CHAPTER 5 – WINTERBURN (NISKU) RESERVOIRS

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INTRODUCTION

The Nisku Fm is a Late Frasnian (Upper Devonian) carbonate occurring immediately above the Ireton Fm in western Canada and northwestern U.S.A. It was deposited across most of Alberta, Saskatchewan, Montana and North Dakota as widespread, laterally continuous, regressive shelf carbonates, in an arid, near equatorial environment (Anderson, 1985). These shelf carbonates surround the Winterburn Basin (Figs. 5.1, 5.2) in west-central Alberta, in which the "Winterburn Shale" (Cynthia Mbr) (Fig. 5.3) was deposited. Nisku reefs occur on the south-east flank of the Winterburn Basin in the Pembina area and in the Obed-Windfall area of the basin.

The Canadian oil industry informally subdivides the widespread shelf deposits of the Nisku Fm of southern Alberta into Upper and Lower units (Fig. 5.3). The Lower Nisku is the main reservoir rock of the Nisku Fm in Southern Alberta. It was deposited as a widespread carbonate bank in a shallow, open marine, middle-shelf environment. The Upper Nisku is most often comprised of interbedded pelloidal wackestones, primary dolostones and laminated anhydrites formed in the subtidal to supratidal environment of a regressive often hypersaline shelf. Machel (1983) proposed the name Dismal Creek Mbr for the less restricted Upper Nisku floatstones and mudstones deposited subtidally on the so-called "Outer Shelf" behind the Upper Nisku Barrier (Figs. 5.1, 5.2).

In the Pembina area of the Winterburn Basin the Nisku Fm has been subdivided into four off-reef members and one reefal member (Fig. 5.3; Chevron Exploration Staff, 1979). The off-reef sequence consists of the Lobstick and Bigoray members (Lower Nisku equivalents), and the Cynthia and Wolf Lake members (Upper Nisku equivalents). The Zeta Lake Mbr is the reefal equivalent of all these members. Further detailed discussions of Winterburn Basin stratigraphy and lithologies is presented below under the section "Zeta Lake Reefs".

It should be noted that the highly productive fields of Stettler and Fenn-Big Valley occur mainly in the Camrose Mbr of the Ireton Fm (Woodbend Gp) which underlies the Nisku in this area (Stoakes, 1977). The Camrose is similar in lithology to the Lower Nisku in the Stettler and Fenn-Big Valley areas and is often mistaken for it.

The Nisku Fm was deposited after a slight depositional hiatus on the gently west-dipping upper surface of the Ireton Fm. Shales of the Ireton Fm are the final Woodbend Basin filling sediments in Alberta (Stoakes, 1980). The Winterburn - Woodbend break within the Winterburn Basin is marked by a hardground surface. This surface has a distinct sigmoidal shape in cross-section known as a clinoform, and a velocity change occurs across the break which results in a regional seismic marker known as the Z-marker (Stoakes, 1987b). It was this final basin filling event that provided the Winterburn Basin's shape and morphology at the beginning of Nisku time (Anderson, 1985, and Stoakes, 1987a).

Zeta Lake "pinnacle" reefs are considered to be downslope coral mud-mounds (Machel, 1983), which were deposited on the shallow southeastern slopes of the basin. The Upper Nisku Barrier which fringes the basin occurs slightly east and shelfward of these build-ups (Fig. 5.1). The Lower Nisku Barrier occurs several miles east and shelfward of the Upper Barrier. The region between the earlier and later barriers was termed the "Outer Shelf" by Chevron (Chevron Exploration Staff, 1979). This area is actually the middle shelf, lagoonal area of the Upper Nisku which lay behind the Upper Nisku Barrier and was filled by deposits of Machel's Dismal Creek Mbr.

Porosity and permeability of the Nisku Fm is controlled by a complex sequence of diagenetic processes. The occurrence or absence of intermediate burial dolomitization is the most important factor governing porosity and permeability of the Zeta Lake Mbr (Watts, 1987a, Machel, 1985, Anderson, 1985). According to Guy Masson (pers. comm.), who preformed petrographic studies of the Nisku shelf reservoirs in southern Alberta for Canterra Energy Ltd in 1985, the intensity of the subsequent anhydritization process is the variable factor in reservoir development on the shelf. The Lower Nisku of the shelf complex is consistently pervasively dolomitized showing little variation in intensity. It appears that the lack of infilling of early solution vugs and molds with secondary anhydrite, after dolomitization was completed, controls reservoir preservation.

The Nisku Fm contains 170.6 x $10^6 m^3$ of initial recoverable oil reserves and 40,334 x $10^6 m^3$ of initial marketable gas reserves. These reserves occur (Fig. 5.1) in eight main pool types as follows:

1) Zeta Lake "pinnacle" reefs occurring on the southeast flanks of the Winterburn Basin. These are small build-ups that grew in relatively deep water, downslope of the Upper Nisku Barrier. Examples of this pool type would be at Pembina, Brazeau River and Bigoray. Seismic examples and reviews of the Brazeau Nisku K and S pools, Whitehorse Nisku pool, Bigoray Nisku D, E, H and K pools, and Pembina Nisku F pool are presented in this chapter;

2) Shelf margin reefs, channeled banks, patch reefs and grainstone shoals within the Upper Nisku Barrier and 'Outer Shelf' areas surrounding the Winterburn Basin. Examples of these types of pools are Meekwap, the Brazeau River Nisku P gas pool and Goose River;

3) Reefs, mounds and shoals which were initiated on, and deposited over Leduc reefs in the Winterburn Basin. Examples of these pool types would be Obed, Apetowun and Windfall. A seismic example and review of the Apetowun pool is presented in this chapter;

ACKNOWLEDGEMENTS

Nigel Goody and Frank Hutnik made major contributions to this chapter, particularly in the work they did on the Apetowun example. Brenda Curtis and Larry Mewhort are thanked for their many helpful suggestions. The authors are grateful to Lise Bourbonnais for technical assistance, Cathy Robertson and Victoria Kempt for typing, and to John Wiigs and Paul Triffen for drafting. A special note of thanks is due to Dick Yuen of Seispro Consultants Ltd. for the great seismic processing job that he did. The authors are particularly grateful to the management of Canterra Energy and Husky Oil Operations Ltd for the support and assistance they gave to this project.

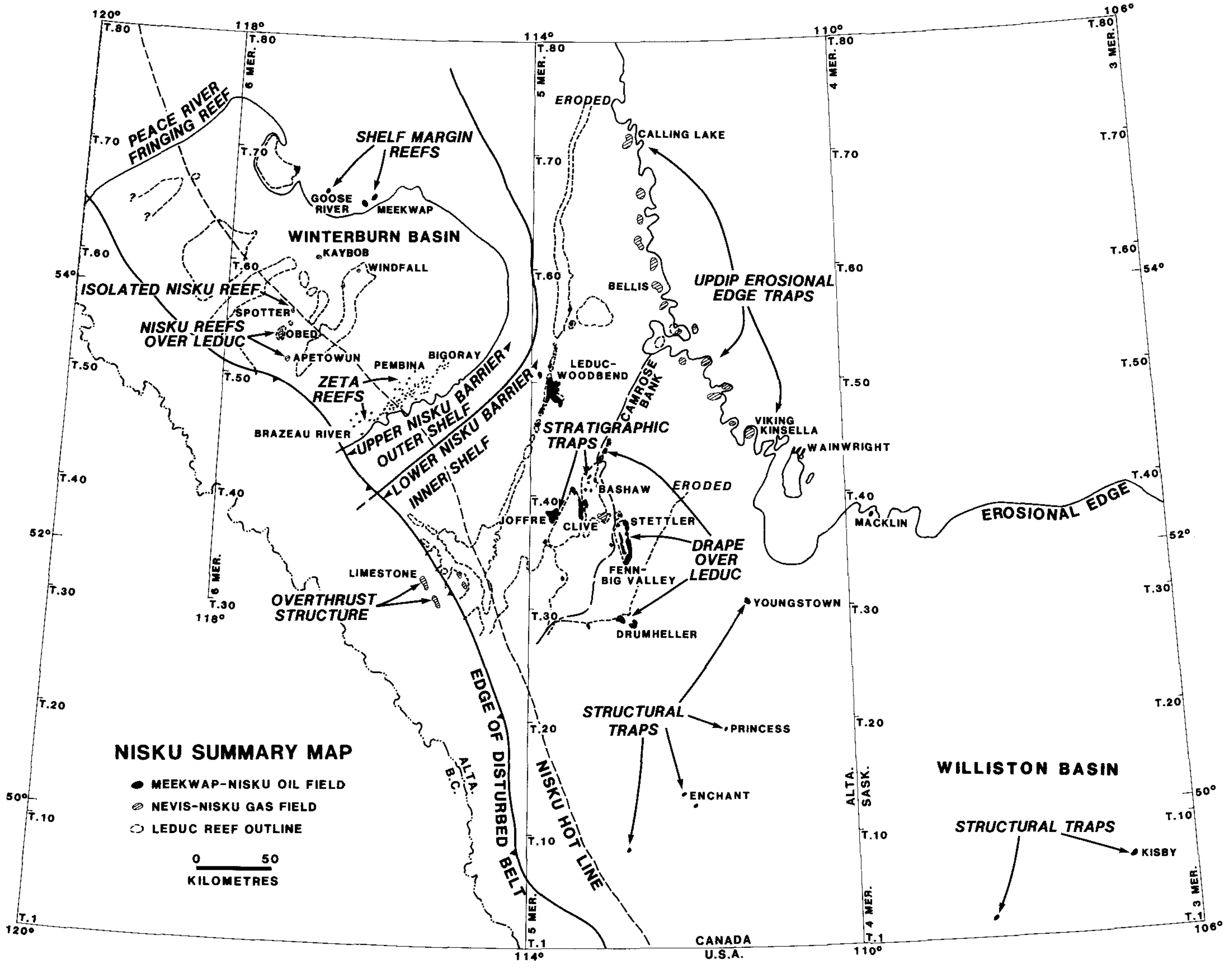

Figure 5.1. Western Canada Nisku summary map.

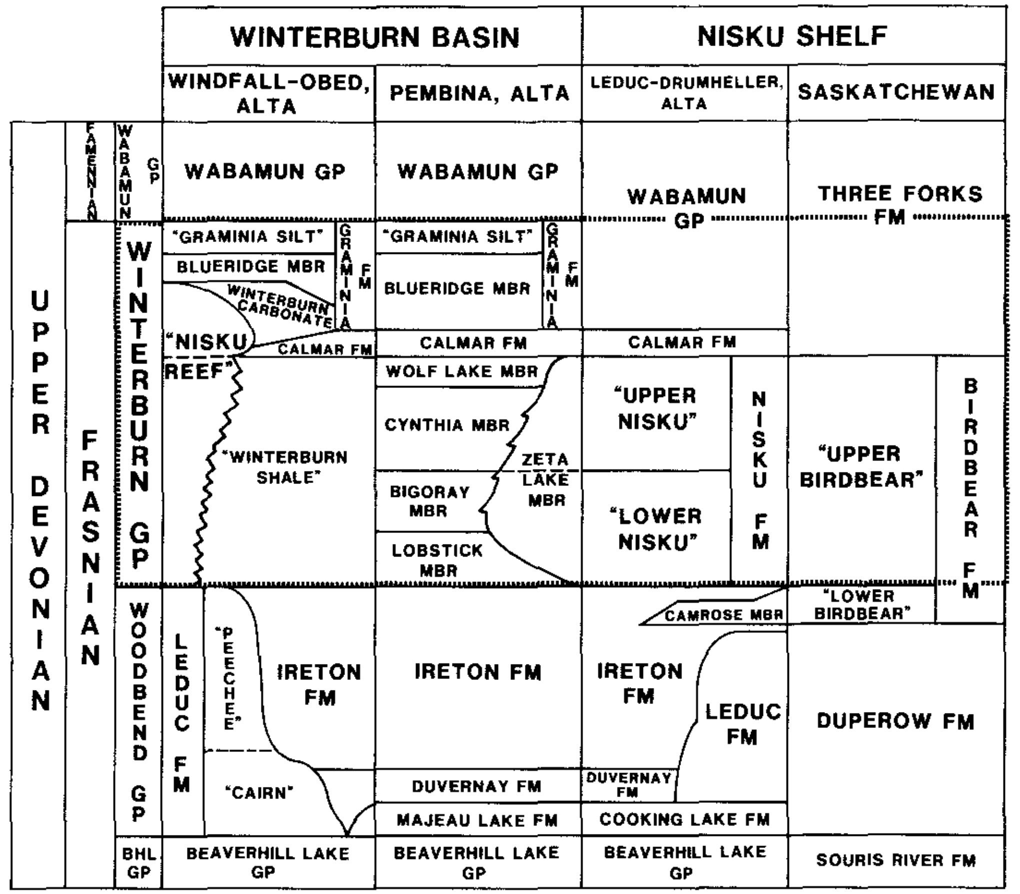

Figure 5.3. Chart showing stratigraphic nomenclature of the Upper Devonian used in this chapter.

4) Isolated reefs, mounds and shoals not associated with or initiated on Leduc reefs in the Winterburn Basin. Examples of these pool types are Kaybob and Unocal Spotter 16-24-56-22 W5M (drilled in 1986);

5) Structural drape traps where porous dolomitized shelf carbonate reservoirs occur over Leduc reefs. Examples of these types of pools are Stettler, Leduc-Woodbend, Clive and Drumheller. Seismic examples for this pool type are presented under the discussion of Leduc reefs in Chapter 4;

6) Structural traps occurring in dolomitized shelf carbonate reservoirs related to basement tectonics and underlying salt dissolution in southern Alberta and the Williston Basin area of Saskatchewan. Examples of these types of pools would be Youngstown, Enchant, Princess and Kisby (Saskatchewan);

7) Stratigraphic traps comprised of shelf biohermal banks, patch reefs, and grainstone shoals, in southern Alberta and the Williston Basin which are not related to Leduc reef highs and paleostructure. The most important example of this pool type is the Joffre pool; and

8) Updip erosional edge traps in eastern Alberta, where solution related porosity enhances reservoir quality. Traps occur in updip escarpment edges. Examples of these types of pools are the Bellis gas pool and the Wainwright heavy oil pool.

ZETA LAKE REEFS

INTRODUCTION

Nisku "pinnacle" reefs of the Pembina area were discovered in January 1977 by the drilling of the Nairb Pembina 11-22-49-12 W5M well (Chevron Exploration Staff, 1979). Over 50 productive reefs have been discovered since. The reefs average 2 km in diameter and 100 m in thickness and were deposited as low relief coral mud-mounds on the slope of the Winterburn Basin (Anderson and Machel, 1987). They are confined to a mature exploration fairway 40 km wide and 120 km long which trends NE-SW through the Pembina, Bigoray and Brazeau regions of west-central Alberta, corresponding to the southeastern slope of the basin (Fig. 5.1).

The term "pinnacle reef" for Zeta Lake reefs is actually a misnomer, probably resulting from their appearance in vertically exaggerated cross-sections. These reefs are actually low relief mud-mounds with funnel-shaped bases. The term "reef" is used for these build-ups in keeping with current practice.

These reefs were deposited downslope of the Upper Nisku Barrier which developed on the bank edge (Figs. 5.1, 5.2). This barrier is considered to be comprised of typical Zeta Lake Mbr reefal facies as seen basinward in the isolated reefs, except that it was deposited in a continuous, linear trend rimming the basin (Machel, 1983). Estimations of the paleoslopes from bank to basin show a constant dip of 0.1° with no major break in slope in the vicinity of the bank edge (Anderson, 1985, p. 47). Breaks in the linear trend and

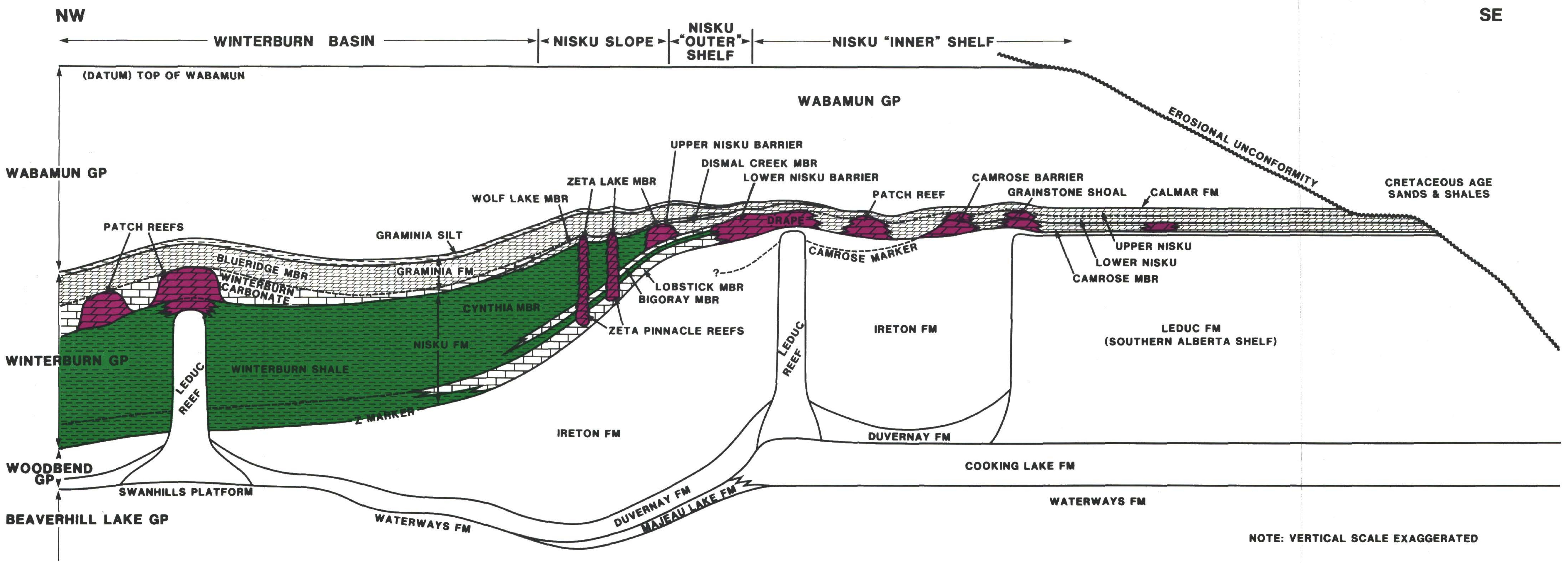

Figure 5.2. Nisku regional schematic cross section.

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channels cutting this barrier present stratigraphic traps and hydrocarbon pools along the updip terminating bank reef edges (i.e. the Brazeau River Nisku P Pool). This barrier shows considerable lateral variation in thickness and often contains shale tongues near the basin edge (Machel, 1983). It formed after the deposition of the Bigorary Fm as the time equivalent of the Cynthia Mbr in the basin, and the Dismal Creek Mbr on the bank or so-called "outer shelf".

The stratigraphy and nomenclature of Nisku basinal units is shown in Figure 5.3. An initial transgression, comprised of two shoaling up cycles, termed the Lobstick and Bigoray members, was deposited on top of Ireton shales. The Lobstick Mbr is described as being partially dolomitized argillaceous bioclastic limestones, siltstones and calcareous siltstones and the Bigorary Mbr as being wackestones, calcareous siltstones and dolomitized argillaceous siltstones overlain by silty argillaceous bioclastic wackestones and packestones (Watts, 1987b).

Stabilization and colonization of Zeta Lake reefs on these ramps was accomplished by corals (Chevron Exploration Staff, 1979; Anderson, 1985; Machel, 1985; and Watts, 1987b) possibly on small irregular highs (Stoakes, 1987a). Water depths are estimated at approximately 55 m (Anderson, 1985). Reefs initiated as early as Lobstick time, but the majority began growth during Bigoray time (Machel, 1983).

Reef growth kept pace with subsidence during the early part of the Lobstick and Bigoray cycles, but was thought by Chevron Exploration Staff (1979) to have exceeded subsidence at the end of both cycles. They concluded that subaerial exposure of Zeta Lake reef highs may have occurred at the end of each cycle. Solution vugging and matrix dolomitization was considered by Chevron to have been particularly intense at the end of Bigoray time. However, Anderson (1985) and Machel (1985) concluded that no significant subaerial exposure occurred until the end of Nisku time.

The deposition of the Cynthia and Wolf Lake members represented the third and final shoaling upward cycle. Reef growth resumed with disphyllid corals dominating and ended with laminar stromatoporoids dominating (Watts, 1987b; Chevron Exploration Staff, 1979).

Deposition of deep-water argillaceous siltstones of the Cynthia Mbr occurred in off-reef areas. The Cynthia Mbr shoals upward and is overlain by the Wolf Lake Mbr. Reef growth was terminated by drowning and an influx of terrigenous clays at the beginning of Wolf Lake time. Moderate to low energy carbonates of the Wolf Lake Mbr were deposited over the reefs (Anderson, 1985). The Wolf Lake was considered by Watts (1987b) to have been deposited in a tidal flat environment. The reefs are capped and sealed by argillaceous siltstones of the Calmar Fm.

Diagenesis of the Zeta Lake Mbr is extremely complex with over 20 sequences and processes currently recognized (Machel, 1986). Our present understanding of the many phases and sequences is bounded by the current limited knowledge of basin hydrology during the many unconformities (Anderson, 1985). Current understanding on processes and sequences can be best understood by reference to Anderson (1985), Machel (1985) and Watts (1987a). One major joint conclusion from Anderson (1985) and Machel (1985) worth mentioning is that pervasive dolomitization was a late process, occurring at intermediate burial depths of 300 - 1000 m, and that oil migration occurred after this in Late Cretaecous time. The dolomitizing fluids are considered by these authors to be "chemically modified sea water" that migrated through the reefs. This was thought to be more complete where syncompactional faults and fractures focused these fluids into the reefs (Anderson and Machel, 1987).

APETOWUN AREA

The Nisku Fm has reservoir and hydrocarbon potential in the Obed-Apetowun area of the "Deep Basin" where Nisku reefs initiate on underlying Leduc build-ups. The largest and most significant pool of this type is the Obed D2A gas pool (1860 x $10^6 m^3$ of marketable gas reserves) discovered in 1966 (Fig. 5.1). A seismic section across the Apetowun Nisku gas pool (360 x $10^6 m^3$ of marketable gas reserves) is presented in this chapter.

The stratigraphy and nomenclature of the Woodbend Gp in this region of the Winterburn Basin is shown in Figure 5.3. The Canadian oil industry's term "Winterburn Shale" is adopted in this chapter to refer to the 200 to 250 m thick sequence of argillaceous limestone and calcareous shales which overlie the Ireton Fm. These argillaceous deposits are equivalent to the Cynthia Mbr in the Pembina area except that they are more calcareous. They are believed to have clinoformed into the basin from the Nisku shelf overlying the Leduc shelf to the west. This shelf occurred on a Cambrian high known as the West Alberta Ridge (R. Workum, pers. comm.).

The industry's term "Winterburn Carbonate" is adopted in this chapter to refer to the 80 m thick sequence of slightly argillaceous limestones that occurs between the Winterburn Shale and the Graminia Fm. Disagreement amongst Canadian oil industry geologists working this play type exists as to the age of this unit. It can be interpreted as being a time equivalent of either the Nisku Fm or the Graminia Fm, depending on how the stratigraphy of the Winterburn Gp section is correlated to exposed Upper Devonian sections of the Rocky Mountains, and also to subsurface type sections at Pembina. The Calmar Fm is not recognizable on logs in the area, but regional correlations show that it might lie at the top of the Winterburn Shale unit (F. Hutnik, Husky Oil, pers. comm.). If so, then the Winterburn Carbonate should be regarded as the basal member of the Graminia Fm.

Nisku reefs from 100 to 150 m thick grew on top of Leduc reefs in the Winterburn Basin. Such reefs grew contemporaneously with the deposition of the Winterburn Shale, which was deposited in the surrounding deeper waters.

All major Leduc complexes that lie within the Winterburn Basin are overlain by Winterburn age reefs which backstep the underlying Leduc reef margins. The term "Nisku Reef" (Fig. 5.3) is used by the Canadian oil industry in reference to these build-ups. It should be noted, however, that such reefs probably grew continuously from Nisku to early Graminia time.

The vertical seal for these reefs are the tight dolostones of the Blueridge Mbr and the anhydrites and shales of the "Graminia Silt" equivalent (Fig. 5.3). One of the concerns and exploration risks associated with this play type is the effectiveness of the Graminia Fm as a good seal rock.

Nisku reefs are also present in the Obed-Apetowun-Spotter area without Leduc build-ups underlying them (for example, Unocal Spotter 16-24-56-22-W5M; Nisku gas well - AOF 645,000 m^3/d). These reefs most likely initiated on local bathymetric highs which occurred in the basin, unrelated to Leduc reefs.

BRAZEAU RIVER NISKU 'K' AND 'S' POOLS

GEOLOGICAL CROSS-SECTION

Figure 5.4 gives the location of the east-west geological cross-section (Fig. 5.5) which illustrates the barrier to basin transition in the Brazeau River area. The reef to off-reef relationships of three dolomitized Zeta Lake reefs are shown.

The well at 6-15-47-16 W5M (shut-in Mississippian gaswell) illustrates the regional basin stratigraphy. The gaswell at 2-11-47-15 W5M was drilled into the Brazeau River Nisku 'K' gas pool (Table

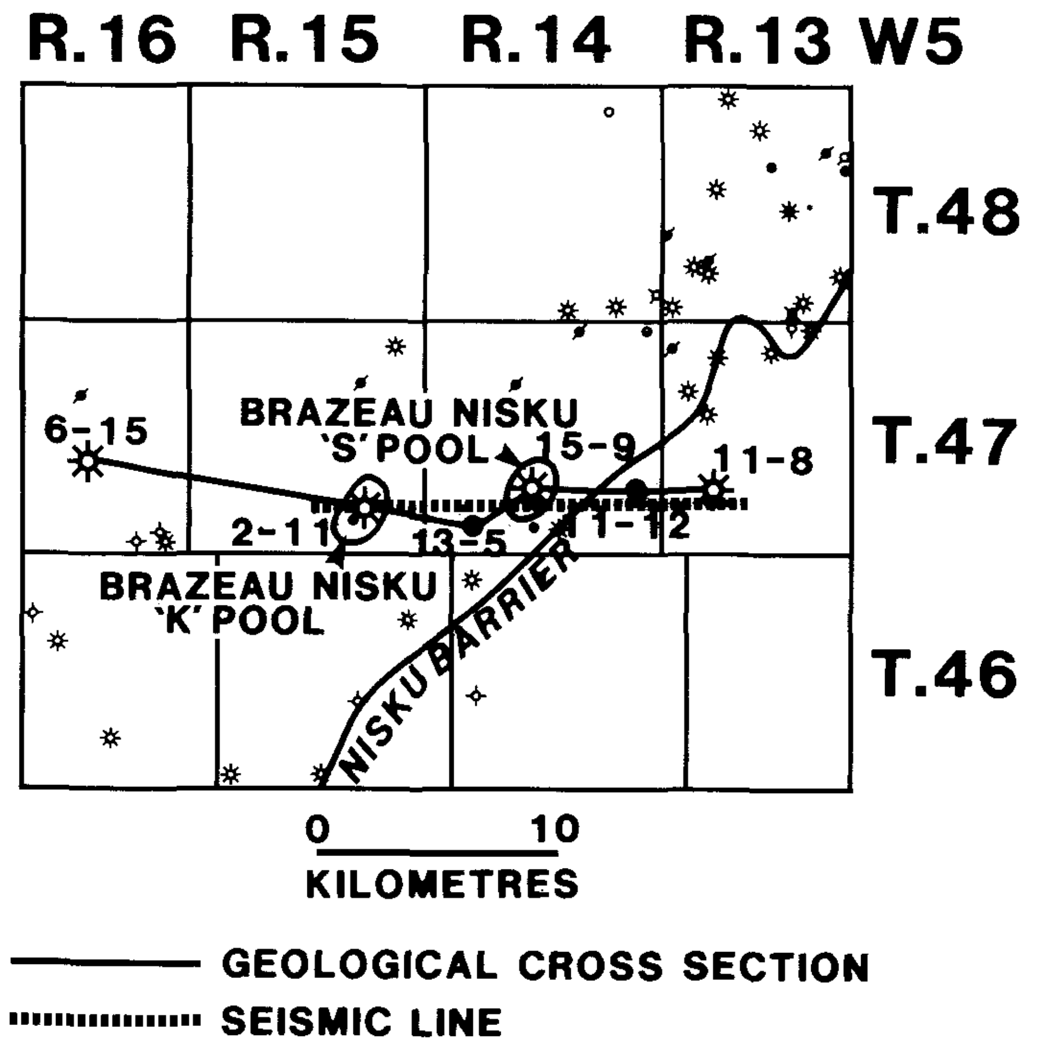

Figure 5.4. Index map of Brazeau River Nisku 'K' and 'S' pool area.

5.1) and drillstem tested 210,000 m^3/d of gas and 221.5 m^3/d of condensate prior to being shut-in. The reef initiated at the base of the Bigoray Fm and is 65 m thick with 4 m of net porosity (>3%).

The well at 13-5-47-14 W5M (shut-in Cardium oilwell) encountered only 6 m of gas pay over water in a Zeta Lake reef and hence the Nisku zone was abandoned. The reef initiated at the base of the Cynthia Fm and is 31 m thick with 26 m of net porosity (>3%).

The well at 15-9-47-14 W5M was drilled into the Brazeau River Nisku 'S' gas pool (Table 5.1). The reef initiated in the Bigoray Fm and is 52 m thick with 36 m of net porosity.

The wells at 11-12-47-14 W5M (abandoned Cardium oilwell) and 11-8-47-13 W5M (shut-in Mississippian gaswell) were drilled into the Zeta Lake barrier complex, also referred to as the Upper Nisku Barrier (Fig. 5.2), which rims the Winterburn Basin. The barrier is wet at this locality and reaches a thickness of 34 m at the 11-8 location, where it has 7 m of net porosity (>3%). Growth of the reef barrier complex is believed to have initiated at the top of the Bigoray Fm.

SEISMIC SECTION

Figure 5.4 gives the location of this seismic example which is an east-west line through the Brazeau River Nisku 'K' and 'S' pools and extends over the Nisku barrier at the east end. The seismic line has been divided into two parts: west (Fig. 5.6) and east (Fig. 5.7).

Two Zeta Lake reefs are penetrated by the wells at 2-11 and 15-9 (Fig. 5.6). The Zeta Lake reef encountered at the 2-11 well is interpreted between traces 523 and 566 at 1.92 - 1.95 seconds two way traveltime. The reef is recognized mainly by the disappearance of the reflection from the top of the Cynthia Mbr shale over the reef. The top Cynthia event is a peak on the seismic section, which is normal polarity in the Society of Exploration Geophysicists polarity convention (i.e. a seismic event from an increase in velocity is shown as a trough). The top Ireton Fm reflection diminishes under the flanks of the reef due to defocusing of the reflection caused by the lens shape of the reef. The Ireton Fm reflection reappears under the crest of the reef. A particularly interesting feature of this reef is the prominent anticlinal structure which is recognizable from the Beaverhill Lake Gp to Viking Fm interval. The amplitude of this anticline is as follows: 16 ms at the Beaverhill Lake Gp; 10 ms at the Wabamun Gp, and 9 ms at the Viking Fm. Roll-over of reflections beneath the reef can mostly be accounted for by velocity pull-up created by the slower velocity Cynthia Mbr shale being replaced by the higher velocity carbonates of the Zeta Lake reef. Structural roll-over of reflections above the reef can be attributed to drape due to differential compaction of the Zeta Lake carbonate and Cynthia Mbr shale.

Table 5.1. Reserves and reservoir parameters of Nisku pools

	Oil Initial Volume in Place E3 m3	Raw Gas Initial Volume in Place E6 m3	Oil Reserves Primary Recovery E3 m3	Marketable Gas E3 m3	Rec. Factor %	Gas Surface %	Average Pay Thickness metres	Area ha	Porosity %	Water Sat. %	Shrinkage %	Temp. Gas deg C	Compress. Gas %	Initial Pressure kPa
NISKU OIL POOLS:														
Bigoray Nisku D	2,200		880		40		18.5	190	8.8	11	80	80		29,100
Bigoray Nisku E	2,000		700		35		45.5	100	6.0	10	81	80		28,448
Bigoray Nisku H	2,200		660		30		46.0	58	12.0	18	84	73		18,740
Bigoray Nisku K	860		256		30		29.2	64	7.2	23	82	69		19,360
Bigoray Nisku F	2,100		735		35		16.7	170	11.9	18	76	83		26,640
NISKU GAS POOLS:														
Apet		873		360	75	45	57.7	200	4.0	35		109	90.3	36,300
Brazeau R. Nisku K		812		429	N/A	N/A	26.1	255	5.3	25		117	167.8	70,730
Brazeau R. Nisku K		1,021		694	85	20	49.7	128	6.5	10		110	103.4	37,880
Whitehorse		502		342	80	15	21.5	128	8.9	5		117	98.2	29,140

The 13-5 reef is not seen on the seismic section. The crest of the reef is probably not crossed by the profile.

The Zeta Lake reef encountered by the well drilled at 15-9 is interpreted between traces 270 and 320 at 1.90 - 1.93 seconds two way traveltime. The reef is recognized by the disappearance of the reflection from the top of the Cynthia Mbr shale over the reef. The top Ireton Fm reflection diminishes on the flank of the reef and reappears under the crest of the reef. In this example a weak amplitude reflection representing the top Nisku Fm can be followed over the reef at 1.90 seconds two way time. This reflection could be caused by a very porous Nisku Fm and may indicate that the reef penetrated by 15-9 is more porous than the reef at 2-11. The amplitude of the top Cynthia Mbr shale reflection decreases from traces 320 to 400. This decrease in amplitude could be caused by the Cynthia Mbr shale becoming more calcareous and thinning as it approaches the reef. There is no significant drape in the formations overlying the Zeta Lake reef penetrated by the 15-9 well. Velocity pull-up under the reef is very slight compared to the Zeta Lake reef penetrated by the well at 2-11. The absence of significant drape indicates that the Zeta Lake reef at 15-9 is not as thick as the Zeta Lake reef at 2-11.

The east half of the seismic line (Fig. 5.7) shows the seismic expression of the Nisku Fm barrier from traces 1 to 168 at 1.85 - 1.89 seconds two way time. The peak marking the top Cynthia shale in the 'basinal' areas disappears over the Nisku Fm barrier. The top Ireton Fm reflection dims under the entire Nisku Fm barrier. Drape structures of up to 10 ms at the Wabamun Gp are visible in the overlying beds. Velocity pull-up under the barrier is about 15 ms at the top Beaverhill Lake Gp reflection.

Structures also occur in the Viking Fm to Wabamun Gp interval of the section. These are probably related to Laramide tectonics which have also caused minor thrusting in part of the Lower Cretaceous, around trace 144 to 312 and 528 to 624 at 1.2 to 1.4 seconds two way traveltime.

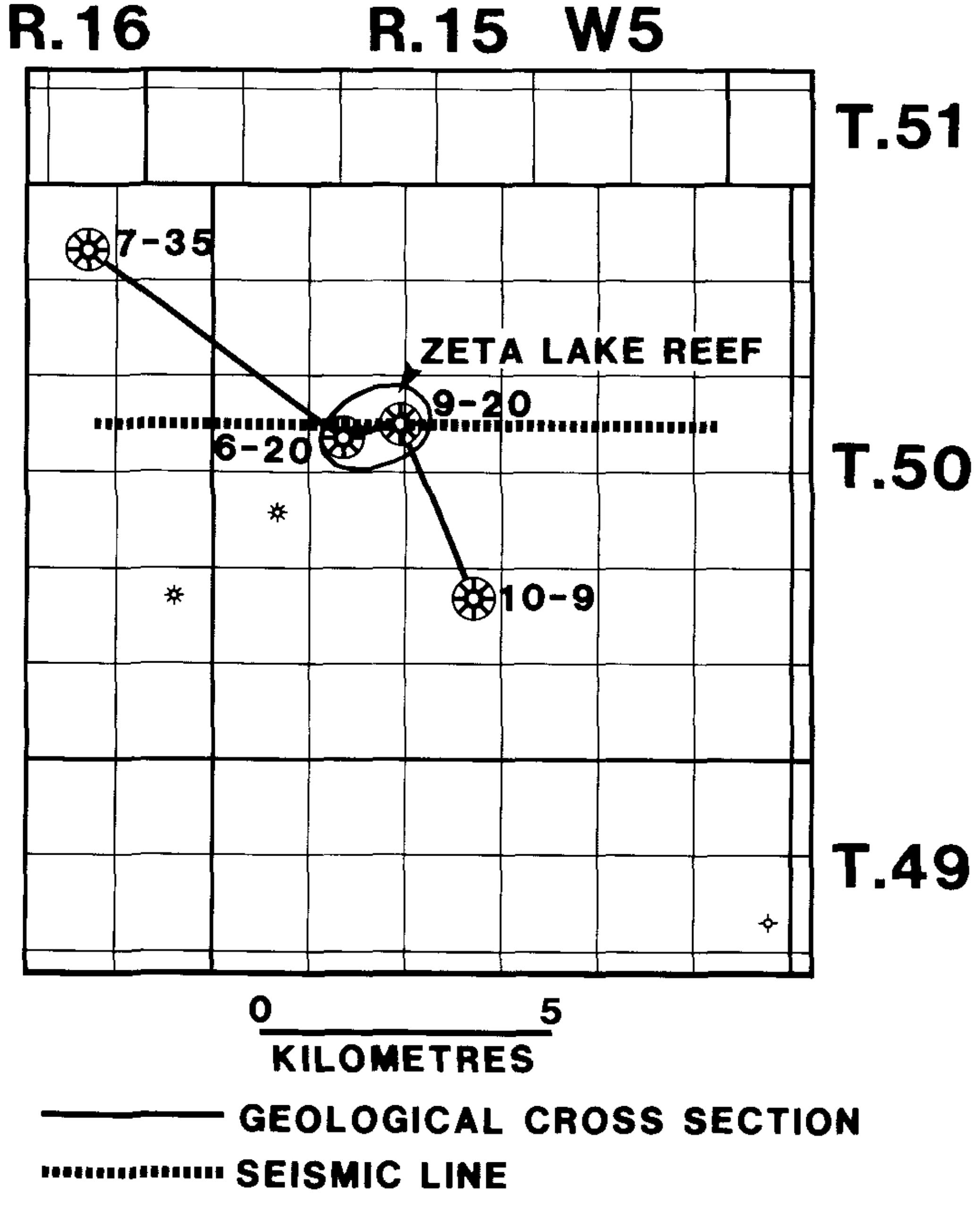

Figure 5.8. Index map of Whitehorse Nisku pool area.

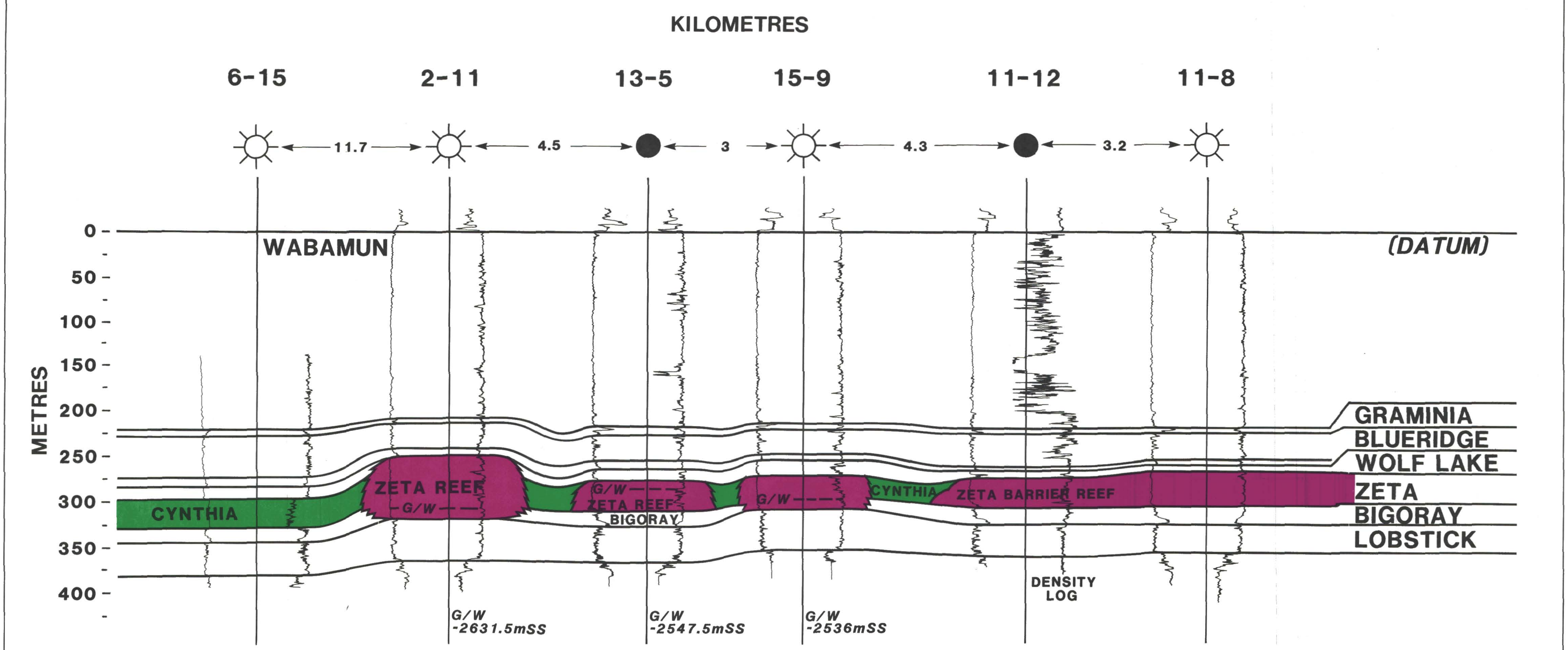

Figure 5.5. Geological cross-section through Zeta Lake reef: Brazeau River Nisku 'K' and 'S' pool area.

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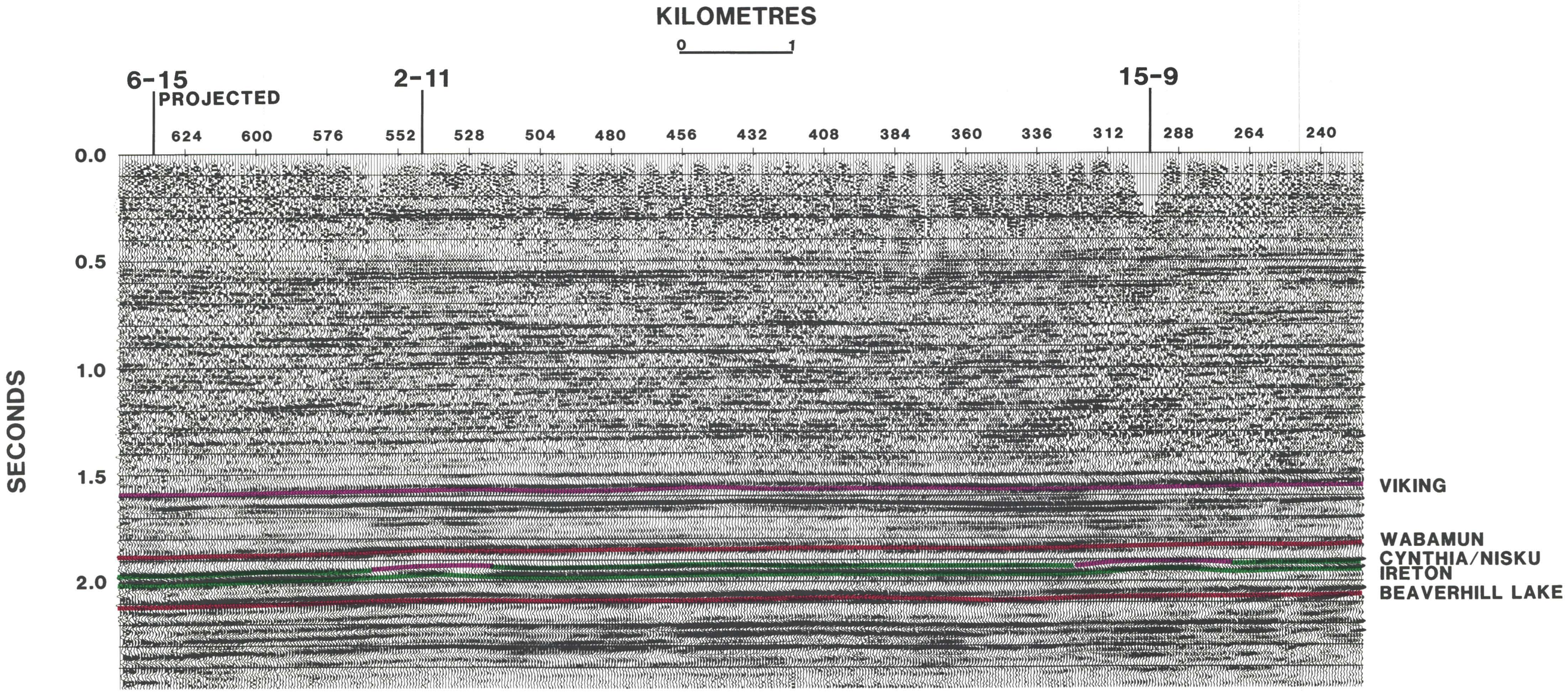

Figure 5.6. Seismic section (west half) through Brazeau River Nisku 'K' and 'S' pool area.

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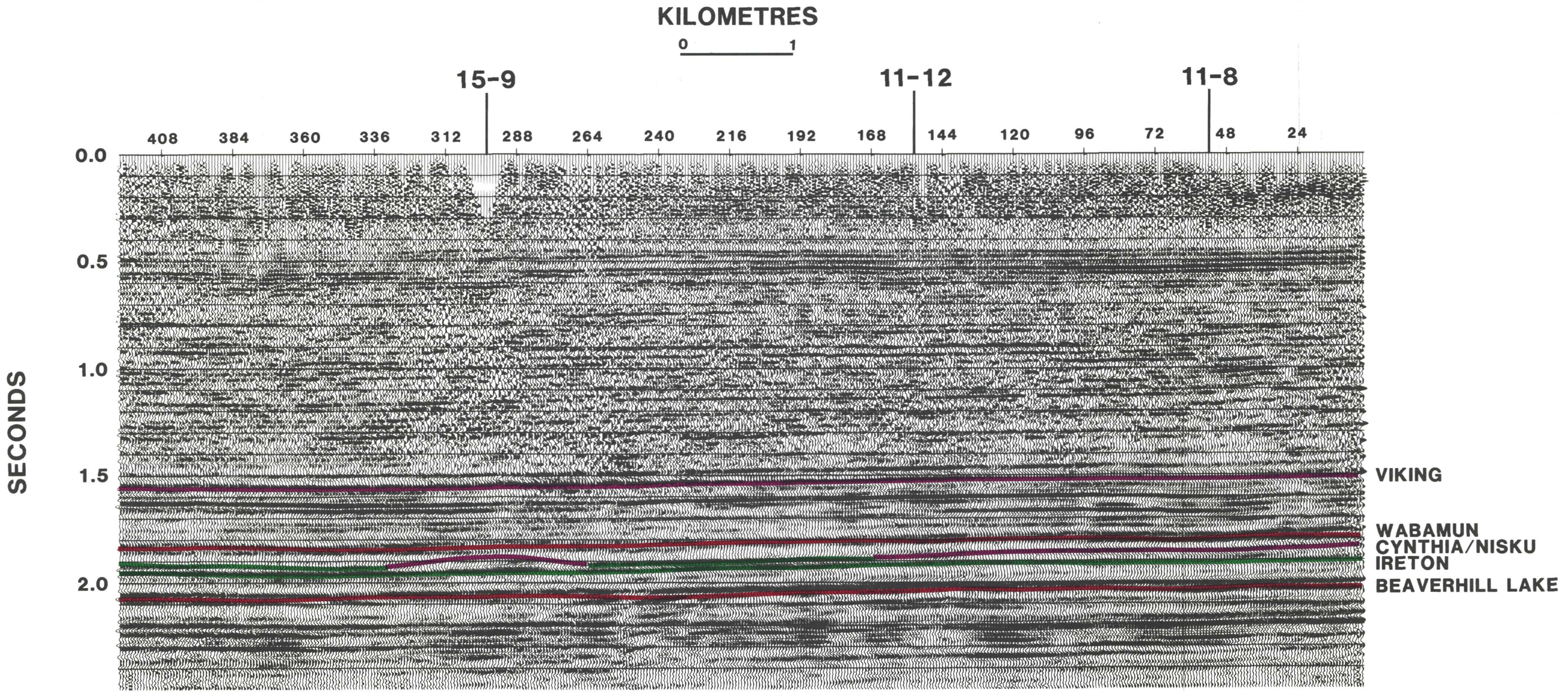

Figure 5.7. Seismic section (east half) through Brazeau River Nisku 'K' and 'S' pool area.

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WHITEHORSE NISKU POOL

GEOLOGICAL CROSS-SECTION

Figure 5.8 gives the location of the northwest-southeast geological cross-section (Fig. 5.9) which shows the reef to off-reef relationships of a shut-in, gas-bearing dolomitized Zeta Lake reef (Whitehorse Nisku gas pool). The wells at 7-35-50-16 W5M and 10-9-50-15 W5M illustrate the regional basin stratigraphy.

The well at 6-20-50-15 W5M (shut-in Rock Creek gas well) was drilled into the Whitehorse Nisku gas pool (Table 5.1). The pay zone was only 1 m thick and hence the Nisku zone was abandoned. The reef initiated at the top of the Lobstick Fm and is 76 m thick with 48 m of net porosity at this location.

The well at 9-20-50-15 W5M (shut-in Nisku gas well) was also drilled into the Whitehorse Nisku gas pool. The Zeta Lake Mbr in this well was perforated and tested gas at 207,270 m^3/d on production test with a 7.5 mm choke. The reef at this location also initiated at the top of the Lobstick Fm and is 82 m thick with 55 m of net porosity (>3%).

SEISMIC SECTION

This seismic example is an east-west line over a Zeta Lake reef penetrated by two shut-in gas wells, 6-20 and 9-20 (Fig. 5.8). The seismic line is displayed at SEG normal polarity (Fig. 5.10). A Zeta Lake reef is interpreted between traces 148 and 204 at 1.70 seconds two way traveltime. The amplitude of the peak representing the top of the Cynthia Mbr diminishes over the anomaly where the lower velocity shale is replaced by the higher velocity carbonates of the Zeta Lake reef.

The dimming of the Ireton Fm reflection immediately under the flanks of the reef is particularly well demonstrated in this example. The cause of this phenomenon is likely due to a combination of: 1) a complex tuning response as the higher velocity Zeta Lake carbonates gradually replace the lower velocity Cynthia Mbr shale; and 2) a defocussing effect caused by refraction through the lens shaped Zeta Lake reef. Events deeper than the Ireton Fm do not consistently show this effect.

Prominent anticlinal structures are recognizable from the Beaverhill Lake Gp through the Viking Fm. Roll-over of reflections beneath the reef of up to 20 ms at the Beaverhill Lake Gp can be partly accounted for by velocity pull-up. Structural roll-over of reflections above the reef of up to 15 ms at the Wabamun Gp can be attributed to drape due to differential compaction of the Zeta Lake carbonate and Cynthia Mbr shale.

BIGORAY NISKU 'D' AND 'E' POOLS

GEOLOGICAL CROSS-SECTION

Figure 5.11 gives the location of the northwest-southeast geological cross-section (Fig. 5.12) which shows the reef to off-reef relationship of two oil bearing limestone Zeta Lake reefs in the

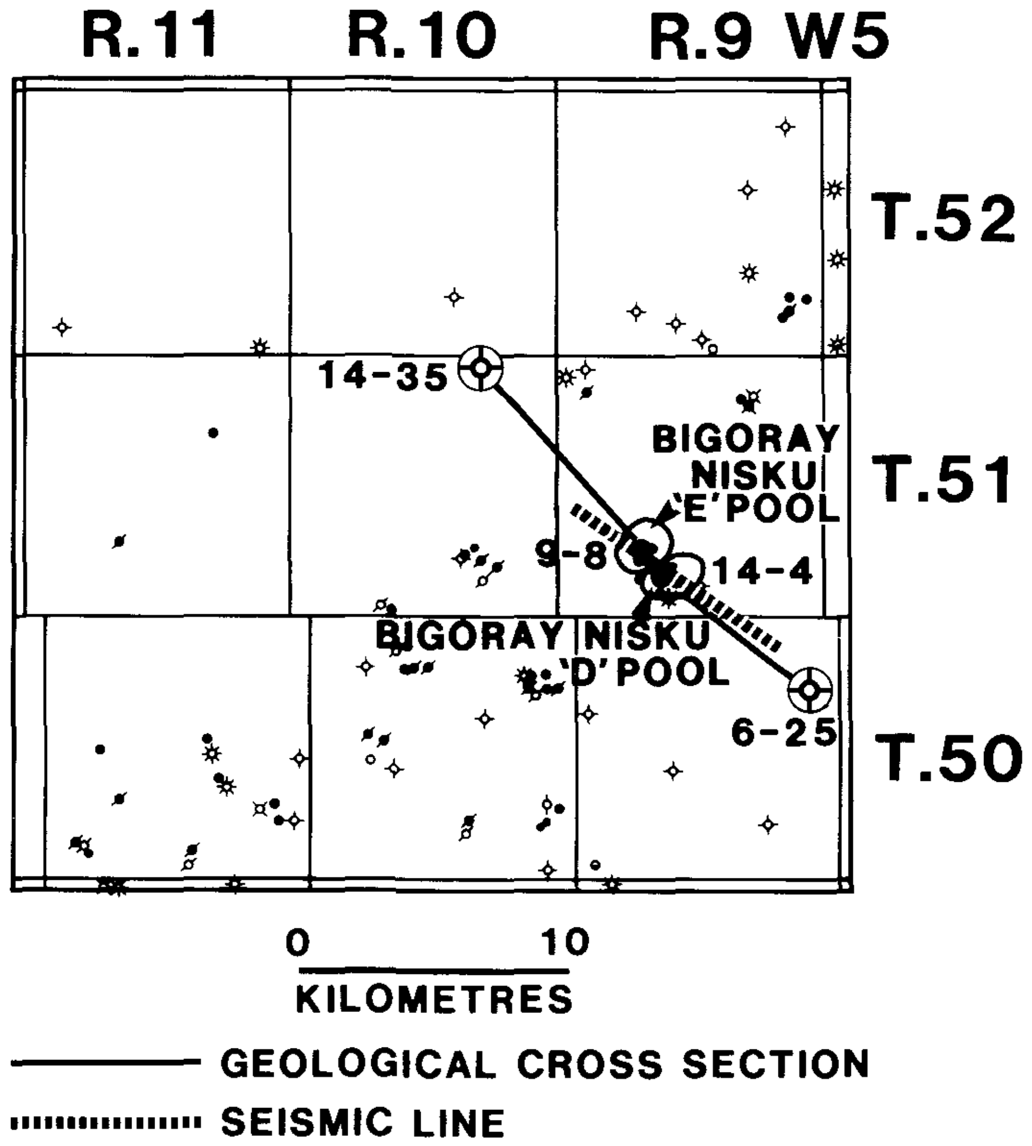

Figure 5.11. Index map Bigoray Nisku 'D' and 'E' pool area.

Bigoray area. The wells at 14-35-51-10 W5M and 6-25-50-9 W5M illustrate the basin stratigraphy. The 9-8-51-9 W5M oilwell was drilled into the Bigoray Nisku 'E' oil pool (Table 5.1). The reef initiated at the top of the Lobstick Fm and is 88 m thick with 42 m of net porosity (>3%) at 9-8. The Bigoray Nisku 'E' pool O/W contact occurs structurally lower than the reef base at the 9-8 location.

The 14-4-51-9 W5M oilwell was drilled into the Bigoray Nisku 'D' pool (Table 5.1). The reef initiated at the top of the Lobstick Fm and is 92 m thick with 24 m of net porosity (>3%) at 14-4. The Bigoray Nisku 'D' pool O/W contact occurs structurally lower than the reef base at the 14-4 location.

SEISMIC SECTION

Figure 5.11 gives the location of the northwest-southeast trending seismic section (Fig. 5.13) through the Bigoray Nisku 'D' pool penetrated by the well at 14-4 and the Bigoray Nisku 'E' pool penetrated by the well at 9-8. The seismic line is displayed at SEG normal polarity.

Two Zeta Lake reefs are interpreted on this line between traces 96 and 122 and traces 136 and 157 at 1.4 seconds two way traveltime. The amplitude of the peak representing the top of the Cynthia Mbr diminishes over the anomalies where this lower velocity shale is replaced by the higher velocity carbonate of the Zeta Lake reef.

Dimming of the peak representing the top Ireton Fm is evident under the reef flanks and continues to remain dim for approximately one kilometre in the off-reef position. The amplitude of the Ireton Fm reflection increases under the reefs.

The separation between the two reefs is poorly imaged but can be justified by:

1) A subtle character change in the trough/doublet trough event immediately below the top Nisku Fm/Cynthia Mbr event;
2) The amplitude increase of the peak representing the top Ireton Fm is not seen in the area between the reefs; and
3) The weak top Nisku Fm/Cynthia Mbr reflection seems to be low in the gap between the reefs. The characteristic strong Cynthia Mbr shale amplitude is not seen, perhaps indicating that a normal off-reef section is not present between the features.

Very subtle drape can be observed on the top Wabamun Gp reflection above the reefs. Pull-up effects of the reefs are slight, up to 10 ms, at the top Beaverhill Lake Gp reflection under the crest of the reef encountered by the 14-4 well.

PEMBINA NISKU 'F' POOL

GEOLOGICAL CROSS-SECTION

Figure 5.14 gives the location of the east-west geological cross-section (Fig. 5.15) which shows the reef to off-reef relationships of the dolomitized Zeta Lake reef which comprises the Pembina Nisku 'F' oil pool. The wells at 12-9-51-11 W5M (producing Cardium

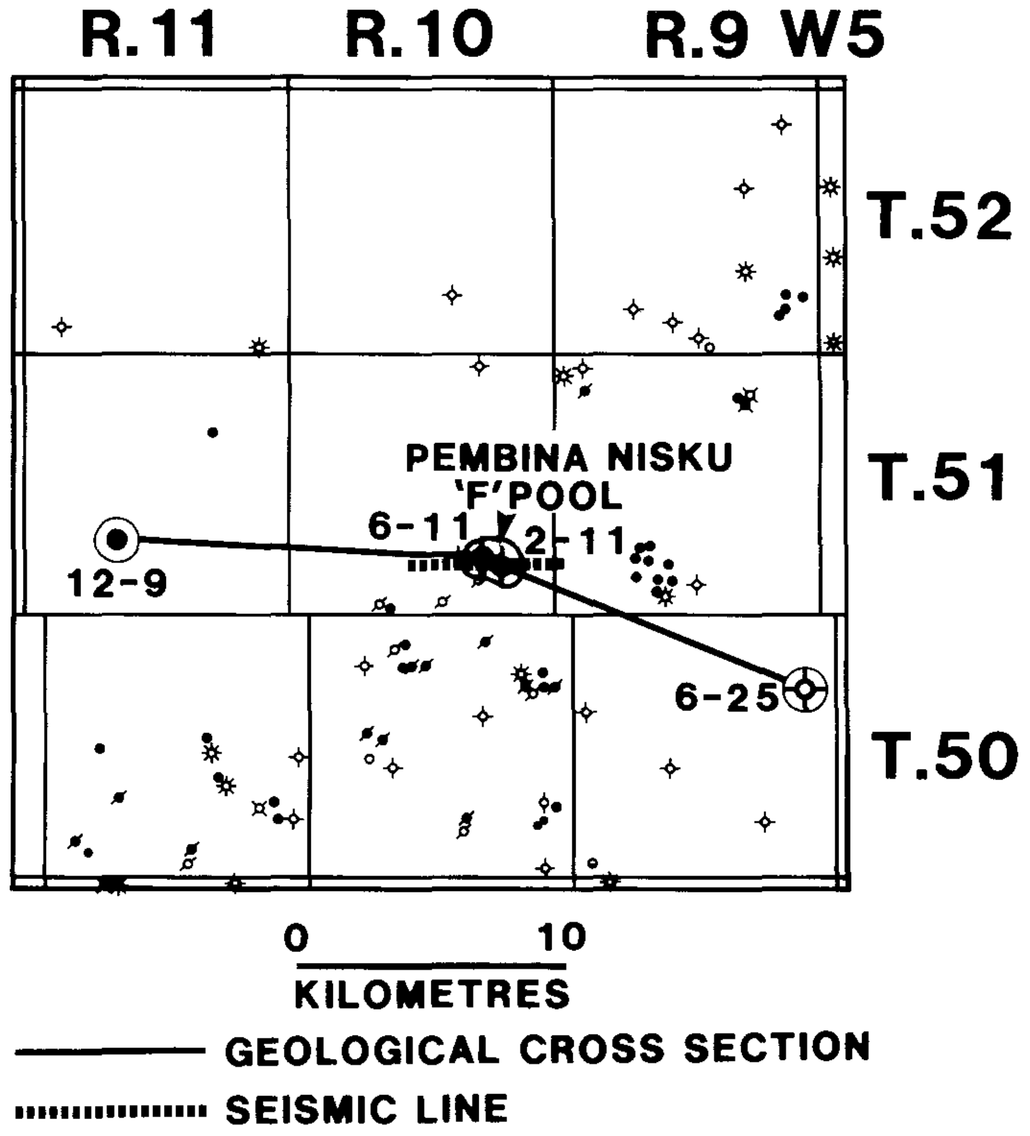

Figure 5.14. Index map of Pembina Nisku 'F' pool area.

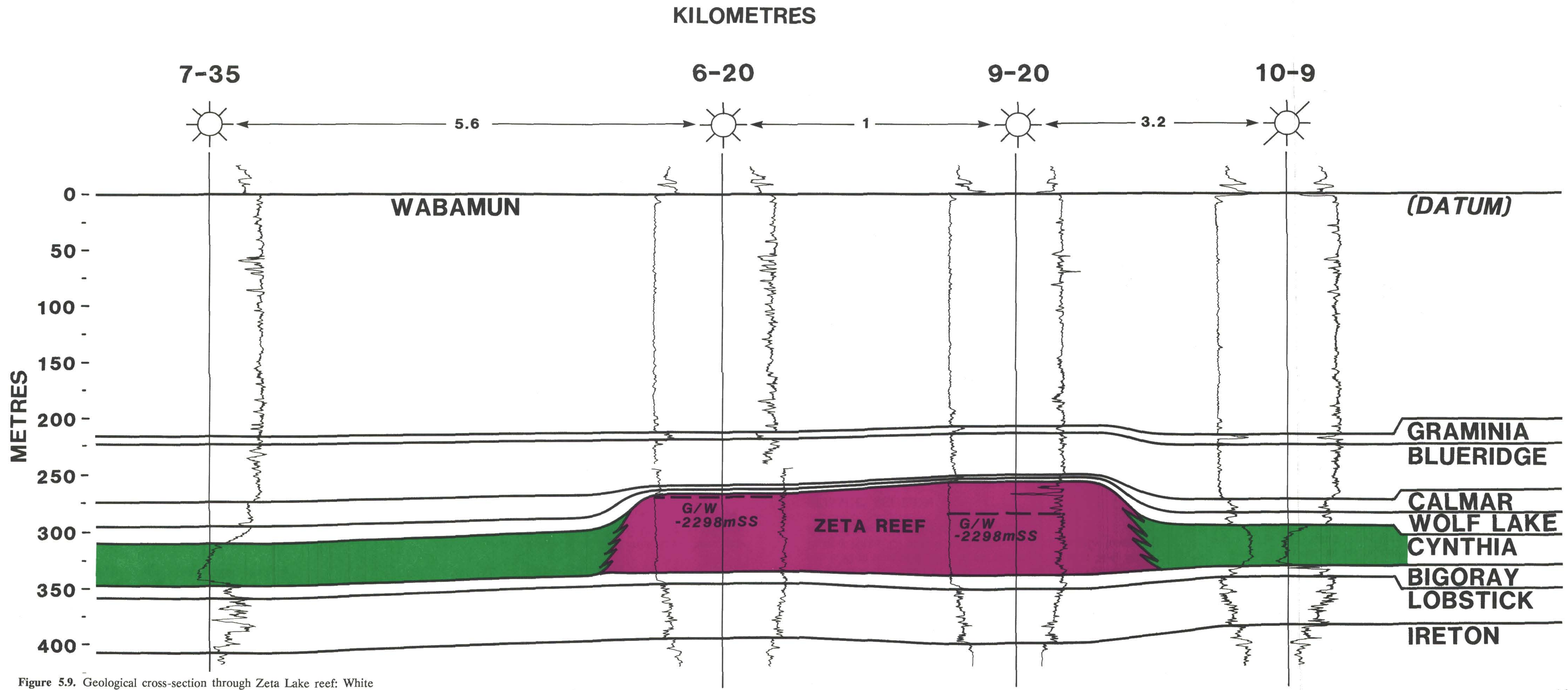

Figure 5.9. Geological cross-section through Zeta Lake reef: White Horse Nisku pool area.

DRAFTING: P. TRIFFEN | LOG PLOTS: | AUTHOR: W. LEYLAND

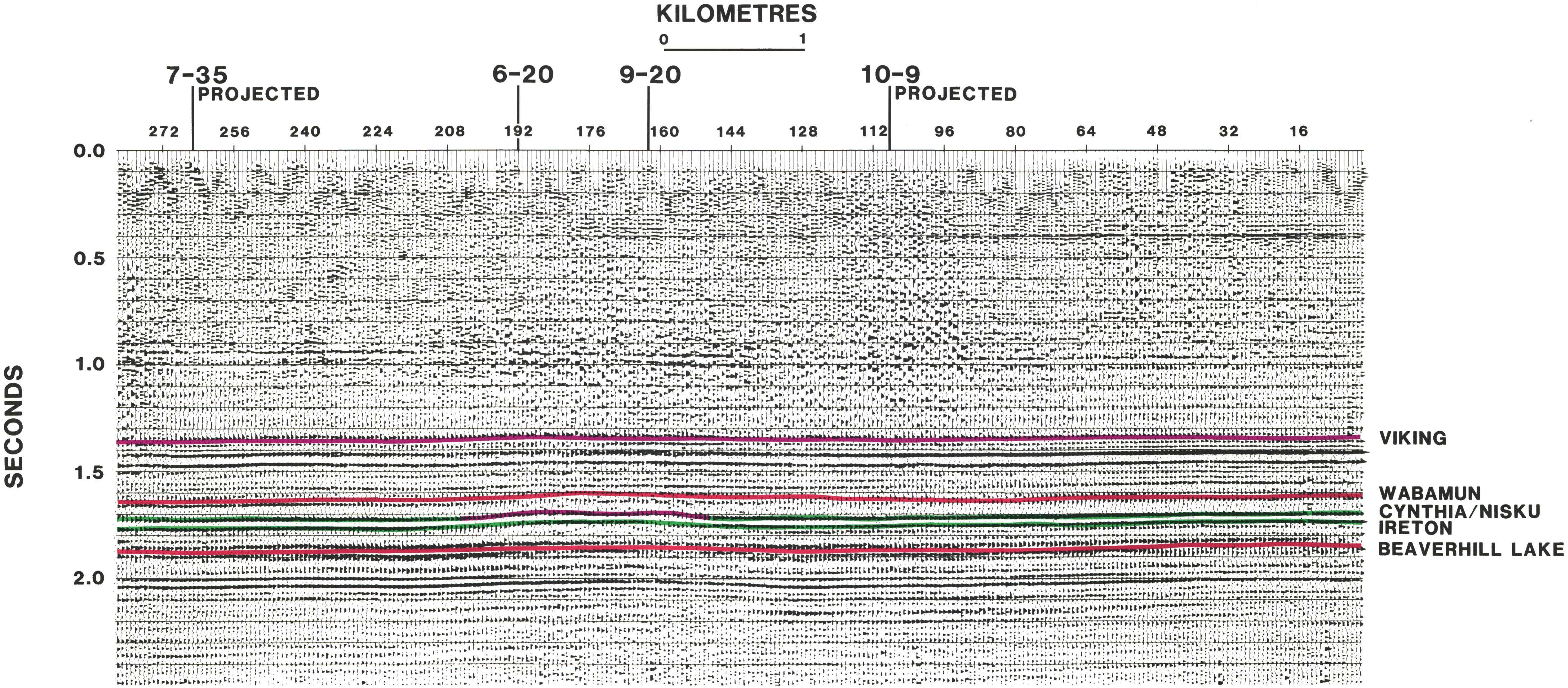

Figure 5.10. Seismic section through Whitehorse Nisku pool area.

DONOR: CHEVRON CANADA	PROCESSOR: SEIS-PRO CONSULTANTS LTD.	AUTHOR: W. RENNIE/A. SKUCE

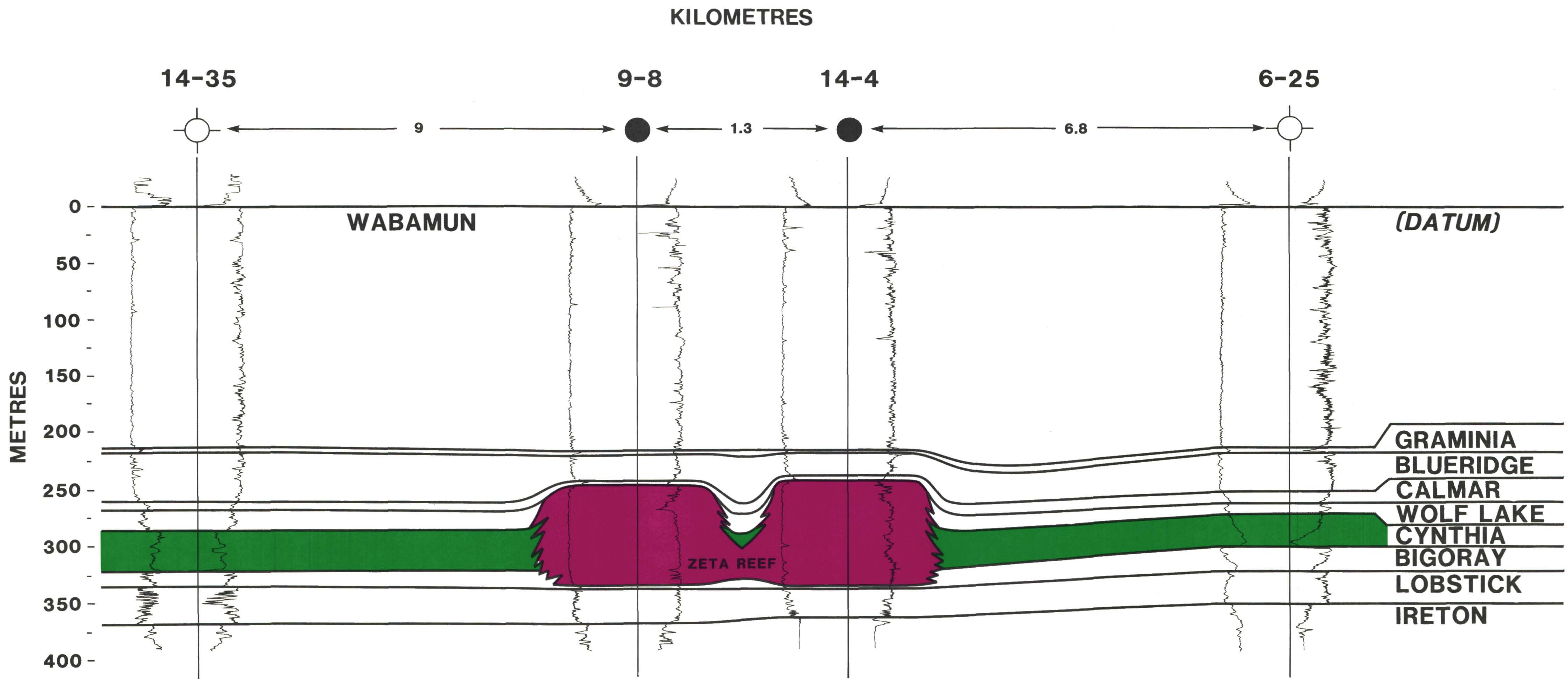

Figure 5.12. Geological cross section through Zeta Lake reef: Bigoray Nisku 'D' and 'E' pool area.

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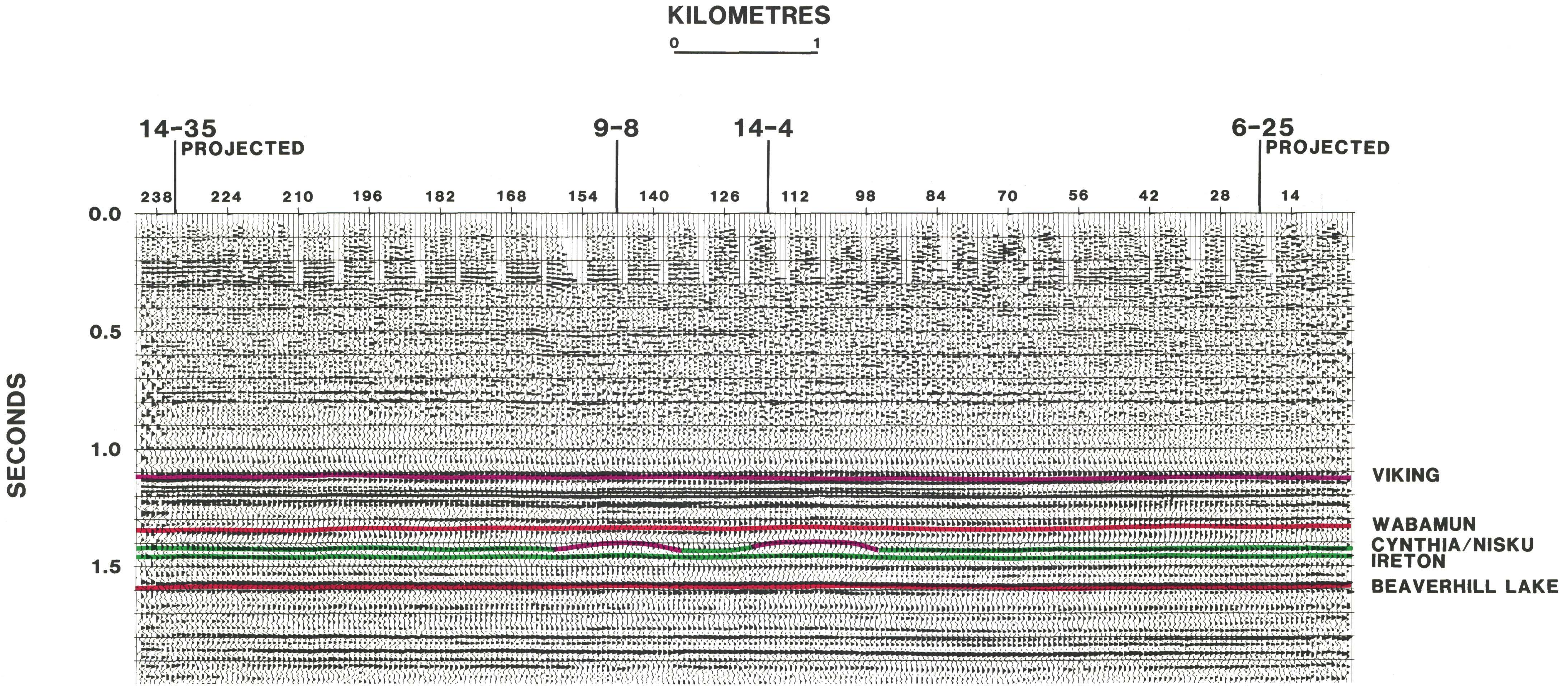

Figure 5.13. Seismic section through Bigoray Nisku 'D' pool 'E' pool area.

DONOR: CHEVRON CANADA | PROCESSOR: SEIS-PRO CONSULTANTS LTD. | AUTHOR: W. RENNIE/A. SKUCE

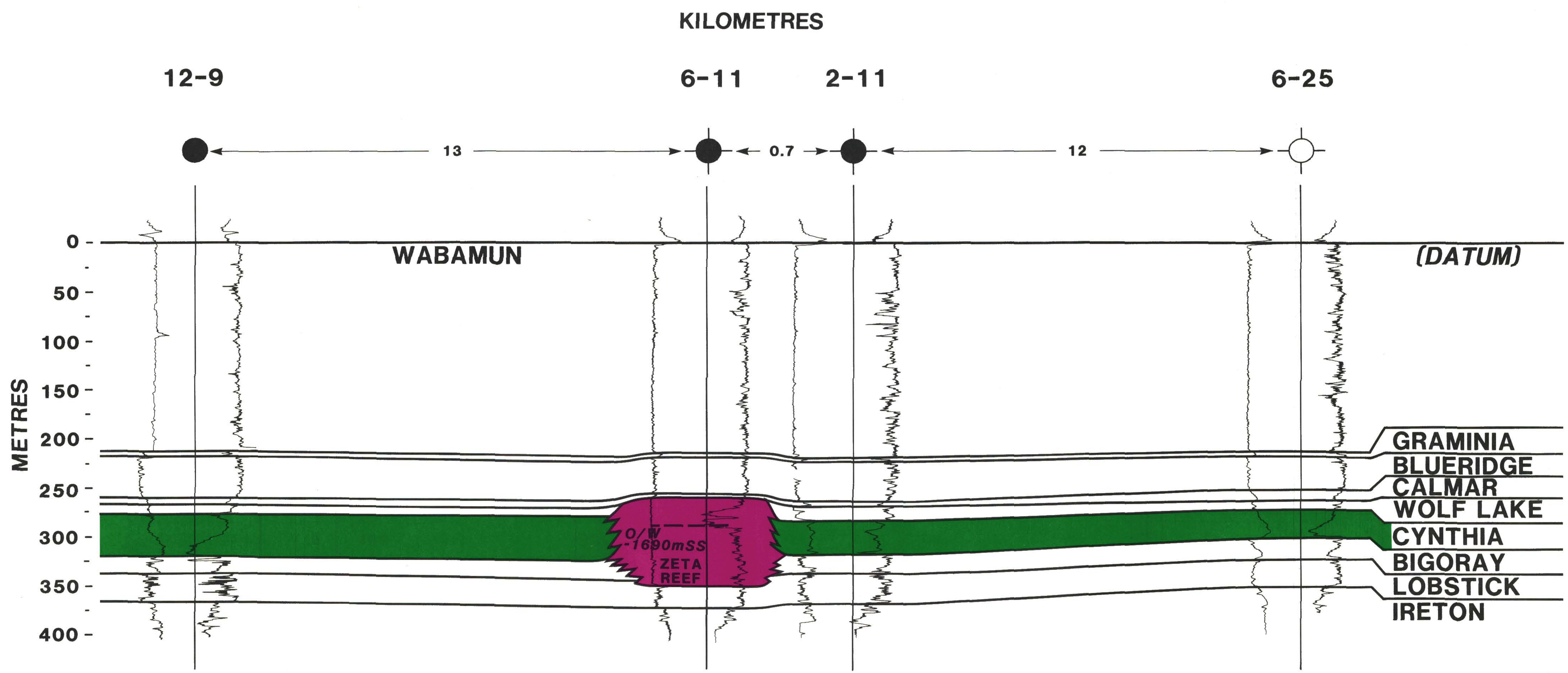

Figure 5.15. Geological cross section through Zeta Lake reef: Pembina Nisku 'F' pool area.

DRAFTING: J. WIIGS | LOG PLOTS: | AUTHOR: W. LEYLAND

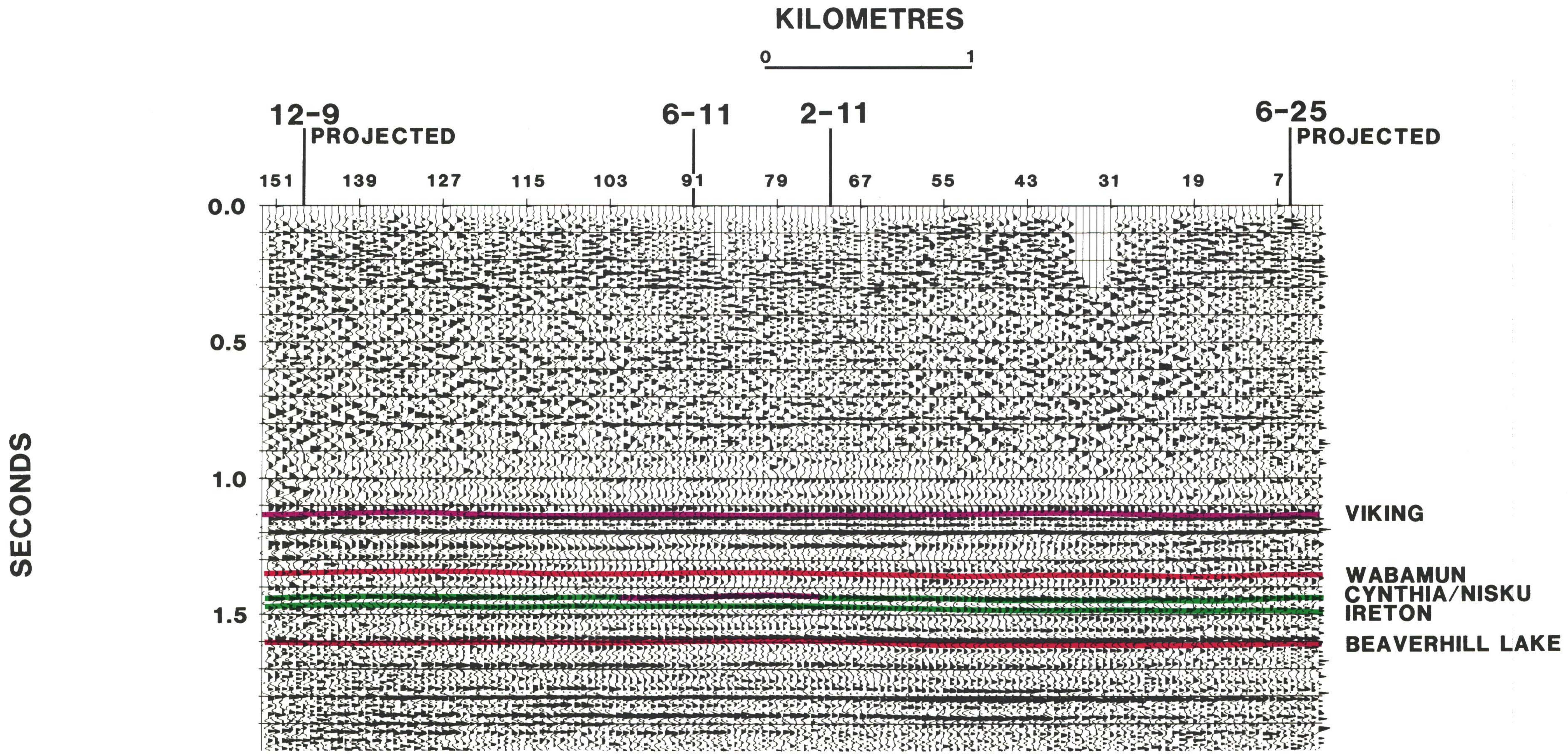

Figure 5.16. Seismic section through Pembina Nisku 'F' pool area.

DONOR: CHEVRON CANADA	PROCESSOR: SEIS-PRO CONSULTANTS LTD.	AUTHOR: W. RENNIE/A. SKUCE

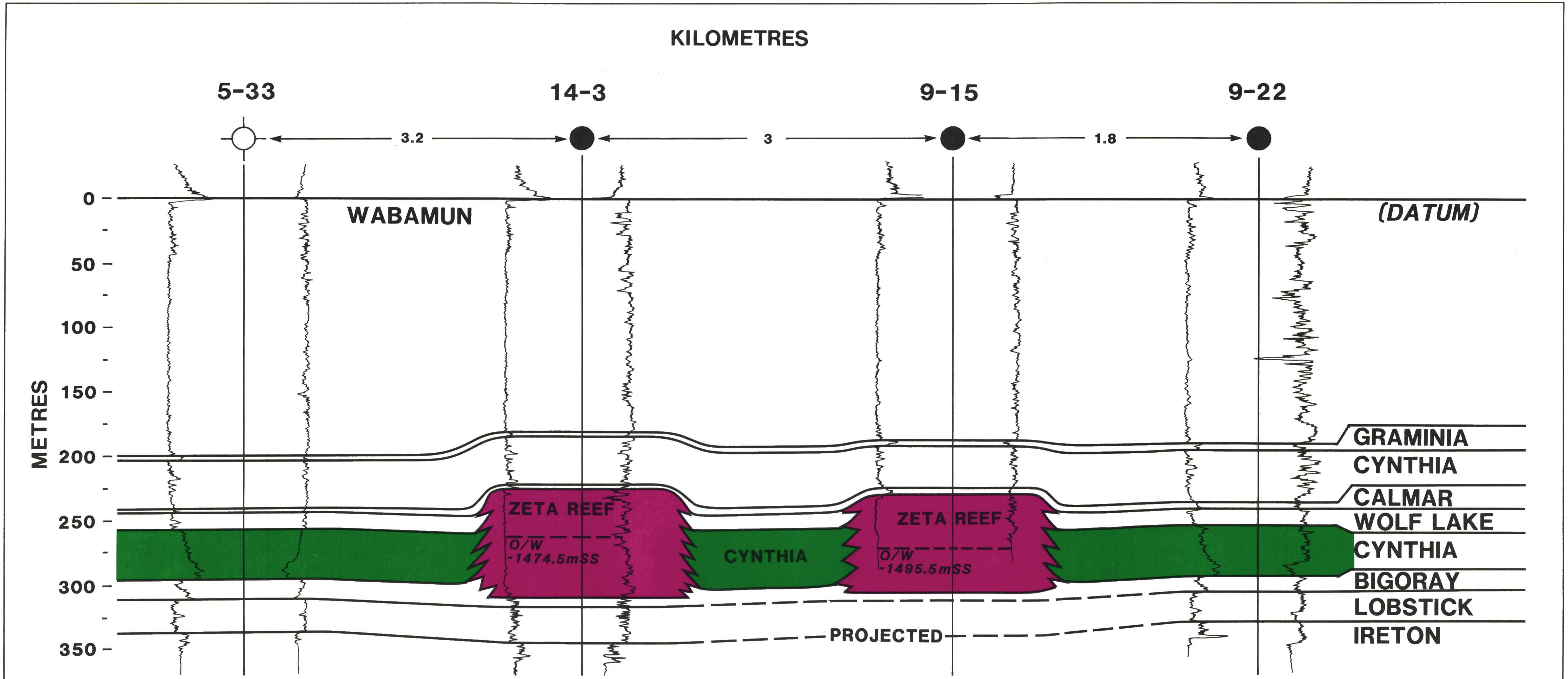

Figure 5.18. Geological cross section through Zeta Lake reef: Bigoray Nisku 'H' and 'K' pool area.

DRAFTING: J. WIIGS | LOG PLOTS: | AUTHOR: W. LEYLAND

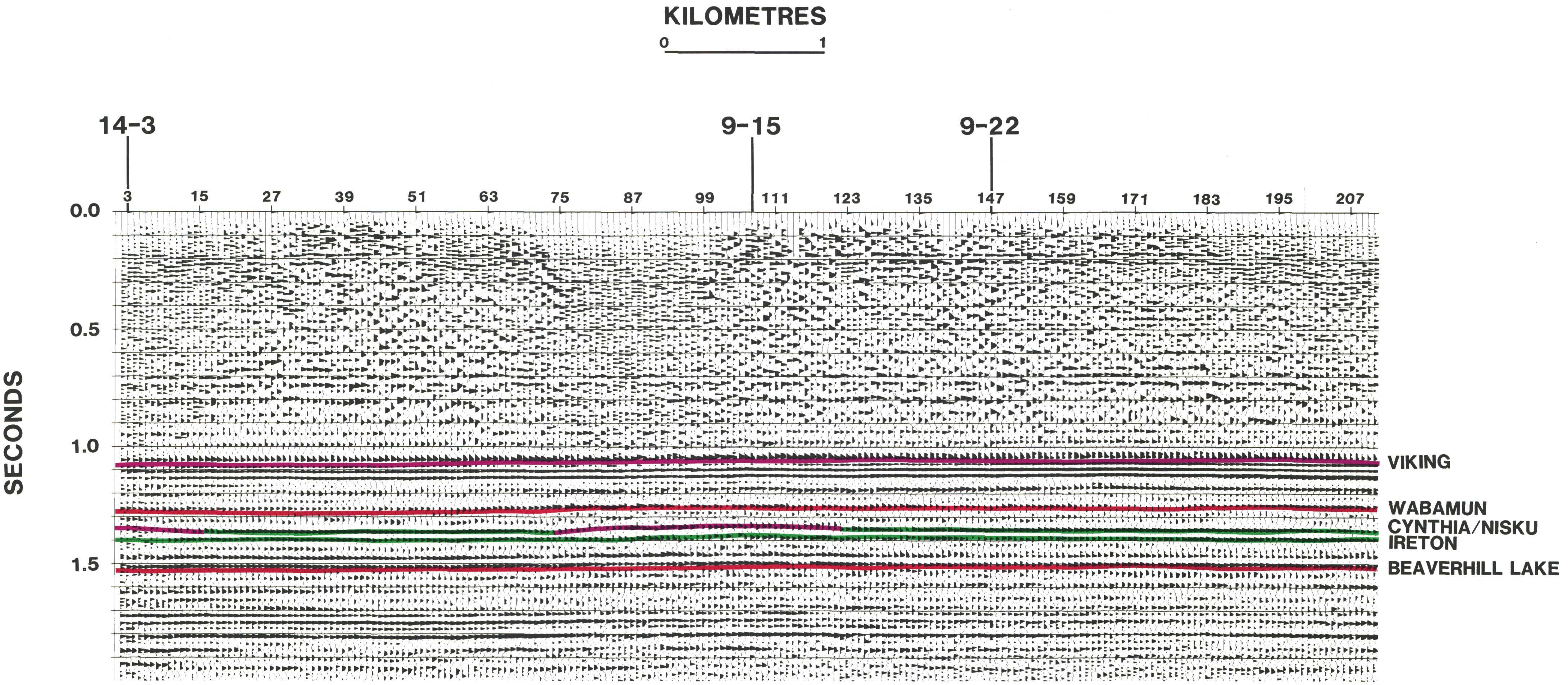

Figure 5.19. Seismic section through Bigoray Nisku 'H' and 'K' pool area.

DONOR: CHEVRON CANADA	PROCESSOR: SEIS-PRO CONSULTANTS LTD.	AUTHOR: W. RENNIE/A. SKUCE

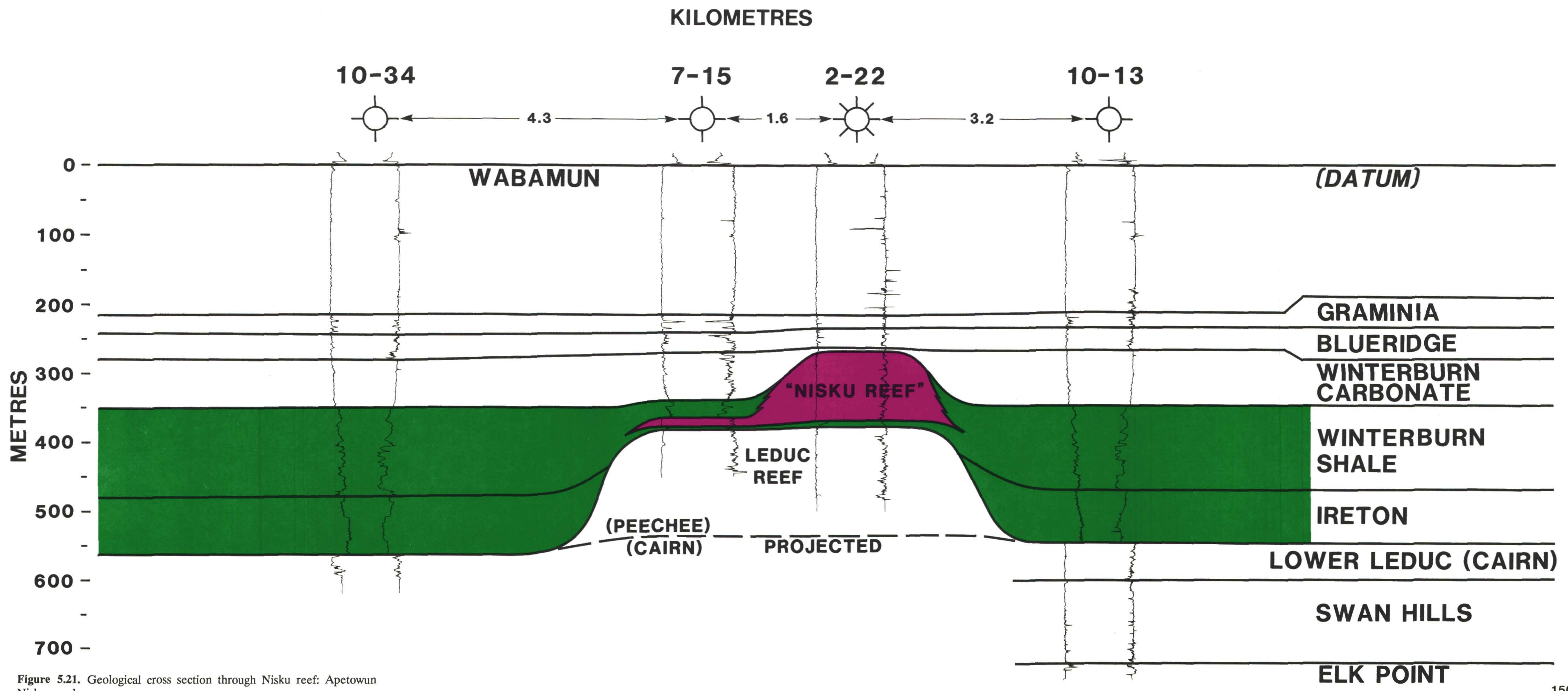

Figure 5.21. Geological cross section through Nisku reef: Apetowun Nisku pool.

DRAFTING: J. WIIGS | LOG PLOTS: | AUTHOR: F.HUTNIK/W. LEYLAND

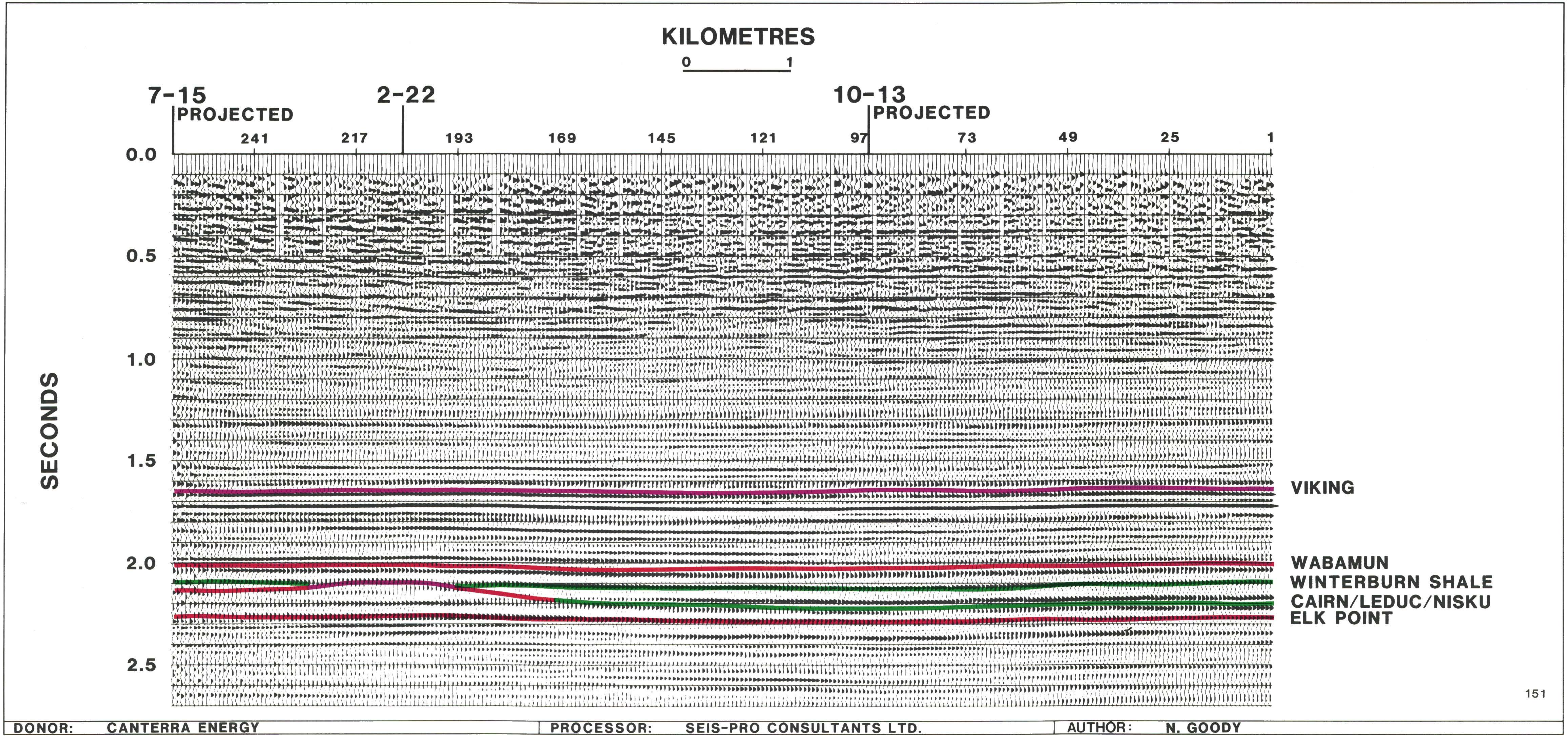

Figure 5.22. Seismic section through Apetowun Nisku pool.

oilwell) and at 6-25-50-9 W5M (dry and abandoned) illustrate the regional basin stratigraphy.

Well 6-11-51-10 W5M is an abandoned Nisku oilwell drilled into the the Pembina Nisku 'F' oil pool (Table 5.1). The reef initiates in the Lobstick Fm and is 90 m thick with 68 m of net porosity (>3%) at the 6-11 location.

The well at 2-11-51-10 W5M is an off-reef abandoned Nisku (Wolf Lake Mbr) oilwell, which produced 1158 m^3 of oil prior to abandonment. This zone is in communication with the main Zeta Lake reef encountered at the 6-11 location.

SEISMIC SECTION

This seismic example (Fig. 5.16) is an east-west seismic section through the Pembina Nisku 'F' pool penetrated by the wells located at 2-11 and 6-11 (Fig. 5.14). The seismic line is displayed at SEG normal polarity.

A Zeta Lake reef is interpreted on the seismic section between traces 73 and 101 at 1.43 seconds two way time. Seismic detection of the reef is difficult because dimming of the peak representing the top Cynthia Mbr shale is not seen. The very porous carbonate of the Zeta Lake reef causes the top Cynthia Mbr/Nisku Fm reflection to remain strong over the entire reef. Also, the top Ireton Fm reflection is strong under the reef crest but weak under the reef flank and remains weak in the off-reef position.

Structural drape of the top Wabamun Gp reflection (approximately 10 ms roll-over) due to differential compaction of the Zeta Lake carbonate and Cynthia Mbr shale is visible on the seismic section. The structural drape effects seem to extend over an area wider than the extent of the reef proved by drilling, and it would be difficult not to predict a reef at the 2-11 location, however the well at 2-11 did not encounter any Zeta Lake reef. Slight pull-up effects are evident on reflections beneath the Zeta Lake reef (approximately 5 ms on the top Beaverhill Lake Gp reflection). Pull-up effects are minimal because of the highly porous nature of the reef.

BIGORAY NISKU 'H' AND 'K' POOLS

GEOLOGICAL CROSS-SECTION

Figure 5.17 gives the location of the north-south geological cross-section (Fig. 5.18) and shows the reef to off-reef relationships of two oil-filled dolomitized Zeta Lake reefs of the Bigoray field. The wells at 5-33-51-8 W5M (dry and abandoned) and 9-22-52-8 W5M (Ostracod oilwell) illustrate the regional basin stratigraphy.

The well at 14-3-52-8 W5M is drilled into the Bigoray Nisku 'K' oilpool (Table 5.1). The reef initiated in the Bigoray Fm and is 81 m thick with 39 m of net porosity.

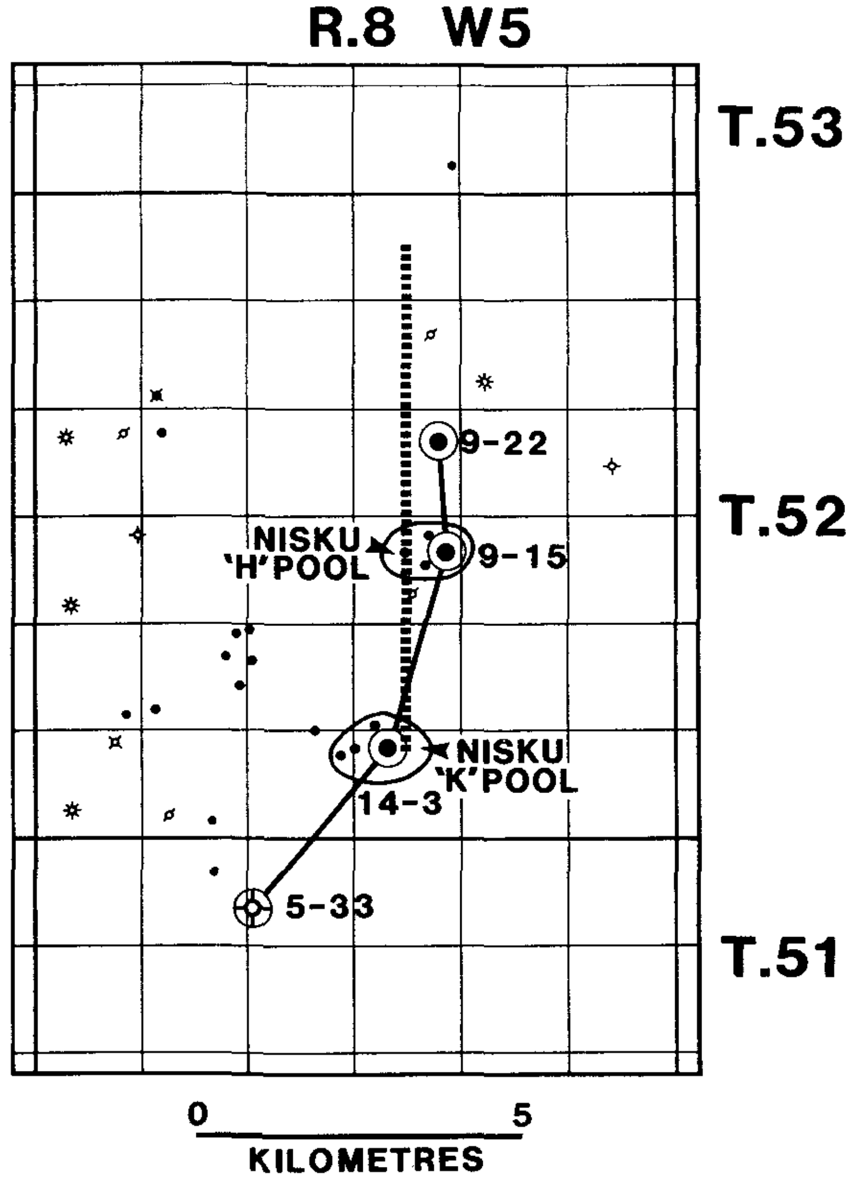

Figure 5.17. Index map Bigoray Nisku 'H' and 'K' pool area.

The well at 9-15-52-8 W5M is drilled into the Bigoray Nisku 'H' oil pool (Table 5.1). This well does not fully penetrate the Zeta Lake reef as drilling was stopped before reaching its base. The reef is estimated to be 75 m thick with net porosity thicker than 34 m (>3%).

SEISMIC SECTION

This seismic example is a north-south seismic section through the Bigoray Nisku 'H' pool penetrated by the well at 9-15 and the Bigoray Nisku 'K' pool penetrated by the well at 14-3 (Fig. 5.17). The seismic line is displayed at SEG normal polarity (Fig. 5.19).

Two Zeta Lake reefs are interpreted on the seismic line between traces 1 and 15 at 1.36 seconds two way traveltime and between traces 74 and 123 at 1.35 seconds two way traveltime. The Zeta Lake reef between traces 1 and 15 is difficult to interpret because it is located at the end of the seismic line. Dimming of both the top Cynthia Mbr shale and top Ireton Fm reflections are some seismic indications of the reef encountered by the well at 14-3.

The reef between traces 74 and 123 clearly exhibits dimming of the peak representing the top Cynthia Mbr shale reflection. The top Nisku Fm/Cynthia Mbr shale reflection shows about 10 ms of relief over the reef. The peak marking the top of the Ireton Fm is dim under the entire reef, in contrast to the previous examples where the dimming occurred only under the flanks of the reef.

Structural drape of the Wabamun Gp reflection (10 ms of rollover) due to differential compaction of the Zeta Lake carbonate and Cynthia Mbr shale is evident on the seismic section. Reflections under the Zeta Lake reef show 5 to 10 ms of relief, which can be largely ascribed to velocity pull-up under the reef.

APETOWUN NISKU POOL

GEOLOGICAL CROSS-SECTION

Figure 5.20 gives the location of the southwest to northeast geological cross-section (Fig. 5.21) which shows the reef to basin relationship of the "Nisku reef" which comprises the Apetowun Nisku gas pool. It shows the intimate association and development of the "Nisku reef" over the Leduc reef.

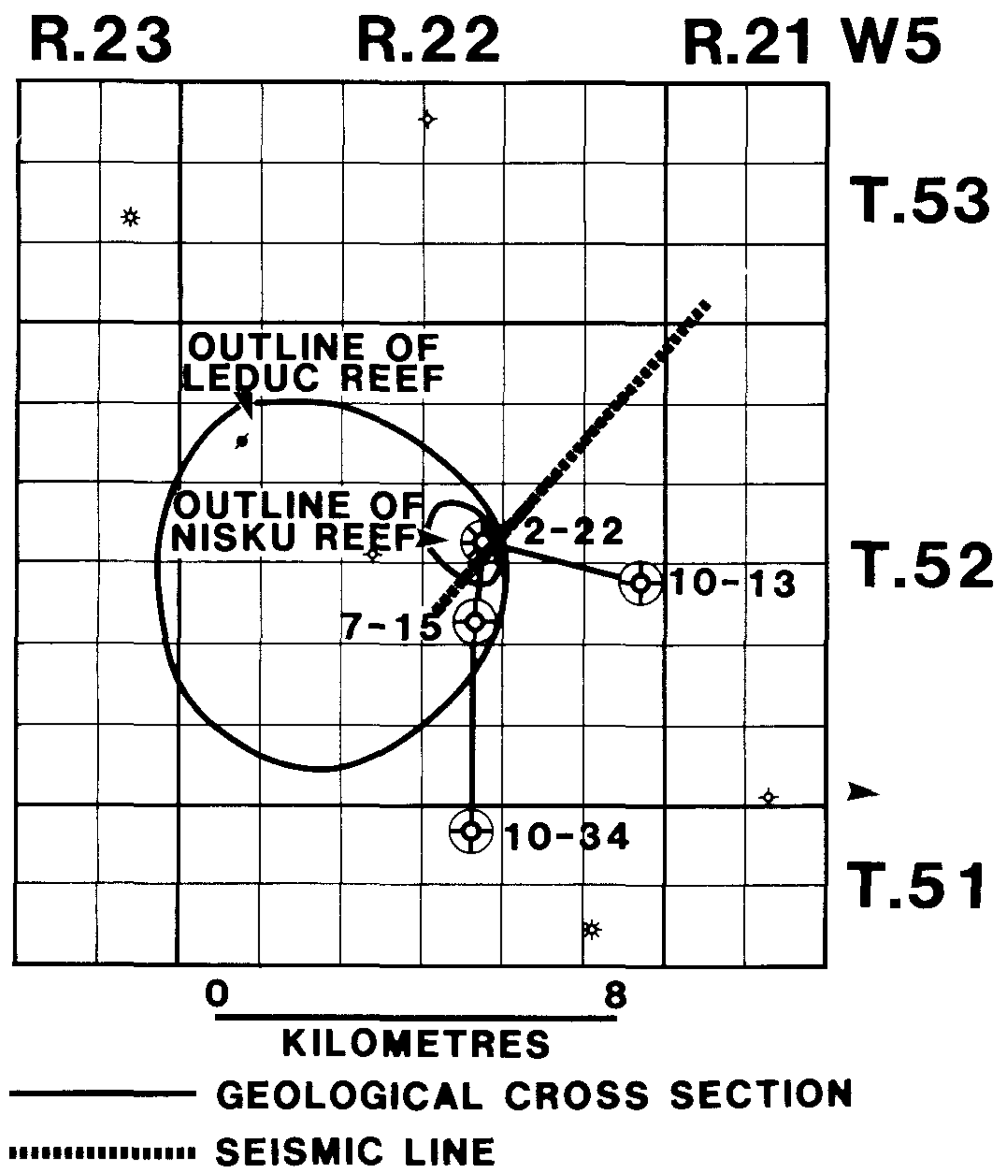

Figure 5.20. Index map of Apetowun Nisku pool.

The dry and abandoned well at 10-34-51-22-W5M illustrates the regional basin stratigraphy of the Upper Devonian sequence in the Woodbend "West Ireton Shale Basin" (Stoakes, 1980, Fig. 2) and overlying Winterburn Basin (Fig. 5.1). A total of 83 m of Ireton Fm shale and 128 m of Winterburn Shale were deposited above the Lower Leduc or Cairn Fm. In this location a very thin Cairn Fm (approximately 35 m) is present above the Swan Hills Fm.

The dry and abandoned well at 7-15-52-22-W5M was drilled into a full Leduc build-up. This well penetrated a 13 m thick zone of clean Nisku carbonate which is separated from the Leduc Fm by 5 m of Winterburn Shale.

The Nisku gas well at 2-22-52-22-W5M is the discovery well and currently the only well recognized as having recoverable gas reserves in the Apetowun Nisku gas pool. This well encountered a full thickness of clean Nisku carbonate which is separated from the underlying Leduc by 8 m of Winterburn Shale. The Nisku Fm has 28 m of net porosity (>3%) and the reservoir contains 360 x $10^6 m^3$ of gas (Table 5.1).

The dry and abandoned well at 10-13-52-22-W5M shows the return to the regional basin stratigraphy. A total of 77 m of Ireton Fm shale and 124 m of Winterburn Shale were deposited over 56 m of Lower Leduc Fm at this location.

SEISMIC SECTION

This seismic example (Fig. 5.22) is a northeast-southwest seismic section through the Apetowun reef complex tying the 2-22, 7-15 and 10-13 wells (Fig. 5.20). The seismic line is displayed at SEG normal polarity. A Nisku reef is interpreted on this line between traces 191 and 230 at 2.1 seconds two way traveltime. This Nisku reef differs from those of the West Pembina area in that it is underlain by a full Leduc Fm reef.

The top of carbonate (Cairn Fm) reflector climbs and dims near the edge of the Leduc reef. The Ireton Fm is marked by a peak immediately above the Cairn Fm horizon. The Ireton marker and the overlying broad trough also dim and lose their coherency as the Ireton Fm shales are replaced by the Leduc Fm. The Winterburn Shale peak diminishes as the off-reef material is replaced by high velocity carbonates of the Nisku reef at the 2-22 location. Also note that the trough immediately above the Winterburn Shale/Nisku Fm reef interval thins over the reef.

A drape effect of approximately 10 ms in magnitude can be observed on the top of Wabamun Gp reflector above the reef. Pull-up of the Elk Point Gp and lower reflectors is readily observable below the reef crest.

SEISMIC CRITERIA FOR THE IDENTIFICATION OF NISKU REEFS

A number of criteria are used to identify Zeta Lake reefs on seismic sections. Some Zeta Lake reefs may not show all of these characteristics. These features are:

1) Dimming of the Cynthia Mbr reflection which is a result of the replacement of Cynthia Mbr shale with the higher velocity carbonates of the Zeta Lake reef;

2) Dimming of the Ireton Fm reflection immediately under the flanks of the Zeta Lake reef which is the result of a defocussing effect caused by refraction of the wave front through the lens shaped Zeta Lake reef. The reflection from the Ireton Fm reappears under the crest of the Zeta Lake reef;

3) Structural roll-over of reflections above the Zeta Lake reef which is attributed to drape due to differential compaction of the Zeta Lake Mbr carbonate and Cynthia Mbr shale. Structural roll-over of up to 15 ms at the Wabamun Gp reflection is present on the seismic; and

4) Roll-over of reflections beneath the Zeta Lake reef which is attributed to velocity pull-up created by the replacement of the Cynthia Mbr shale with the higher velocity carbonates of the Zeta Lake reef. Roll-over of up to 20 ms is present at the Beaverhill Lake Gp reflection on the seismic. Sometimes the roll-over is more than expected from velocity pull-up effects. Some workers have suggested that pre-existing highs may be present in some areas.

Nisku reefs in the Obed-Apetowun area of the Deep Basin are recognized using the following criteria:

1) Dimming and sometimes total loss of the Cairn Fm reflection near the edge of the Leduc reef;

2) Dimming and loss of coherency of the Ireton Fm reflection as the Ireton Fm shales are replaced by the Leduc Fm;

3) The Winterburn Shale reflection diminishes as the off-reef material is replaced by higher velocity carbonates of the Nisku reef;

4) Roll-over of reflections above the Nisku and Leduc reefs due to differential compaction of the reef and off-reef sediments; and

5) Velocity pull-up effects under the reefs due to higher velocity of the reefal section compared to the off-reef section.

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