fm (an estimate obtained from the 1-27-36-28 W4M well). Generally the Leduc Fm directly overlies the Cooking Lake Fm (Fig. 4.1). These basinal carbonates could represent either an early stage of reef growth or alternatively detritus from the Bashaw complex.

The contoured values on the structure map of Figure 4.7, represent the top of the full reef, where present, and the top of the basinal carbonates elsewhere. The single well, Leduc Fm, D-3A pool (9-28-36-27 W4M), is situated where the raised rim of the Bashaw complex is locally closed, presumably as a result of differential compaction within the reef.

The Leduc Fm is overlain by Ireton Fm shale, the top of which was probably more or less planar at the time of deposition. As a result of differential compaction, this horizon is up to 75 m higher

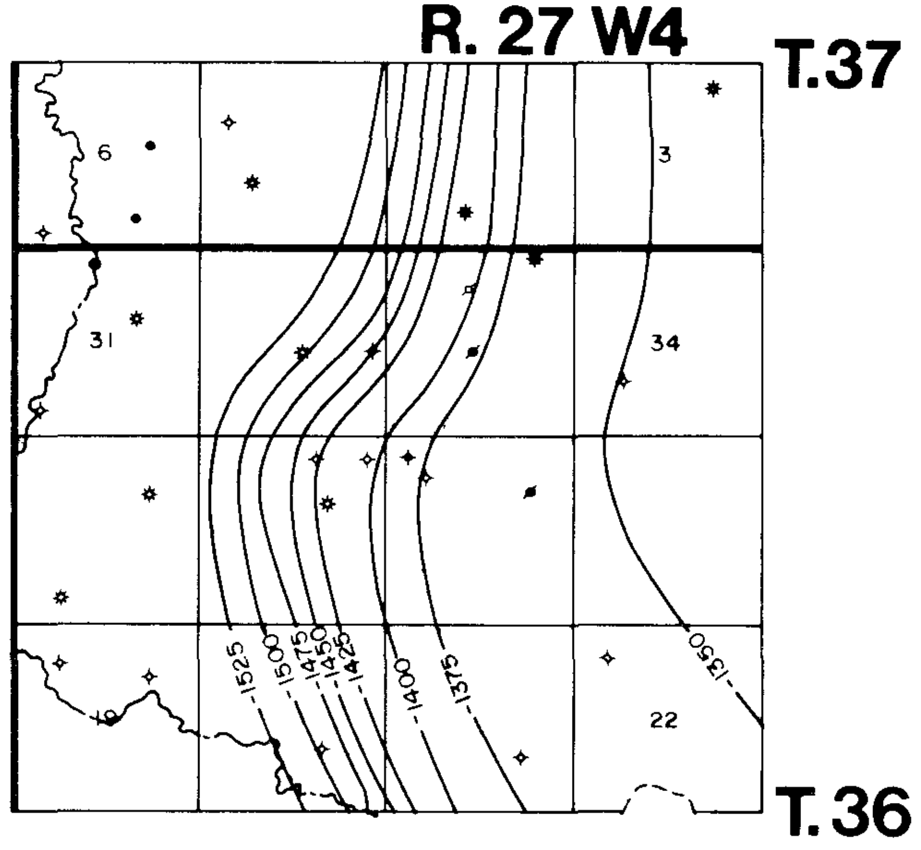

Figure 4.7. Contour map (in metres relative to mean sea level) of the Leduc Fm top.

across full reef than above the basinal carbonate. The Wabamun Gp and Mississippian (pre-Cretaceous unconformity) horizons are similarly about 60 m and 50 m, respectively, higher above the Bashaw complex (Figs. 4.8 and 4.9). It is significant to note that the tops of the Wabamun Gp and the Mississippian are approximately parallel implying that erosion during the pre-Cretaceous was strongly influenced by pre-existing (compaction induced) structure. Drape at the Lea Park Fm is about 30 m (Fig. 4.10).

As noted previously, the Nisku D-2A pool and the Viking C and D pools (Fig. 4.3) are all located along and structurally closed across the rim of the Bashaw complex. Closure is attributed to differential compaction of reef and off-reef sediment. In contrast, the Ellerslie Fm reservoirs (Mannville A and B pools) are basinward of the full reef suggesting that the early Cretaceous drainage system, in which these fluvial sediments were deposited, was strongly influenced by pre-existing drape within Mississippian strata (Fig. 4.4).

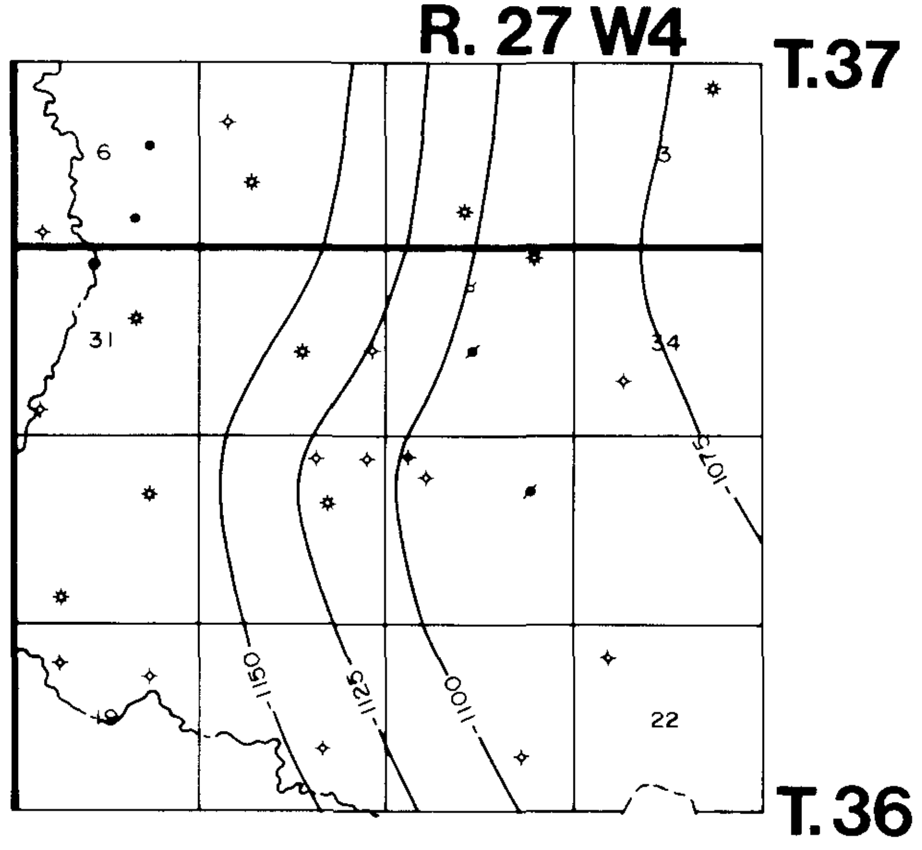

Figure 4.8. Contour map (in metres relative to mean sea level) of the Wabamun Gp top.

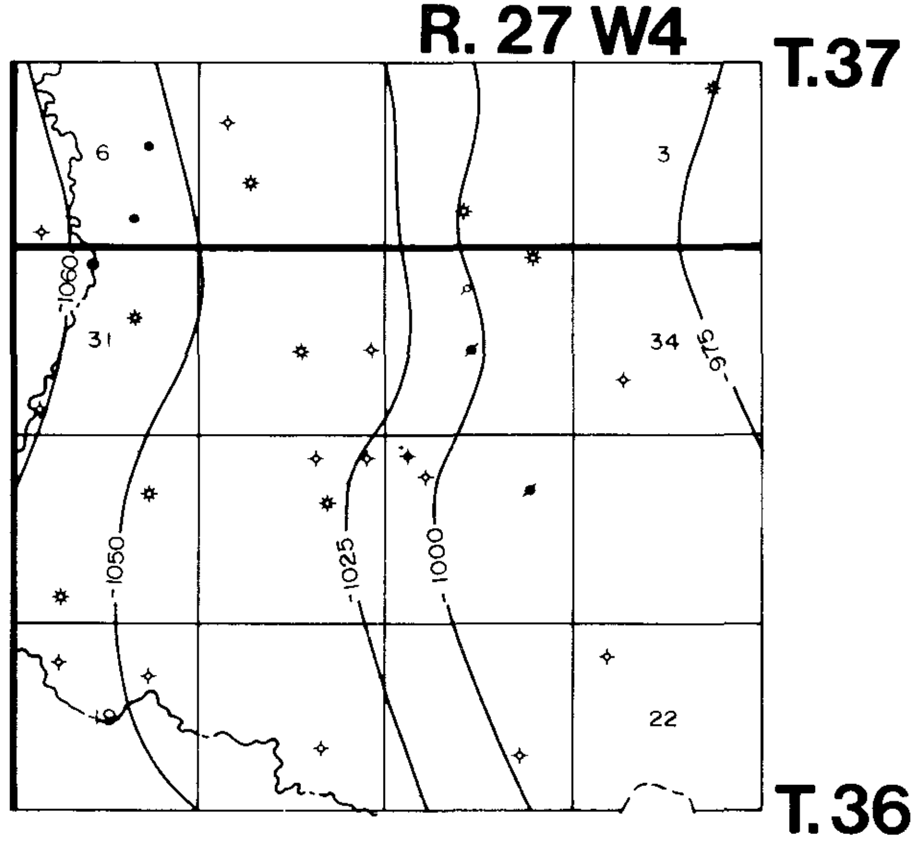

Figure 4.9. Contour map (in metres relative to mean sea level) of the Mississippian top.

SEISMIC SECTION

The example seismic section (Fig. 4.6) crosses the western rim of the Bashaw complex and extends into the east Ireton shale basin. These data were acquired using a dynamite source (single charges of 4 kg at 18 m depth), a 2145 m split spread, 90 m shot spacing and a 30 m group interval.

In Figures 4.11 and 4.12, a full-reef (9-28-36-27 W4M) seismogram and a synthetic seismic section respectively, are presented as interpretational aids. Note that the deepest reflection identified on the example seismic section, the Cooking Lake event, is not penetrated by any of the wells in the area and that this reflection was confidently identified from more regional well-log and seismic control. This event is as much as 20 ms higher beneath full reef than basinal carbonate and more or less parallel to underlying reflections suggesting that this observed relief is pull-up, due to lateral variations in the thicknesses of overlying sediment. This event is

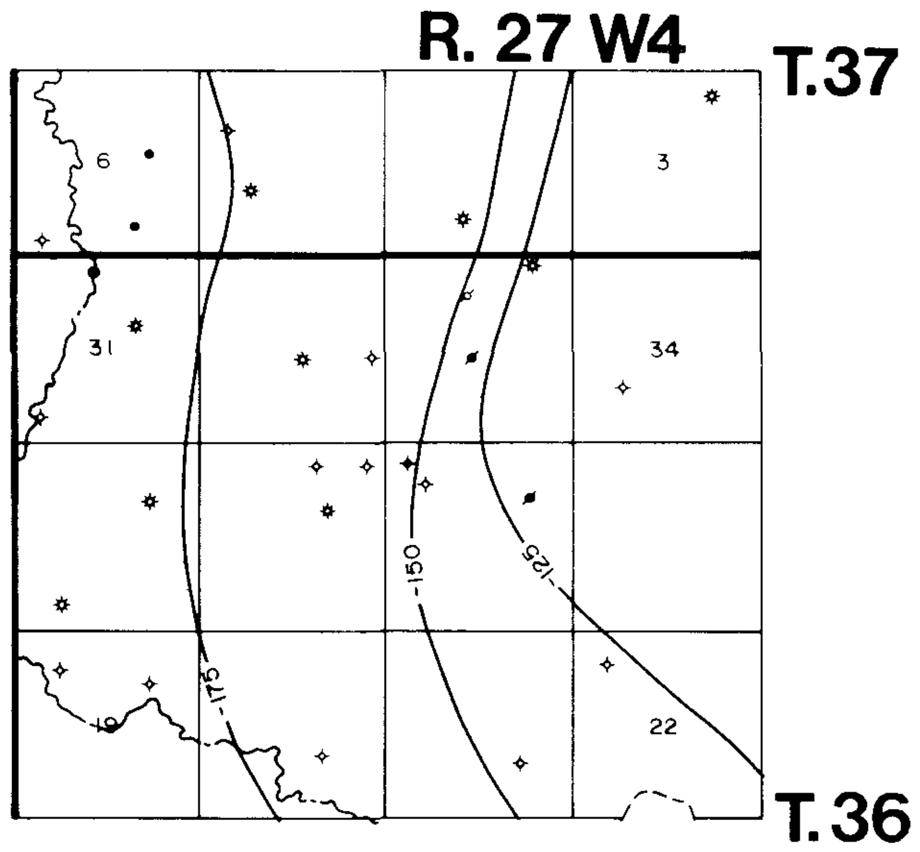

Figure 4.10. Contour map (in metres relative to mean sea level) of the Lea Park Fm top.

variably low- to moderate-amplitude and laterally continuous across the seismic section.

The Cooking Lake Fm, basinward of the Bashaw complex, is overlain by about 45 m of Duvernay Fm. Although the Cooking Lake reflection is continuous across the seismic line, the Duvernay event terminates abruptly against the flank of the seismic image of the reef, suggesting that the Innisfail complex rests directly on the Cooking Lake Fm.

The Leduc Fm on the seismic section can be differentiated into reef and basinal carbonate. The seismic image of the reef consists of laterally discontinuous, low-amplitude reflections bounded by the moderate-amplitude Leduc event and the variably low- to moderate-amplitude Cooking Lake event. In contrast the seismic image of the basinal carbonates is dominated by the moderate-amplitude Leduc and Duvernay events. Any internal reflection pattern is effectively masked by these two closely spaced events. The Duvernay reflection

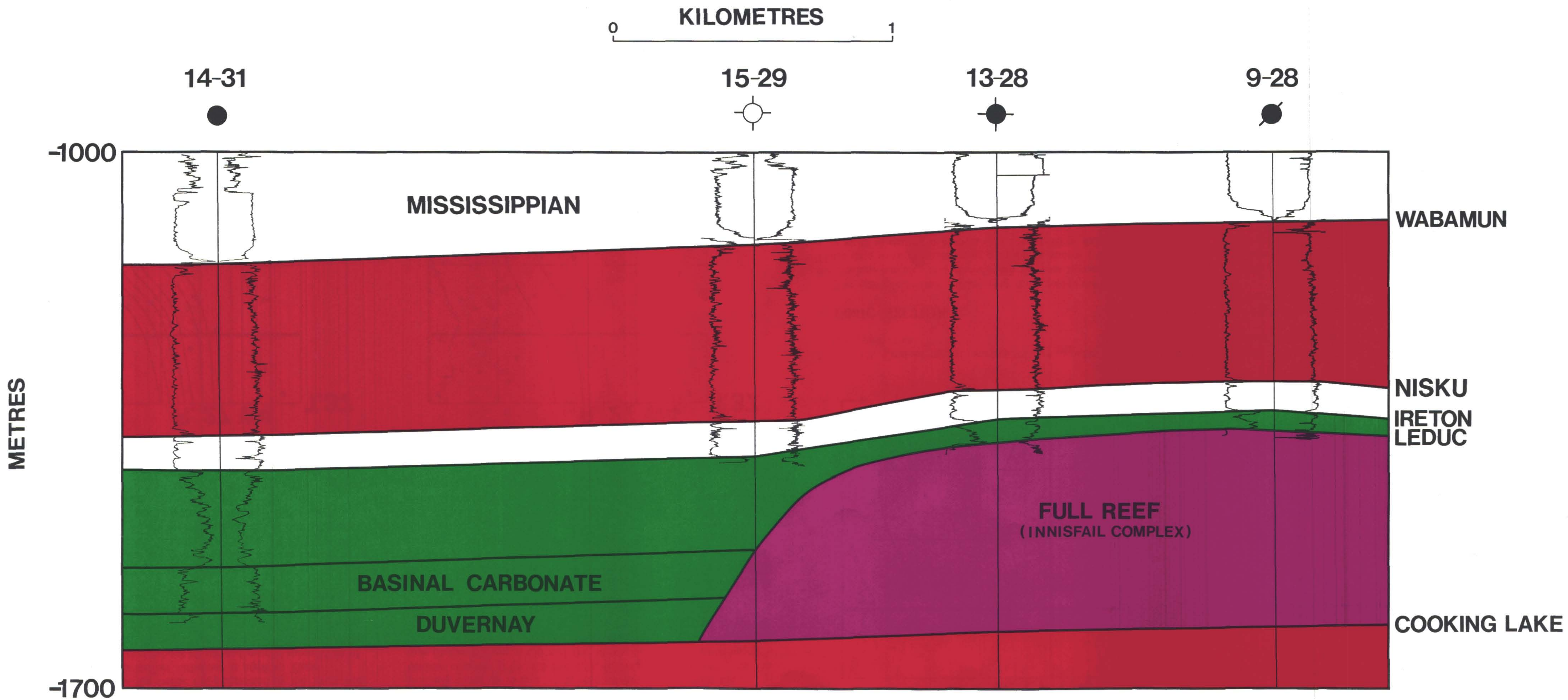

Figure 4.5. Geological cross-section, Penhold study area.

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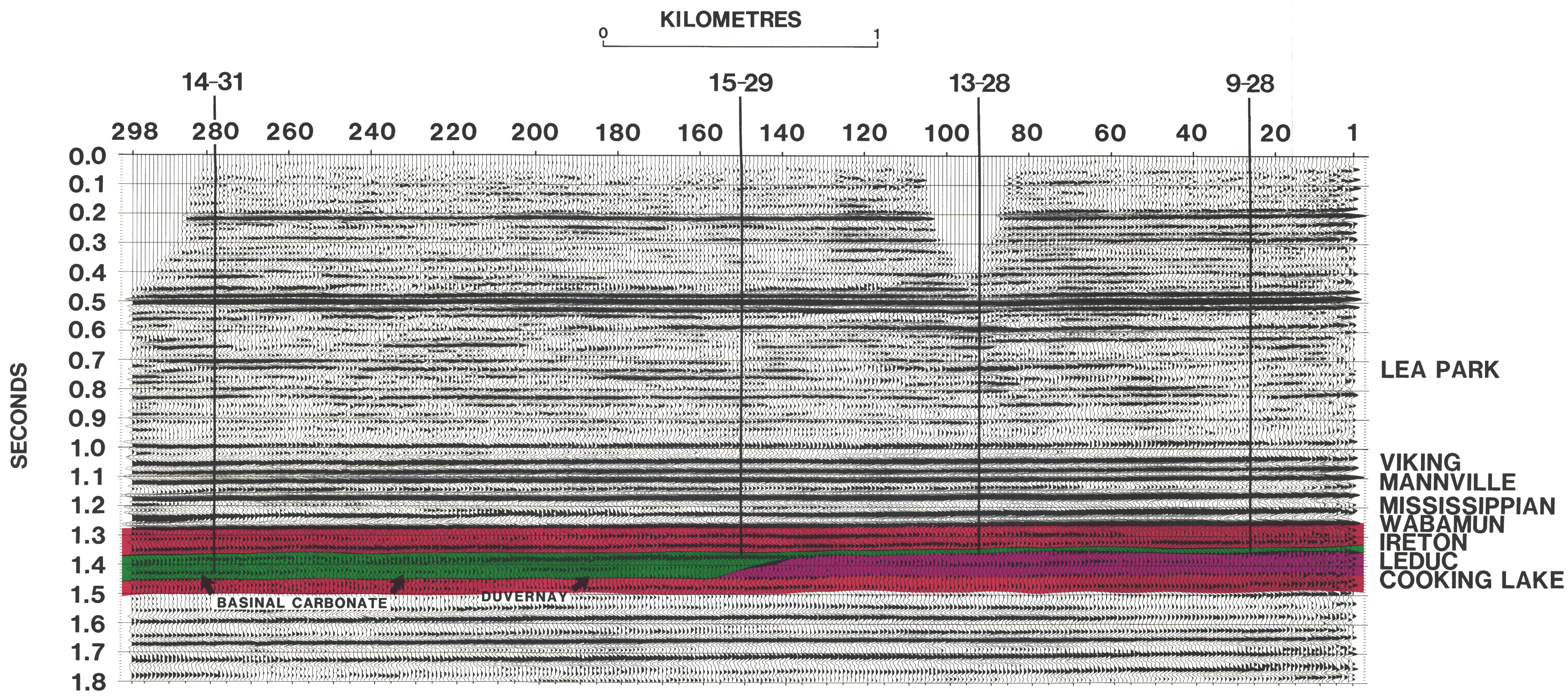


Figure 4.6. Normal polarity seismic section, Penhold study area.

DONOR: COREXCANA LTD.

PROCESSOR: GEOPHYSICAL SERVICE INCORPORATED

AUTHOR: N. ANDERSON

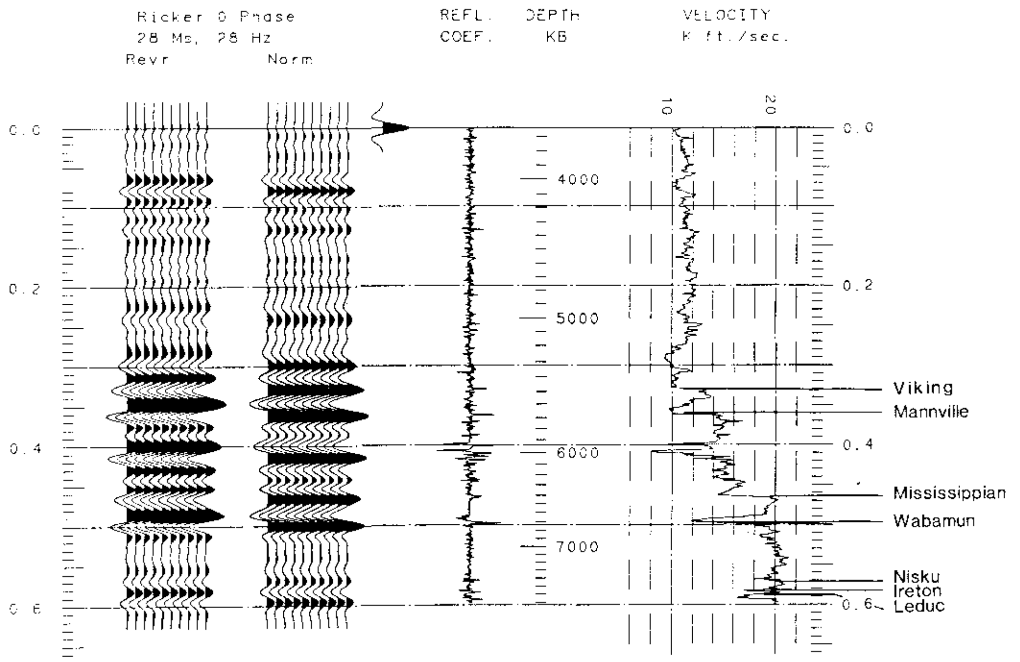


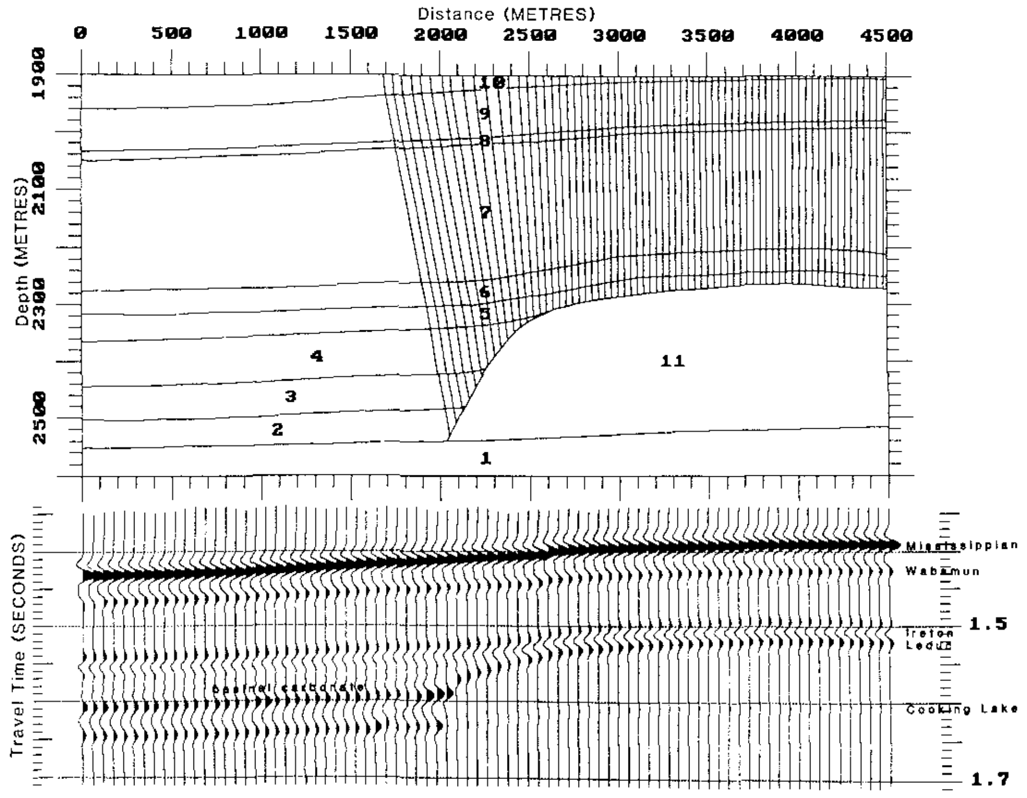
Figure 4.11. Seismogram for the 9-28-36-27W4M full reef well.

terminates abruptly against the flank of the seismic image of the reef, whereas, the basinal carbonate event appears to merge with the reflection from the top of the reef.

The seismic image of the overlying Ireton Fm in basinal locations is easily distinguished from that of the reef and consists of low- to high-amplitude, laterally continuous reflections bounded by the moderate-amplitude Ireton and Leduc Fm (basinal carbonate) events. In contrast, without well-log control, the basinal carbonates would be difficult to delineate on seismic data as their signature is similar to that of lower Ireton Fm shales.

The Ireton event, (Fig 4.6) is up to 30 ms higher above the reef than above the basinal carbonate. The Wabamun, Mississippian and Mannville events are similarly about 20 ms, 15 ms and 10 ms respectively higher above the Bashaw complex. The Mannville/ Mississippian, Mississippian/Wabamun and Wabamun/Ireton intervals are relatively constant above the reef, uniformly divergent across the edge of the complex and relatively constant above the basinal carbonate.

Average sonic-log interval velocities are presented, in Table 4.3, for four wells within the study area, all of which are within 400 m of the example seismic line. Note that these velocities differ by between



	Velocity (m/s)	Density (kg/m³)		Velocity (m/s)	Density (kg/m³)
(1) Cooking Lake	6000 6000	2750 2750	(2) Duvernay	5400 5400	2650 2650
(3) Basinal carbonate	5600 5600	2750 2750	(4) Shale	4800 4800	2650 2650
(5) Ireton	5200 5200	2650 2650	(6) Nisku	6100 6100	2750 2750
(7) Wabamun	5800 5800	2750 2750	(8) Exshaw	4900 4900	2650 2650
(9) Mississippian	5600 5600	2750 2750	(10) Cretaceous	3100 3100	2650 2650
(11) Leduc	5800 5800	2750 2750			

Figure 4.12. Synthetic seismic section generated from the geological cross-section (Fig. 4.5) using a zero-phase, normal polarity, 30-Hz, Ricker wavelet.

10% and 15%. Table 4.3, also presents average seismic interval velocities for the seismic line/well-log tie points. Note that the seismic velocities vary by less than 5%. Compare the two sets of average interval velocities. Although well-log and acoustic horizons are probably slightly different significant conclusions can certainly be drawn. Specifically the 10% to 15% variation in the sonic-log average interval velocities is indicative of the inherent error of

Table 4.3. A comparison of sonic-log and seismic velocities in the Penhold area (Anderson et al, 1988b)

Geological Interval	Mannville/ Mississippian	Mississippian/ Wabamun	Wabamun/ Ireton
Interval velocity (m/s) 9-28-36-27W4M	3550	4725	5525
Interval velocity (m/s) 13-28-36-27W4M	4150	5375	6000
Interval velocity (m/s) 15-29-36-27W4M	4125	5450	5975
Interval velocity (m/s) 16-29-36-27W4M	4175	5550	6150
Interval velocity (m/s) Trace 26 9-28 tie point	3925	4975	6000
Interval velocity (m/s) Trace 92 13-28 tie point	3925	5050	5950
Interval velocity (m/s) Trace 150 15-29 tie point	3950	5100	6150
Interval velocity (m/s) Trace 120 16-29 tie point	3950	5025	5900

absolute sonic-log measurements on early vintage well-logs (Anderson et al., 1988a, 1988b).

LEDUC-WOODBEND FIELD

INTRODUCTION

Leduc-Woodbend field is geographically situated in southcentral Alberta (Fig. 4.2) along the north-northeast trending Rimbey-Meadowbrook series of Leduc Fm reefs which separate the east and west Ireton shale basins. A more northerly reef in the Rimbey-Meadowbrook trend, Clyde Reef, is incorporated into the geological cross-section A-A in the Introduction to this Atlas (well 2-15-55-25 W4M) and illustrates the stratigraphical and structural relationships between these build-ups and the adjacent sedimentary section.

Leduc-Woodbend field is divided into 66 assigned and unassigned pools, four of which are wholly or partially in the study area (Fig. 4.13, Table 4.5). Three of these pools, the D-3A D-3E and D-3F are Leduc Fm reservoirs, the other, D2A, produces from the Nisku Fm. The D-3A pool produces from the Leduc-Woodbend atoll, the D-3E and D-3F pools from adjacent pinnacles and the D-2A pool where the biostromal Nisku Fm is draped across Leduc Fm build-ups.

The Leduc Fm, is herein differentiated into reef and basal-reef. The reef towers about 200 m above the platform facies and is easily visually differentiated from the off-reef Ireton Fm and Duvernay Fm shales on the basis of seismic image, drape and velocity pull-up. In contrast, the basal reef, in the absence of well control, could be misinterpreted as either Duvernay Fm or lower Ireton Fm shale.

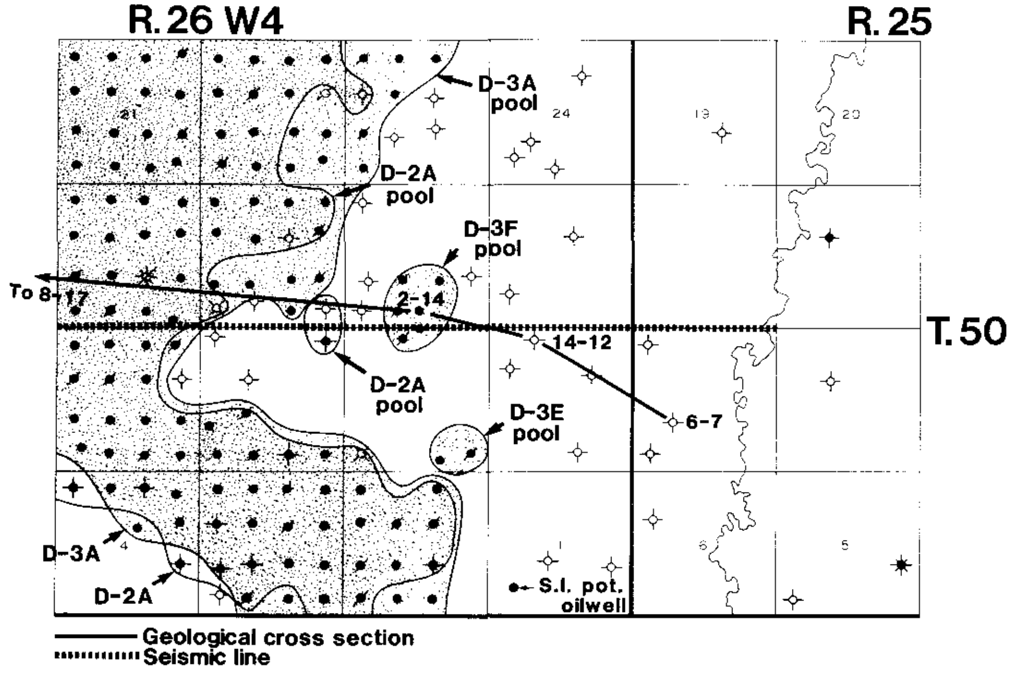


Figure 4.13. Leduc-Woodbend study area. Pool outlines, the four wells incorporated into the geological cross-section and the approximate location of the seismic section are shown.

Table 4.4. Production data for the four assigned pools in the Leduc-Woodbend area

FIELD	POOL	PRODUCING ZONE	NUMBER OF WELLS	CUMULATIVE PRODUCTION Oil (m^3)	Gas (E^3 m^3)	Water (m^3)
Leduc-Woodbend	D-3A	Leduc	527	38,800,455	803,718	20,663,766
Leduc-Woodbend	D-2A	Nisku	485	14,078,614	3,038,388	4,201,701
Leduc-Woodbend	D-3E	Leduc	3	26,107	13,416	123,642
Leduc-Woodbend	D-3F	Leduc	5	566,059	59,248	72,898

Leduc-Woodbend field was selected as an example Woodbend Gp reservoir for two reasons:

1) The Leduc-Woodbend D-3A pool reef, is a significant reservoir from an economic perspective. Production to-date is about 38 x $10^6 m^3$ of oil and 800 x $10^6 m^3$ of gas (Table 4.4); and

2) The seismic line is exceptionally well oriented for illustrative purposes, crossing the eastern edge of the Leduc-Woodbend

atoll, an adjacent pinnacle and the eastern edge of the low relief Leduc Fm sediment, herein referred to as basal-reef.

GEOLOGICAL CROSS-SECTION

The locations of the four wells incorporated into the geological cross-section and the seismic section are shown in Figure 4.13. As illustrated, the geological and seismic sections (Figs. 4.14 and 4.15 respectively) extend across the eastern edge of the Leduc-Woodbend atoll, an adjacent pinnacle and into the east Ireton shale basin. With respect to the geological cross-section, note that the Leduc-Woodbend field was developed in the early 1950's and consequently for many of the wells electrical logs were run. In order to utilize sonic- and neutron-logs, it was necessary to incorporate off-line wells of more recent vintage.

The Beaverhill Lake Gp, which is the deepest horizon labelled on the geological cross-section (Fig. 4.14), underlies the Cooking Lake Fm. The latter is the platform facies for the Leduc Fm. Note that the slope of the Beaverhill Lake Gp cannot be determined from the utilized wells and has been estimated from more regional control. On the log suite for the 8-17-50-26W4M well, the Cooking Lake Gp cannot be confidently distinguished from the Leduc Fm, despite the apparent lateral continuity of the Cooking Lake event across the seismic section. The slope of this horizon, therefore, has been extrapolated westward from the 6-7-50-26W4M well, parallel to the Beaverhill Lake Gp.

Figure 4.14 illustrates that the Leduc Fm can be differentiated into reef and basal-reef. The term reef is applied to the Leduc-Woodbend atoll and the adjacent pinnacles which attain thicknesses, excluding the platform facies, of about 200 m. The term basal-reef is applied to the lower relief (about 50 m thick, excluding the platform facies) Leduc Fm sediment present basinward of the atoll and about the periphery of the pinnacles. The basal-reef could represent either an early stage of reef growth or alternatively detritus from the reefs. Herein it is referred to as basal-reef as it exhibits an abrupt eastern edge on the seismic section, a feature more characteristic of reefs than reef detritus.

With respect to the full reef, note that the atoll has a raised rim (about 20 m structurally higher than the reef interior) and is separated from the adjacent pinnacle. Relief at the Leduc Fm level between the atoll and the pinnacle is estimated from the seismic data as the wells in this area were abandoned in the Ireton Fm. Figure 4.16, illustrates structure at the top of the Leduc Fm where present and Cooking Lake structure elsewhere . Note that the pinnacle (D-3F pool) does not exhibit a raised rim and that the basal-reef, as contoured, has an abrupt eastern edge.

The Leduc Fm is sealed by impermeable shales of the Duvernay and Ireton formations, which are the primary source rock for the hydrocarbons in reefal reservoirs. Presumably at the end of the Woodbend time, the Ireton Fm was more or less flat within the area. Now, however, as a result of compaction, this surface is up to 40 m higher above the reef than above the basal-reef.

Similarly, post-Ireton Fm strata are draped across the reef. The Calmar Fm, Wabamun Gp (pre-Cretaceous unconformity) and Mannville Gp are about 40 m, 30 m and 10 m respectively higher above reef than elsewhere (Figs. 4.17, 4.18, 4.19). Note that significantly more relief is observed at the Wabamun Gp than along the Mannville Gp suggesting that sub-Cretaceous erosional patterns were affected by pre-existing drape.

As indicated previously, three of the four pools are Leduc Fm reservoirs, whereas, the other produces from the Nisku Fm. Hydrocarbons within the Leduc Fm are principally confined to the up-dip edge of the atoll (D-3A) and to the adjacent pinnacles (D-3E, D-3F), whereas the Nisku Fm (D-2A) is productive where these

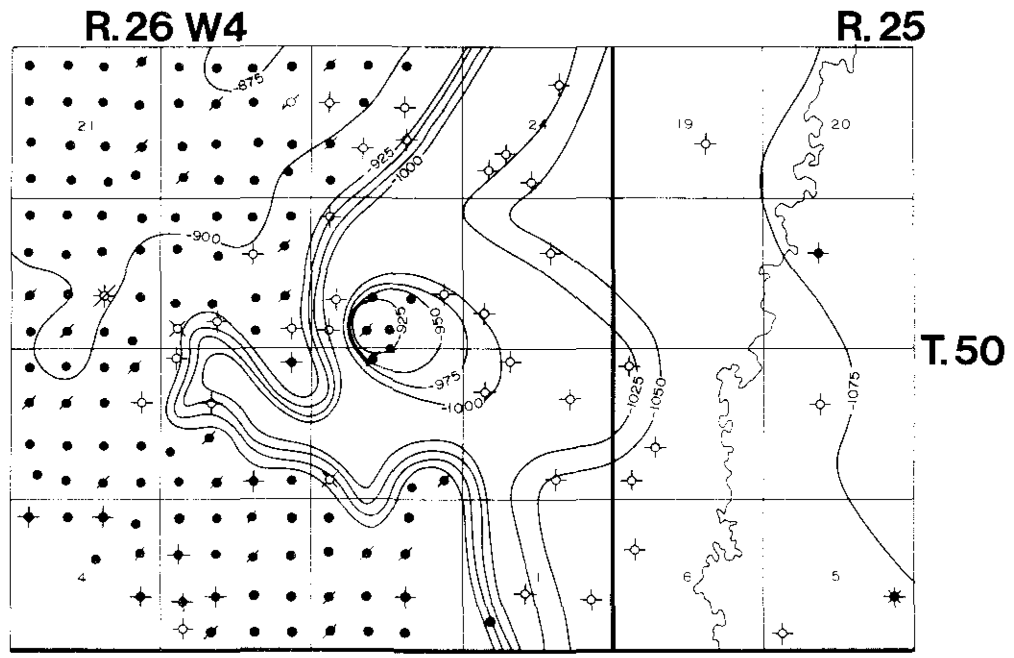


Figure 4.16. Contour map (in metres relative to mean sea level) of the Leduc Fm top (or, in its absence, the Cooking Lake Fm top).

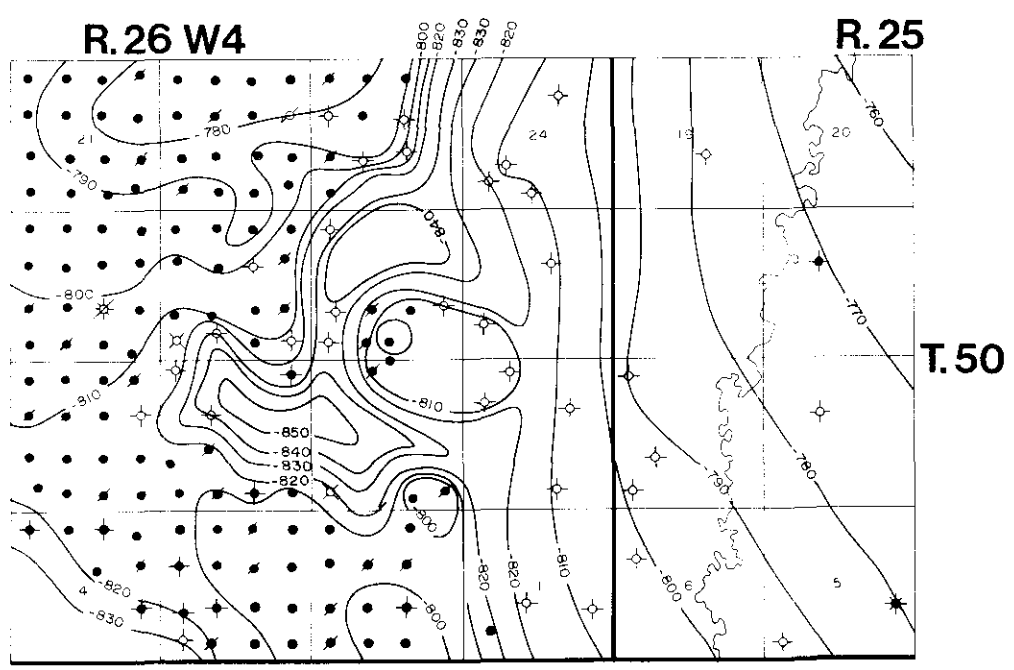


Figure 4.17. Contour map (in metres relative to mean sea level) of the Calmar Fm top.

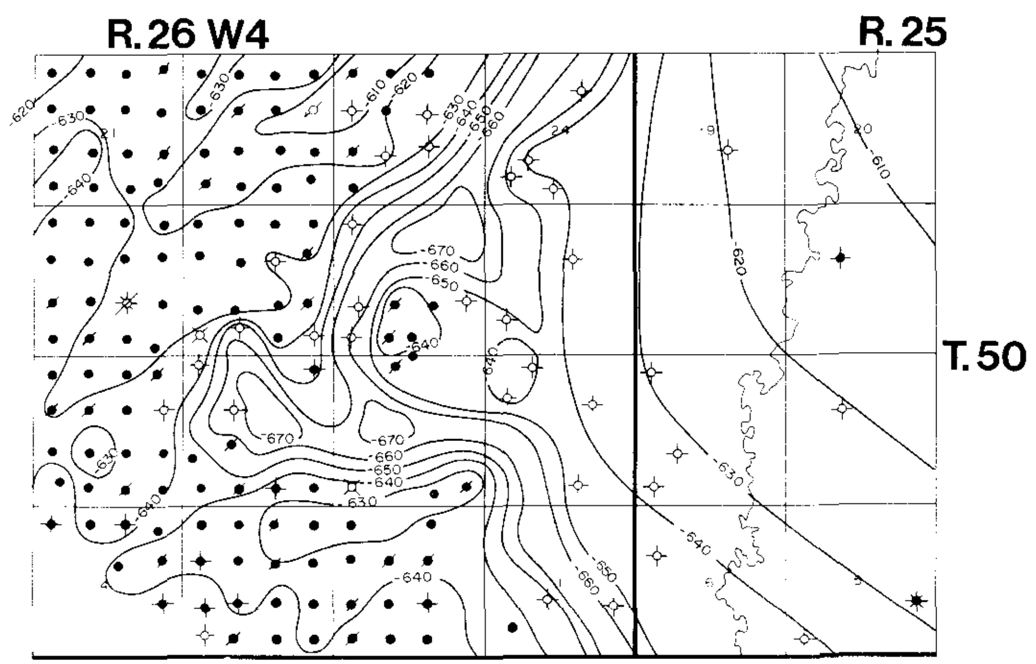


Figure 4.18. Contour map (in metres relative to mean sea level) of the Wabamun Gp top.

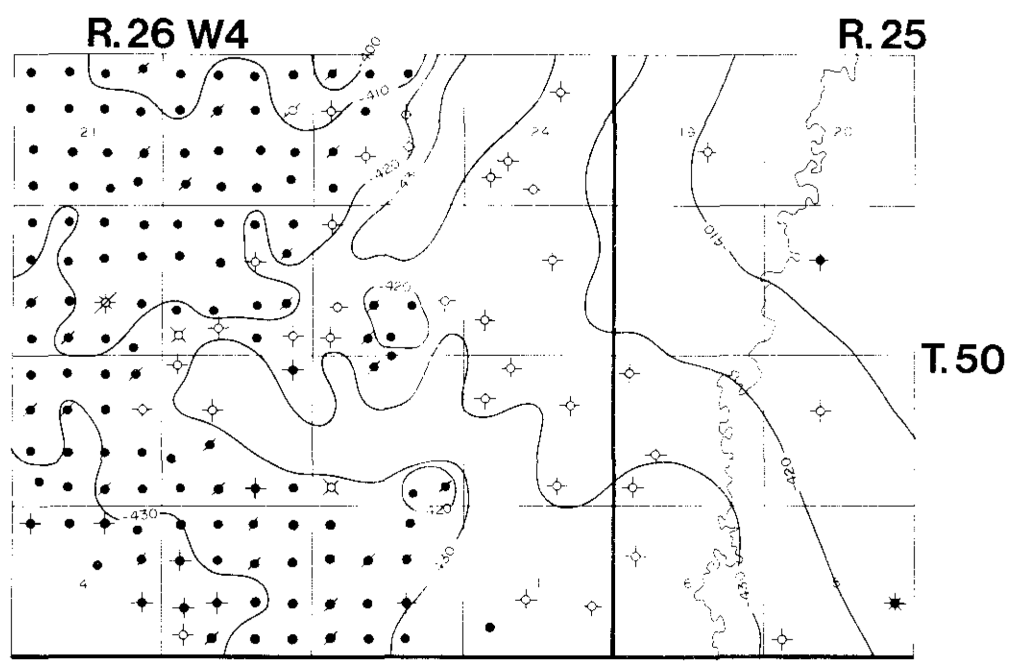


Figure 4.19. Contour map (in metres relative to mean sea level) of the Mannville Gp top.

biostromal carbonates are draped across underlying Leduc Fm build-ups.

SEISMIC SECTION

The approximate location of the seismic section (Fig. 4.15) is given in Figure 4.13. These data were recorded in 1983 using a vibroseis source (12-85-Hz), 1675-m split spreads, a 134-m source interval and a 33.5-m group interval. Figures 4.20 and 4.21, are a seismogram and a synthetic seismic section respectively for the 14-12-50-26W4M well.

The deepest reflection identified on Figure 4.15, the Cooking Lake event, is as much as 40 ms higher beneath the reef than elsewhere and yet more or less time-structurally parallel to underlying reflections. Relief is therefore attributed to velocity pull-up which, as demonstrated by Anderson et al. (1988b), is primarily a function of lateral variations in the thicknesses of overlying sediments. On the geological cross-section the thickness of the Leduc Fm ranges from 0 to in excess of 200 m; conversely the Ireton Fm, Winterburn Gp, Wabamun Gp and Cretaceous sediments

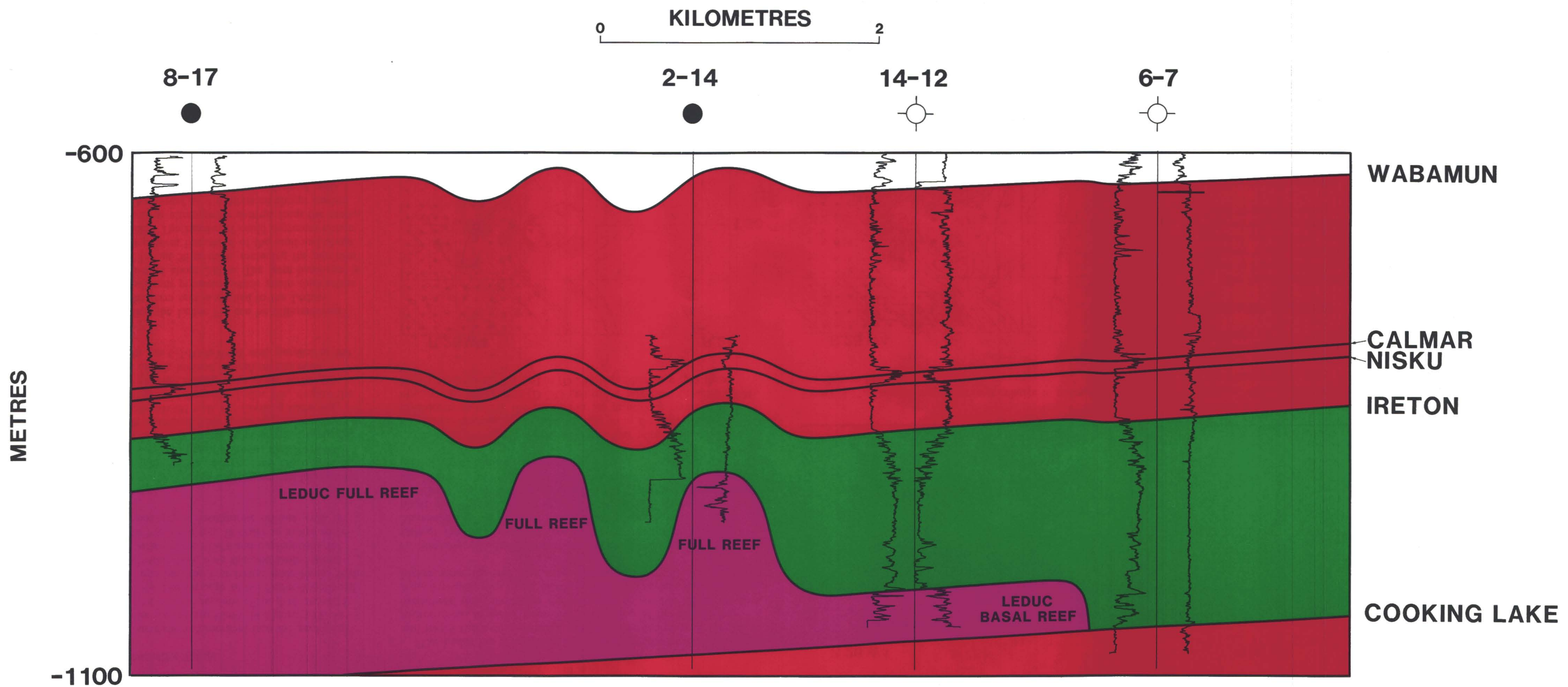


Figure 4.14. Geological cross-section, Leduc-Woodbend study area.

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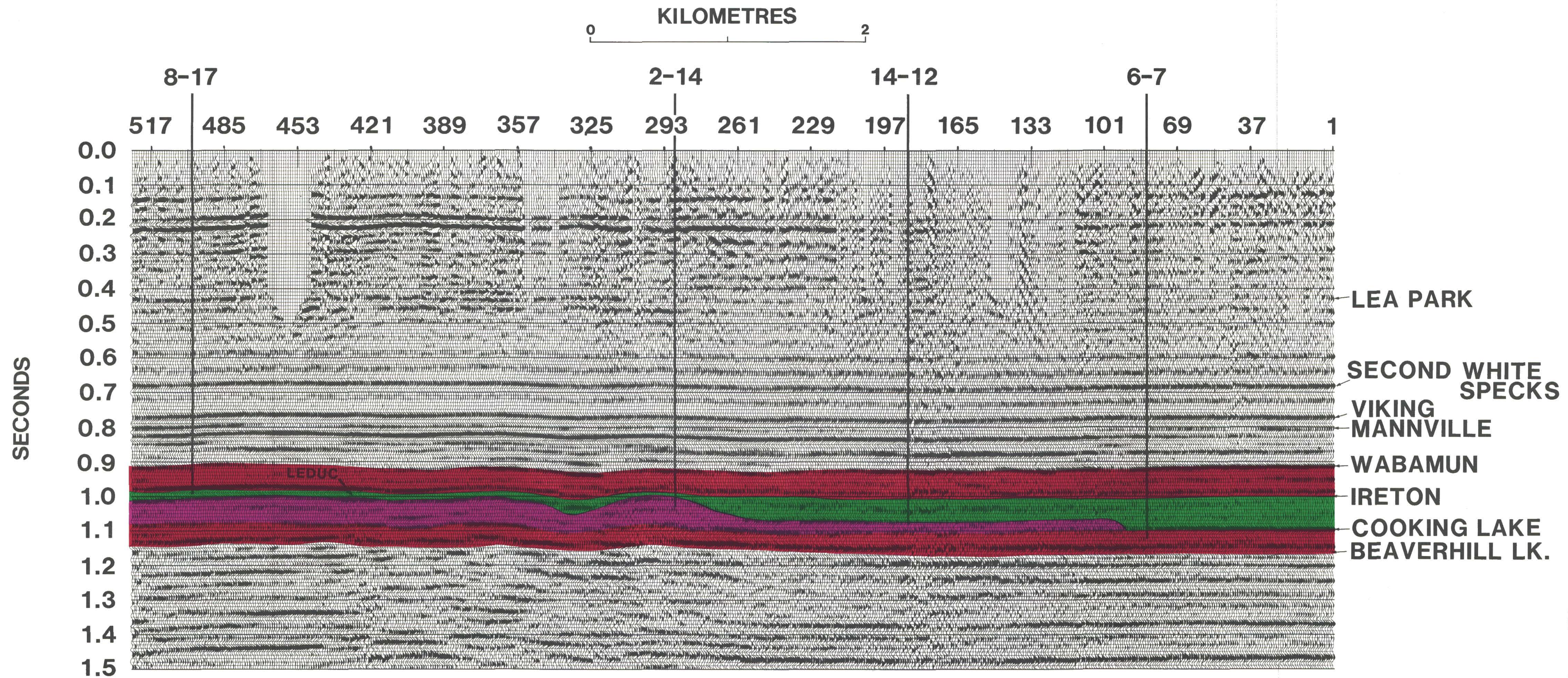


Figure 4.15. Normal polarity seismic section, Leduc-Woodbend study area.

DONOR: PULSE '87 | PROCESSOR: VERITAS SEISMIC LTD. | AUTHOR: N. ANDERSON are thinnest above the reef. There is no evidence of significant lateral velocity variations within these upper Paleozoic and Mesozoic strata within the area (Fig. 4.13). The Cooking Lake event is generally low-amplitude beneath the Leduc Fm and a slightly higher moderate-amplitude event where it is overlain by the Duvernay Fm.

The Leduc event is generally high-amplitude. Exceptions occur as a result of defocusing and diffractions between the atoll and adjacent pinnacle. Here, the Leduc event exhibits a classic "bow tie" effect and relief (Fig. 4.15) is estimated based on an analysis of time-structure along the Cooking Lake event. The thicknesses of the Ireton and Leduc formations were estimated relative to the observed pull-up beneath full-reef. Note that the basal-reef event terminates near trace 101 suggesting that these sediments have an abrupt eastern edge (Fig. 4.16), and supporting the premise that they represent an early stage of reef growth as opposed to reef detritus.

The seismic image of the reef consists of low-amplitude, laterally discontinuous reflections bounded by the high-amplitude Leduc event and the low- to moderate-amplitude Cooking Lake reflection. The seismic image of the basal-reef in contrast is dominated by the closely spaced Leduc and Cooking Lake events, such that, any internal reflection pattern is effectively masked. The basal-reef event appears to merge visually with the reflection from the flank of the reefs.

The overlying Ireton event is of higher amplitude across the reef than elsewhere. In these locations its amplitude is enhanced as a result of constructive interference with the Leduc event. The seismic image of the Ireton and Duvernay formations consists of moderate- to high-amplitude, laterally continuous reflections bounded by the high-amplitude Ireton event and the low- to moderate-amplitude Cooking Lake Fm event.

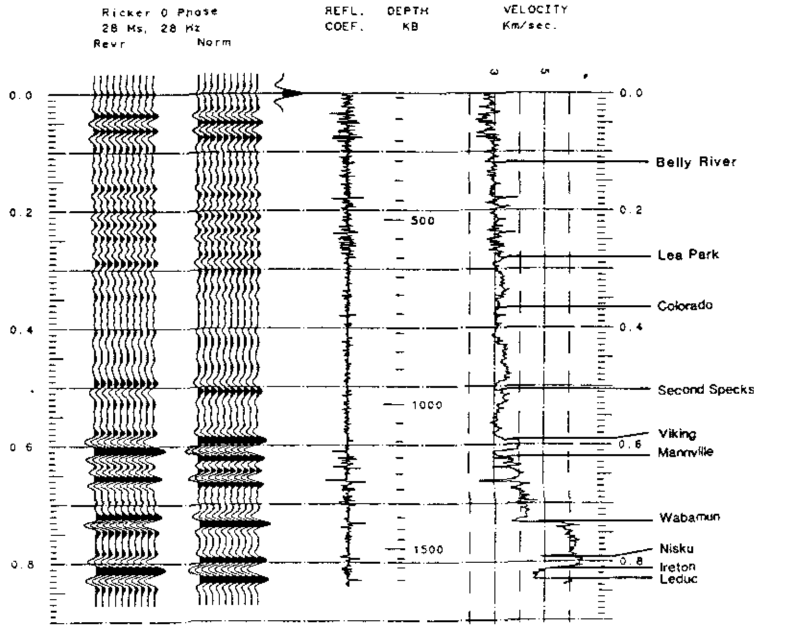
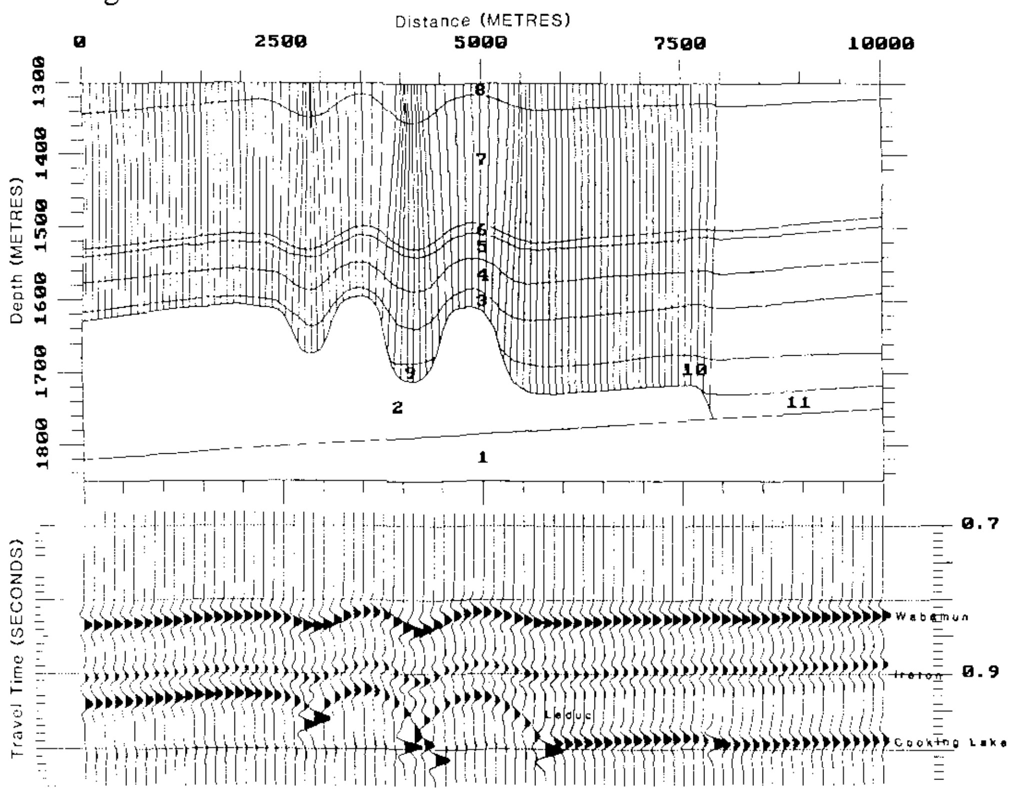


Figure 4.20. Seismogram for the 14-12-50-26 W4M well.



	Velocity (m/s)	Density (kg/m³)		Velocity (m/s)	Density (kg/m³)
(1) Cooking Lake	5900 5900	2750 2750	(2) Leduc	5500 5500	2750 2750
(3) Shale	3900 3900	2650 2650	(4) Shale (top of Ireton)	3900 3900	2700 2700
(5) Nisku	5800 5800	2750 2750	(6) Calmar	4900 4900	2650 2650
(7) Wabamun	5700 5700	2750 2750	(8) Cretaceous	3800 3800	2650 2650
(9) Shale	3700 3700	2650 2650	(10) Shale	3700 3700	2650 2650
(11) Shale	5300 5300	2700 2700			

Figure 4.21. Synthetic seismic section generated from the geological cross-section (Fig. 4.14) using a zero-phase, normal polarity, 30-Hz, Ricker wavelet.

MORINVILLE/ST. ALBERT-BIG LAKE FIELDS

INTRODUCTION

The Morinville and St. Albert-Big Lake fields are located in southcentral Alberta along the north-northeast Rimbey-Meadowbrook series of Leduc Fm reefs which separate the east and west Ireton shale basins (Fig. 4.2). Clyde reef, a more northerly build-up in the trend, is depicted on the geological cross-section A-A in the Introduction to this Atlas (well 2-15-55-25 W4M) and illustrates the structural and stratigraphical relationships between Leduc Fm reefs and the adjacent sedimentary section.

Table 4.5. Production data for the eight assigned pools in the Morinville/St. Albert-Big-Lake area

FIELD	POOL	PRODUCING ZONE	NUMBER OF WELLS	CUMULATIVE PRODUCTION Oil (m³)	Gas (E³ m³)	Water (m³)
St. Albert-Big Lake	D-3B	Leduc	5	878,601.5	61,629.8	154,718.6
St. Albert-Big Lake	D-1D	Wabamun	7	116,097.6	228,602.2	42,056.3
St. Albert-Big Lake	Ostracod A	Ostracod	10	0.0	2,739,677.9	1,548.0
Morinville	D-3B	Leduc	13	1,562,435.6	97,288.4	123,956.0
Morinville	Upper Mannville D	Glauconite	1	0.0	1,246.1	4.0
Morinville	Viking B	Viking	1	0.0	5,192.9	1.2
Morinville	Lower Mannville H	Ostracod	1	0.0	113,082.3	4,637.5
Morinville	Lower Mannville K	Ellerslie	1	0.0	9,906.2	118.9

Table 4.6. Production data for the Morinville/St. Alberta-Big Lake study area

WELL	FIELD	POOL	PRODUCING ZONE	PRODUCTION DATE	CUMULATIVE PRODUCTION Oil (m³)	Gas (E³ m³)	Water (m³)
3-1-54-26W4	St. Albert-Big Lake	D-3B	Leduc	01/53	228,916.7	15,812.0	58,787.2
3-1-54-26W4	St. Albert-Big Lake	D-1D	Wabamun	08/77	32,685.4	7,716.0	1,904.8
5-1-54-26W4	St. Albert-Big Lake	D-3B	Leduc	12/55	68,577.4	3,940.3	9,274.9
5-1-54-26W4	St. Albert-Big Lake	D-1D	Wabamun	04/85	50.8	0.0	18.3
6-1-54-26W4	St. Albert-Big Lake	Ostracod A	Ostracod	08/55	0.0	89,488.5	512.0
8-2-54-26W4	St. Albert-Big Lake	D-1D	Wabamun	08/82	10,027.1	2,370.1	2,587.5
10-2-54-26W4	St. Albert-Big Lake	Ostracod A	Ostracod	01/57	0.0	137,472.9	1,226.5
16-11-54-26W4	Morinville	D-3B	Leduc	03/82	968.8	100.4	1,629.5
12-12-54-26W4	Morinville	Mannville D	Glauconite	06/85	0.0	1,246.1	4.0
12-12-54-26W4	Morinville	Viking B	Viking	06/85	0.0	5,192.9	1.2
4-13-54-26W4	Morinville	D-3B	Leduc	05/65	64,824.6	3,899.7	618.7
5-13-54-26W4	Morinville	D-3B	Leduc	04/65	337,579.3	22,354.9	60,024.0
7-13-54-26W4	Morinville	D-3B	Leduc	08/63	4,078.1	247.0	2,556.1
1-14-54-26W4	Morinville	D-3B	Leduc	06/65	338,760.5	25,173.6	6,462.6
2-14-54-26W4	Morinville	D-3B	Leduc	08/65	379,308.0	22,669.5	1,623.7
2-14-54-26W4	Morinville	D-3B	Leduc	09/86	38,641.6	3,083.3	10,350.7
7-14-54-26W4	Morinville	D-3B	Leduc	10/65	88,032.7	5,210.9	0.0
8-14-54-26W4	Morinville	D-3B	Leduc	12/64	184,663.3	11,177.8	2,747.2
8-14-54-26W4	Morinville	D-3B	Leduc	04/84	77,065.1	4,235.1	1,187.1
2-23-54-26W4	Morinville	Mannville H	Ostracod	12/62	0.0	113,082.3	4,637.5
6-24-54-26W4	Morinville	Mannville K	Ellerslie	09/53	0.0	9,906.2	118.9

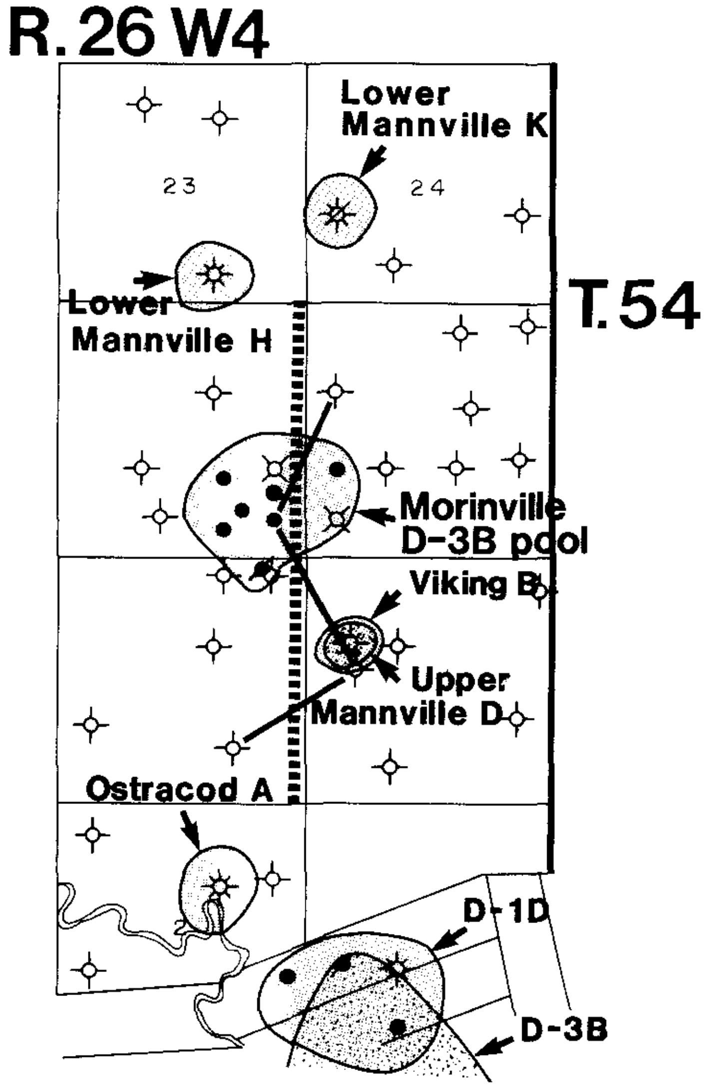


Figure 4.22. Morinville/St. Albert-Big Lake study area. Pool outlines, the four wells incorporated into the geological cross-section and the approximate location of the seismic line are shown.

Morinville field is subdivided into 36 assigned and unassigned pools, five of which are within the Morinville/St. Albert-Big Lake area (Table 4.5 and Fig. 4.22). The St. Albert-Big Lake field is similarly comprised of eight pools (Table 4.5), only three of which are either wholly or partially in the study area. Of the five Morinville pools only one, D-3B, is a Leduc Fm reservoir, whereas the Lower Mannville H, Lower Mannville K, Upper Mannville D and Viking B produce from the Cretaceous. Similarly, only one of the three St.

Albert-Big Lake pools, D-3B, is a Leduc Fm reservoir, whereas the D-1B and Ostracod A produce from the Wabamun Gp and Ostracod Mbr respectively. Table 4.6, summarizes cumulative production for the Morinville/St. Albert-Big Lake fields.

The Leduc Fm in the area is differentiated into reef and basal-reef. The reef, typified by the St. Albert-Big Lake D-3B pool reef (Fig. 4.22) towers some 250 m above the Cooking Lake Fm platform. In contrast the basal-reef, typified by the Morinville D-3B pool build-up, stands only 100 m above the platform. Both build-ups are productive.

The Morinville/St. Albert-Big Lake fields were selected as Woodbend Gp reservoir examples for two reasons:

1) Although Morinville D-3B reef and St. Albert-Big Lake D-3B reef are closely spaced Leduc Fm build-ups, they attained startlingly dissimilar heights, implying that reef growth terminated at different times in reefs of the same age; and

2) Morinville D-3B reef is an excellent example of a basal-reef reservoir.

GEOLOGICAL CROSS-SECTION

Figure 4.22 gives the locations of the wells incorporated in the geological cross-section (Fig. 4.23) and the seismic section (Fig. 4.24). Both the geological cross-section and seismic section extend north-south across the Morinville D-3B pool reef. Note that the geological cross-section is structurally datumed and that the wells utilized are not linearly oriented. As a result, there are slight discrepancies between the interpretations of the geological and seismic sections, particularly with respect to estimates of structural drape across the reef.

The deepest horizon identified on the geological cross-section, the Cooking Lake Fm, is the platform facies. The off-reef carbonates penetrated by the 2-11 and 2-23 wells are interpreted as Cooking Lake Fm, elsewhere structure at this level was determined by interpolation using these two control points. Local structural relief along the platform, which could have initiated reef growth, cannot be discerned on the seismic data nor estimated from well control (due to the difficulty in distinguishing the Leduc and Cooking Lake formations on well-logs).

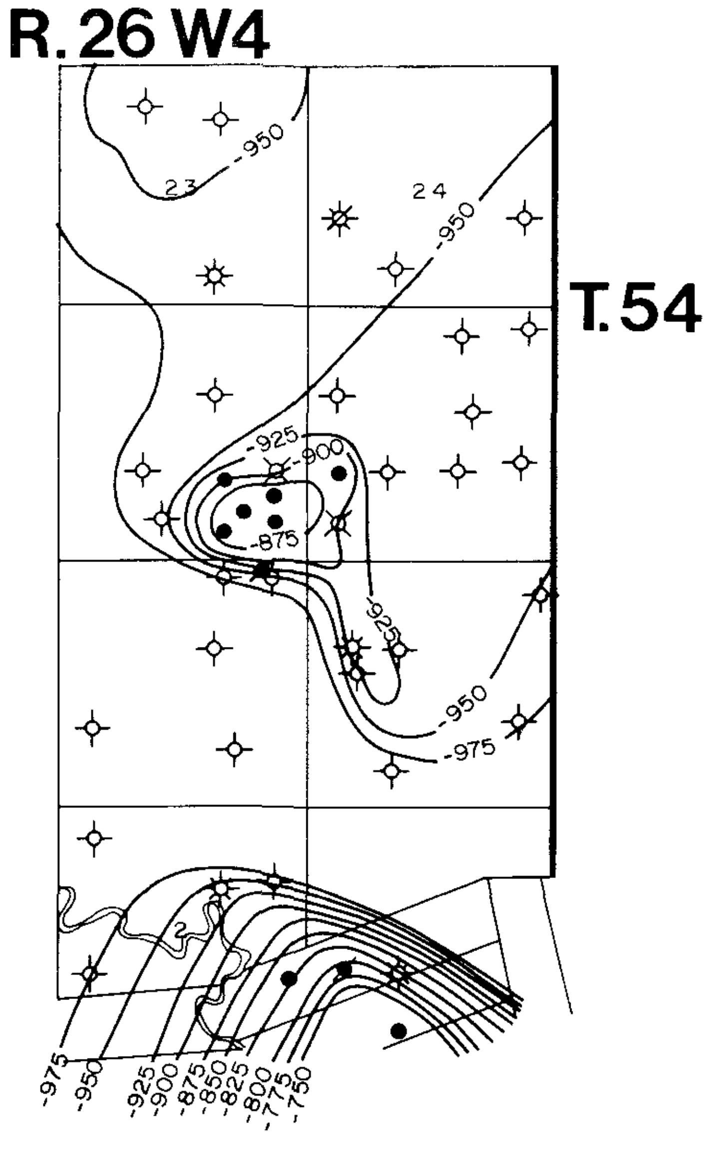


Figure 4.25. Contour map (in metres relative to mean sea level) of the Leduc Fm top (or, in its absence, the Cooking Lake Fm top).

The Cooking Lake Fm is overlain by the Leduc Fm where present, and elsewhere by the Duvernay Fm. A map of Leduc/Cooking Lake structure (Fig. 4.25) shows that the northern, western and eastern edges of the Morinville reef are abrupt, thinning from 100 m to near-zero over a distance of about 0.2 km. In contrast, the southeastern margin appears to thin from 100 m (1-14), to 50 m (12-12) to near zero over a distance of about 1.5 km. This southward thinning could be gradational or step-like. It may also be indicative of a second isolated build-up. A wedge shaped slope would be consistent with a sheltered leeward shelf edge or leeward detrital edge, whereas a step-like thinning could be indicative of episodic back stepping phases of reef growth or, perhaps, wave cut terraces. An alternative explanation is that a second isolated build-up lies to the south of the D-3B pool (Fig. 4.22). The abrupt northern, eastern and western edges are possibly representative of reef growth in a high energy environment. As contoured, the Morinville reef does not exhibit a raised rim.

Off-reef, the Cooking Lake Fm is overlain by shales of the Duvernay and lower Ireton formations. These shales are of relatively high velocity and terminate against the flank of the Morinville D-3B reef. More specifically, the lower Ireton wedges out near the apex of the reef. These relationships are critical to the interpretation of the seismic section. As is discussed below, the lower Ireton event merges laterally with the reflection from the top of the Morinville reef.

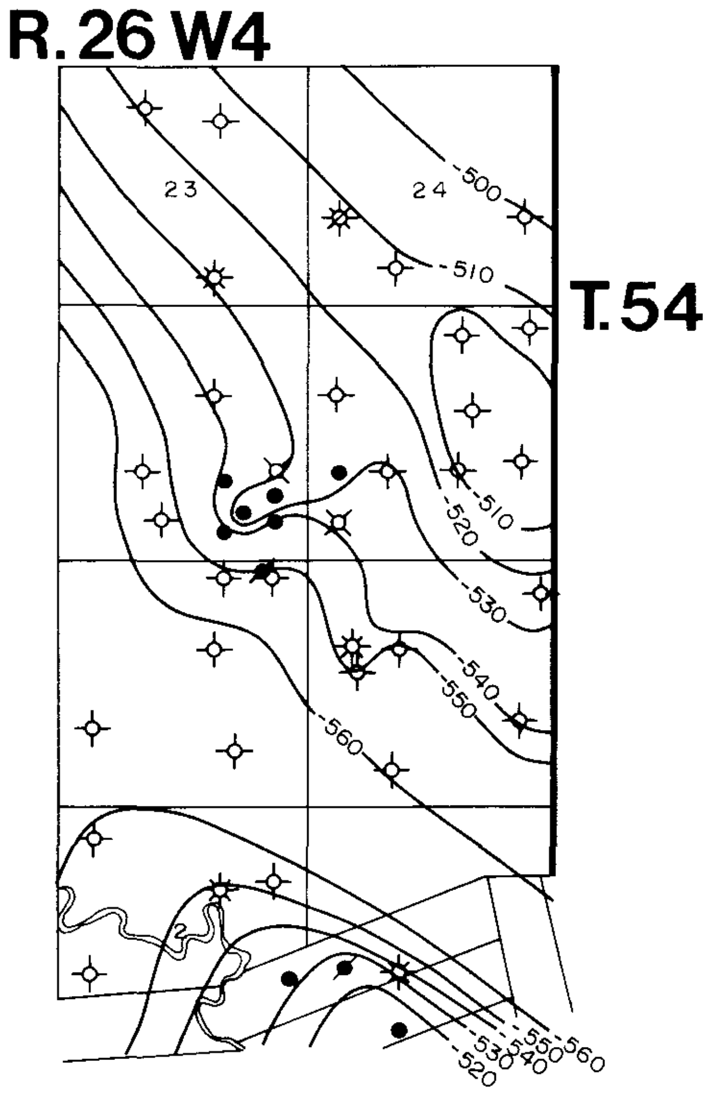


Figure 4.26. Contour map (in metres relative to mean sea level) of the Wabamun Gp top.

The Ireton Fm also drapes across the Morinville D-3B reef (Fig. 4.23). The Ireton Fm is about 20 m higher over the reef apex relative to the apparent regional dip, which is determined by interpolation between the two off-reef wells: 2-11 and 2-23.

Figure 4.26 illustrates that the pre-Cretaceous unconformity (the top of the Wabamun Gp), also drapes across the Morinville reef. Relief at this level is about 10 m, significantly less than that on the top of the Ireton Fm. This suggests that pre-Cretaceous erosion bevelled the Paleozoic surface within the area, as opposed to being controlled by differential resistance to erosion. The top of the Mannville Gp is similarly about 10 m higher on-reef than off-reef, again supporting the thesis that erosional patterns within the area, were not controlled by pre-existing drape.

SEISMIC SECTION

Data for the Morinville D-3B reef example was recorded in 1983 using a P-shooter (60-drop) source, a 1530 m split spread, a 60 m

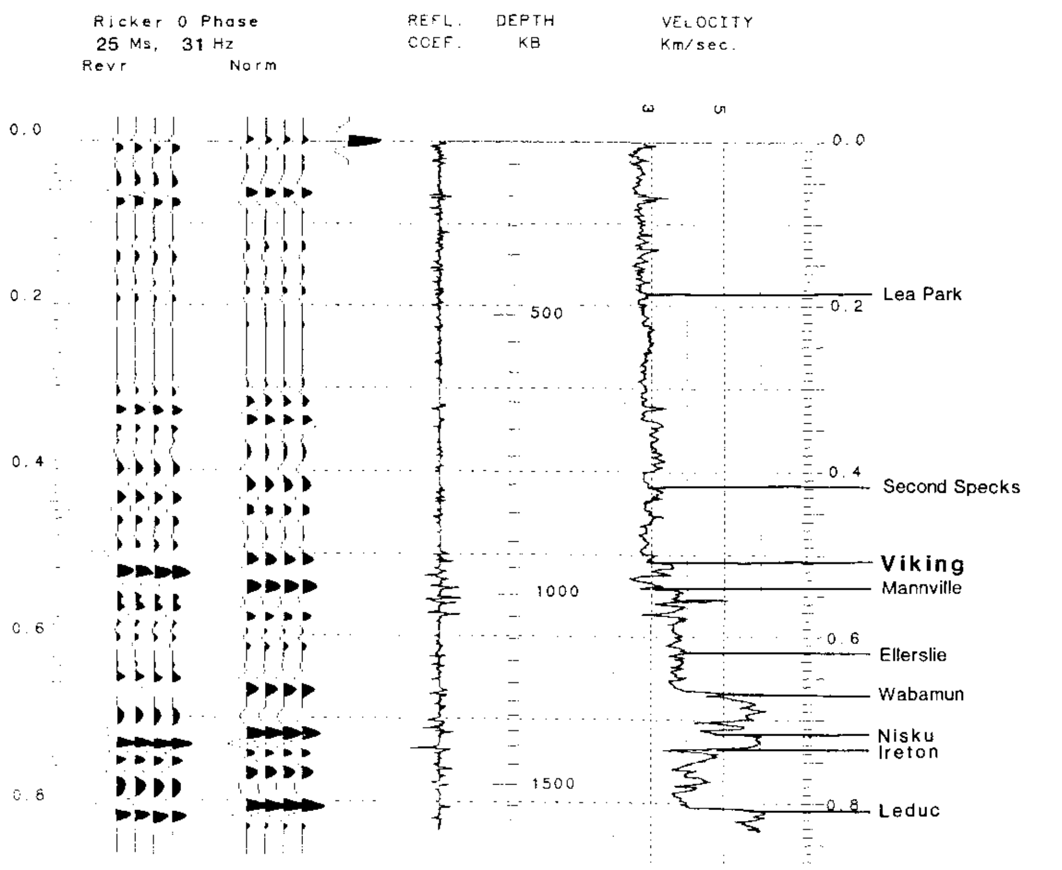


Figure 4.27. Seismogram for the 8-14-56-26 W4M well.

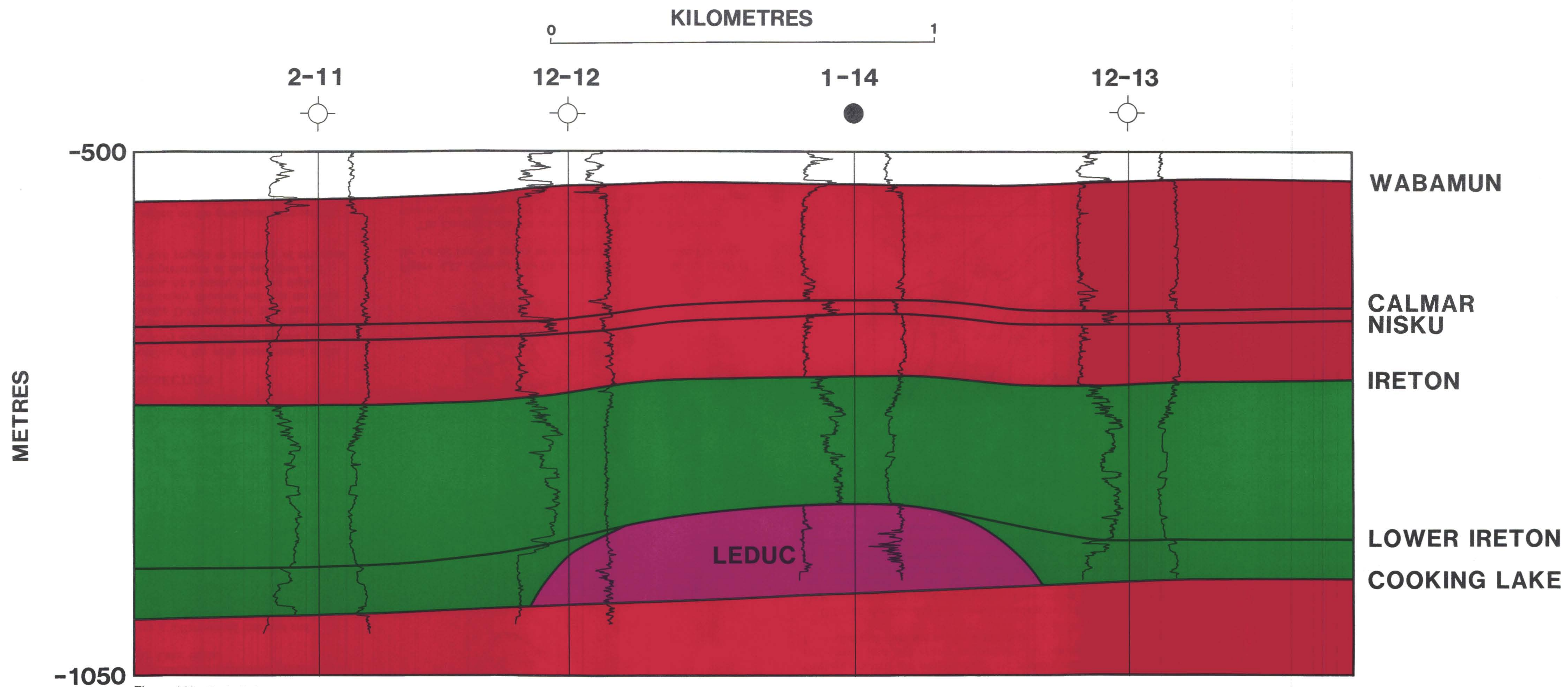


Figure 4.23. Geological cross-section, Morinville/St. Albert-Big Lake study area.

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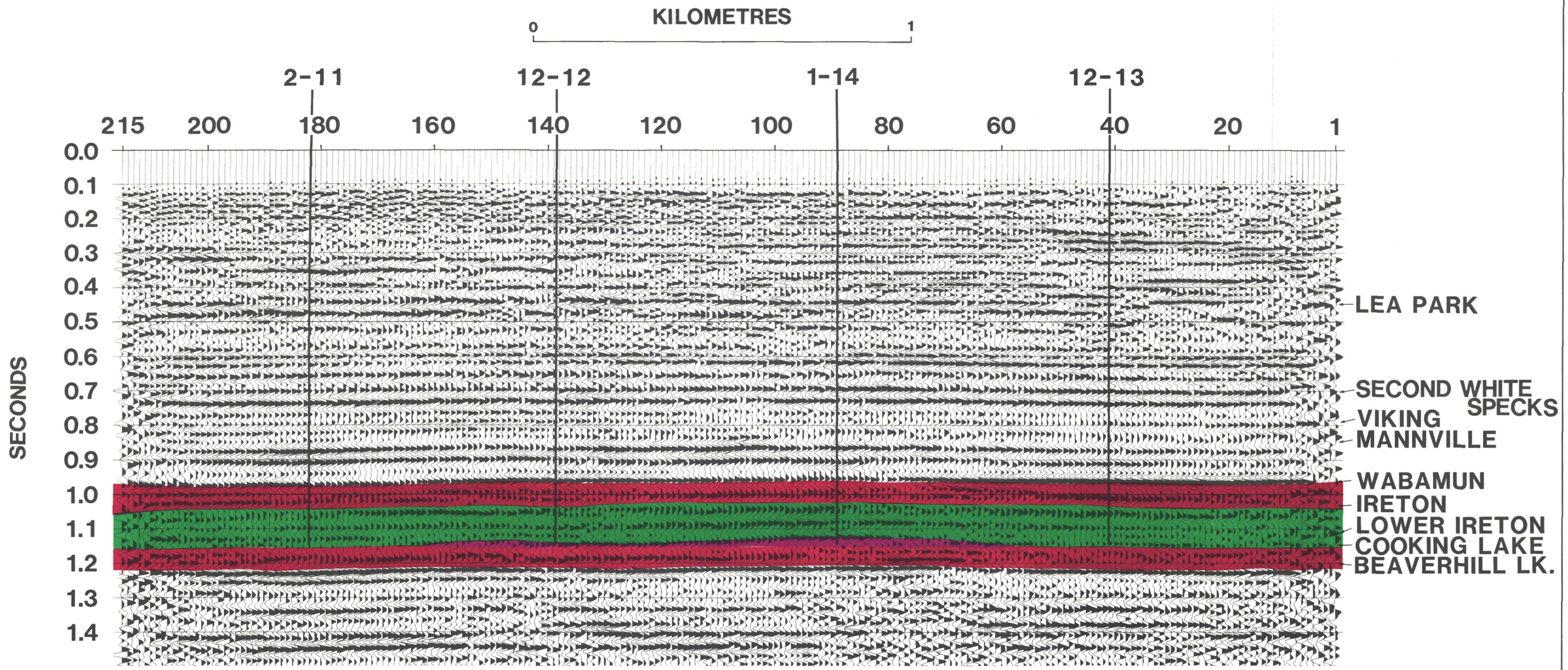
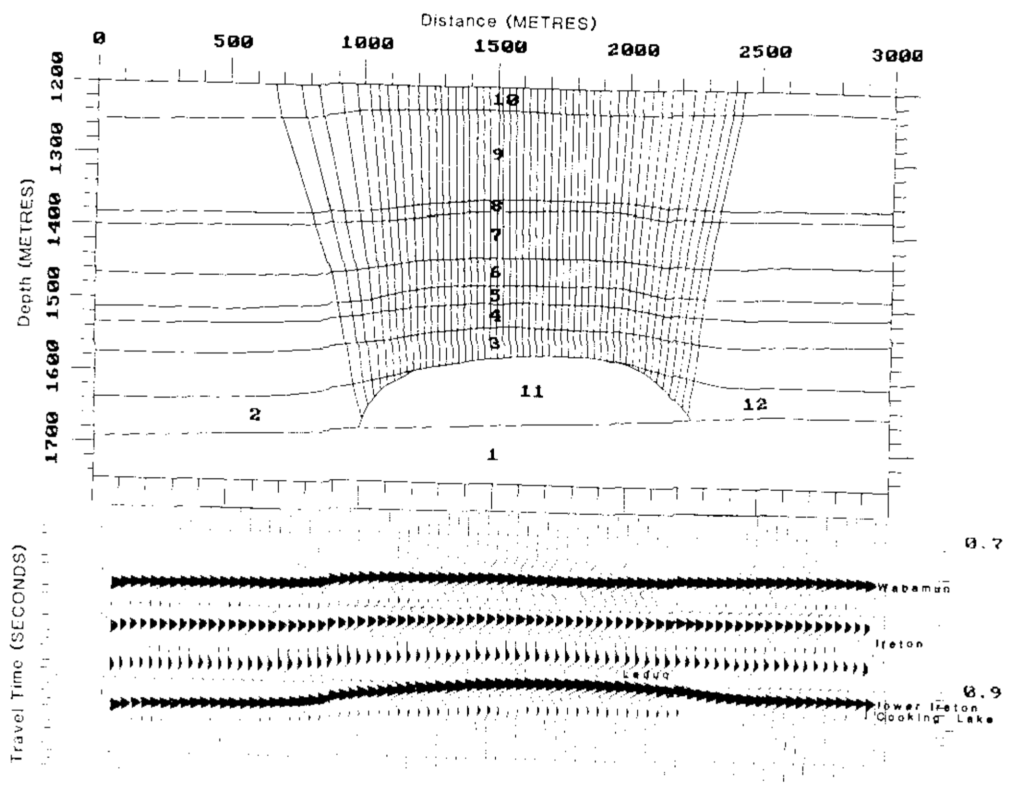


Figure 4.24. Normal polarity seismic section, Morinville/St. Albert-Big Lake study area.

DONOR: CGG GEOPHYSICS CANADA LTD. | PROCESSOR: CGG GEOPHYSICS CANADA LTD. | AUTHOR: N. ANDERSON shot spacing and a 30 m group interval. Figures 4.27 and 4.28 present a seismogram and a synthetic seismic section respectively for the 8-14-54-26W4M on-reef well. The 8-14 well is on the map of the Morinville/St. Albert-Big Lake area (Fig. 4.22) and is incorporated in the geological cross-section (Fig. 4.23).



	Velocity (m/s)	Density (kg/m³)		Velocity (m/s)	Density (kg/m³)
(1) Cooking Lake	5900 5900	2750 2750	(2) Shale	5300 5300	2650 2650
(3) Shale	3700 3700	2650 2650	(4) Shale	4100 4100	2650 2650
(5) Shale	3800 3800	2650 2650	(6) Shale (top Ireton)	5000 5000	2650 2650
(7) Nisku	5800 5800	2750 2750	(8) Calmar	4800 4800	2650 2650
(9) Wabamun	5700 5700	2750 2750	(10) Cretaceous	2700 3800	2650 2650
(11) Leduc	5500 5500	2750 2750	(12) Shale	5300 5300	2650 2650

Figure 4.28. Synthetic seismic section generated from the geological cross-section (Fig. 4.23) using a zero-phase, normal polarity, 30-Hz, Ricker wavelet.

The deepest reflection labelled on the seismic section is the Cooking Lake event. As anticipated from the analysis of the geological cross-section, this reflection is of relatively low-amplitude both on-reef and off-reef. Both the Duvernay and Leduc formations are of relatively high P-wave velocity (typically 5200 m/s and 5500 m/s respectively) and the acoustic impedance contrast between these sediments and the underlying Cooking Lake Fm carbonates (typically 6000 m/s) is relatively low. Note that the Cooking Lake event is pulled-up by about 10 ms beneath the Morinville reef as a result of lateral variations in the thicknesses of overlying strata. For example, the thickness of the Leduc Fm ranges from 0 to in excess of 100 m. In contrast the overlying Paleozoic and Mesozoic strata are thickest off-reef. The net result is that the average velocity from the seismic datum to the Cooking Lake Fm is greater on-reef than off-reef. Inasmuch as the Cooking Lake event approximately parallels underlying reflections it is unlikely this time-structural relief is attributable to real structure.

The seismic image of the overlying Leduc Fm is shaded purple (Fig. 4.24). Between traces 70 and 110, the Morinville reef protrudes through the lower Ireton Fm, whereas in flank positions it is overlain by either the Duvernay Fm or lower Ireton Fm (Fig. 4.23). Where the Leduc Fm protrudes through the lower Ireton Fm, this event is a high-amplitude peak. In flank positions, in contrast, it is effectively masked by the high-amplitude lower Ireton event. The lower Ireton wedges out near the apex of the Morinville reef (Fig. 4.23). As a consequence, the lower Ireton event merges with the Leduc event near the crest of the reef and here the two events cannot be differentiated visually.

The seismic image of the Morinville reef is dominated by the high-amplitude Leduc event and the low-amplitude Cooking Lake event, two closely spaced reflections which mask any internal character pattern. Similarly, the lower Ireton to Cooking Lake interval is dominated by the closely spaced high-amplitude lower Ireton and low-amplitude Cooking Lake events and any internal reflection pattern is also effectively masked. Consequently the flank of the reef cannot be mapped confidently on the basis of character pattern alone and is therefore estimated on well control, drape, velocity pull-up and lateral changes in the seismic image of the upper Ireton Fm as described below.

Figure 4.24 shows that the upper part of the Ireton Fm thins significantly across the Morinville reef. As a result of such thinning the seismic image is variable, being comprised of lower amplitude reflections on-reef than off-reef, possibly as a result of changes in the overall interference pattern. The Ireton event is time-structurally highest across the apex of the reef, lower across the reef flank and lowest off-reef. This relief, primarily due to drape, is accentuated by velocity pull-up. Recall from Figure 4.23 that the Upper Paleozoic and Mesozoic strata thin across the apex of the reef.

The Wabamun event (the pre-Cretaceous unconformity), is also time-structurally higher across the reef than elsewhere, and approximately parallel to the Mannville event supporting the premise that erosion during the pre-Cretaceous more or less peneplained the Paleozoic surface.

RICH FIELD

INTRODUCTION

Rich field (Fig. 4.29) is located in the southern part of the east Ireton shale basin, southwest of the Fenn-Big Valley reef complex, west of the southern Alberta shelf carbonate complex and east of the Bashaw reef complex (Fig. 4.2). In the study area, which includes the southwest edge of the Fenn-Big Valley field, there are 10 assigned and unassigned pools. Eight of these pools are in the Rich field (Fig. 4.29, Table 4.7) and two are in the Fenn-Big Valley field. Two of the seven pools in the Rich field, D-3A and D-2A, are Devonian

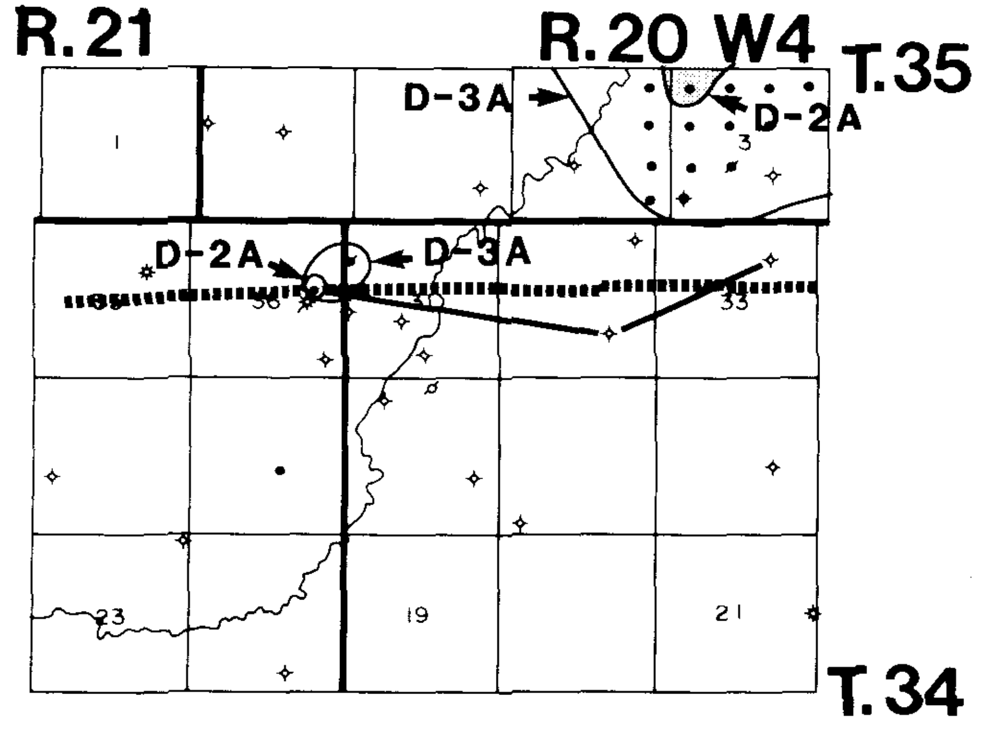


Figure 4.29. Rich study area. Pool outlines, the three wells incorporated into the geological cross-section and the approximate location of the seismic section are shown.

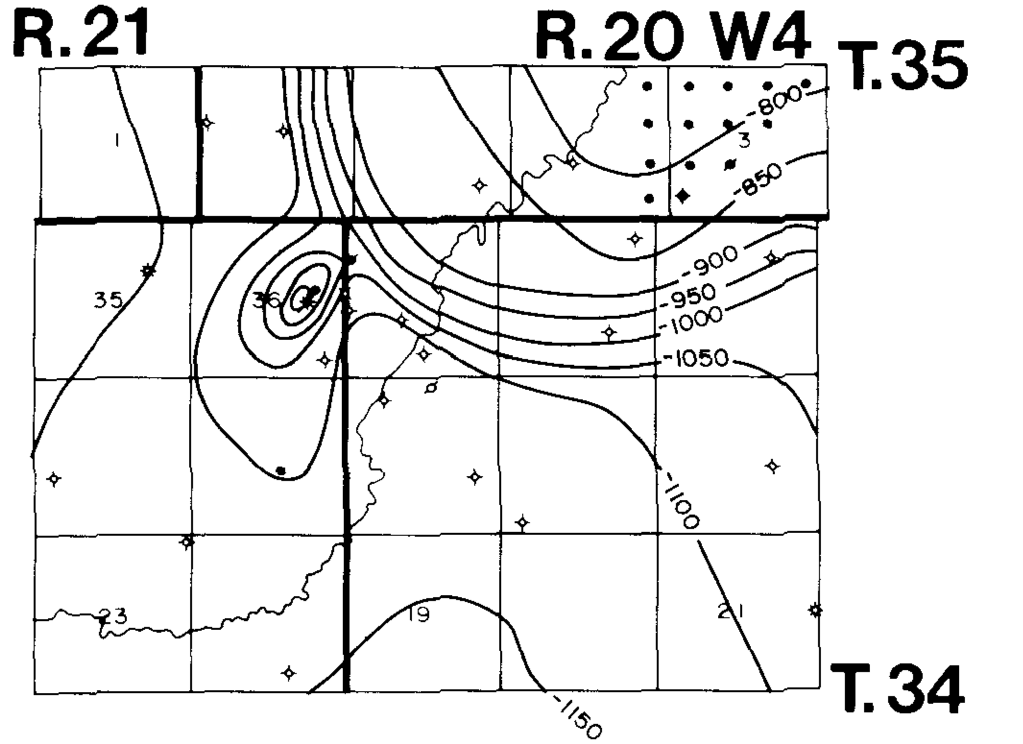


Figure 4.32. Contour map (in metres relative to mean sea level) of the Leduc Fm (or in its absence, the Cooking Lake Fm).

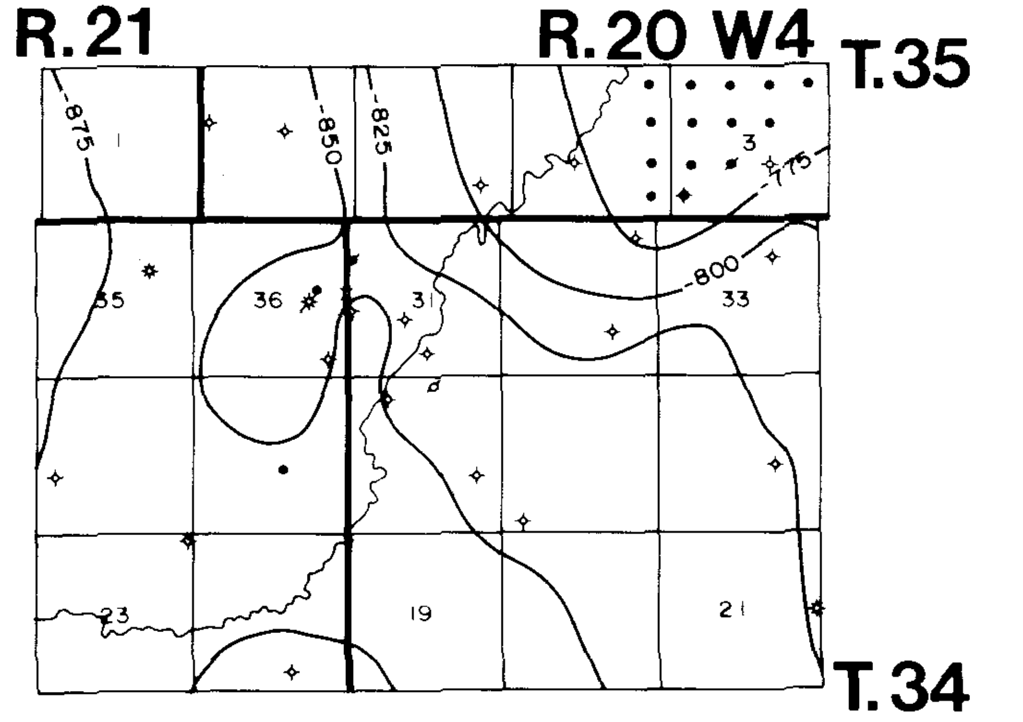


Figure 4.33. Contour map (in metres relative to mean sea level) of the Calmar Fm.

Table 4.7. Production data for the Rich study area

WELL	FIELD	POOL	PRODUCING HORIZON	PRODUCTION DATE	CUMULATIVE PRODUCTION Oil (m^3)	Gas (E^3 m^3)	Water (m^3)
08-21-34-20W4	Rich	Glauconite B and C	Glauconite	84/02	0	47,917	314
12-29-34-20W4	Rich	Glauconite B and C	Glauconite	85/05	0	20,257	139
12-31-34-20W4	Rich	D-3A	Leduc	83/09 Injection: 84/07	359	4	1,988
10-32-34-20W4	Rich	Glauconite B and C, Belly River B	Glauconite Belly River	84/12 85/12	0 0	44,760 12,501	266 29
07-25-34-21W4	Rich	Winnipegosis A	Winnipegosis	86/06	3,374	0	92
10-35-34-21W4	Rich	Unassigned		0	14	0	0
08-36-34-21W4	Rich	Viking A	Viking	83/07	0	143	9
09-36-34-21W4	Rich	D-3A OFFTARGET	Leduc	82/08	573,803	30,727	217,930
09-36N-34-21W4	Rich	D-2A OFFTARGET	Nisku	83/09	26,272	1,857	17,552
04-03-35-20W4	Fenn-Big Valley	D-2A	Nisku	63/10	1,659	99	4,749
05-03-35-20W4	Fenn-Big Valley	D-2A	Nisku	51/12	76,115	5,411	121,041
06-03-35-20W4	Fenn-Big Valley	D-2A	Nisku	51/08	23,351	1,590	27,224
10-03-35-20W4	Fenn-Big Valley	D-2A	Nisku	51/09	121,744	8,335	50,731
11-03-35-20W4	Fenn-Big Valley	D-2A	Nisku	52/10	82,932	5,863	89,831
12-03-35-20W4	Fenn-Big Valley	D-2A	Nisku	51/01	59,306	3,910	54,093
00/13-03-35-20W4	Fenn-Big Valley	D-2A	Nisku	52/03	139,044	9,707	46,037
02/13-03-35-20W4/02	Fenn-Big Valley	D-3A D-2A	Leduc Nisku	84/07 84/07	21,851 14,863	1,815 8,106	2,444 12,678
14-13-35-20W4	Fenn-Big Valley	D-2A	Nisku	51/07	110,078	7,672	125,775
15-03-35-20W4	Fenn-Big Valley	D-2A	Nisku	52/07	40,371	2,688	21,641
16-03-35-20W4	Fenn-Big Valley	D-2A	Nisku	51/02	73,061	4,838	92,226
01-04-35-20W4	Fenn-Big Valley	D-2A	Nisku	54/11	44,764	2,875	57,647
08-04-35-20W4	Fenn-Big Valley	D-2A	Nisku	51/10	106,795	8,096	69,525
09-04-35-20W4	Fenn-Big Valley	D-2A	Nisku	51/10	31,770	2,433	63,875
16-04-35-20W4	Fenn-Big Valley	D-2A	Nisku	52/02	17,407	1,156	9,932

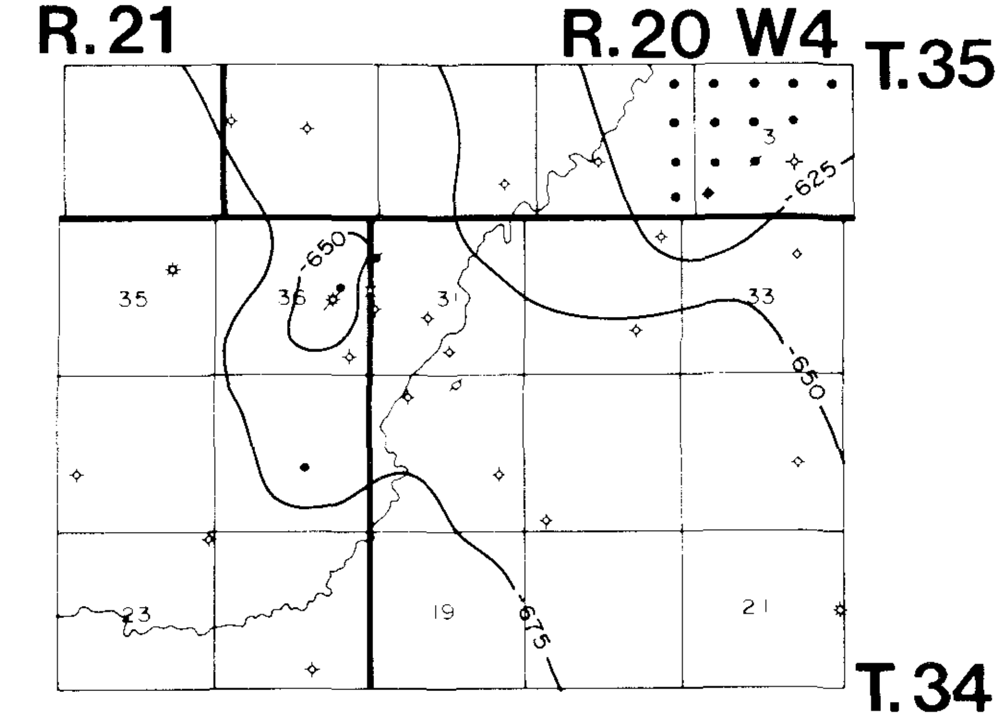


Figure 4.34. Contour map (in metres relative to mean sea level) of the Wabamun Fm.

reservoirs (Leduc Fm and Nisku Fm, respectively). Four of the pools, the Glauconite B, Glauconite C, Belly River B and Viking A are Cretaceous reservoirs. The unassigned pool is a shut-in potential gas well capable of producing from the Mannville. The D-3A pool produces from the Rumsey 9-36 Leduc pinnacle reef well and the D-2A pool produces from the biostromal Nisku Fm which drapes across this Leduc pinnacle.

The Leduc Fm in the area developed as isolated pinnacles and larger atolls. The Rich field pinnacle (D-3A pool) is located basinward of the Fenn-Big Valley Leduc reef complex. Pinnacles in this area typically attain heights of 200 m and are overlain by Ireton Fm shales. The Rich field was selected as an example Woodbend Gp reservoir for three reasons:

(1) The Leduc Fm, D-3A pool is a significant reservoir from an economic perspective. Production, as of December 1987, from this pinnacle and from the overlying D-2A pool was 574 x 10^3m^3 of oil and 30,000 10^3m^3 of gas, and 36 x 10^3m^3 of oil and 18,000 x 10^3 m^3 of gas, respectively;

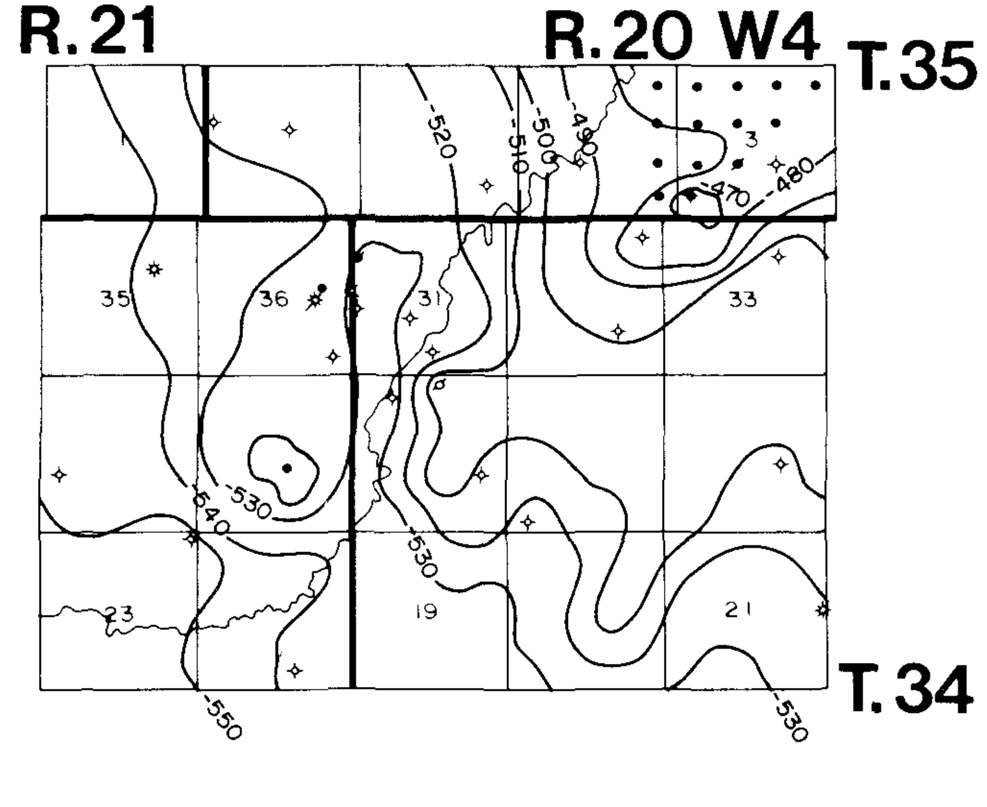


Figure 4.35. Contour map (in metres relative to mean sea level) of the Banff Fm.

(2) The seismic line displays a significant variation in the seismic signature of the Wabamun salts (due to partial dissolution); and

(3) The seismic line is well orientated for illustrative purposes, crossing the D-3A pinnacle and the southeastern edge of the Fenn-Big Valley Leduc Fm reef complex.

GEOLOGICAL CROSS-SECTION

Figure 4.29 gives the locations of the three wells incorporated into the geological cross-section (Fig. 4.30) and the seismic section (Fig. 4.31). Two of the wells are approximately 500 m from the seismic line, whereas the third lies on the seismic line. Such extrapolation is necessary for interpretation purposes as the geological cross-section illustrates the 25 m (minimum) variation of the thickness of the Wabamun salts in the area, and demonstrates the effect of dissolution, particularly in the vicinity of the 7-32 well. The top of the Wabamun Gp in this well is 20m structurally low relative to many of the surrounding wells. Relief due to salt dissolution is complicated as a result of drape across underlying reefs.

The contoured Leduc/Cooking Lake structure map is shown as Figure 4.32. The Leduc D-3A pinnacle is isolated from the Fenn-Big Valley reef complex to the northeast. The inner contour of -900 m sub-sea across the pinnacle is 50 m lower than the Fenn-Big Valley reef contour of -850 m suggesting that the 9-36 well may not have penetrated the apex of the pinnacle. The Leduc Fm is overlain by the upper Ireton Fm and the Winterburn Gp. In off-reef areas the Ireton overlies the Duvernay Fm shale. The Calmar Fm structure map (Fig. 4.33) shows that the Calmar drapes across both the pinnacle and the reef complex.

Without the effect of partial salt dissolution, the Wabamun Gp, more typically, would drape across both the D-3A pinnacle reef and Fenn-Big Valley reef complex. The Wabamun Gp is 7 m lower immediately to the east of the 9-36 well than in this well (Fig. 4.34). However, the Wabamun Gp top is 25 m lower (-659 versus -634 m sub-sea) at the 7-32 well than at the neighbouring reef complex well, 15-33. This could be interpreted as drape due to differential compaction except for the fact that the Calmar depth values in the same two wells differ by only 13 m (Figs 4.30 and 4.33). Wabamun Gp structure, therefore, must be related to partial dissolution of the Wabamun Gp salts.

The Glauconite B,C, Viking A and Belly River pools overlie relative structural lows at the Wabamun and Banff levels. The Belly River B pool in the 10-32 well appears to lie within the structural low caused by the salt dissolution in the area of the 7-32 well. The Viking A pool lies across the Leduc D-3A pinnacle and appears to be influenced by the drape due to differential compaction. The other two pools do not appear to be associated with anomalous Wabamun Gp structures.

SEISMIC SECTION

Figure 4.29 shows the location of the seismic line (Fig. 4.31) which crosses the D-3A pinnacle reef and extends onto the southwestern edge of the Fenn-Big Valley reef complex. These data were acquired using the Vibroseis source (4 in-line with a 12-second 90-10-Hz sweep length), a 1530-m split spread, 120-m shot spacing and a 30-m group interval.

Figures 4.36 and 4.37 present a seismogram and synthetic seismic section, respectively, of a pinnacle reef (9-36-34-21W4M). The

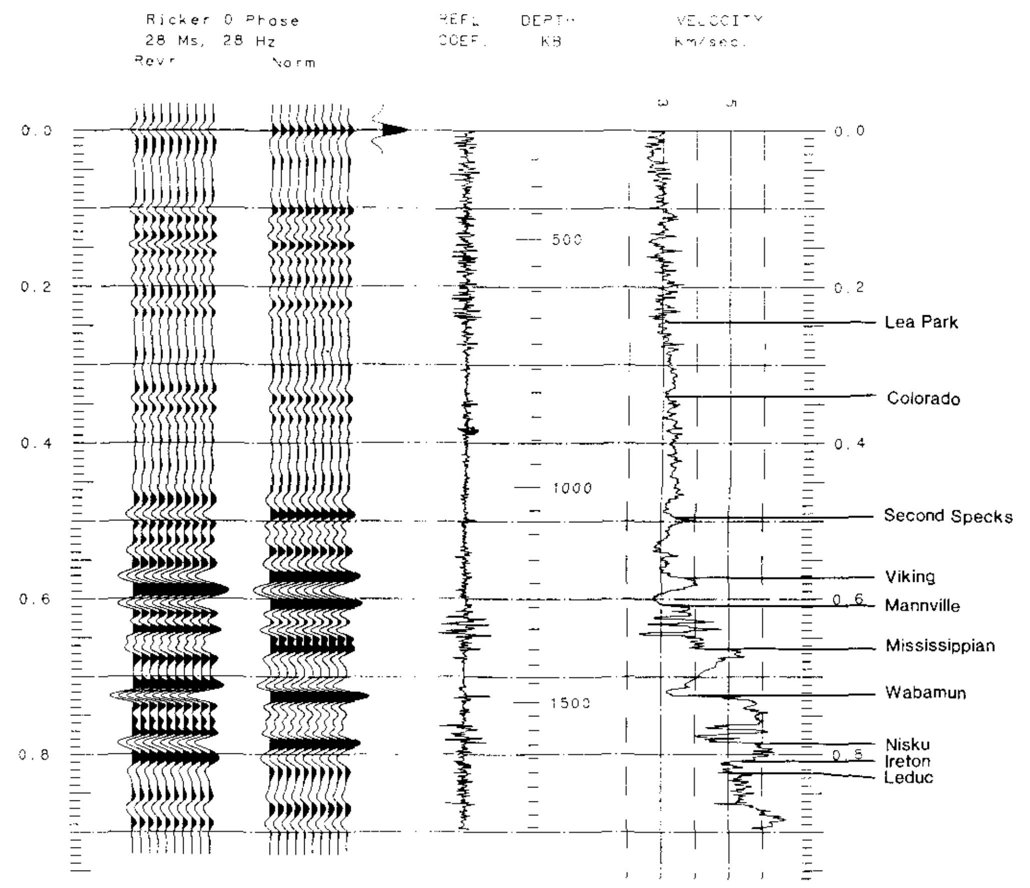


Figure 4.36. Seismogram for the 9-36-34-21W4M well.

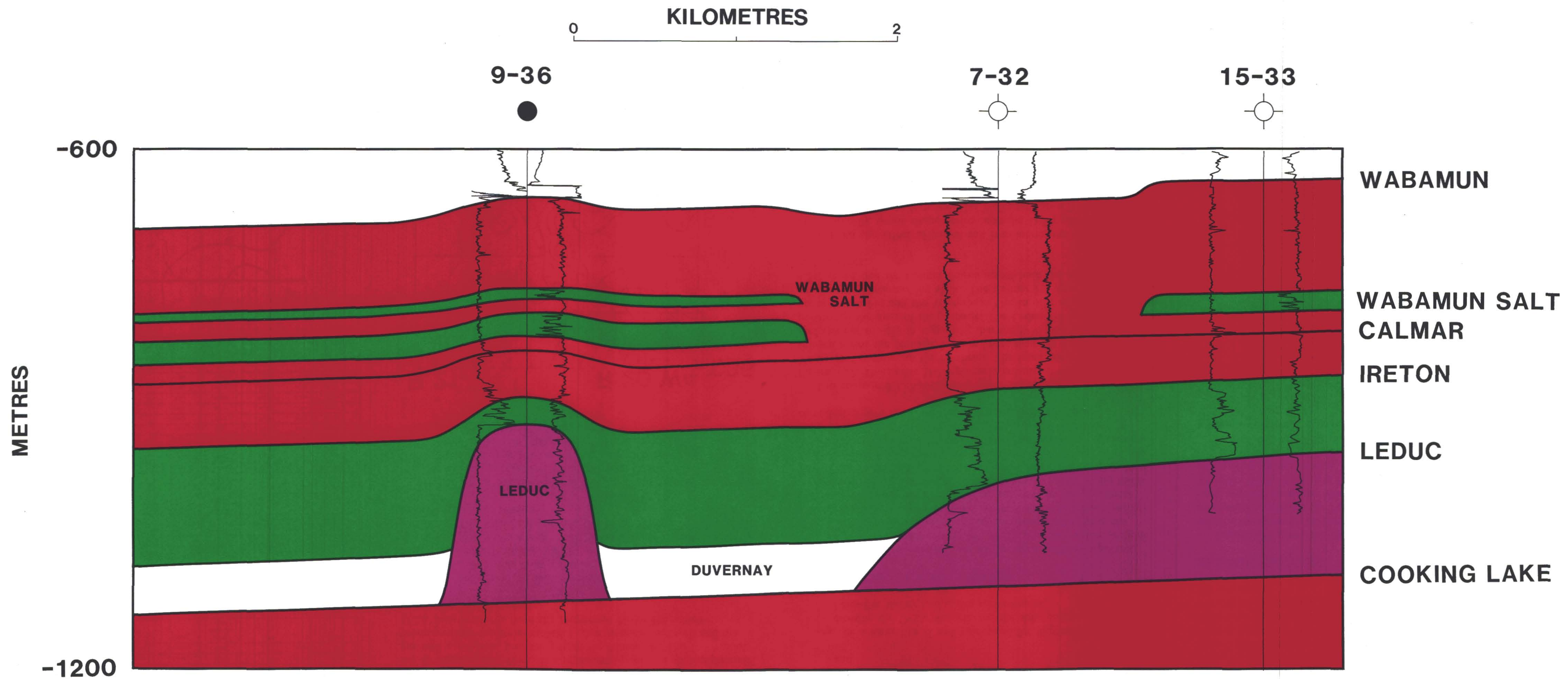


Figure 4.30. Geological cross-section, Rich study area.

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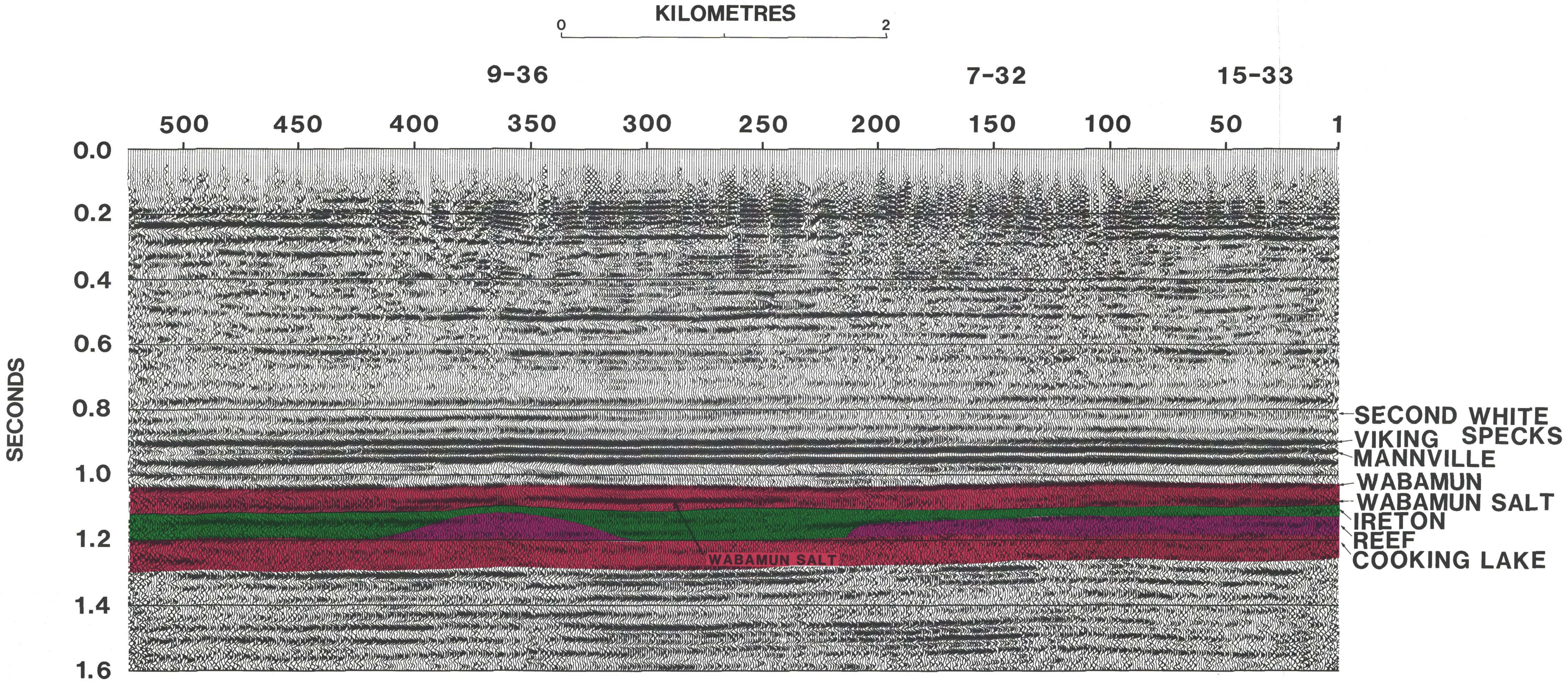

Figure 4.31. Normal polarity seismic section, Rich study area.

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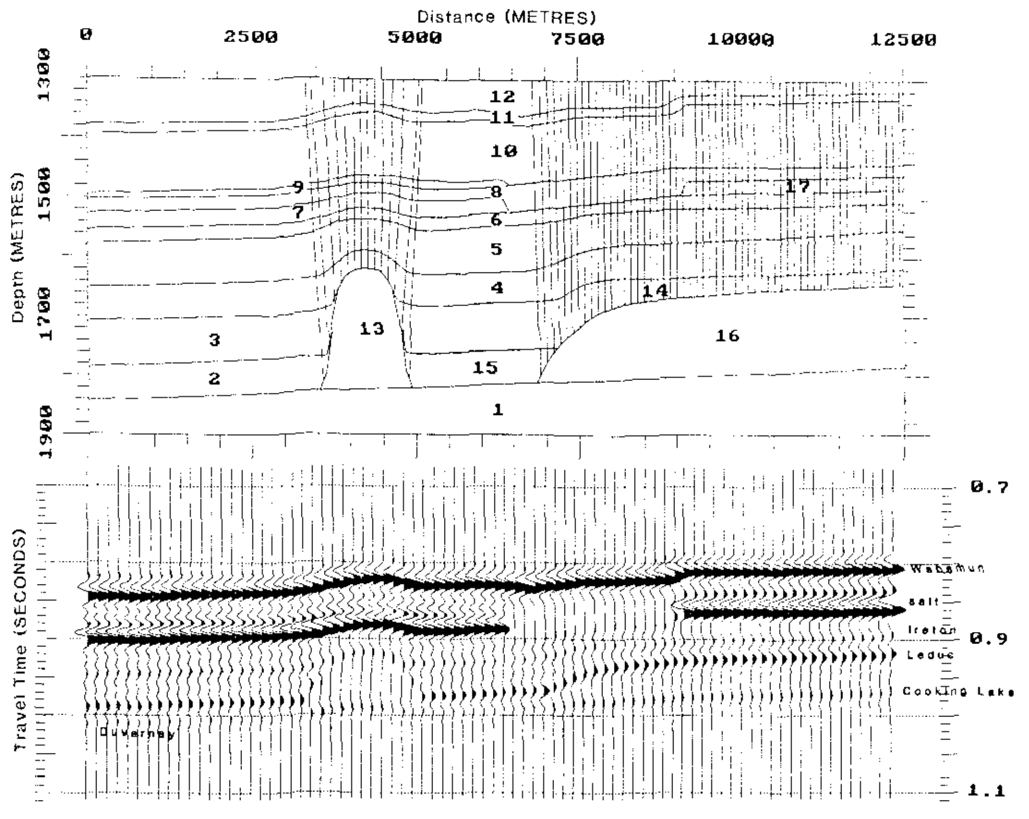

	Velocity (m/s)	Density (kg/m^3)		Velocity (m/s)	Density (kg/m^3)
(1) Cooking Lake	6200 6200	2750 2750	(2) Duvernay	5800 5800	2700 2700
(3) Ireton	4800 4800	2650 2650	(4) Ireton	5400 5400	2650 2650
(5) Nisku	5900 5900	2750 2750	(6) Wabamun	5900 5900	2750 2750
(7) Salt	4300 4300	2200 2200	(8) Wabamun	5900 5900	2750 2750
(9) Salt	4300 4300	2200 2200	(10) Wabamun	5900 5900	2750 2750
(11) Exshaw	3200 3200	2650 2650	(12) Mississippian	4000 4000	2650 2650
(13) Leduc	5600 5600	2700 2700	(14) Ireton	4800 4800	2650 2650
(15) Duvernay	5800 5800	2700 2700	(16) Leduc	5600 5600	2700 2700
(17) Salt	4300 4300	2200 2200			

Figure 4.37. Synthetic seismic section generated from the geological cross-section (Fig. 4.31) using a zero-phase, normal polarity, 30-Hz, Ricker wavelet.

Cooking Lake Fm is not penetrated by the 9-36 well and regional seismic control as well as other synthetics were used for the interpretation of this marker on the seismic data. On the seismic section, the Cooking Lake event is as much as 20 ms time-structurally higher beneath the pinnacle than off-reef, due primarily to lateral variations in the thicknesses of Leduc Fm and Wabamun Gp salts. Less pull-up is observed beneath the Fenn-Big Valley reef complex at the eastern end of the seismic line probably due to the fact that the reef complex is relatively thin in this area.

The Ireton Fm shale event, off-reef, is a strong peak on the seismic section. On-reef, this reflection diminishes in amplitude and undergoes a character change due to interference with the Nisku event. It is difficult to interpret variations of Nisku porosity on seismic data because of these interference effects.

Drape at the Wabamun Gp (on the order of 5 ms) is affected by the presence or absence of the Wabamun salts. The salt affects the seismic interpretation in that the drape across reefs due to compaction of reef and off-reef strata may be affected by the discontinuous nature of these salts (Anderson et al. 1988a). For example, drape across the D-3A pool reef is accented by the thinning of the salt from the 9-36 well to the 2-31 well (to the east). In contrast, drape at the Wabamun level on the eastern part of the seismic section is diminished by the absence of salt in the 7-32 well (at the edge of the reef complex) and the presence of salt off-reef.

The Cretaceous markers exhibit closure across the reef that could be affected by the dissolution of the Wabamun Gp salts. Above the pinnacle D-3A pool reef the Viking marker drapes some 10 ms and does not exhibit closure until the area of the 7-32 well. East of the 7-32 well, the Viking drapes across the edge of remnant salt. This abrupt change in relief along the Cretaceous (Viking) could be misinterpreted as drape across of an underlying Leduc reef. The presence of the more or less continuous Ireton marker below the salt dissolution allows the identification of off-reef shale in the seismic section.

Interpretation of the seismic data in those areas where remnant Wabamun Gp salts are present is done in two steps:

(1) estimate the relative thickness of the Wabamun Gp; and

(2) after mapping the salts, analyse the seismic data for features characteristic of Leduc reefs. Such features would include pull-up, drape, lateral variations in the seismic image of the Woodbend Gp and lateral amplitude changes along specific seismic events.

REDWATER FIELD

INTRODUCTION

The 600 km^2 Redwater Leduc Fm reef complex is located 10 km east of the Clyde reef at the northern end of the Rimbey-Meadowbrook trend, 40 km northeast of the city of Edmonton (Fig. 4.2). The reef, which reaches a maximum thickness of over 270 m, forms a roughly triangular build-up characterized by a pronounced rim, defined by well control on the eastern side, which probably extends

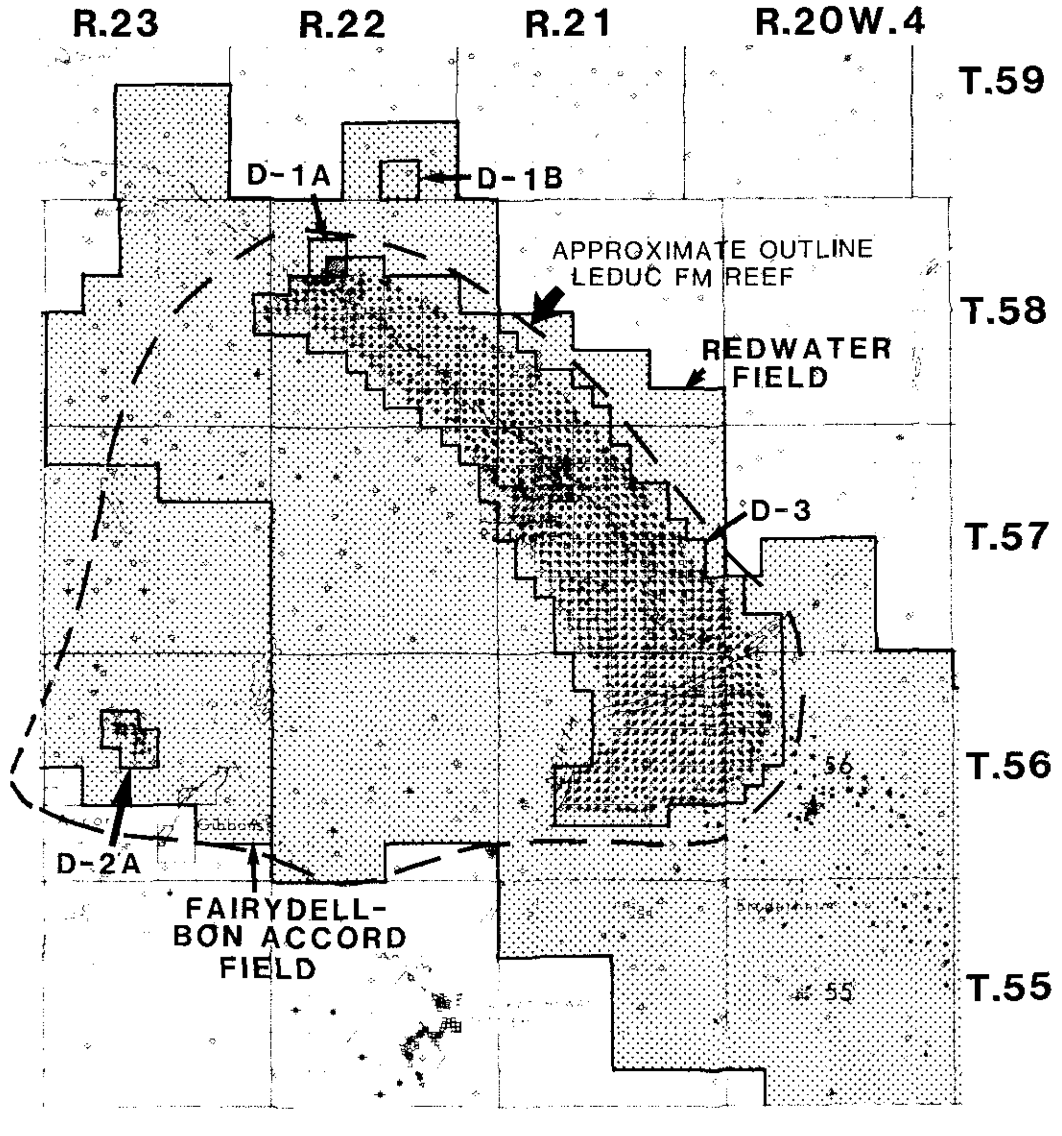

Figure 4.38. Fields and Devonian pools in the Redwater area.

around its periphery. Thus the term "atoll" as defined by Mossop (1972), is used interchangeably with "reef" in reference to the Redwater complex throughout this interpretation.

The Redwater complex produces hydocarbons from both the Redwater and Fairydell-Bon Accord fields located respectively on the east and west sides of the atoll as shown in Figure 4.38. The larger Redwater field contains three Devonian pools, two small D-1 pools (Wabamun Gp) near the northern corner of the complex and a D-3 (Leduc Fm) pool with over 1000 wells which extends along the updip (northeast) edge of the reef. Hydrocarbons in the D-3 pool are stratigraphically trapped at a depth of approximately 330 m subsea (Fig. 4.39) by impermeable Ireton Fm shales which enclose the reef.

The D-2A (Nisku Fm) pool assigned to the Fairydell-Bon Accord Field on the western side of the complex constitutes the only other Devonian pool associated with the Redwater reef. The trap in this pool is likely created by drape over a prominant feature on the Leduc complex below. Table 4.8 contains production and reserve data for these three pools, however data for the numerous post-

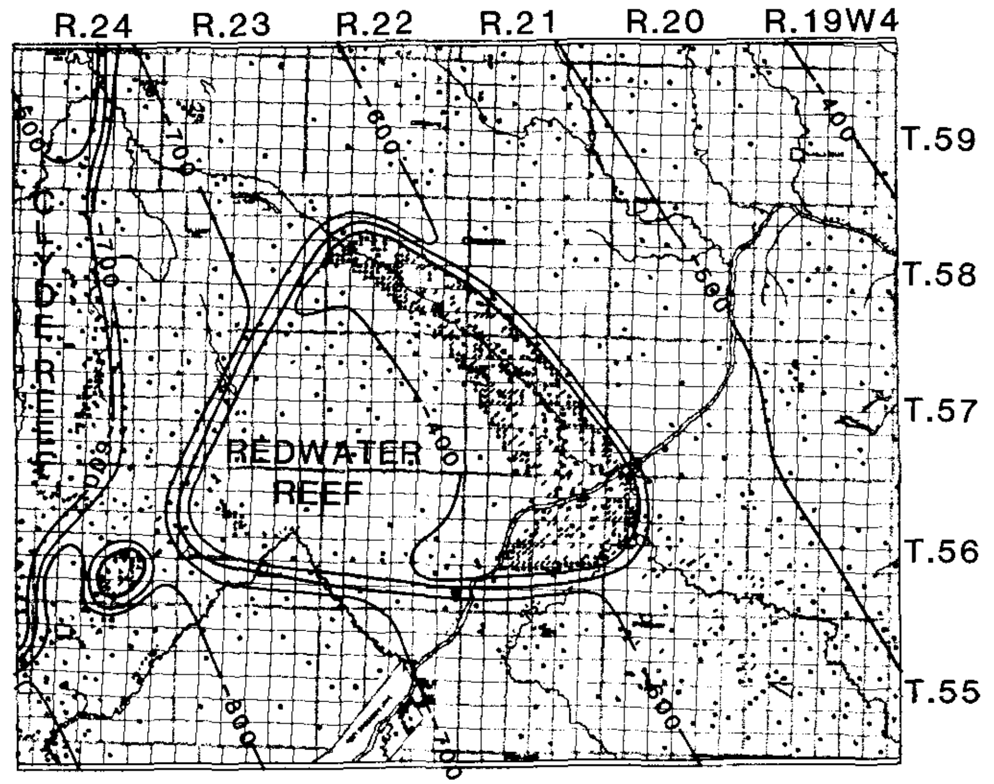

Figure 4.39. Contour map (in metres relative to mean sea level) of the Leduc Fm top (or in its absence, the Beaverhill Lake Gp top). The location of profile 'A-B' (Fig. 4.44) is shown.

Table 4.8. Reserve and production statistics for Devonian pools associated with the Redwater complex (Fig. 4.38) up to Dec. 31, 1987

	Year on Production	Number of wells	1987 Oil Prod 10^6 m^3	Cumulative Oil Prod 10^6 m^3	[illegible] Initial Established Oil Reserves 10^6 m^3	1987 Gas Prod 10^6 m^3	Cumulative Gas Prod 10^6 m^3
Redwater							
D-1A	1958	3	-	-		-	158.4
D-1B	1978	[illegible]	-			-	49.8
D-3	1948	1035	2.828	124.1	[illegible]	46.9	[illegible]
Fairydell-Bon Accord							
D-2A	1949	13	-	[illegible]	[illegible]		3.3

Data supplied by Virtual Computing Services Ltd.
* Data furnished by the Energy Resources Conservation Board.

Devonian pools which are also part of the Redwater and Fairydell-Bon Accord fields has been omitted.

Unlike many of the Leduc Fm reefs discussed in this chapter, Redwater is not pervasively dolomitzed and as a result, its lithology and stratigraphy have been extensively studied since its discovery by Imperial Oil in 1948. Core studies by Andrichuk (1958) and Klovan (1964) have identified distinctive fore-reef and organic-reef belts which appear to enclose an extensive back-reef area. The study area is also anomalous in that over 50 m of "Duvernay Fm" shale separates the reefal Leduc Fm into upper and lower units.

GEOLOGICAL CROSS-SECTION

As shown on Figure 4.40, the geological cross-section (Fig. 4.41) and associated seismic section (Fig. 4.42) extend eastwards across the rim of the atoll and into the Ireton Fm shale basin. The structural features highlighted in the interpretation are similar to those indicated by Klovan (1964) in his cross-section no. 5.

The geological cross-section consists of seven wells selected for their depth of penetration, availability of sonic-logs, proximity to the seismic line and representative geological section. It displays a transition from full reef to shale basin and correlates closely to the seismic section.

The deepest complete sequence sampled by the well control is the Beaverhill Lake Gp. It overlies the Elk Point Gp and underlies the 70 m thick Cooking Lake Fm which is the partially dolomitized platform carbonate upon which the Leduc Fm reefs in the Redwater area formed. Wendte (1974) concluded that reef growth initiated on a broad pre-Cooking Lake high which became more localized with each rise in sea level. Mossop (1972), however, found that 99.6% of

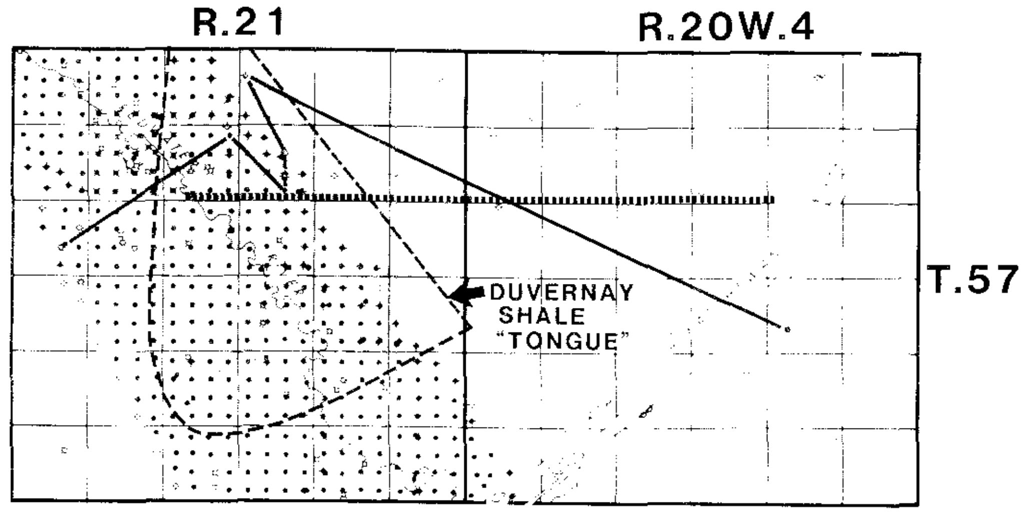

Figure 4.40. Redwater study area. The locations of the geological cross-section (Fig. 4.41) and seismic section (Fig. 4.42) are shown.

the variance of the Beaverhill Lake Gp surface could be fitted to a plane, implying that relief was very slight.

The 50 m of slightly argillaceous limestone which overlies the Cooking Lake Fm in the area is herein referred to as the "lower Leduc unit". It is separated from a generally clean, approximately 120 m thick limestone, which is termed the "upper Leduc unit" by 50 m of brownish black Duvernay Fm (?) shale and argillaceous limestone which spread westwards into the reef body over an area of 50 km^2 (Mossop, 1972).

Off-reef, the 70 m thick Duvernay section in overlain by 180 m of Ireton Fm limestone and calcareous shale. The green shale of the upper Ireton thins from 50 m over the reef edge to 25 m at the western end of the cross-section and to less than 20 m in the central portion of the build-up. This would suggest that the bioherm originally had a broadly convex shape. Comparing this to its present day atoll-like form, virtually mirrored by the top of the Ireton Fm as depicted by the Base Fish Scales to Ireton Fm isopach of Figure 4.43 and assuming no initial relief on the Ireton surface, leads to the conclusion that significant post depositional structure has occurred.

The Redwater complex is broadly divisible into three regions, each with a distinctive structural history. They are: 1) the reef rim, a zone 2-3 km wide around the periphery of the atoll characterized by the highest concentrations of framework building organisms in the upper Leduc Fm (Klovan, 1964) and to which compaction in other areas is referenced; 2) the back-reef or lagoonal area, which since the end of Woodbend deposition has subsided from 12 m above the present day rim to a position 35 m below (Mossop, 1972); and 3) the portion of the fore-reef on the eastern side underlain by Duvernay Fm shale and distinguished by a broad 20 m saddle in the raised

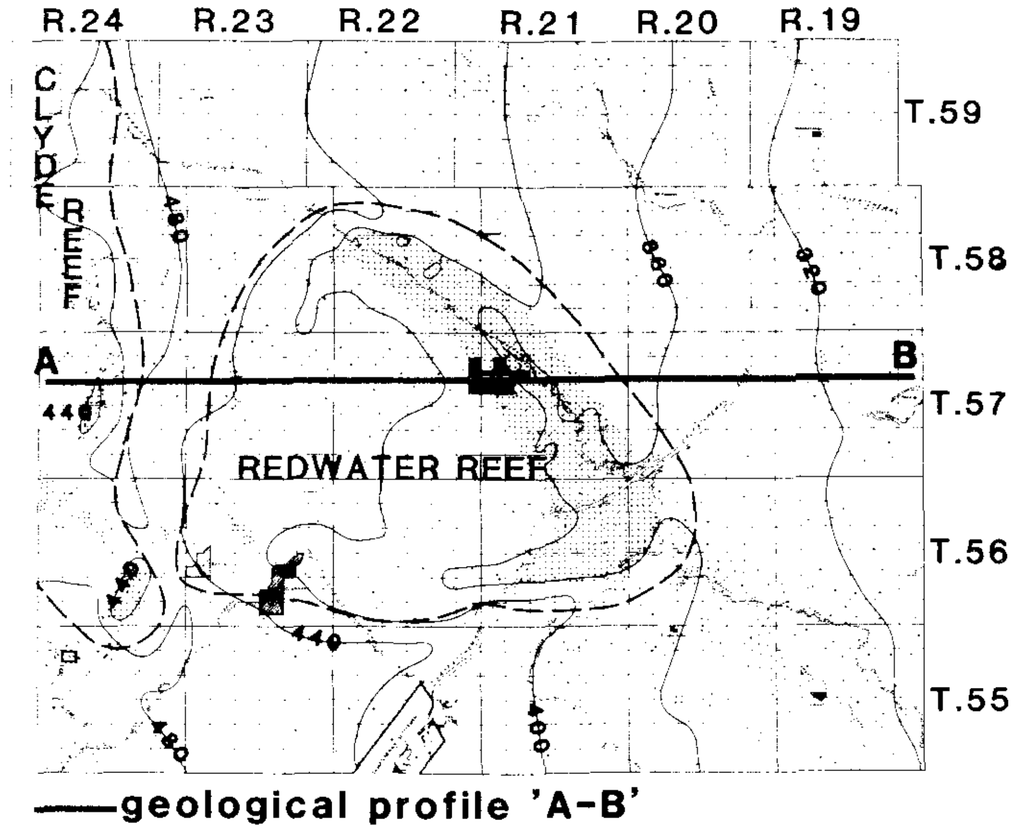

Figure 4.43. Contour map of Base Fish Scales to Ireton interval (in metres). The location of profile 'A-B' (Fig. 4.44) is shown.

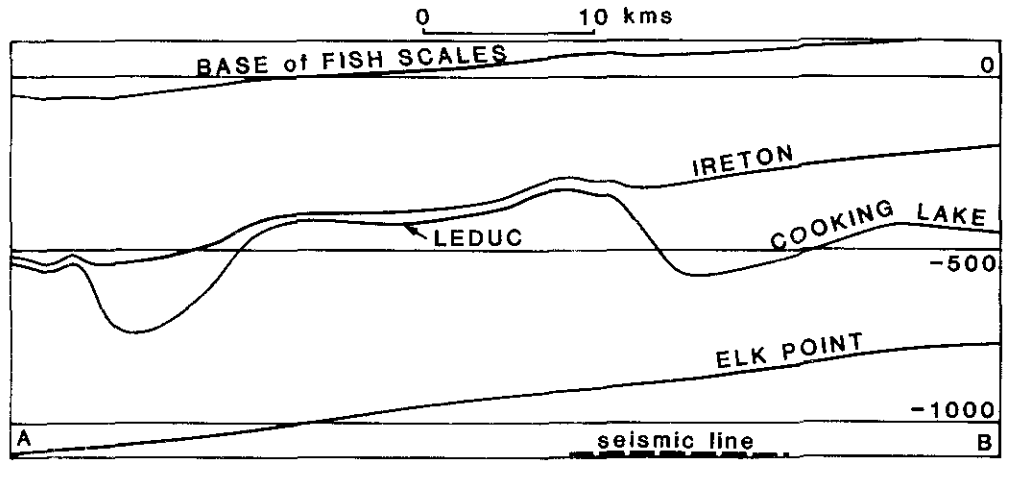

Figure 4.44. Profile A-B across the Redwater reef. Refer to Figures 4.39 or 4.43 for location.

fore-reef area likely caused by differential compaction of the shale "tongue".

Using intervals mapped from first order residuals and regression analysis, Mossop (1972) demonstrated that 63% of the present day relief on the Leduc Fm between the rim and the back-reef area occurred prior to the Cretaceous and the remainder at some time following the deposition of the Lea Park Fm. However, O'Connor and Gretener (1974) in their comparison of compaction curves from both rim and rim-saddle areas, discovered that the latter underwent significant differential compaction throughout the Cretaceous. The profile 'A-B' in Figure 4.44 shows that the Ireton Fm drapes by about 30 m into the shale basin to the east and thins over a narrow, 15+ m high rim (?) on the periphery of the reef. The decrease in thickness of the Ireton section over the "rim" implies that it is at least in part a depositional feature.

The pre-Cretaceous unconformity generally cuts down through the Wabamun section from the west, exposing the Nisku Fm in the eastern half of the area. However, this trend is locally reversed along the cross-section such as at the 10-27 location. Drape in the Cretaceous horizons is limited as the Base Fish Scales exhibits only 10 m of structure across the edge of the Leduc reef.

SEISMIC SECTION

The seismic line presented in Figure 4.42 is oriented from west to east across the northeastern edge of the Redwater reef (Fig. 4.40). Relevant acquisition and processing parameters are listed in Table 4.9.

The eleven horizons correlated across the seismic section correspond closely to the formations annotated on the geological cross-section of Figure 4.41. Of the three parallel sub-Woodbend events highlighted on the seismic interpretation, the "lower

Table 4.9. Acquisition and processing parameters for the example seismic section (Fig. 4.41) across the Redwater field

ACQUISITION PARAMETERS	
DATE SHOT:	August 1978
SOURCE:	dynamite, 5 lbs
SOURCE ARRAY:	single hole, 50 ft.
SOURCE INTERVAL:	440 ft.
GEOPHONE INTERVAL:	220 ft.
GEOPHONE ARRAY:	9 over 160 ft, 10 Hz
SPREAD:	5170 ft. - 110 ft x (split)
CHANNELS:	48
SAMPLE RATE:	2 ms

PROCESSING PARAMETERS	
DEPHASING:	instrument & geophone
DECONVOLUTION:	spiking, 80 ms op, 1% pw
STRUCTURE STATICS:	elevation only
DATUM:	2100 ft ASL
V REPLACEMENT:	8000 ft/sec
STACK:	1200%
FINAL FILTER:	10/15-50/60 Hz
POLARITY:	peak positive

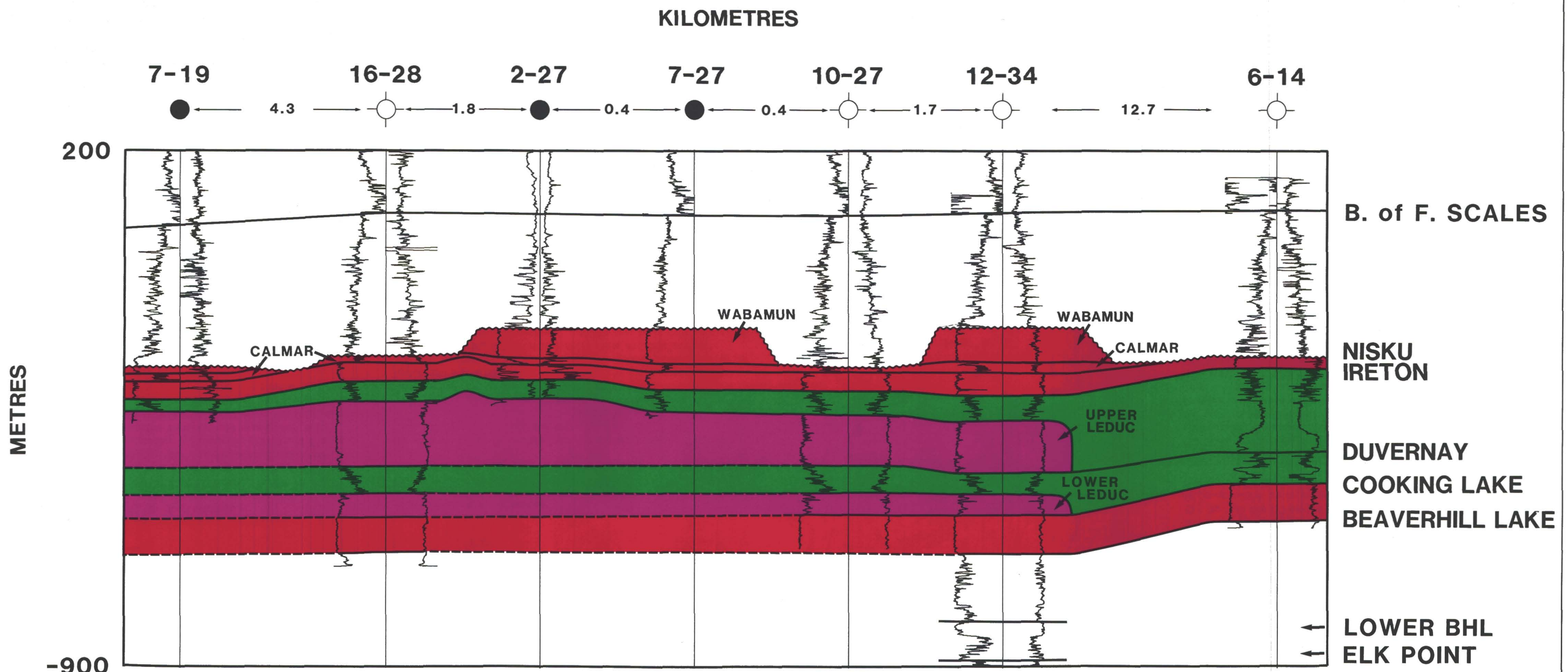

Figure 4.42. Geological cross-section, Redwater study area.

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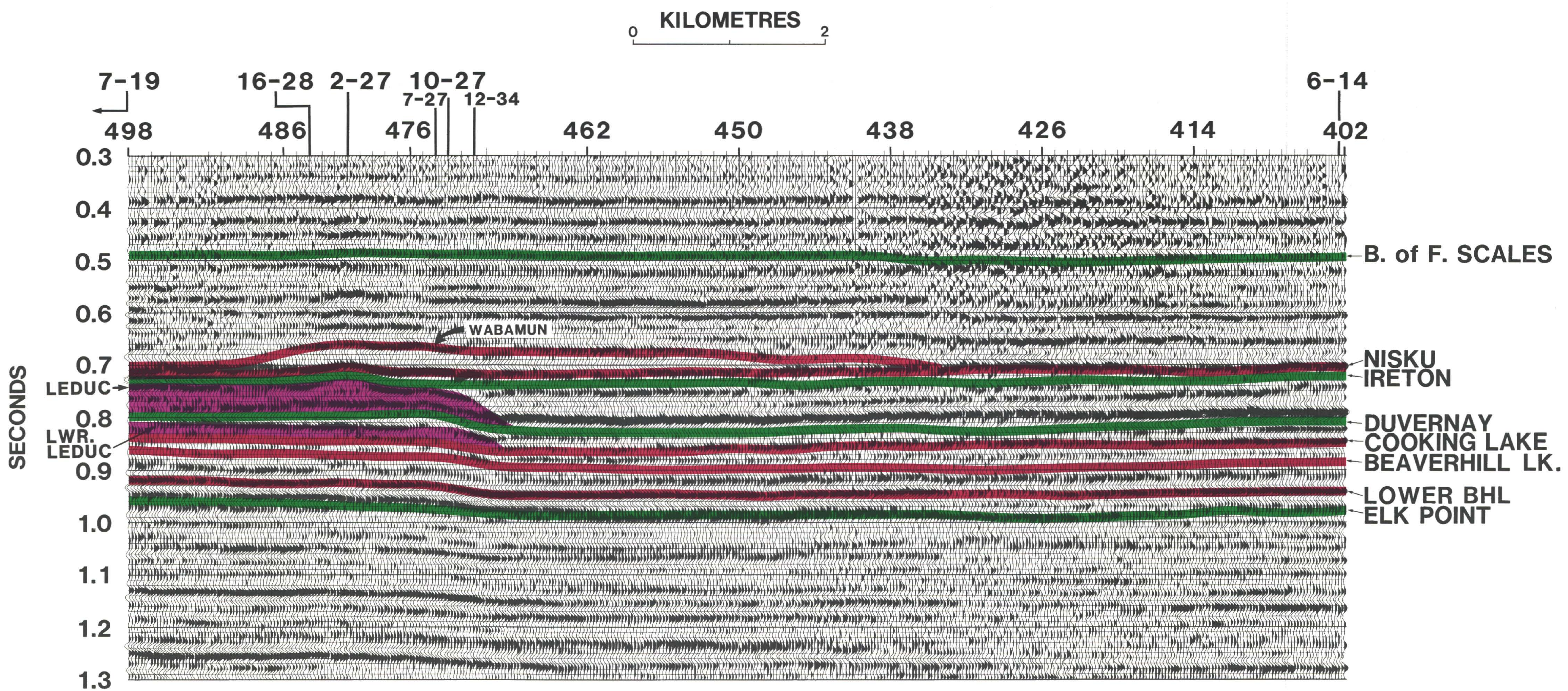

Figure 4.41. Normal polarity seismic section, Redwater study area.

DONOR: CHEVRON CANADA RESOURCES LTD. | PROCESSOR: VERITAS SEISMIC LTD. | AUTHOR: D. WHITE

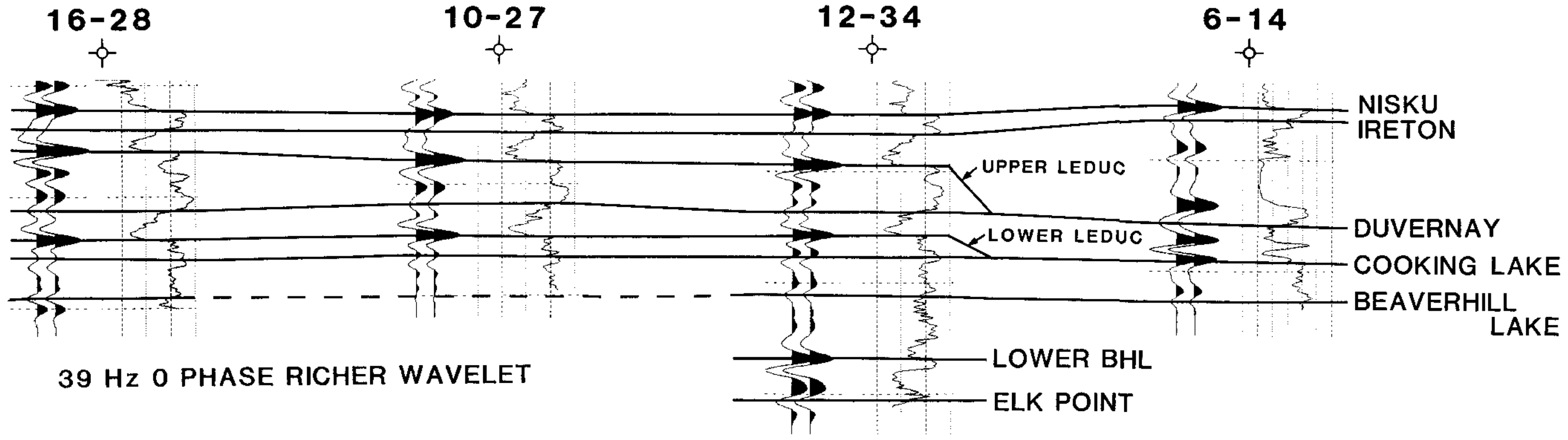

Figure 4.45. Synthetic seismograms for the acoustic logs in Figure 4.41.

Beaverhill Lake marker" is chosen as a suitable sub-Leduc datum due to its coherent, regionally consistent signature and its lack of significant depositional relief.

The Cooking Lake reflection, which occurs 35 ms above the weak Beaverhill Lake event, is a distinct seismic event only in the off- reef position east of trace 470, where it is overlain directly by low velocity Duvernay Fm shales. To the west, where the Cooking Lake Fm is capped by the high impedance lower Leduc unit the acoustic impedance contrast across the interface becomes very small as demonstrated by the synthetic model of Figure 4.45. The Duvernay event off-reef, appears to be roughly correlative to the reflection originating at the top of the Duvernay shale tongue which overlies the lower Leduc and underlies the upper Leduc unit. It is clearly visible at 0.8 seconds between the reef edge and trace 495. West of this point the shale pinches out and the upper and lower Leduc units become seismically indistinguishable.

The 25 ms of time structure evident on all the sub-Leduc events between traces 460-485 is interpreted to be "pull-up" due to the velocity difference between off-reef and on-reef sections as summarized in Table 4.10.

The Ireton Fm overlies the Duvernay Fm east of station 470 and the upper Leduc unit to the west. All reflections within the off-reef

Table 4.10. Comparison of on-reef to off-reef interval times for Woodbend Gp (from Figure 4.42)

LOCATION	IRETON-COOKING LAKE INTERVAL (m) (from Fig. 4.41)	INTERVAL TIME (sec) (from Fig. 4.42)	INTERVAL VELOCITY (m/s)	INTERVAL TIME V=3815 m/s (sec)	INTERVAL TIME DIFFERENCE OFF-REEF vs. REEF ("PULL-UP") (sec)
10-27-51-21 W4 (On-reef)	265	0.114	4649	0.139	0.025
6-14-57-20 W4 (Off-reef)	248	0.130	3815		

Ireton section terminate at the reef edge except for the uppermost event which drapes by 5-10 ms over the build-up. The gradual westward thinning of the shale predicted by geological control is displayed on the seismic data by a steady decrease in the Nisku to upper Leduc interval, coupled with amplitude changes particularly along the Ireton and upper Leduc reflections. At trace 490, these amplitudes are quite weak but increase towards the western end of the line. The fluctuation is probably due to destructive then constructive interference between the Nisku, Ireton and upper Leduc events as the Ireton section thins. This regional trend is locally interupted by an abrupt 10+ ms (25 m?) thickening of the upper Leduc section near trace 481. Both the Ireton and Nisku formations display 10 ms of drape and 5 ms (total) of thinning over this 0.5 km wide mound shaped feature which, in profile, appears to represent either a narrow rim or alternately a small build-up, locally developed on the slope break on the eastern edge of the atoll.

The narrow band of Winterburn Gp subcrop near the 10-27 location is evident on the seismic section near trace 492 close to the apex of the broad rim mapped by Mossop (1972). The Wabamun Gp, which subcrops beneath the Cretaceous on either side of this feature, extends eastwards to approximately trace 434. Here the Nisku reflection strengthens, implying direct contact of the Nisku Fm and the Lower Cretaceous.

Intervals within the Cretaceous exhibit little change across the edge of the Redwater reef, an observation consistent with Gretener and Labute's (1972) findings at Wizard Lake 100 km to the southwest. The approximately 10 m (5 ms) of drape expected from geological control at the Base Fish Scales level is consistent with the seismic data.

REMARKS

Due to its abrupt eastern margin and the presence of a strong, coherent upper Leduc event, the Redwater reef is particularly easy to locate on reflection data. Seismic indicators of the Redwater build-up include: 1) subtle drape along the Ireton and Nisku events; 2) reflector terminations within the Woodbend section at the reef edge; and 3) 25 ms of "pull-up." A minor amount of drape in Cretaceous strata is also indicative of the reef.

Using hydrocarbon detection methods unrelated to seismic, Sikka (1960) concluded that zinc, uranium, ground radon and airborne radium, data all indicate that a partially developed ratioactive "halo" exists around the flanks of the Redwater D-3 pool. In general however, radiometric surveys cannot be targeted to a specific horizon and as such would be of limited value in detailing Devonian reservoirs.

OBED FIELD

The Obed field (Twp 54, Rge 23W5M) discovered by Imperial Oil in 1964, is situated in the midst of an 8000 km^2 Leduc Fm carbonate complex bounded by the Bigstone and Windfall build-ups to the north and south-east respectively and by the Fir/Pine Creek/ Marlboro reef chain to the northeast (Fig. 4.46). As of 1988, neither the D2-A pool (Fig. 4.47) nor the gas in the Leduc Fm has been put on stream therefore no production data is available, however the Energy

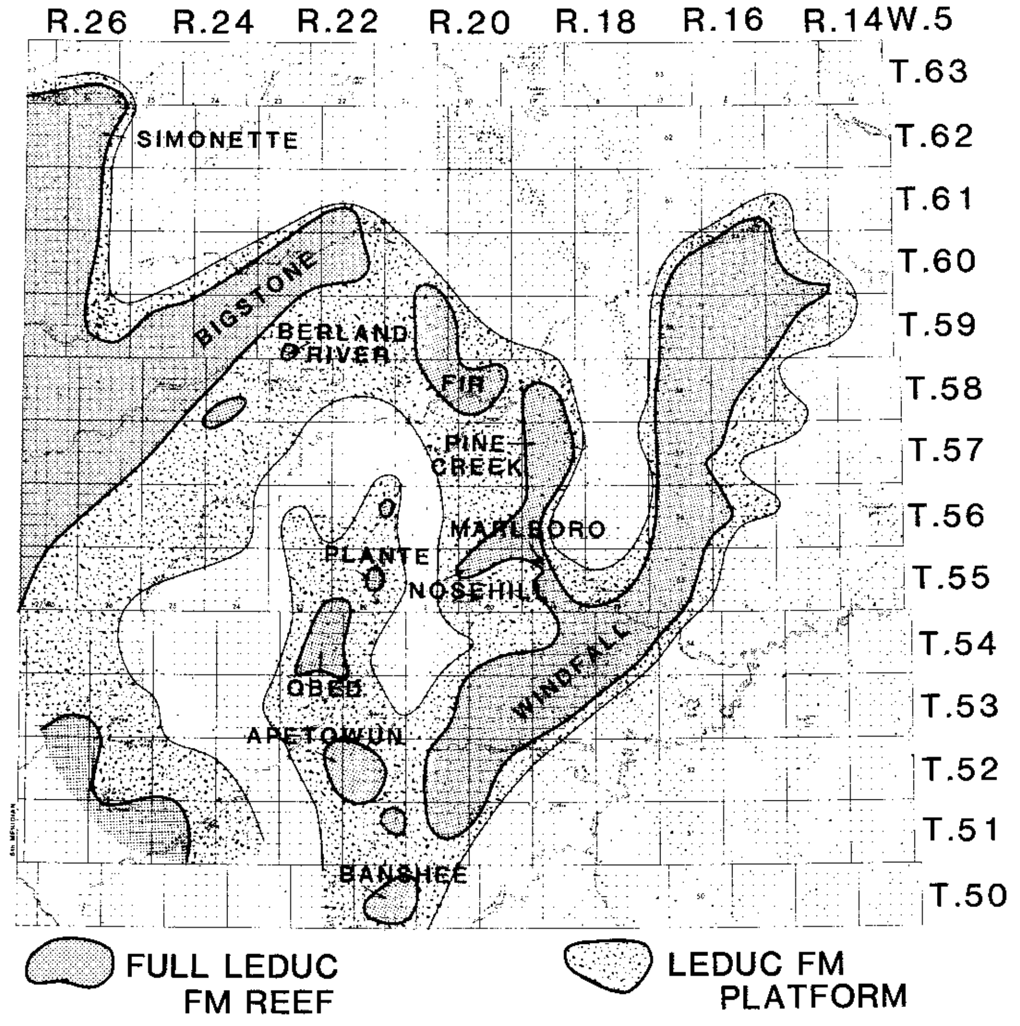

Figure 4.46. The Windfall/Bigstone complex and Obed area.

Resources Conservation Board estimates that with a recovery factor of 75% and a surface loss of 35%, the volume of raw recoverable gas in the dolomitized Winterburn Gp carbonates is 1860 Mm^3. The predominantly dolomitized Leduc Fm contains an additional 814 Mm^3 raw recoverable gas with a recovery factor of 50% and a surface loss of 40%. The surface loss for both oil and gas consists largely of hydrogen sulfide gas, a common constituent of Devonian reservoirs in the Windfall/Bigstone complex.

The Obed reef covers an area of roughly 90 km^2 and displays a pronounced peripheral rim. It developed on what appears to be a finger of basal Leduc Fm averaging 75 m in thickness, which extends northwards into an arcuate inner basin where Ireton Fm shales completely replace the carbonate section (Fig. 4.48). The reef (including basal member) reaches a thickness of over 275 m with

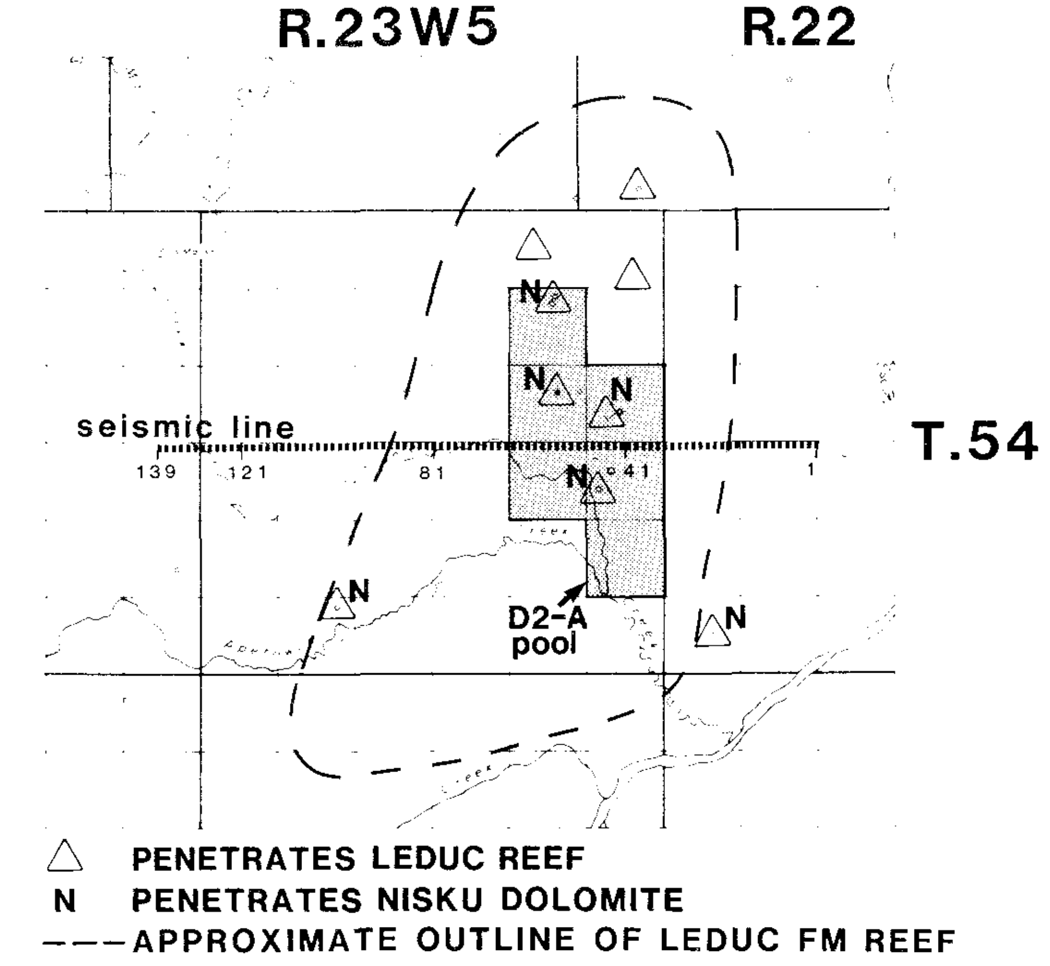

Figure 4.47. D-3 pool boundary, seismic line (Fig. 4.50) and Nisku dolomite occurrences, Obed area.

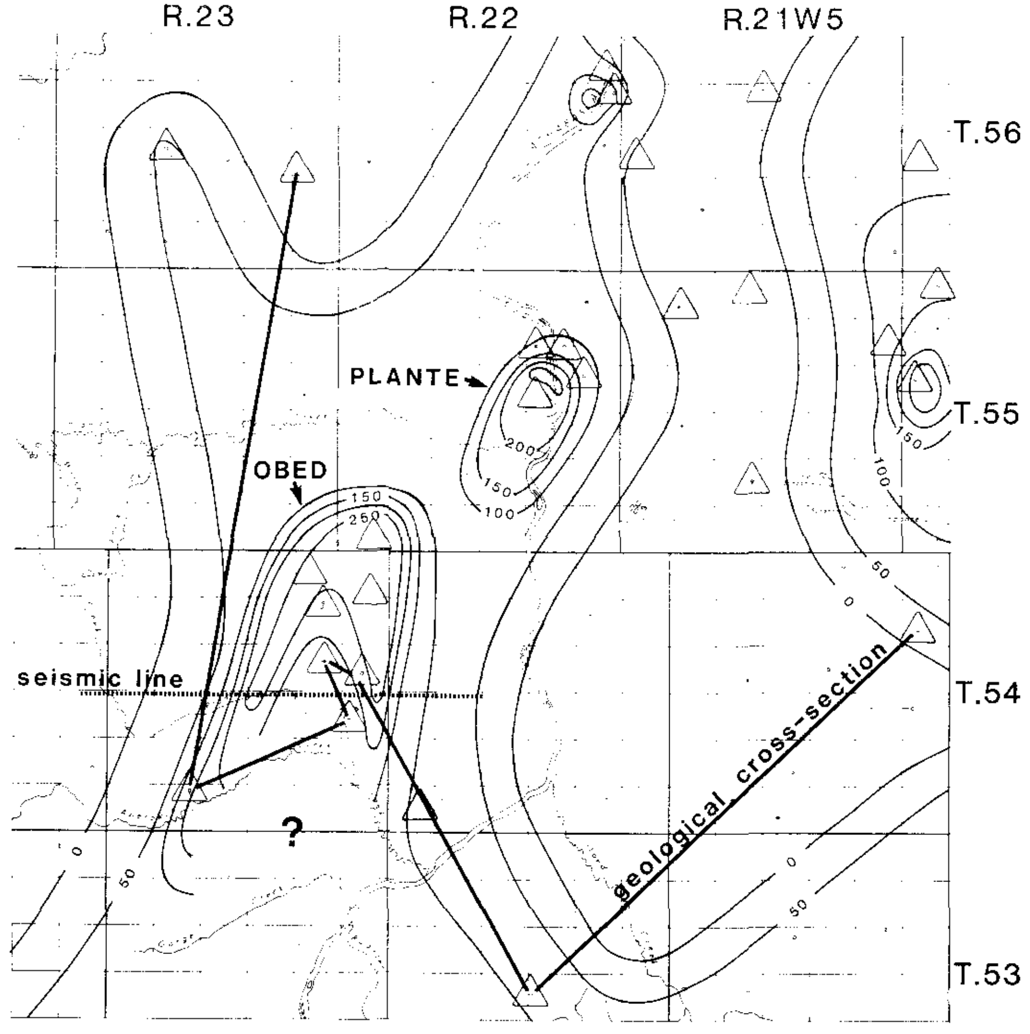

Figure 4.48. Leduc Fm isopach for the Obed area constructed with an interpolated Elk Point Gp surface and a Beaverhill Lake Gp thickness of 145 m. The location of the geological cross-section (Fig. 4.49) is shown.

little or no shale capping the build-up. This level of reef development is common to much of the nearby Windfall complex.

At 2900 m subsea, (4000 m subsurface) gas is trapped within the updip edge of the porous Leduc Fm by tight carbonates and marlstones which overlie the laterally sealing shales, forming a stratigraphic trap. In possible reservoir communication are up to 90 m of Nisku Fm dolomite, commonly associated with Leduc reefs in the Windfall/Bigstone complex, which overlie the Obed reef and grades laterally to tight argillaceous limestones two kilometres downdip (southwest) from its updip edge.

GEOLOGICAL CROSS-SECTION

The geological cross-section (Fig. 4.49) is comprised of seven wells oriented in a roughly southeasterly direction (Fig. 4.48), selected for their synthetic seismogram response and correlation to the east/west seismic line of Figure 4.50.

The deepest horizon correlated on the geological cross-section is the shale of the Watt Mountain Fm. These sediments are overlain by the Beaverhill Lake Gp, an aerially extensive "platform" carbonate with little apparent relief upon which the Woodbend reefs were formed.

The top of the essentially planar Elk Point Gp has been extrapolated to each of five cross-section wells which terminate in the Leduc Fm using a surface calculated from data over a 200 township area to the north, south and east of the field (Waddington, pers. comm.); while the Beaverhill Lake Gp interval is assumed to be a uniform 145 m (its average thickness in the 6-25-54-21W5M and 4-13-56-23W5M wells).

Overlying the Beaverhill Lake Gp is the aerially less extensive Leduc Fm of the Woodbend Gp. It can be divided broadly into a 50 to 100 m thick basal unit and an upper reef forming unit which at Obed is a gray, massive dolomite built up to a level 275 m above the Beaverhill Lake Gp. Together they form the stratigraphic equivalent of the off-reef Ireton Fm which is composed primarily of shales grading to marl and argillaceous limestone towards the top. The Ireton Fm is interpreted to extend from the underlying carbonate to an indefinite, often gradational contact near the base of the "generally clay free" Winterburn Gp, however, it should be noted that this definition can lead to problems, such as at the 8-5 location where the "Ireton" section could include strata laterally equivalent to the overlying Nisku Fm of the Winterburn Gp.

Over 250 m thick in a basinal setting, the Ireton Fm thins to less than 30 m across the eastern rim of the build-up defined by 50 m of thickening in the Leduc to Elk Point interval in relation to the back-reef area penetrated by the 10-23 well. Here, the Ireton section thickens and a distinctive transition zone is developed near the top of the Leduc Fm carbonate. In the vicinity of the 5-13 well, the equivalent of the upper Ireton Fm is a limestone. Unfortunately, the lack of reliable markers immediately overlying the reef makes it difficult to determine the original shape of the complex, however the interpretation of the geological cross-section suggests that the rim was at least partially developed before the cessation of Ireton deposition. In fact, the overall Wabamun to inferred Elk Point interval displays only 10 m of thickening from the 10-23 to the 6-24 location, 10 m to 15 m less than expected from the seismic data. Although the reason for this discrepancy is uncertain, it could be related to the fact that the Wabamun structure in the vicinity of the 6-24 well is over 25 m lower on a third order residual than the 15-26 and 2-36 locations only two kilometres to the north (Waddington, pers. comm.).

The lithologically complex Winterburn Gp which overlies the Ireton Fm, is herein divided into two broadly defined units. The lower unit is the "Nisku" interval, which in the vicinity of the Obed complex contains up to 90 m of porous, dolomitized biostromal carbonates containing greater gas reserves than the Leduc reef itself. Well control indicates that marlstones grading upwards to tight limestones form the lateral ("off-reef") seal for the Winterburn reservoir, whereas the Ireton Fm appears to separate it from the Leduc Fm below, this vertical seal may however be incomplete. These porous dolomites, either massive or in stringers, are dispersed throughout the Nisku section over all but the northeasternmost corner of the reef, however regional aerial extent and continuity is uncertain.

The Wabamun Gp overlies the anhydrites and silty carbonates of the upper Winterburn Gp (Graminia Fm). This brown, dolomitic limestone reaches a thickness of over 200 m in the Obed area and its erosional upper surface represents the top of the Devonian section. The Mississippian unconformity displays a strong (20+ m) third order residual high over the Obed reef with respect to basinal areas (Waddington, pers. comm.). Drape, created by differential compaction in the Woodbend Gp and modified by post-Devonian faulting (more fully analyzed in the seismic interpretation), extends upwards to at least the Base Fish Scales and is an indirect indicator of Leduc Fm build-ups.

SEISMIC SECTION

The 14 km long seismic section reproduced as Figure 4.50 is oriented from east to west across the Obed reef (Fig. 4.47). A brief summary of salient acquisition and processing parameters is contained in Table 4.11. Although these parameters are strictly conventional, it is important to note that long impulse and geophone arrays used in the field caused severe attenuation of the first breaks, thus no attempt was made to calculate near surface velocity or drift control and surface consistent statics were not applied.

The lowermost formation identified is the Watt Mountain of the Elk Point Gp. This horizon is commonly selected as a sub-Leduc Fm datum for isochron mapping throughout the Windfall complex due to its minimal relief and generally consistent seismic character. It is also the deepest formation penetrated by many of the Devonian

Table 4.11. Acquisition and processing parameters for the seismic section (Fig. 4.50) across the Obed reef

FIELD PARAMETERS		PROCESSING PARAMETERS	
DATE SHOT:	February 1978	DECONVOLUTION:	spiking, 80 ms op, 1% pw
SOURCE:	Vibroseis (4)	STRUCTURE STATICS:	elevation only
SOURCE ARRAY:	32 sweeps 330 ft.	DATUM:	4000 ft ASL
SWEEP:	10 sec, 12-60 Hz	V REPLACEMENT:	12,000 ft/sec
SOURCE INTERVAL:	660 ft.	STACK:	1200%
GEOPHONE INTERVAL:	330 ft.	FINAL FILTER:	10/15-55/65 Hz
GEOPHONE ARRAY:	18 over 330 ft	POLARITY:	peak positive
SPREAD:	9240 ft - 1650 ft - x (split)		
CHANNELS:	48		
SAMPLE INTERVAL:	4 ms		

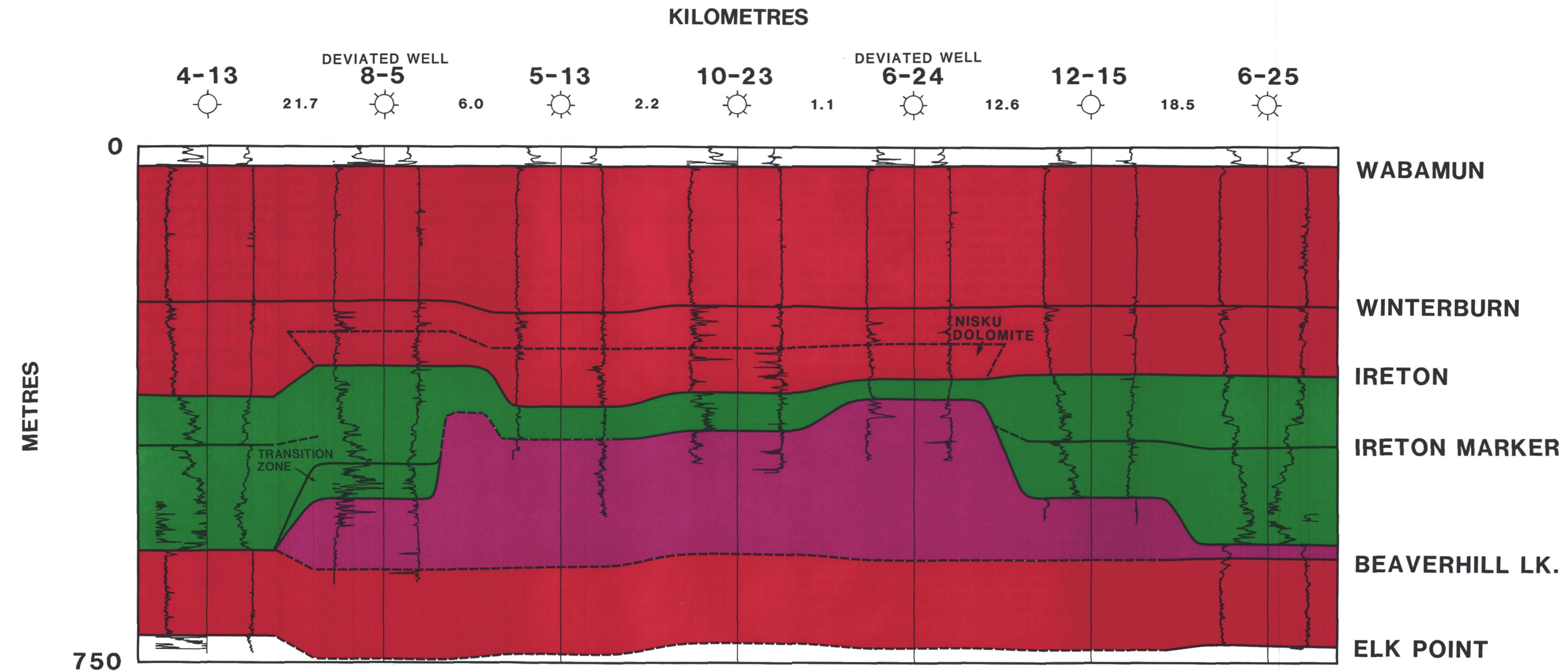

Figure 4.49. Geological cross-section, Obed study area.

DRAFTING: | LOG PLOTS: RILEY'S DATASHARE INTERNATIONAL LTD. | AUTHOR: D. WHITE

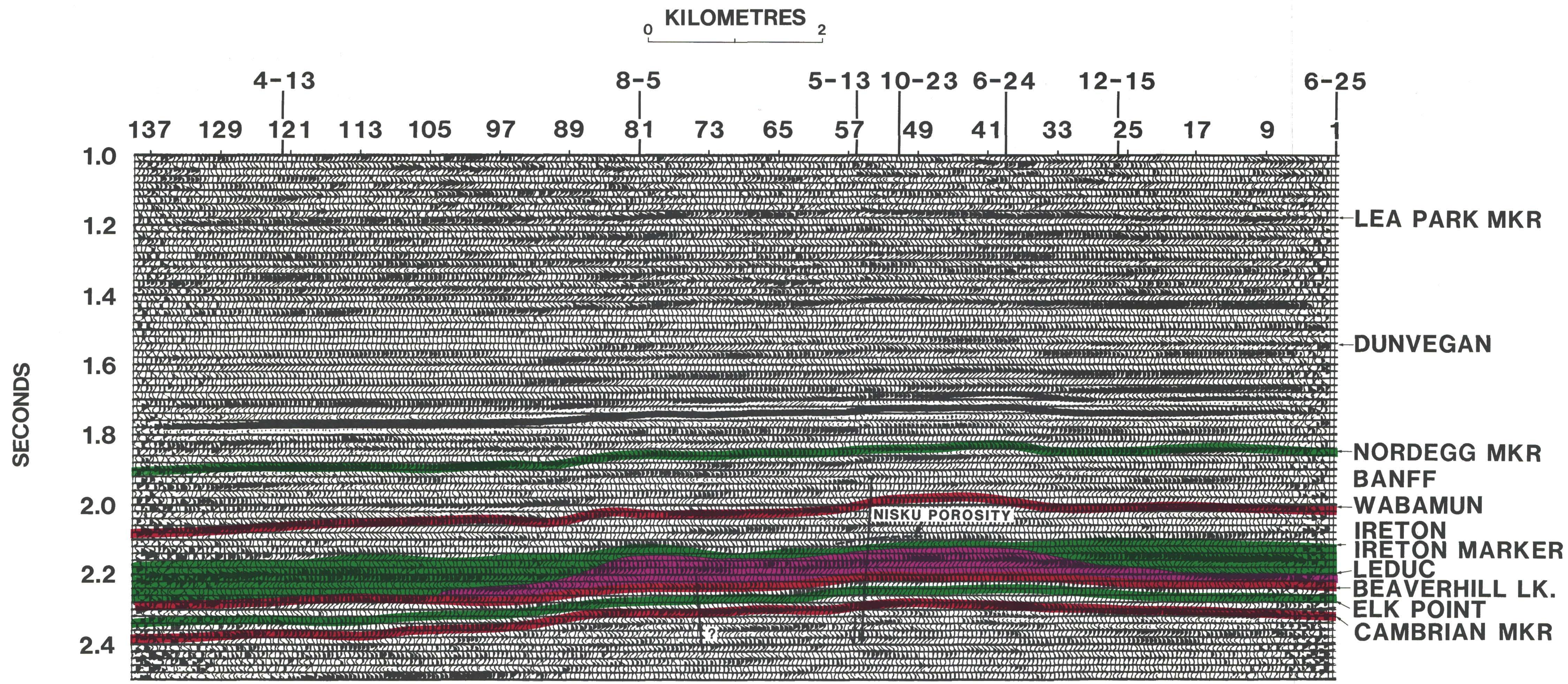

Figure 4.50. Normal polarity seismic section, Obed study area.

DONOR: CANADIAN OCCIDENTAL PETROLEUM LTD. | PROCESSOR: VERITAS SEISMIC LTD. | AUTHOR: D. WHITE tests. Unfortunately, the seismic section displays a particularly poor Watt Mountain event in the vicinity of the Obed reef. Examination of the common offset gathers (not reproduced in this paper) reveals that strong multiple interference, which occurs through-out the Devonian section and an overall decrease in amplitude of the Watt Mountain reflection towards the middle of the seismic line, act together to seriously degrade its coherency. In the following interpretation, a high-amplitude Cambrian (?) marker 35-40 ms below the top of the Elk Point Gp has been used to extrapolate this horizon over most of the line.

As is mentioned in the introduction to this chapter, velocity "pull-up" of sub-Leduc Fm events is an important seismic indicator of Woodbend reefing. At Obed, an isochron from the Dunvegan to the Elk Point or Cambrian reflectors (Fig. 4.51) exhibits 20+ ms of thinning over the eastern rim of the reef due to the large difference in interval velocity between the carbonates and the off-reef shales and to some extent by the velocity effect of drape in the overlying section.

To the east of the reef, the Leduc event is the lower-most high-amplitude positive reflection above the Elk Point horizon. Towards the west end of the line, a low signal to noise ratio contributes to the blurring of the Leduc/Beaverhill Lake event over more than 15 ms, although the overall character change of this reflection from single peak to doublet is consistent with the synthetic response at the 4-13 location. Note that the reflection at the top of the Beaverhill Lake Gp

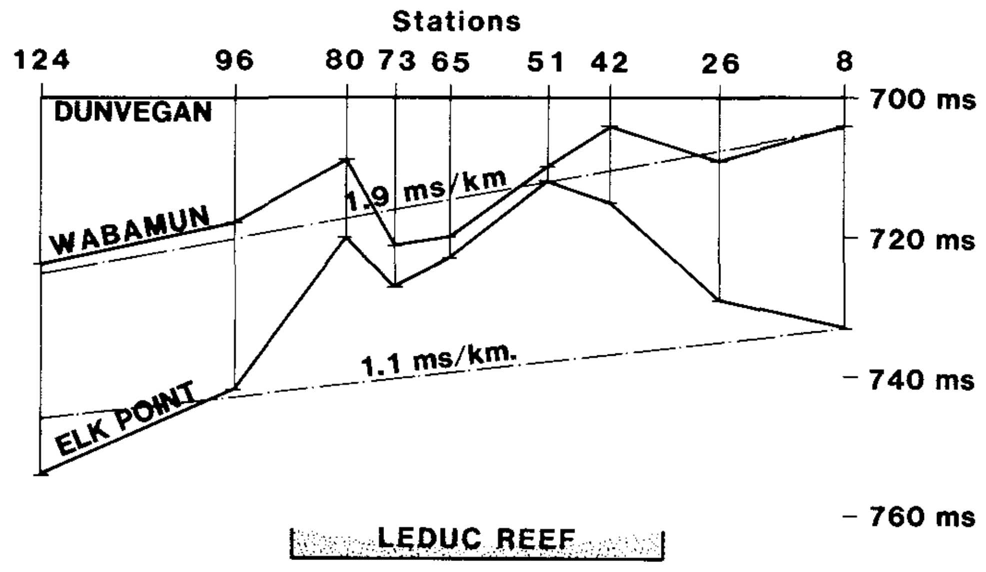

Figure 4.51. Dunvegan to Elk Point interval time difference profile - Dunvegan datum.

is not easy to correlate beneath the Obed reef. In fact, the only significant acoustic interfaces between the base of the Beaverhill Lake and the top of the Leduc Fm are likely due to variations in porosity and degree of dolomitization.

The event labelled "Ireton Marker" appears to pass through the reef margin and continue eastward towards its center, however a time to depth conversion relative to the Wabamun and Elk Point reflectors using the velocities in Table 4.12 indicates that the intra-reefal event is stratigraphically lower than the "Ireton Marker" by 35 m. The presence of strong multiple energy in this interval with no recognizable primary also discredits this as a reliable correlation. At station 50, a strong single peak at 2.16 seconds appears within the Leduc interval and extends eastward at a constant 95 ms above the Elk Point for almost three kilometres. Its coherency and lack of move out on the common off-set gathers indicate a valid reflection, possibly a contact between porous and non-porous carbonate units approximately 30 ms or 90 m below the top of the build-up. Off-reef, it defines a one kilometre wide terrace. The sudden weakening of this event at its eastern end could indicate porosity or some other form of transitional contact with the Ireton Fm shales. A similar, but stratigraphically lower, platform is also apparent on the western side of the complex.

Table 4.12. Time to depth conversion at Trace no. 42 (Fig. 4.50) compared to the 6-24 well (Fig. 4.49). The interval velocities are also used for the time to depth conversions of Figures 4.51, 4.53, 4.54 and 4.55

	STATION 42				6-24
	Time (ms)	Interval Velocity (m/ms)	Depth (m)	Interval (m)	Interval (m)
Datum	0	1.8	1219	2106	2080
Lea Park Marker	1170	1.9*	-887	684	700
Dunvegan	1530	2.0*	-1571	608	591
Nordegg	1834	2.8*	-2179	448	465
Wabamun	1994	3.1	-2627	360	345
Ireton	2110	3.0+	-2987	15	23
Leduc	2115	3.1	-3002	403	393
Elk Point	2245		-3405		
4.R to Elk Point Interval				2518	2517

* Calculated from the 15A-26-54-23 W5 well.
+ In an off-reef position, an interval velocity of 2.3 m/ms was used for time to depth conversions.

The approximate location of the Obed reef can be determined indirectly by mapping "pull-up" of over 20 ms and drape up to 10 ms (Fig. 4.51) or from relatively subtle changes in reflection character and amplitude in the regionally consistent Ireton section at or near the edges of the complex. Identification of the top of the reefal Leduc Fm however, is important in the exploration stage for predicting reservoir size and quality and for determining optimal drilling locations. Unfortunately, it is particularly difficult to track this event across the top of the reef or near the reef margins where it may be capped by a thick sequence of interbedded carbonates and shales which form a gradational velocity contact with the overlying Ireton Fm. The 8-5 sonic-log is a good illustration of this problem. Here, the possibility of misinterpreting the Leduc by picking the event too high is further increased by the presence of a 15 m thick band of argillaceous limestone within the shaly section 75 m above the top of the "clean" carbonate. This is a common occurrence near reef margins in the Windfall area. On-reef west of station 60, the Ireton event is no longer recognizable and the reflection coefficient at the top of the Leduc Fm appears to have weakened or become negative (due to porosity effects ?) as at the 2-36 location. Where a transitional contact similar to that displayed by the 10-23 well exists, the top of the Leduc Fm is virtually undefinable either geophysically or geologically. These effects are illustrated by the synthetic model (Fig. 4.52) which was generated using the seven wells in the geological cross-section and the 2-36 well.

The Winterburn interval poses similar problems for the seismic interpreter. Although a porous zone in the Nisku section is

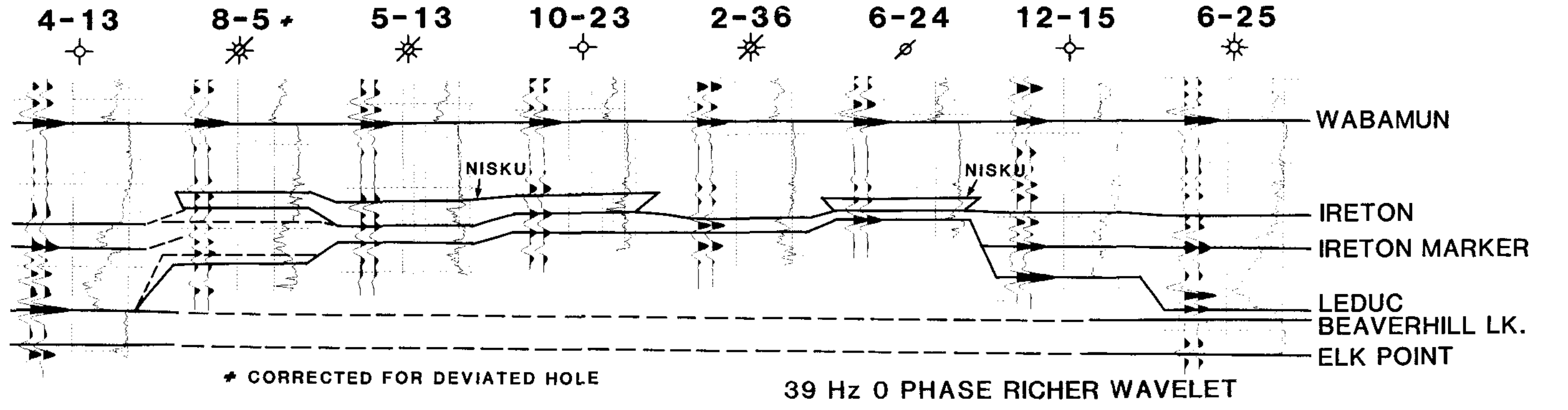

Figure 4.52. Synthetic seismograms for the acoustic logs in Figure 4.49

tentatively identified in Figure 4.50, the presence of strong multiple interference, particularly evident at the Wabamun level between traces 42-57 and 78-115, not only obscures the important Wabamun event to which much of the Devonian stratigraphy is referenced, but also alters the appearance of the generally weak reflections originating within the Winterburn Gp.

The abrupt variations in time structure throughout the seismic section hinders interpretation of the structural history. Figures 4.53-4.55 are presented to illustrate some of the more important features displayed in profile by the seismic data. In order to minimize velocity effects, the diagrams are based on a time to depth conversion which is outlined in Table 4.12 as a comparison between trace 42 and the 6-24 location. Note that the velocities in the post-Devonian section are assumed to be the same both on-reef and off-reef as concluded by Anderson (1986), whilst the regional dip

Table 4.13. Regional gradients for selected horizons in the Obed area as calculated graphically from Westcan Oil maps (March, 1986). Used for Figures 4.51, 4.53, 4.54 and 4.55

MAPPED FORMATION	PROFILE EVENT	APPROXIMATE DIP (m/km)	EAST-WEST GRADIENT (m/km)
Belly River	Lea Park marker	16 @ 216°	-9.5
Mannville	Dunvegan	16 @ 220°	-10.0
Nordegg	Nordegg marker	19 @ 225°	-13.5
Wabamun	Wabamun	18 @ 231°	-14.0
Elk Point	Elk Point	15 @ 231°	-11.5

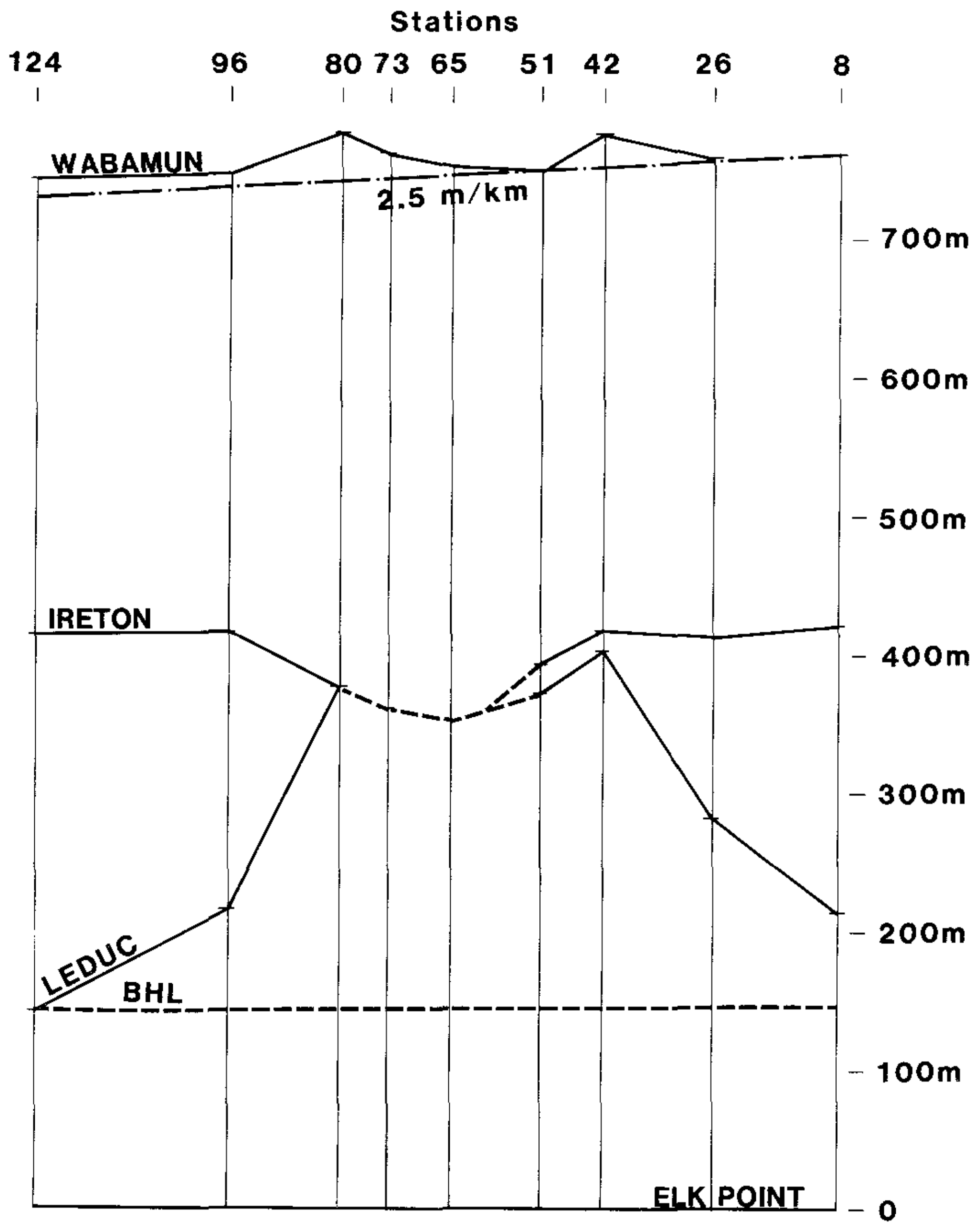

Figure 4.53. Wabamun to Elk Point time to depth converted profile – Elk Point datum.

divergence correction indicated on each of the profiles is calculated from the gradients presented in Table 4.13.

The shape of the Wabamun to Elk Point profile plotted in Figure 4.53 infers that compaction of the back-reef and off-reef sediments exceeded that of the periphery by 20-25 m since the pre-Mississippian unconformity and although the velocities used for the time to depth conversion of the carbonate and clastic sections were necessarily

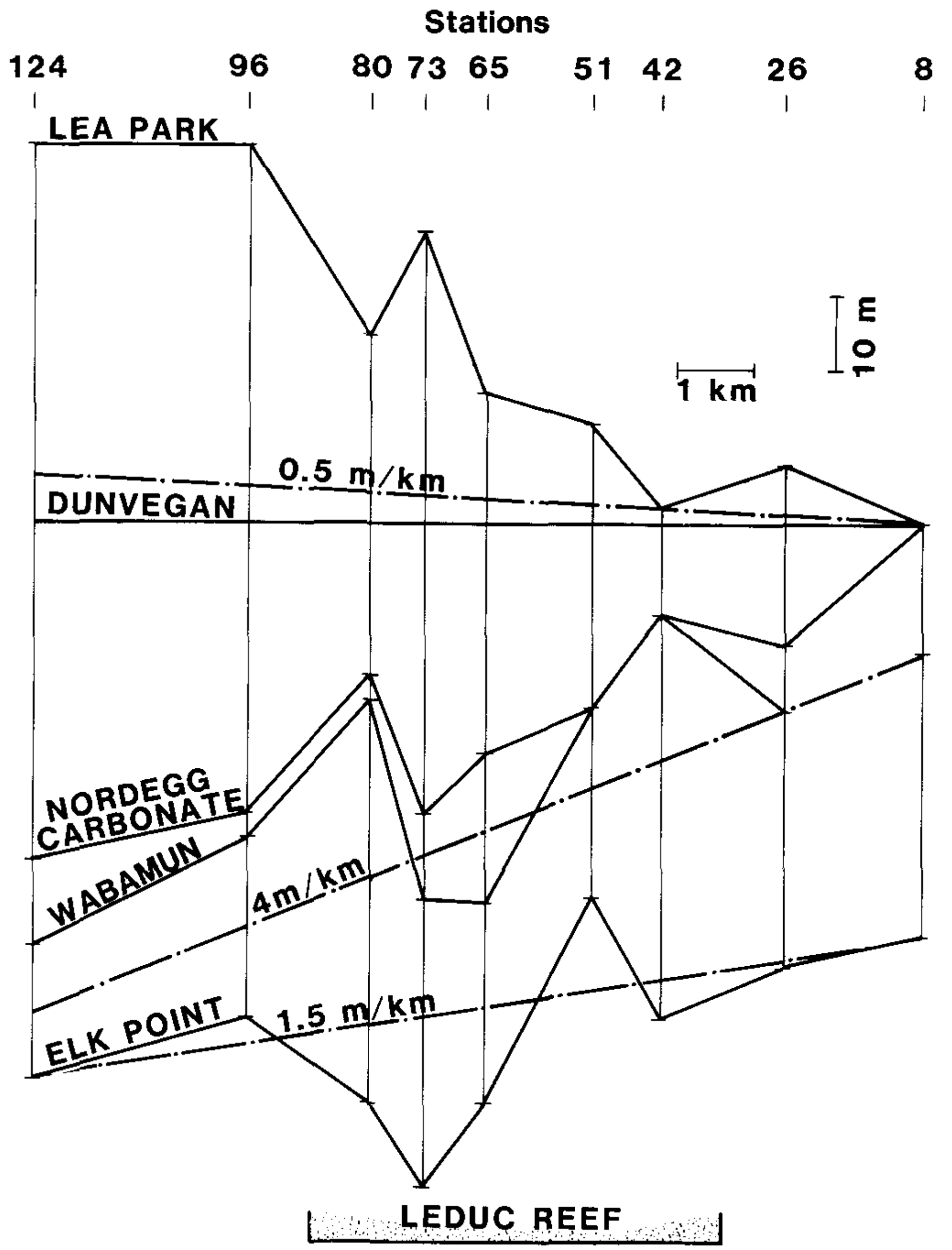

Figure 4.54. Lea Park to Elk Point time to depth difference profile – Dunvegan datum.

approximate, Wabamun drape of this magnitude into the shale basin is substantiated by regional mapping of the Devonian surface (Waddington, pers. comm.). Note that the drape into the back-reef area is not confirmed by well control along the geological cross-section of Figure 4.49 and it is partially because of this discrepancy that the Wabamun picks for traces 42 and 51 are uncharacteristically low in relation to the apparent Wabamun event on the stacked seismic section, whereas, the pick for trace 80 might

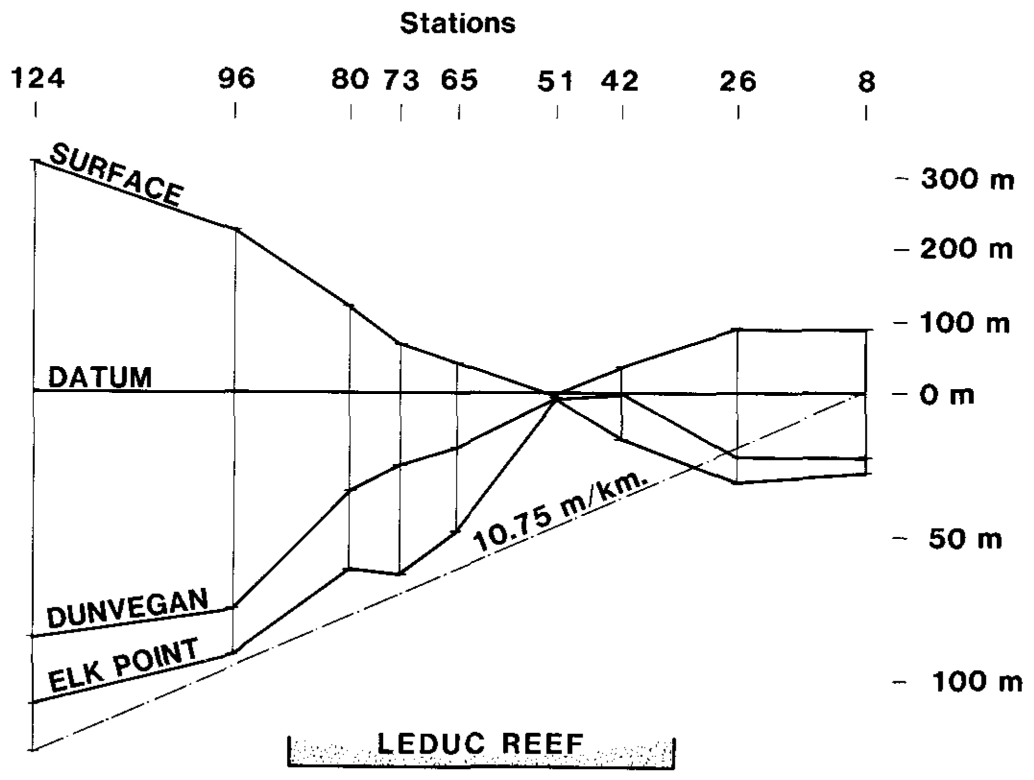

Figure 4.55. Surface to Elk Point time to depth difference profile – structural datum. Dashed line is average regional gradient of the Dunvegan and Elk Point surfaces from Table 4.13.

appear to be slightly high. These deviations are also warranted by the time structure of overlying and underlying horizons and the appearance on the common offset gathers of high-amplitude multiple energy which seriously interferes with the Wabamun reflection in these areas. The strength of the Wabamun event is also influenced by the velocity and event interference from the overlying Banff Fm. The localized depression on the Wabamun surface to the east of the reef edge is of explorational significance. It implies that a time-structure low on this horizon might be an indicator of a nearby Leduc reef.

The Dunvegan Fm to Wabamun Gp interval of Figure 4.54 indicates that most of the Wabamun drape illustrated by Figure 4.53 occurred prior to deposition of the Dunvegan Fm. These results are consistent with compaction studies in eastcentral Alberta by Labute and Gretener (1969). When these two profiles are combined, the resulting Dunvegan to Elk Point interval is anomalously thick in the vicinity of trace 73. This could be due to an error in the Elk Point pick or in the replacement velocity used for the Woodbend section. It could also be caused by post-Devonian movement across faults expressed on the seismic section at traces 56 and 76(?). The striking increase in the Lea Park marker to Dunvegan interval west of trace 65 implies basement subsidence over the western end of the line, possibly related to these zones of structural weakness. Note that the Lea Park marker event between traces 56 and 92 is strongly affected by localized structures originating near the Second White Specks over 200 ms below.

Figure 4.55 shows the surface topography plotted against the apparent depth of the Dunvegan and Elk Point reflectors, both of which display a change in dip direction from westerly to easterly near trace 56 corresponding to a slope reversal on the surface. This implies that the apparent time structure over the reef could be due to lack of near-surface velocity control and the use of an anomalously high replacement velocity.

REMARKS

Summarized below are the main observations concerning the detection and interpretation of the Leduc Fm on seismic data in the Obed area:

1) Within the Windfall/Bigstone complex, the Leduc/Beaverhill Lake event in the off-reef section is usually the first strong, coherent, positive reflection at least 140 m (45 ms) above the top of the Elk Point Gp;

2) Variations in thickness of the Leduc Fm are accompanied by amplitude and character changes or termination of events within the Woodbend interval which are relatively subtle in comparison to many of the other Leduc reefs examined in this chapter;

3) Without adequate well-control, identification of the Leduc Fm on seismic can be difficult in locations where: a) relatively high velocity calcareous stringers are present in the clastic section proximal to carbonate buildups; b) the reflection coefficient at the top of the Leduc Fm is attenuated or phase reversed by the presence of an argillaceous transition zone, porosity at the top of the Leduc or where the Ireton Fm shale is thin to absent, resulting in a carbonate to carbonate contact; and c) events due to porosity/acoustic variations or incomplete multiple cancellation occur within the Leduc section; and

4) Features such as "pull-up" and drape, are good indicators of lateral shale to carbonate transitions within the Woodbend Gp. Since the Obed seismic example has a considerable

amount of velocity induced time structure, a number of time and time to depth converted profiles were constructed from the reflection data. Once in cross-section form, regional trends calculated from geological control can easily be removed and comparison of the time to depth inversions to known or anticipated structural models often provides a good check on the validity of an interpretation. The profiles also facilitate analysis of both the faulting and the compaction history of the reef, information which is useful for predicting reservoir characteristics and facies variations within the Leduc interval.

STURGEON LAKE SOUTH FIELD

INTRODUCTION

The 1000 km^2 Sturgeon Lake reef is centered over Twp 69 Rge 23W5M, 40 km northeast of the Simonette field and 300 km northwest of the city of Edmonton (Fig. 4.2). Oil and gas is stratigraphically trapped in the dolomitized Leduc Fm at a depth of approximately 2500 m or 1900 m subsea (Fig. 4.56) by the enclosing shales of the Ireton Fm. This occurs in three fields located along the irregular up-dip (eastern) edge of the reef: 1) Sturgeon Lake; 2) Sturgeon Lake South; and 3) Little Smoky. The single well Calais D-3A pool produces from the back rim of the complex (Fig. 4.57). Production and reserves statistics for the Devonian pools assigned to these four fields are summarized in Table 4.14.

Differential compaction between back-reef "lagoonal" carbonates, off-reef shales and the more rigid, dolomitized periphery of the build-up has given the complex a broadly atoll-like shape, with drape in the overlying horizons extending into the upper Cretaceous (Fig. 4.58). Numerous hydrocarbon pools in post-Devonian strata are associated with this structure, particularly along the updip edge of the reef (Morgan, 1964), however production data for these pools has not been included in this study.

GEOLOGICAL CROSS-SECTION

Figure 4.59 gives the location of the geological cross-section (Fig. 4.60) and the seismic section (Fig. 4.61). Both are oriented in a northeasterly direction across the reef complex in the Sturgeon Lake South Area. The geological cross-section is based on six wells

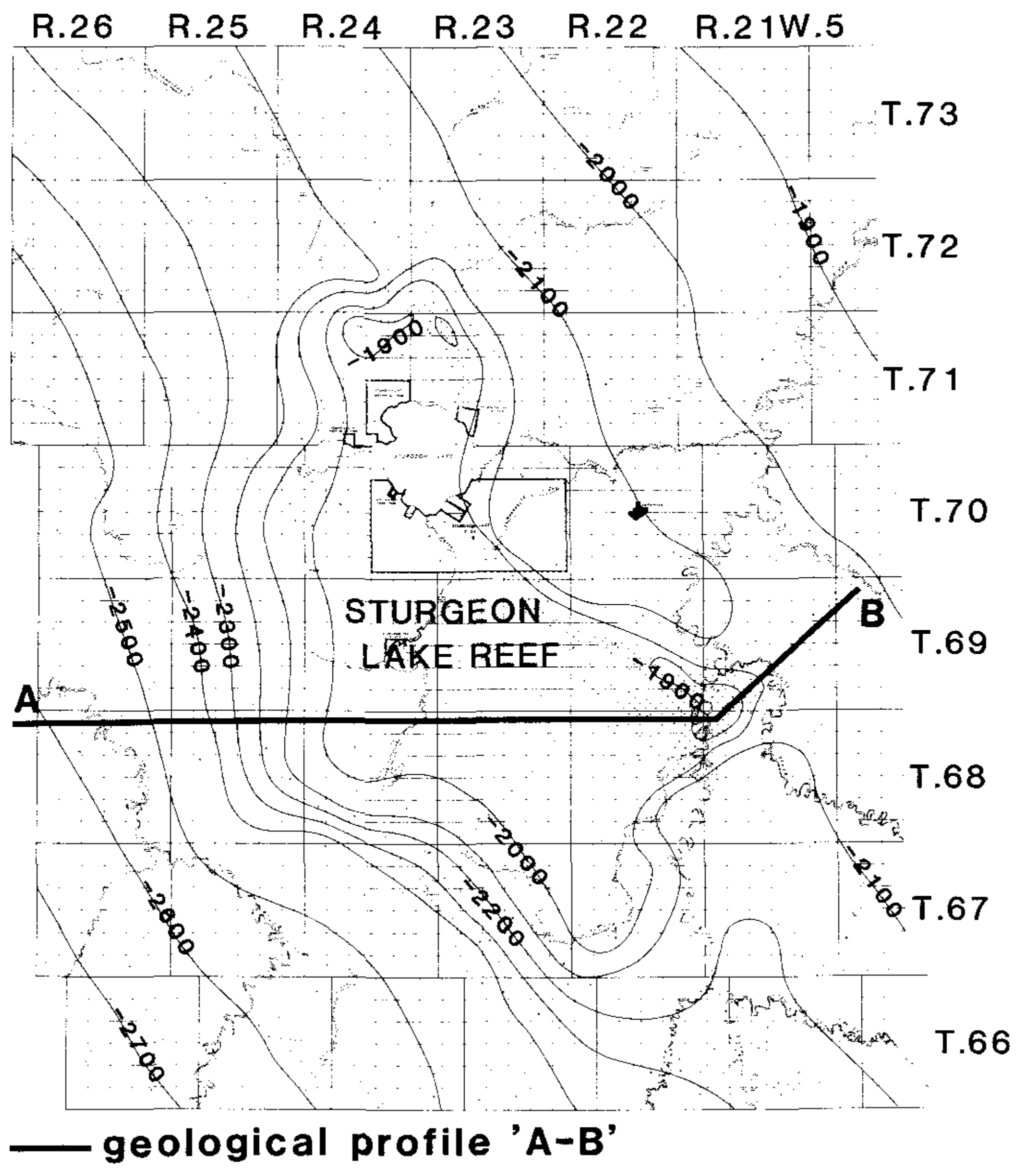

Figure 4.56. Contour map (in metres relative to mean sea level) of the Leduc Fm top (or in its absence, the Beaverhill Lake Fm top). The location of profile A-B (Fig. 4.58) is shown.

selected on the basis of stratigraphy, proximity to the seismic section and availability of sonic log data.

The lowermost horizon on the cross-section is the Watt Mountain Fm of the Elk Point Gp. These siltstones, sandstones and shales are easily distinguishable geologically and geophysically and since paleo-relief is relatively small, this formation provides a good geological and geophysical datum for the analysis of Upper Devonian stratigraphy.

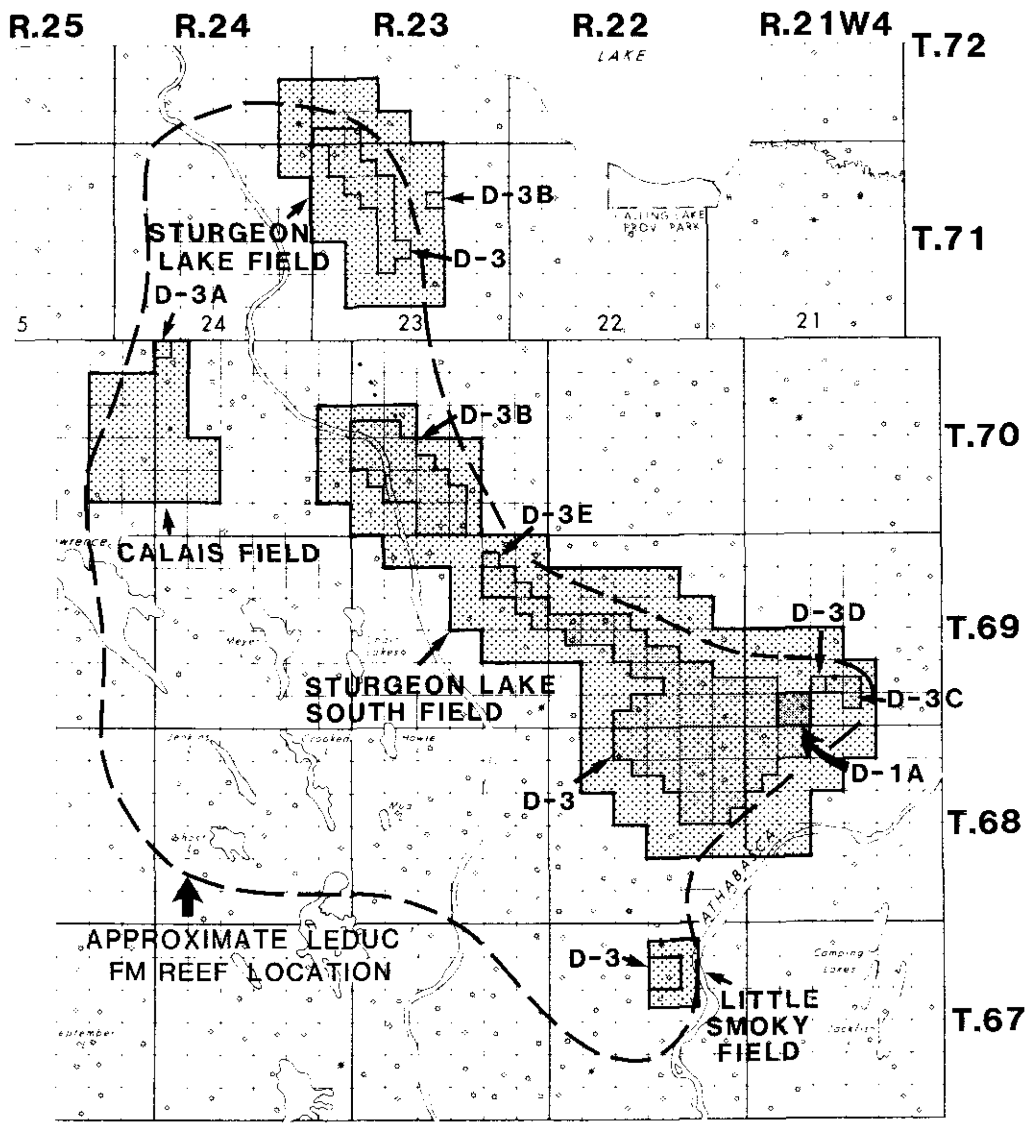

Figure 4.57. Fields and Devonian pools in the Sturgeon Lake area.

Table 4.14. Production and reserves statistics for Devonian pools associated with the Sturgeon Lake complex (Fig. 4.57) up to Dec. 31, 1987

	Year on Production	Number of wells	1987 Oil Prod 10^6 m^3	Cumulative Oil Prod 10^6 m^3	Total* Initial Established Oil Reserves 10^6 m^3	1987 Gas Prod 10^6 m^3	Cumulative Gas Prod 10^6 m^3
Sturgeon Lake							
D-3	1952	22	0.048	3.32	3.53	7.43	541.3
Sturgeon Lake S.							
D-1A	1959	1	-	-	-	-	39.3
Blueridge A	1957	2	negl.	0.125	0.177	0.185	26.7
D-3	1953	143	0.867	20.7	27.8	140.5	3414
D-3 (B,C,D,E)	1964-87	12	0.035	0.270	0.573 ♣	5.17	51.9
Little Smokey							
D-3	1954	4	0.003	0.176	0.199	0.870	49.1
Calais							
D-3A	1987	1	0.030	0.030	N/A	5.23	5.23

Data supplied by Virtual Computing Services Ltd.
* Data furnished by the Energy Resources Conservation Board.
♣ Data for pool D-3E NA

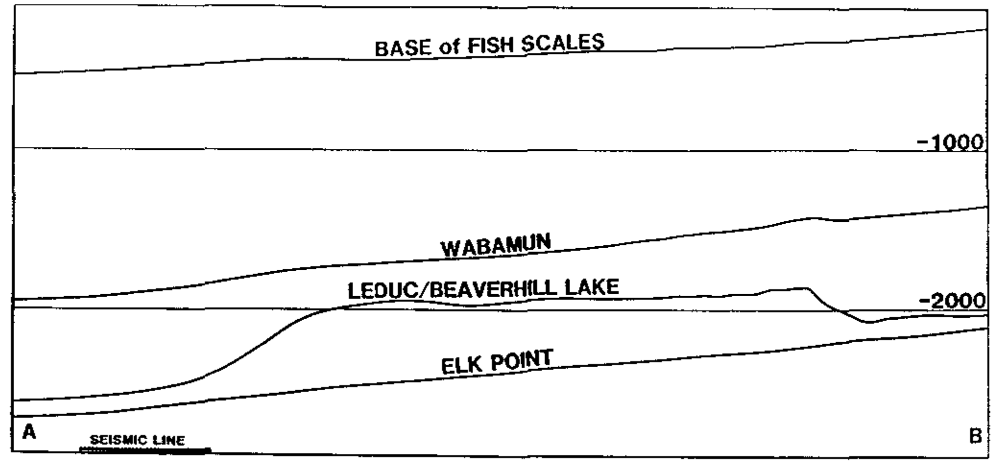

Figure 4.58. Profile A-B across the Sturgeon Lake reef. See Figure 4.56 for location.

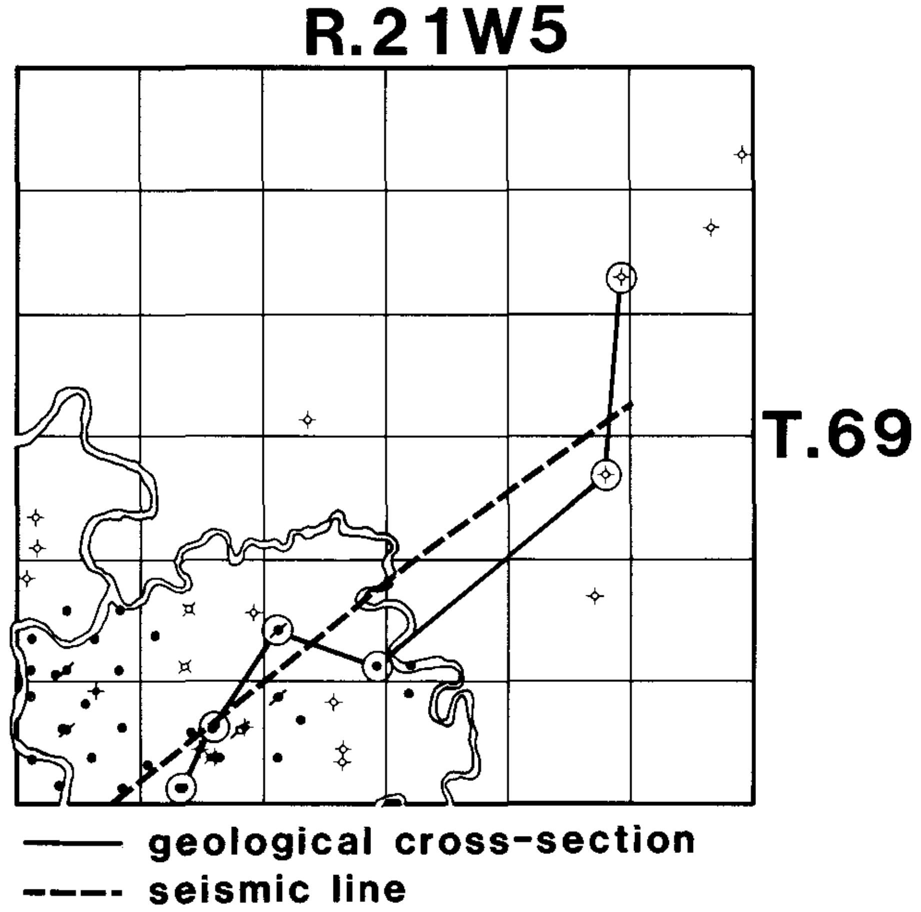

Figure 4.59. Location map for the geological cross-section and seismic section, Sturgeon Lake South field.

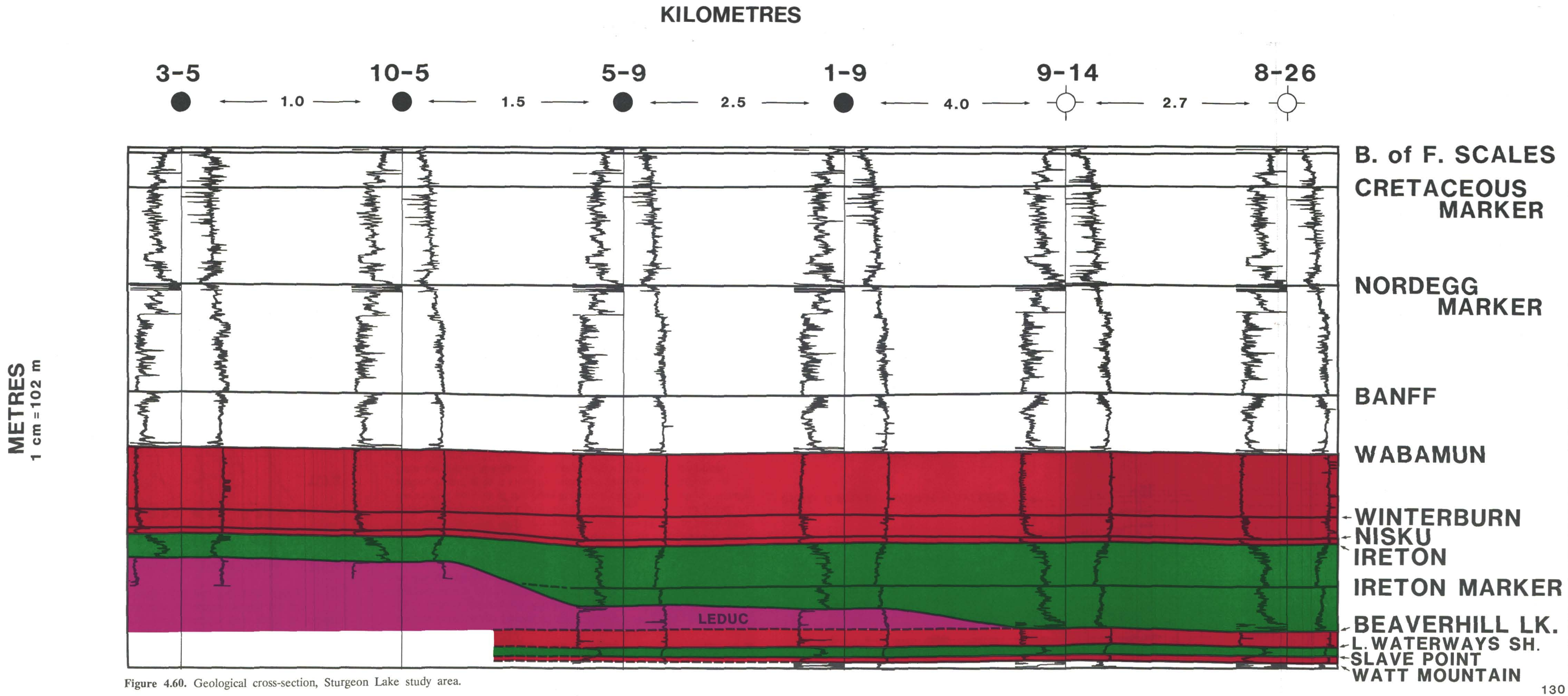

Figure 4.60. Geological cross-section, Sturgeon Lake study area.

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Overlying the Watt Mountain Fm in the area are the Slave Point Fm, and Waterways Fm of the Beaverhill Lake Gp. Reef building organisms, notably absent in the basal limestone, are prevalent in the upper Beaverhill Lake Gp limestone overlying the Waterways shale (Morgan, 1964) and it was upon this widespread carbonate "platform" that the Sturgeon Lake complex developed; its location perhaps influenced by differential movement within the pre-Cambrian during the Paleozoic (Zell and Patterson, 1960).

The Leduc Fm build-up reaches an inferred thickness of 265 m at the 3-5 location and over 400 m on the western side of the reef where it forms a virtually unbroken sequence of reefal carbonates to within

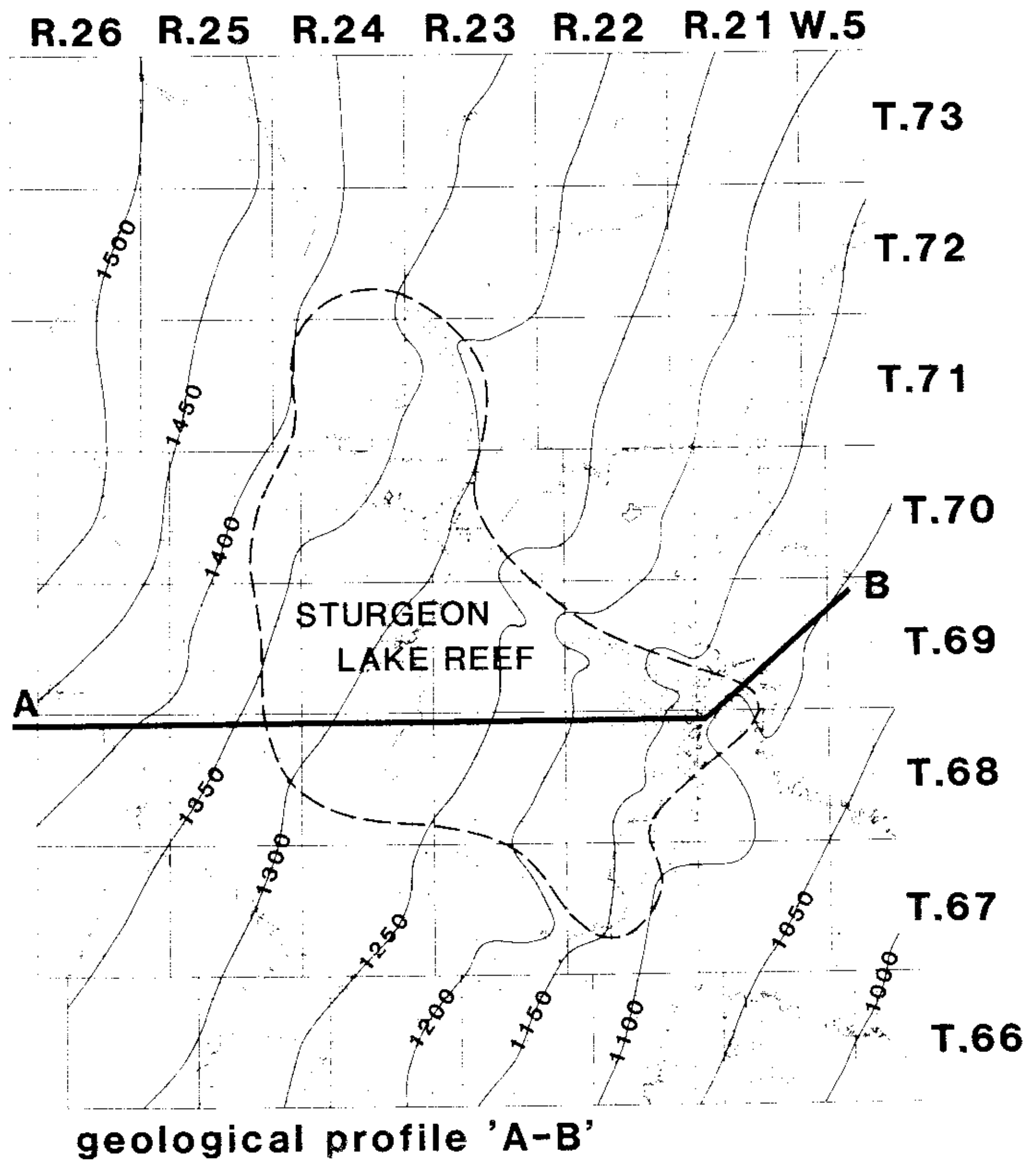

Figure 4.62. Contour map of Base Fish Scales to Wabamun Gp interval (in metres). The location of profile A-B (Fig. 4.58) is shown.

70 m of the base of the Wabamun Gp, a level equivalent to the Nisku Fm (Winterburn Gp) to the east. It occurs as a light coloured, coarsely crystalline dolomite with vuggy, often fracture enhanced porosity grading laterally to darker, slightly argillaceous limestone in the interior of the complex. As illustrated on the cross-section, the contact between the Beaverhill Lake Gp and the Leduc Fm in the study area is indistinguishable on the basis of sonic character. This suggests that a correlatable seismic event is unlikely to be generated at this interface.

Capping the Sturgeon Lake complex in the vicinity of the seismic line are 90 m of green shale and marlstone of the Ireton Fm which off-reef at the 8-26 location reaches a thickness of 320 m (including approximately 30 m of Duvernay equivalent (?) shale at its base). In the central portion of the complex, the Ireton shale is depositionally absent, resulting in a virtually unbroken sequence of carbonates from the top of the lower Waterways shale to the Mississippian unconformity.

Regional facies changes in the overlying Winterburn Gp preclude the use of standard nomenclature for differentiating stratigraphy. For this interpretation the Winterburn Gp has been divided into three units roughly equivalent to the Nisku, Calmar and Blueridge formations. At the base is the well-defined Nisku section, which in the study area consists of 20 m of tight, non-productive limestone grading upwards into the silty limestone and greenish siltstones herein referred to as the Calmar interval. Capping the Winterburn Gp are 55 m of silty dolomite equivalent to the Blueridge Fm. Thirty metres of drape over the edge of the complex has laterally trapped hydrocarbons at the top of this dolomite sequence in a small pool penetrated by the 3-5 well. The vertical seal is provided by the fossiliferous limestone of the 240 m thick Wabamun Gp which completes the Devonian section. Drape at the Wabamun level (Fig. 4.62) mirrors the Winterburn structure, whereas, the Base Fish Scales deviates less than 10 m from regional. Note that the Base Fish Scales to Nordegg marker interval does not thicken appreciably across the edge of the reef (Fig. 4.60) indicating that little differential compaction occurred during this period.

SEISMIC SECTION

The seismic section reproduced as Figure 4.61 is oriented from southwest to northeast across the eastern edge of the Sturgeon Lake reef (Fig. 4.59). The random noise which contaminates the left hand side of the line possibly emanates from nearby production facilities or other mechanical operations. It could be eliminated by a suitable

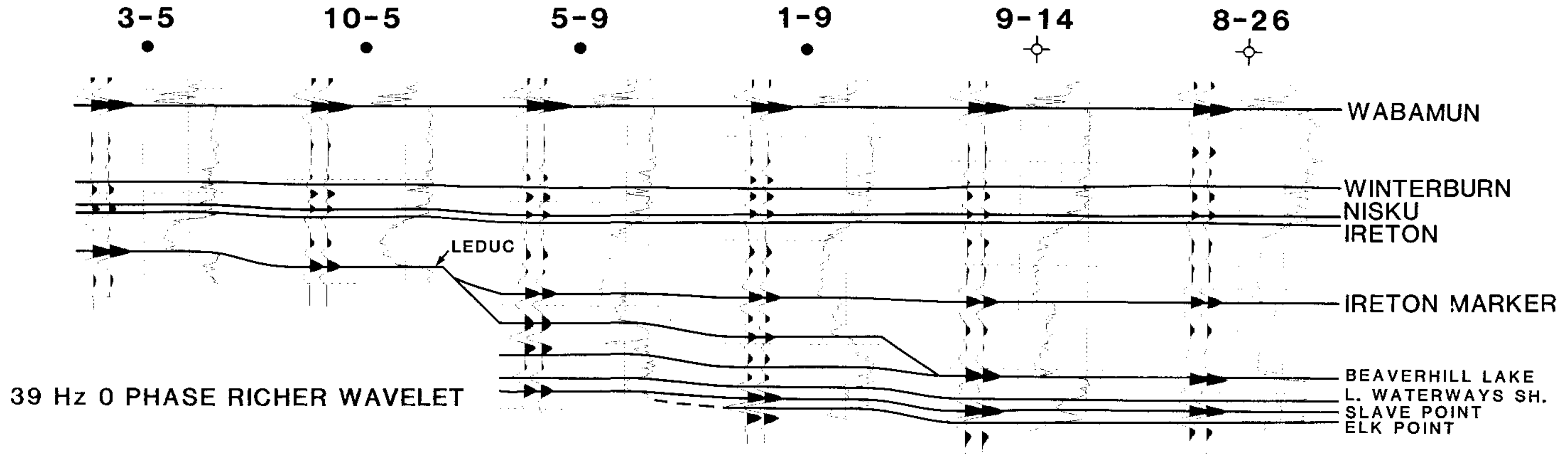

Figure 4.63. Synthetic seismograms for the acoustic logs in Figure 4.60.

Table 4.15. Acquisition and processing parameters for the seismic section (Fig. 4.61) across the Sturgeon Lake South Field.

ACQUISITION PARAMETERS		PROCESSING PARAMETERS	
DATE SHOT:	February 1979	DEPHASING:	instrument and geophone
SOURCE:	dynamite, 5 lbs	DECONVOLUTION:	spiking, 80 ms op, 1% pw
SOURCE ARRAY:	single hole, 40 ft.	STRUCTURE STATICS:	2 layer drift
SOURCE INTERVAL:	440 ft.	DATUM:	2300 ft.
GEOPHONE INTERVAL:	220 ft.	V REPLACEMENT:	8000 ft/sec
GEOPHONE ARRAY:	9 over 110 ft. 10 Hz	STACK:	1200%
SPREAD:	5500 ft - 440 ft - x (split)	FINAL FILTER:	10/15-60/70
CHANNELS:	48	POLARITY:	peak positive
SAMPLE RATE:	2 ms		

coherency type filter, however as indicated by the acquisition and processing parameters listed in Table 4.15, no special techniques were used to enhance the example section.

The lowermost correlated reflection is from the top of the Watt Mountain Fm which caps the Elk Point Gp. This event, along with the reflections generated within the overlying Beaverhill Lake Gp sequence, form a set of coherent, laterally consistent events which provide an excellent seismic datum near the base of the Devonian. West of trace 163, the amplitude of the upper Beaverhill Lake event rapidly decreases as the overlying low-velocity Ireton shale is replaced by Leduc Fm carbonate, greatly reducing the velocity contrast. The reflection that remains is likely generated by density and porosity variations in the surrounding section and as a precursor to the Lower Waterways Fm shale event. The transition from shale

Table 4.16. Drape and velocity "pull-up" associated with the Sturgeon Lake reef (Fig. 4.61)

		On-reef Station 208			Off-reef Station 163		
	Interval Velocity From [illegible] (m/msec)	Time (msec)	Interval Time (msec)	Thickness (m)	Time (msec)	Interval Time (msec)	Thickness (m)
Cretaceous Marker	1.80	866	213	383	861	217	391
Nordegg Marker	2.45	1079	162	397	1078	162	397
Banff	2.[illegible]	1241	84	214	1240	92	235
Wabamun		1325			1332		
Cretaceous Marker to Wabamun			459	994		471	1023
Elk Point		1597			1627		
Cretaceous Marker to Elk Point			731			766	

basin to reef is also characterized by the complete disappearance of all but the uppermost event in the Ireton section, drape along post-Ireton horizons of over 10 ms and by 35 ms of velocity induced "pull-up" evident on all reflections below the Leduc Fm (Table 4.16).

The Leduc event which defines a ramp like "platform" up to 90 m thick and 1.5 km wide at the toe of the build-up, is relatively weak over the rim of the complex when compared to the reflection generated by what is interpreted to be a calcareous "stringer" extending eastwards into the shale section from the uppermost edge of the reef. West of trace 210, a coherent event probably related to porosity variations appears at 1530 ms in the lower Leduc section and the amplitude of the reflection from the top of the Leduc Fm is

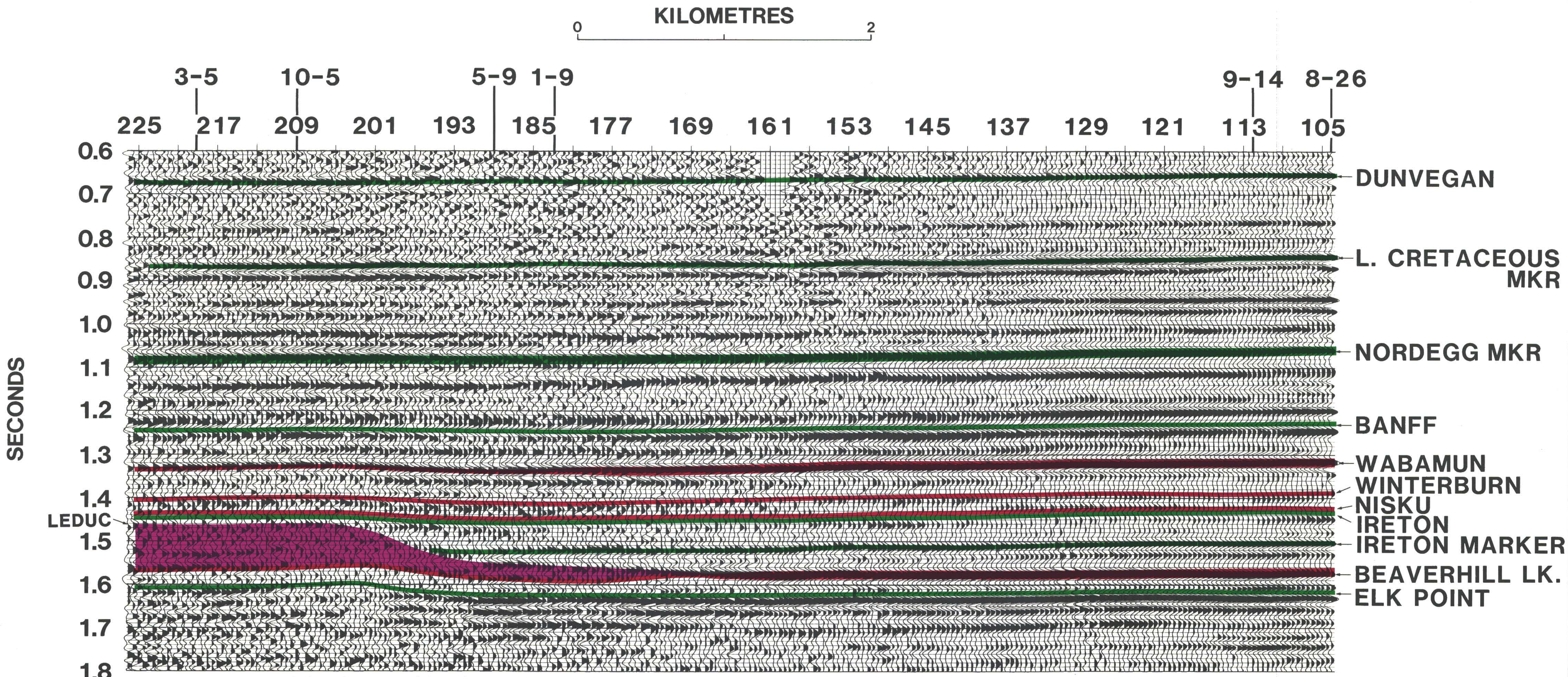

Figure 4.61. Normal polarity seismic section, Sturgeon Lake study area.

DONOR: MERIDIAN OIL INC. | PROCESSOR: VERITAS SEISMIC LTD. | AUTHOR: D. WHITE attenuated even further. This last observation contradicts the synthetic model of Figure 4.63, implying that either the wavelet selected for the model is inappropriate or that noise and loss of fold at the end of the line is responsible for the observed changes in the seismic image of the Leduc Fm.

Overlying the Ireton are the Nisku, Winterburn and Wabamun events. Approximately 12 ms (30 m) of reversal along the Winterburn event at the reef edge defines the Blueridge – A reservoir tapped by the 3-5 well. Although drape is still evident at the Nordegg level, reflections in the Upper Cretaceous, as expected from geological control, exhibit little or no structure over the Sturgeon Lake complex.

REMARKS

Important direct and indirect indicators of the Leduc Fm build-up as exhibited by the example seismic line are; 1) significant velocity "pull-up" of all pre-Leduc Fm reflections occurs beneath the complex; 2) drape along the horizons overlying the build-up extending into the Cretaceous; 3) a "terrace" up to 1.5 km wide associated with the reef in the study area; and 4) the transition from the high-amplitude consistent events within the off-reef Ireton section to the discontinuous, lower amplitude reflections associated with the reef which provides the only direct definition of the reef edge.

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