CHAPTER 9 – UPPER CRETACEOUS RESERVOIRS

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INTRODUCTION

The evolution of the Alberta Basin during Upper Cretaceous time and its effect on the geologic section is covered in the introduction to this text. Strata of the Upper Cretaceous underlie most of the area covered by the Western Canada Sedimentary Basin in an almost continuous sequence of deposition. From the Base of Fish Scales Zone, the approximate boundary between Lower and Upper Cretaceous, to First White Specks is a marine section. The overlying Lea Park is a marine shale within which a lateral facies change in southeastern Alberta gives rise to the Milk River Fm. In southeastern Alberta the Milk River Fm is overlain by the Pakowki Fm shale which is the equivalent of the Lea Park Fm in the central plains (Fig. 9.1).

In the central plains the Lea Park (Campanian) marine shale is overlain by the Belly River Fm. From its depositional limit in east-central Saskatchewan, the marine Belly River Fm thickens and gradually becomes a continental deposit to the northwest (Fig. 9.2). The interaction of the marine and continental environments created shoreline sandstones and off-shore bars within a generally deltaic setting. The Bearpaw Fm overlies the Belly River Fm in southern and eastern Alberta and represents a continuation of marine conditions found in Saskatchewan and Manitoba. Following deposition of the basal Belly River within littoral environments, widespread alluvial sedimentation formed the remainder of the Belly River Fm, Edmonton Gp and their equivalents (Brazeau Fm, Wapiti Gp, Saunders Gp) (Fig. 9.3).

The Bearpaw Fm, over 150 m thick in southcentral Alberta (14-18-2-23W4M), thins to the north and grades into the non-marine sequence of the overlying Horseshoe Canyon Fm (Edmonton Gp).

Production has been obtained from the Upper Cretaceous section for many years. However, prospecting for Upper Cretaceous hydrocarbons did not begin in earnest until the discovery of Cardium production at Pembina in 1952. One of the largest land sales in Alberta history followed this discovery, with Texaco and Imperial paying over $20 million dollars in 1954 for drilling reservations centering over what is now the Pembina Cardium oilfield. Even following the Pembina Cardium discovery the uppermost potential zone was generally regarded as the Viking Fm in the Lower Cretaceous. The pursuit of objectives deeper in the geologic section led to the use of seismic parameters that were not adequate for the detection or delineation of hydrocarbon reservoirs in the shallower section. Following the basic acquisition parameters outlined by Denham (1981), definition of shallow objectives requires short spreads and light charges. These requirements mitigate against the detection of deeper prospects due to attenuation and an inability to suppress multiples.

The Upper Cretaceous section is often regarded as an uphole bail-out for deeper prospects. The following data indicates the importance of and the possibilities for Upper Cretaceous production. Potential reserves for the Upper Cretaceous section are estimated at 1701 x 10^6 m^3 of oil (Podruski et al., 1988) with an indicated initial recovery of 327.9 x 10^6 m^3. The Upper Cretaceous holds approximately 5% of the total oil recoverable in Western Canada. Considering this potential and the shallow nature of most of these pools, it would appear that exploration dollars directed towards them could yield a good rate of return.

The four major Upper Cretaceous reservoirs are: 1) The Cardium; 2) The lower Belly River; 3) The Dunvegan-Doe Creek; and 4) The Belly River fluvial.

The regional Cardium and the Dunvegan are presently considered low potential plays. The regional Cardium forms a sheet sandstone (e.g. Pembina) and comprises the largest pool in Western Canada at Pembina and is considered to be in a mature stage of exploration.

Reservoirs in the Upper Cretaceous section are generally stratigraphically controlled. Production is from marine or alluvial sandstones or conglomerates which are either capped and flanked by shales, (Cardium), sealed updip by a change in lithology and/or sandstone cements, (e.g. Pembina Keystone Belly River B pool), or created by gentle structures involving widespread sandstones, (Atlee Buffalo Belly River A pool), (Shouldice, 1979).

THE CARROT CREEK CARDIUM S POOL

INTRODUCTION

The Carrot Creek Cardium oil field, located approximately 150 km west of Edmonton, Alberta, was discovered in 1963. It has been the subject of detailed geological studies by Bergman and Walker (1987, 1988), Swagor (1975) and Swagor et al. (1976). Interest in exploration for these Cardium Fm conglomerate reservoirs was reactivated in the early 1980's due to the discovery of several new Cardium Fm pools and the recognition that modern seismic reflection technology could be used in their detection (Chappell, 1984, 1985; Wren, 1984). The Carrot Creek Cardium S pool, located in 53-12 and 13 W5M (Fig. 9.4), is a typical example. Its geological characteristics and seismic signature are of interest in that they may be extrapolated to other significant Cardium Fm conglomerate reservoirs in westcentral Alberta.

The reservoir rocks in the Carrot Creek Cardium Fm pools consist of thick (to 20 m) chert pebble conglomerates with a sandstone matrix. These conglomerate deposits have a sharp base and unconformably overlie the regionally pervasive sequence of Cardium Fm strata which is typified by a coarsening upward, bioturbated and thinly laminated succession of mudstones, siltstones and sandstones, that are often capped by a thin veneer of conglomerate pebbles.

Both Bergman and Walker (1987, 1988) and Swagor et al. (1976) correlated the thin veneer of conglomerate that occurs southwest of the Carrot Creek S pool to the top of the thick conglomerate within the pool. Conversely both groups observed a correlation of the veneer conglomerates that occur northeast of the pool with the base of the thick reservoir conglomerates. Both interpreted the basinward direction to the northeast and the landward direction to the southwest with deposition of the thick conglomerates occurring at an observed break or increase in the basinward slope of the regional facies of the Cardium Fm.

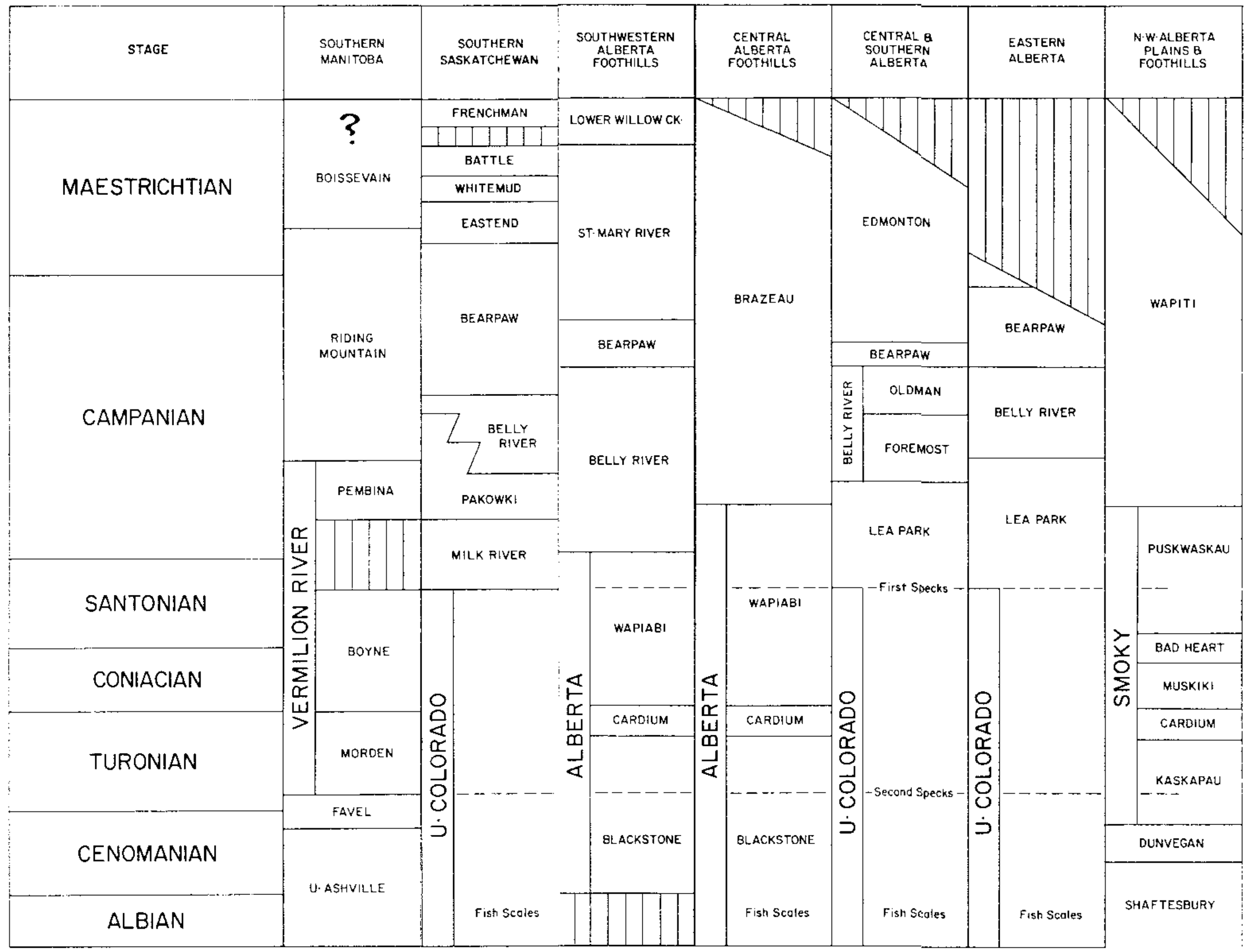


Figure 9.1. Upper Cretaceous correlation chart, Western Canadian Plains and Foothills.

The depositional environment and transport mechanism of the gravels that form the Cardium Fm conglomerate are interpreted differently by the above authors. Observing that the Cardium Fm is encased in marine shales, Swagor et al. (1976) interpreted the depositional environment as an offshore sand bar. They suggested that the pebbles were swept across a broad shallow shelf by storm generated currents and deposited on the steep seaward side of an offshore marine bar. Wright and Walker (1981) questioned the ability of storm generated currents to move gravels across a broad shelf and suggested (Walker, 1983, Wright and Walker, 1981) that turbidity currents could move sands and gravels from a shoreline, interpreted to be scores of kilometres to the west, into the basin.

The most recent interpretation, (Bergman and Walker 1987, 1988) involves a major lowering of sea level and deposition and subsequent redistribution of river transported gravels in a shoreface environment. The thickest gravels, which form the Carrot Creek Cardium Fm pools, were deposited at slope breaks cut in the underlying erosional surface during relative stillstands during the ensuing transgression. This erosional surface and several others within the Cardium basin have been mapped (Plint et al. 1986, 1987). A problem with this interpretation is the lack of evidence of marginal marine or fluvial deposits related to this major lowering of sea level (Hayes and Smith, 1987).

Reservoir characteristics of the Carrot Creek Cardium S pool are shown in Table 9.1. Although conglomerate thicknesses reach 20 m in the Carrot Creek field, the maximum thickness observed in the S pool is 8.5 m (Fig. 9.4). Figure 9.4 also illustrates the linear northwest trends of the pools and their high length to width ratio. Porosities of the conglomerates range between 6 and 15 percent with permeabilities ranging from about 100 to 1000 md. As of 1987 there were 21 Carrot Creek Cardium Fm pools with primary recoverable reserves estimated to be about 2 x $10^6 m^3$. Primary recoverable reserves in the S pool are 43 500 m^3 (ERCB, 1987).

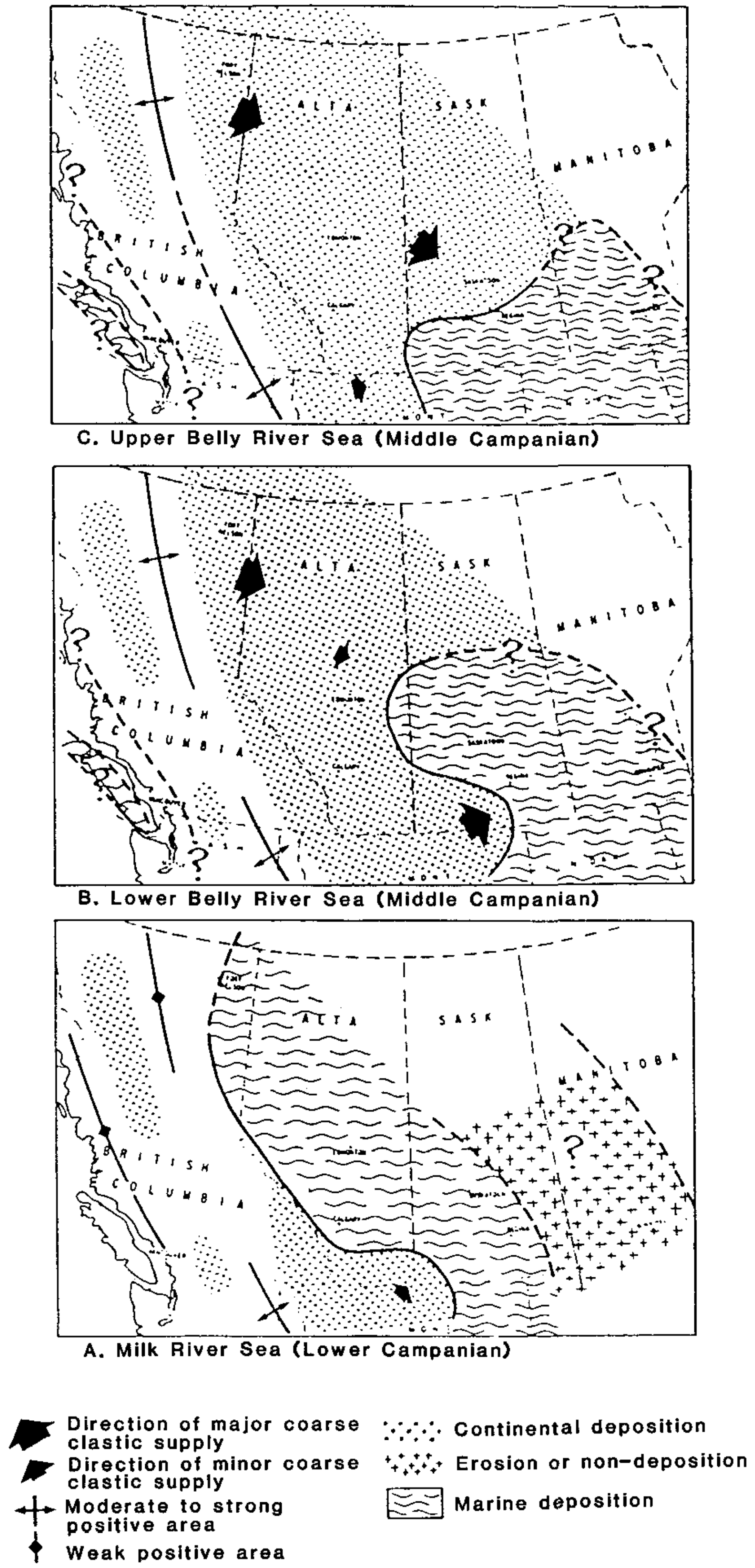
Table 9.1: Reserves and significant reservoir parameters of the Carrot Creek Cardium S pool. (E.R.C.B. 1987)

Initial oil volume in place:	435 x $10^3 m^3$ (2736 Mbbl)
Primary recovery factor:	10 %
Primary recoverable reserves:	43.5 $10^3 m^3$ (273.6 Mbbl)
Cumulative production (June 88):	12.9 $10^3 m^3$ (81.3 Mbbl)
Area:	192 ha (480 acres)
Average pay thickness:	3.74 m (12.27 feet)
Average porosity:	8 %
Water saturation:	11 %
Oil density:	836 kg / cm (37.8° A.P.I.)
Average Depth:	1520 m (4987 ft.)
Discovered:	1984
Total wells in pool:	3
Wells currently producing (June 88):	1

GEOLOGICAL CROSS-SECTION

The position of the geological cross-section (Fig. 9.5) is indicated in Figure 9.4. Note that distances between the wells are measured after projection onto the seismic line.

A marker within the Wapiabi Fm shale of the Colorado Gp is used as a datum. Although the Cardium zone, an informal log



C. Upper Belly River Sea (Middle Campanian)

B. Lower Belly River Sea (Middle Campanian)

A. Milk River Sea (Lower Campanian)

Figure 9.2. (left) Paleogeographic maps of western Canada during the Upper Cretaceous (after Williams and Burk, 1964 and Ogunyomi and Hills, 1977).

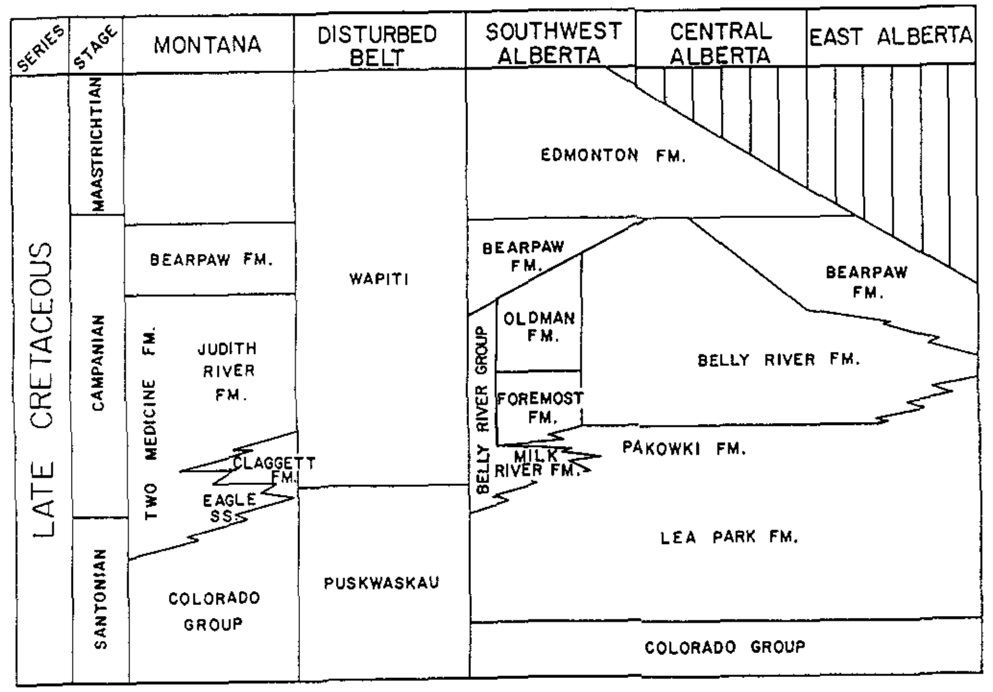


Figure 9.3. Schematic correlation chart, Belly River Fm.

marker commonly used by petroleum industry geologists, is parallel to the datum on this cross-section, it has been shown to have up to 40 m of erosional relief in other areas (Plint et al. 1987) and thus is not a suitable choice for a datum horizon. The marine mudstones and siltstones lying between the Cardium zone and the Cardium Fm conglomerate form the seal for the reservoirs. The top of the regional facies of the Cardium Fm is picked on the basis of log response. No attempt has been made to pick the E5 and E6 erosional surfaces of Bergman and Walker (1988) other than where the E5 surface is clearly evident on well logs at the base of the conglomerate. The contact between the Cardium Fm and the underlying Blackstone Fm shales of the Colorado Gp is transitional and its position on the geological cross-section (Fig 9.5) is uniform but arbitrary.

The unique log signature and the abrupt upper and lower contacts of the Cardium conglomerate are obvious in the 16-13 and 6-18 wells (Fig. 9.5). The section also illustrates the increase in slope of the underlying erosional surface between 16-13 and 6-18 where thicker conglomerates were localized. Basinward the toe of the conglomerate is lower with respect to overlying markers than on the landward side and this represents the original basin bathymetry at the time of conglomerate deposition.

The sequence of events that resulted in the deposition of the Carrot Creek Cardium Fm reservoirs is summarized below, after Bergman and Walker (1987):

1) Deposition of the regional Cardium Fm coarsening upward sequence in a storm dominated open marine environment;

2) Major regression, moving the paleoshoreline to the vicinity of the Carrot Creek field with rivers moving gravels into the basin during this lowstand;

3) Gradual marine transgression punctuated by stillstands during which bevelled shorefaces were cut. Redistribution of gravels by marine processes with maximum accumulations along the bevelled shorefaces; and

4) Continued transgression with erosion of upper shoreface, beach and coastal plain deposits and deposition of marine mudstones.

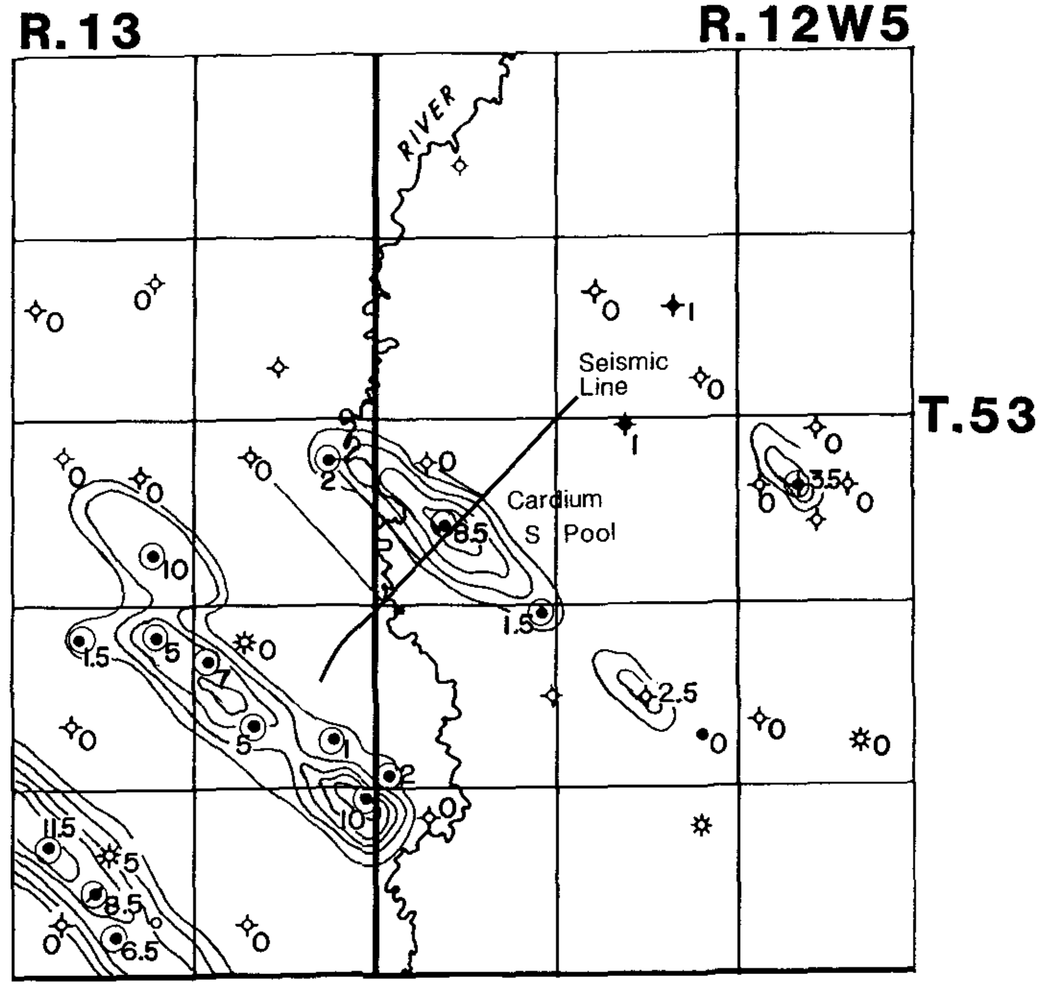


Figure 9.4. Isopach of Cardium conglomerate, Carrot Creek field (contour interval 2.5 m) and location of seismic line.

Although this model explains much of the sedimentology, the lack of evidence of beach and coastal plain deposits associated with the marine regression remains a problem requiring further study.

The sonic log response of the Cardium Fm conglomerate in the Carrot Creek field is significantly different from the adjacent coarsening upward regional Cardium Fm sandstones. The conglomerate has a significantly lower transit time (200-220 µs/m) than the regional Cardium (240 to 250 µs/m), as is clearly illustrated on the geological cross-section (Fig. 9.5). This velocity difference is responsible for the diagnostic seismic response of the reservoir and has been successfully utilized in the development of this play. The limiting thickness of detection changes with the quality of the seismic data but modelling with realizable seismic bandwidths and practical experience suggest that it is in the 6 to 7 m range.

A note on the effect of density variations on modelled seismic response is in order. It has been observed that there is often a small decrease in density of the Cardium Fm conglomerate as compared with a small increase at the top of the regional Cardium Fm. The sonic response predominates though and omitting density values in generating seismic models is not critical. It should also be noted that the shales above and below the Cardium often have anomalously low density readings due to washouts during drilling and using these values without careful editing when modelling the Cardium will result in false anomalies.

Figure 9.8 is a seismic model generated with transit time values from the wells in Figure 9.5. It is displayed in log normal polarity with dominant frequencies of 35 Hz (22 ms Ricker wavelet) and 22 hz (35 ms Ricker wavelet). In both sections the 8.5 m of Cardium Fm conglomerate in the 6-18 well gives rise to a significantly higher amplitude than does the regional Cardium Fm. The 2 m of conglomerate in the 16-13 does not generate an anomaly significantly different from regional in either section whereas the 8.5 m is clearly anomalous in both. It should be noted that the top and base of the Cardium Fm conglomerate are not being resolved in the classical sense of Widess (1973) but is being detected because of its contribution to the amplitude of a complex seismic event encompassing the Cardium zone, the regional Cardium Fm, the Cardium Fm conglomerate where present and the base of the Cardium Fm.

SEISMIC SECTION

The seismic section (Fig. 9.6) across the pool illustrates one of the problems in the Carrot Creek - Cyn-Pem area, ie. extreme variation in data quality due to alternating muskeg and dry ground. This loss in data quality is evident at the southwest end of this seismic line.

The events picked are the Lea Park (trough at 0.89 sec), the Cardium (peak at 1.04 sec), the Viking (peak at 1.25 sec), Mannville (peak immediately below), and the Wabamun (peak at 1.47 sec.) The pre-Cretaceous unconformity has a weak signature on this section (roughly 1.32 sec.). Polarity of the data is readily established by the

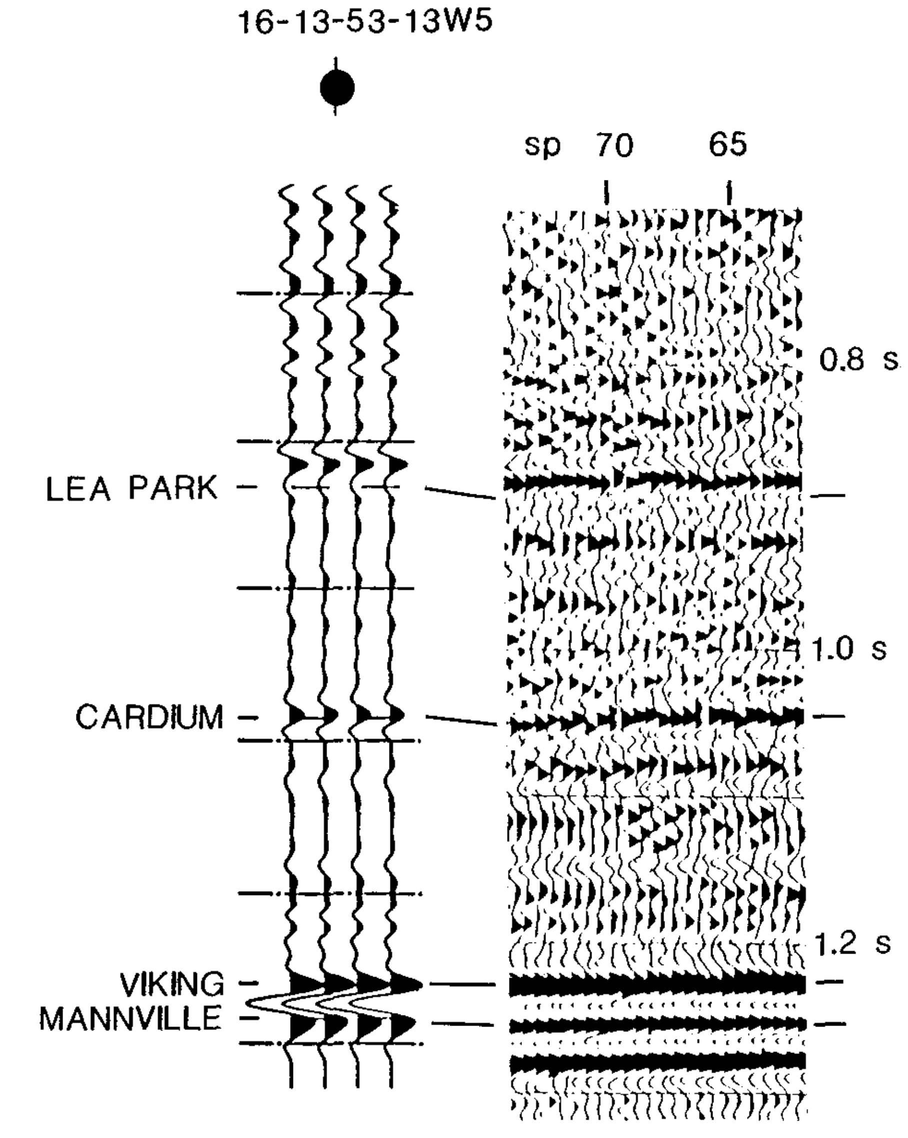


Figure 9.9. Synthetic seismogram and tie to seismic section (16-13-53-13W5M).

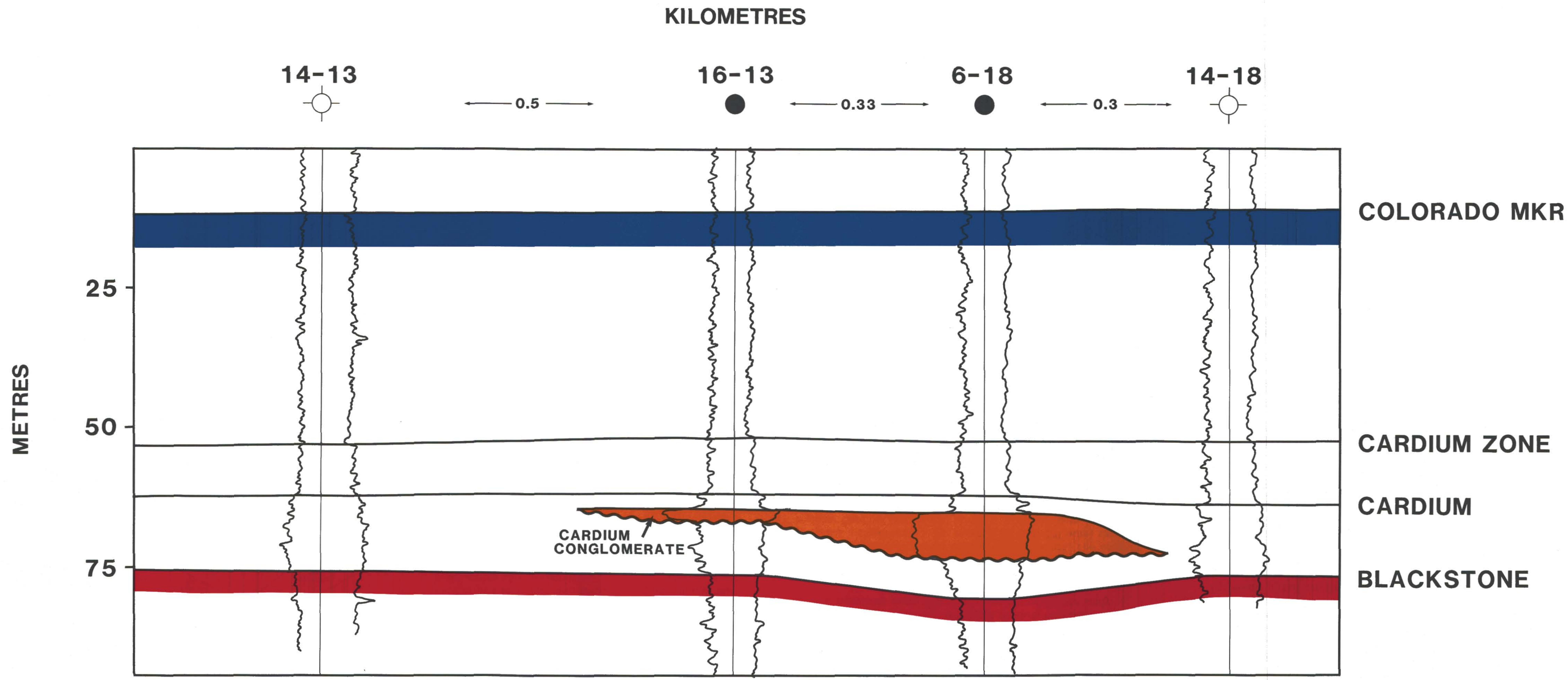


Figure 9.5. Geological cross-cestion Carrot Creek field.

DRAFTING:
LOG PLOTS:
AUTHOR: J.F. CHAPPEL

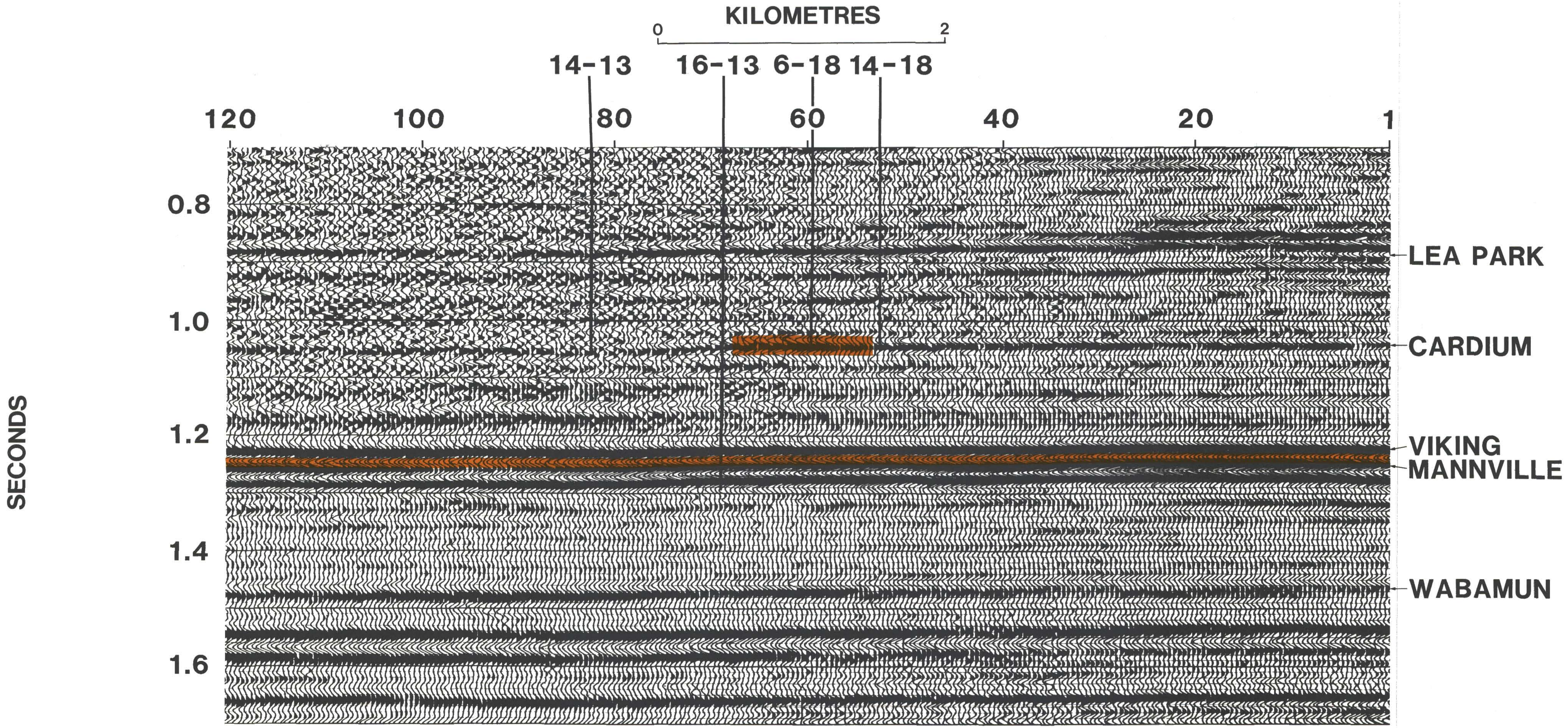


Figure 9.6. Seismic section Carrot Creek field in 1200% stack.

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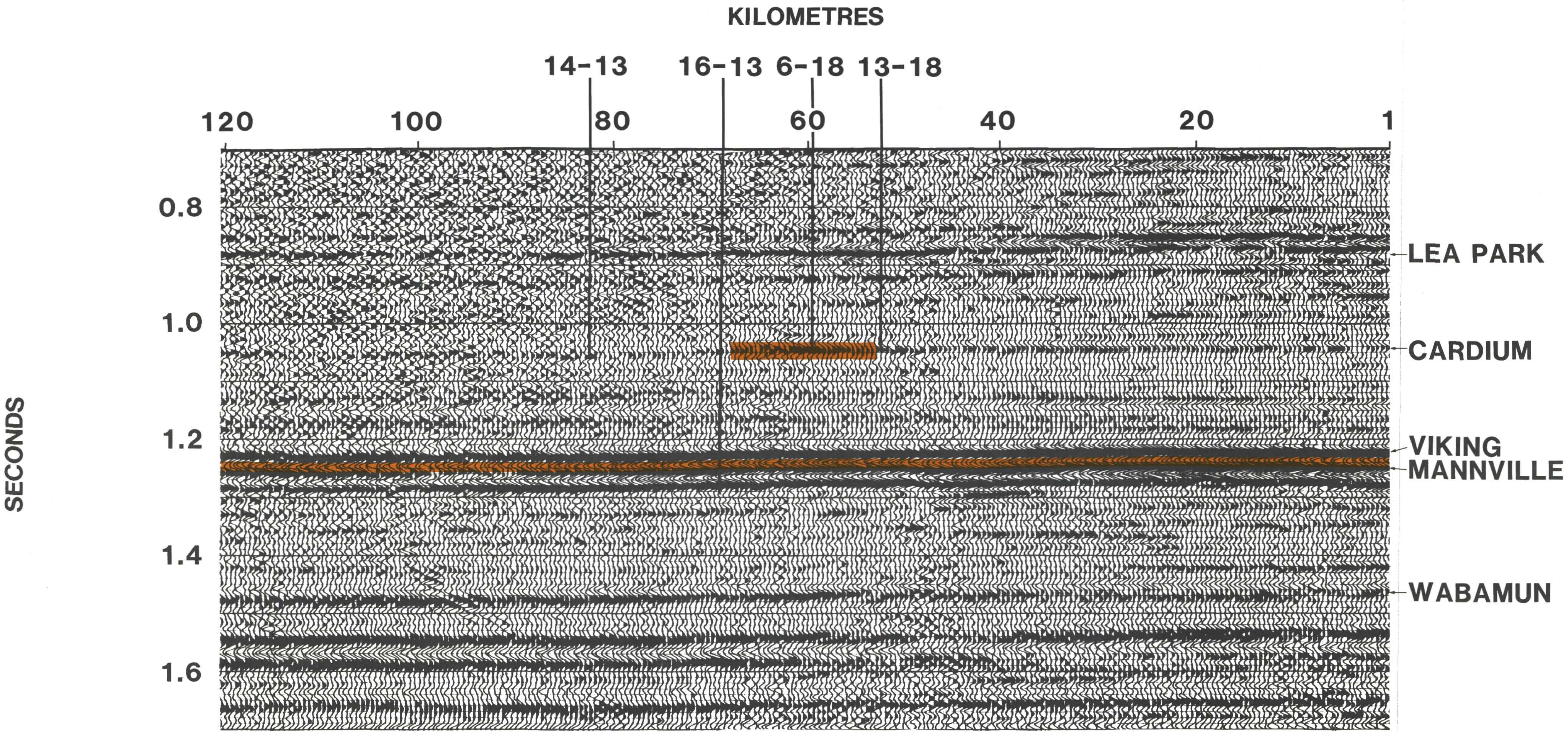


Figure 9.7. Seismic section Carrot Creek field in 300% stack.

DONOR: PETREL ROBERTSON LTD. | PROCESSOR: PETREL SEISMIC PROCESSORS LTD. | AUTHOR: J.F. CHAPPEL match between synthetic traces and the seismic section at the Viking event. In log normal polarity, the Viking event is a strong peak overlain by a weak doublet trough, as illustrated in Figure 9.9. This signature is consistent over a fairly large area in westcentral Alberta.

The data are displayed in both a full 1200 % stack (Fig. 9.6) and a 300 % distance limited stack (Fig. 9.7) with an offset range of 400 to 820 m. At the 6-18 well the amplitude of the Cardium event is strongest on both sections. The anomaly stands out more clearly on the partial stack, the Cardium event being more continuous on the full stack. Wren (1984) has suggested that this strong response of the Cardium event at a selected offset range is a function of different amplitude versus offset response of the Cardium Fm conglomerate reservoirs. Another possible explanation is that in the partial stack, only the higher amplitude Cardium conglomerate emerges above the signal - noise threshold.

The Cardium event is a weak reflector relative to the Viking or the Mannville events. Success in this play rests on being able to correctly interpret amplitude variations in this event. Variations in seismic data quality along a line may appear as amplitude anomalies at the Cardium level. There is also the possibility of amplitude variation in the regional Cardium event due to lithological variation and/or tuning in the Cardium zone - regional Cardium Fm interval. The number of dry holes drilled in the play indicate the inherent risk.

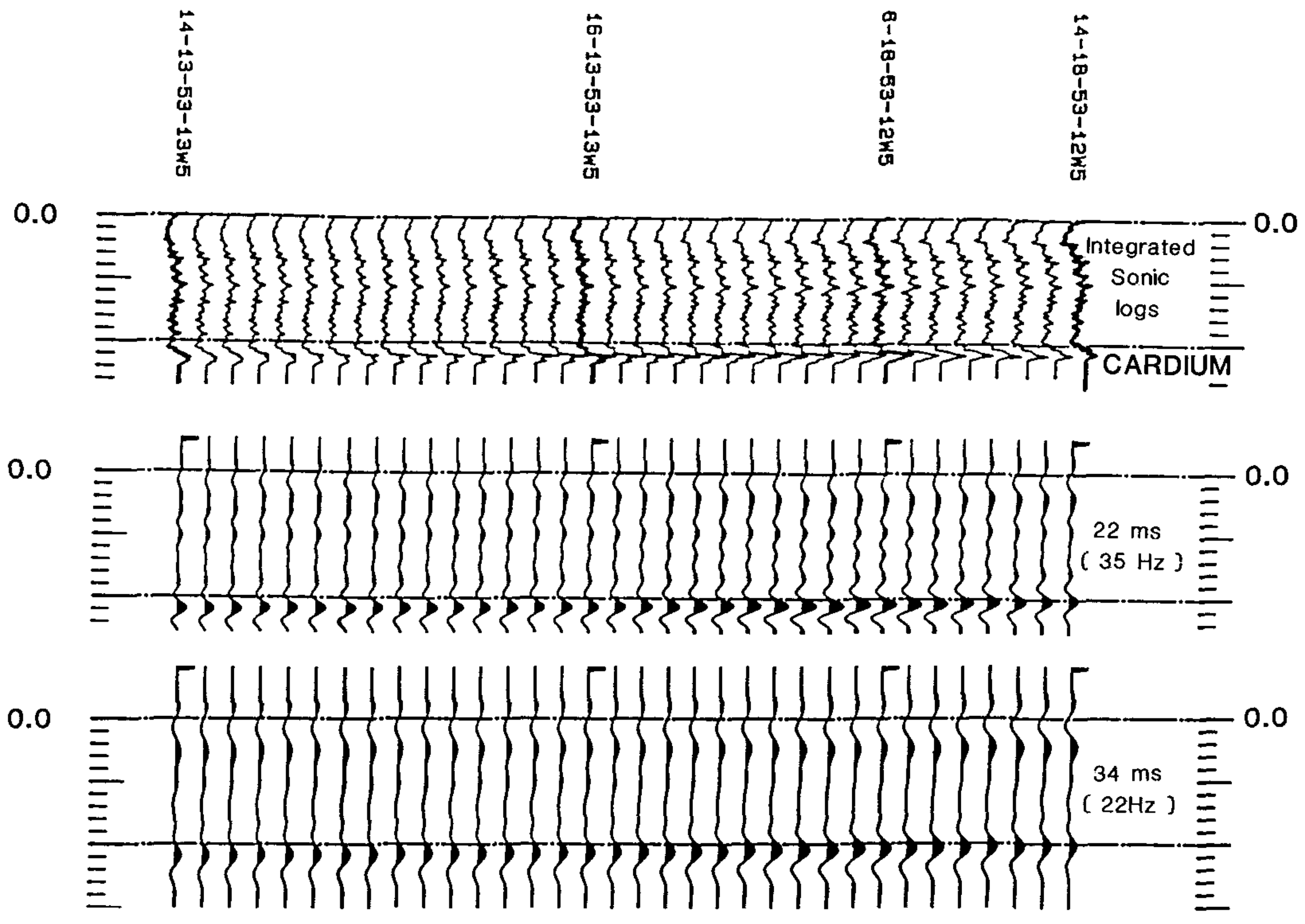


Figure 9.8. Synthetic seismic model generated with transit time values from wells in Figure 9.5.

CONCLUSION

The Carrot Creek Cardium S pool typifies the Carrot Creek - Cyn-Pem Cardium Fm conglomerate play. The reservoir conglomerates rest unconformably on the regionally widespread coarsening upward Cardium Fm sequence and are thickest at slope breaks on the underlying surface. These higher velocity reservoirs give rise to an increase in amplitude of the Cardium seismic reflection and this character has been successfully exploited in the expansion and development of this play.

PEMBINA KEYSTONE BELLY RIVER B POOL

INTRODUCTION

The Pembina Keystone Belly River B pool is located in westcentral Alberta, approximately 70 km southwest of Edmonton (Fig. 9.10). There are numerous separate reservoirs, at various levels in the area which is on the southeast flank of the Pembina Cardium field, (Fig. 9.11). Figure 9.11 indicates the outlines of five different producing

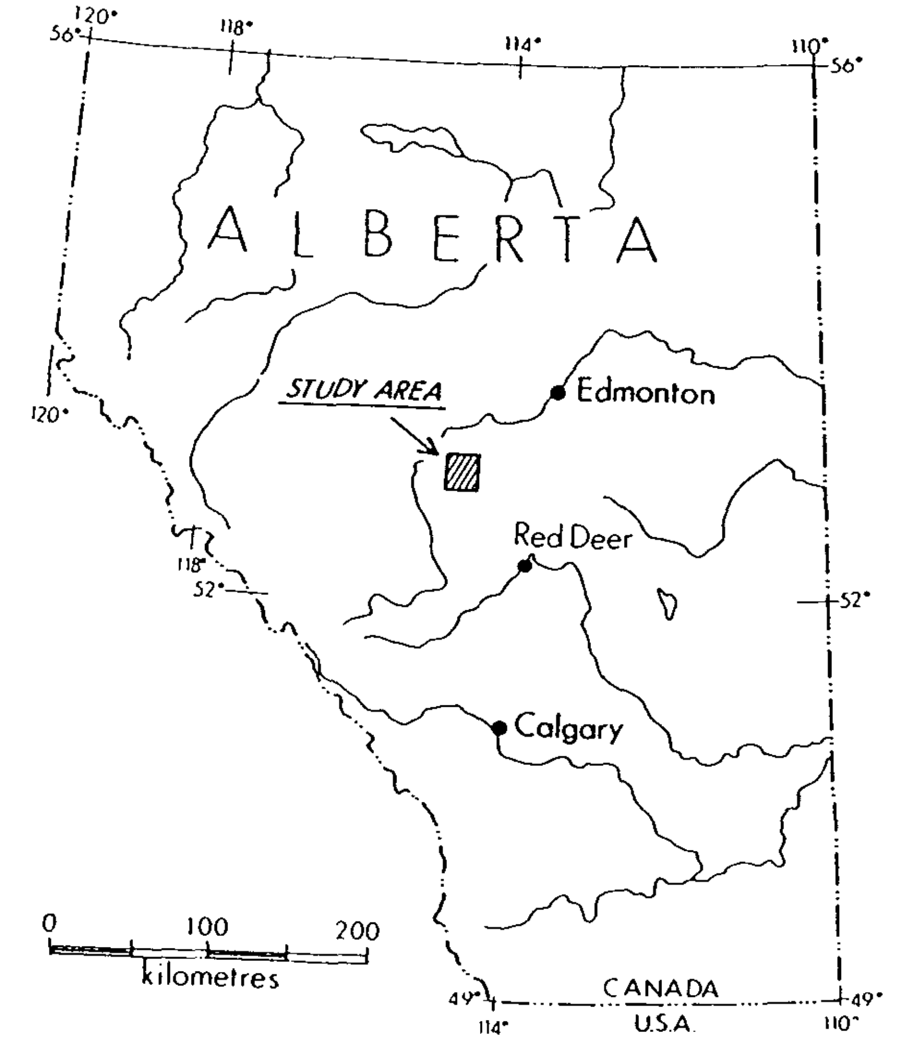


Figure 9.10. Location of the Belly River study area.

pools in the area, the Pembina Keystone Belly River B pool, the Belly River CC, U and X pools and the area that contains Pembina Cardium production. Also indicated is the location of the seismic line which has served to define criteria for lower Belly River sandstone development in this area. This seismic line is used to help define the geological changes that occur and to identify seismic criteria that may be useful in locating these reservoirs. The basic reservoir data for the B pool is given in Table 9.2.

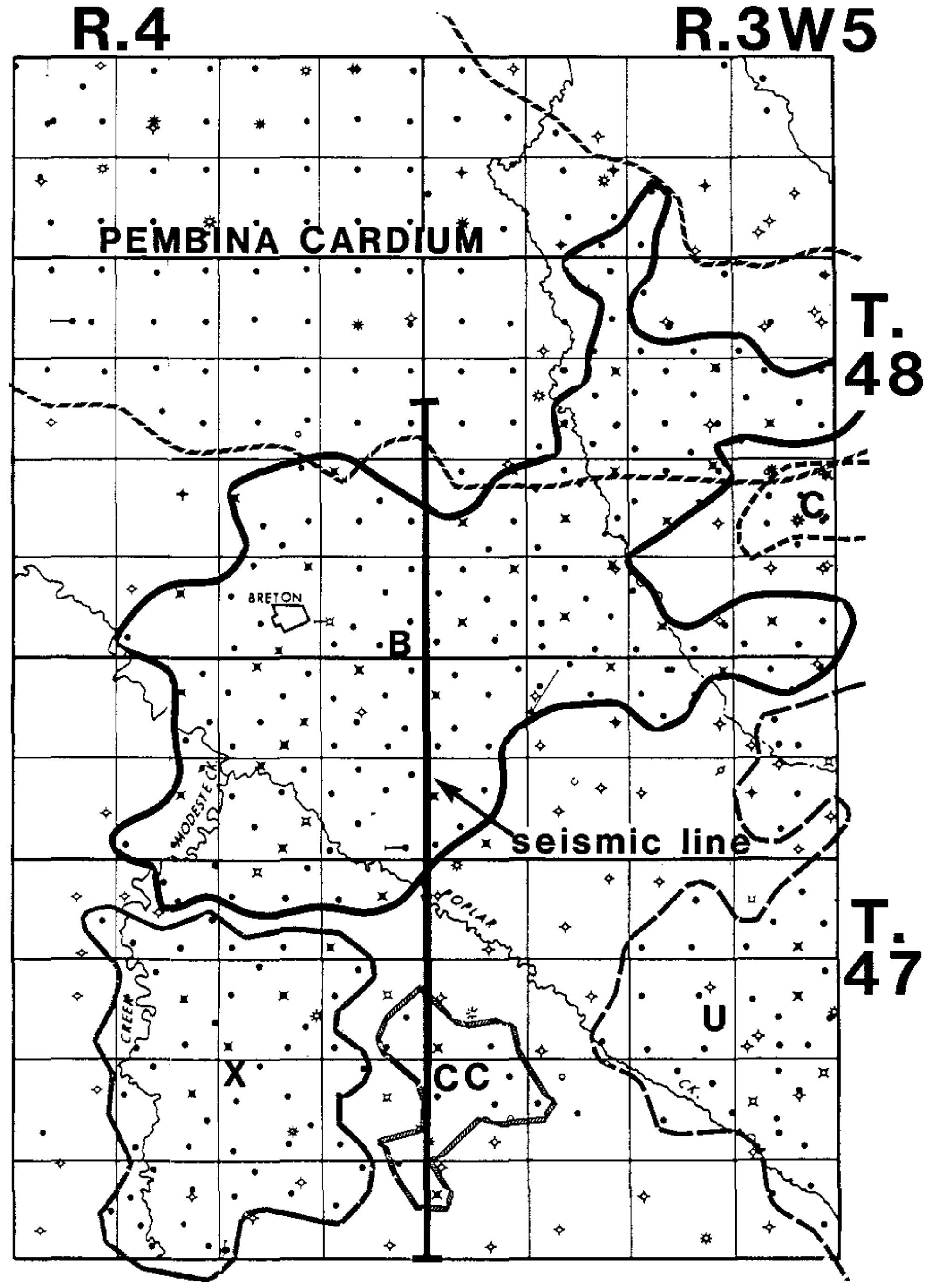


Figure 9.11. Outline of the Pembina Keystone Belly River B, CC, U and X pools and the Cardium Pembina pool.

Table 9.2: Pembina Keystone Belly River "B" Pool

Initial oil in place	29,300 x 10^3 m^3
Primary recovery	10%
Initial established primary reserves	3,740 x 10^3 m^3
Prim. + second. recoverable reserves	6,049 x 10^3 m^3
Area	5,920 ha
Average pay thickness	4.36 m
Porosity	15%
Water Saturation	47%
Shrinkage	0.88
Oil Density	839 kg/m^3
GOR	42 m^3/m^3
Initial Pressure	6,650 KPa
Average depth	978 m
Discovered	1958

GEOLOGICAL INTERPRETATION

Belly River sandstones within the study area are regarded as component parts of a widespread complex sandstone sheet produced by a rapidly prograding shallow-lobate delta (Storey, 1982). Figure 9.12 the structure map for the Pembina Keystone Belly River B pool indicates regional structure with dip to the southwest.

Figure 9.13, the pay isopach map of the Belly River B sandstone, indicates the rapid lateral variability in the sandstone build-up across the area. The area covered by thick sandstone eg., 16-17-48-3W5M, Sec. 36-47-4W5M helps create the minor variations in the structure map. The base of the Belly River Fm is regarded as the top of the Lea Park Fm. Lerbekmo (1963) postulated that during Belly River Fm deposition a low lying coastal plain possibly 150 km wide existed in southwestern Alberta. A similar situation is visualized in the Pembina Keystone area. The regression of the Lea Park sea did not produce a sharp regional lithologic interface. Thus along the geological cross-section, (Fig. 9.11), a well developed sandstone was deposited on the top of the Lea Park surface at 10-13-47-4W5M, whereas at 16-1-48-4W5M there is little or no sand development. Iwuagwu and Lerbekmo (1982) suggested that these shoreline sandstones may also include deltaic sandstones. The geological interval of concern in this section is approximately the basal 50 m of the Belly River Fm. In this paper this interval will be referred to as the lower Belly River Fm.

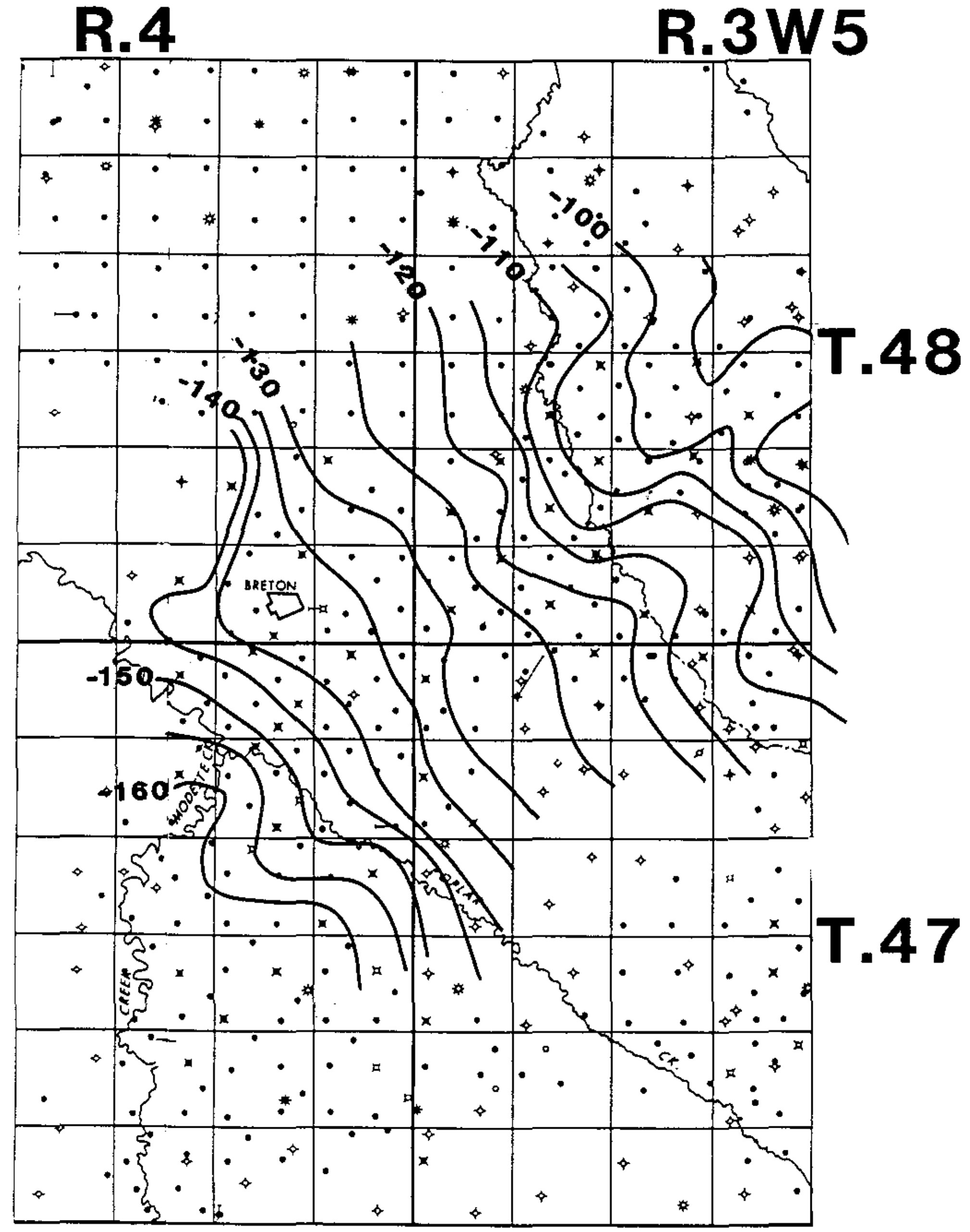


Figure 9.12. Structure on Basal Belly River sandstone (contour interval 5 m).

GEOLOGICAL CROSS-SECTION

The geological cross-section (Fig. 9.14) indicates the variation in sandstone deposition that occurs throughout the lower Belly River Fm. At the south end of the section, there is considerable sandstone development in the zone. Two sandstones of approximately 6 m and 3 m respectively are overlain by 15 m of shale above which lies a sandstone body approximately 6 m thick at 8C-13-47-4W5M. This upper sandstone development is not present at 10-24-47-4W5M nor 10-25-47-4W5M. The Belly River CC sandstone at 8C-13, which is also present at 10-13-47-4W5M represents the northern limit of the

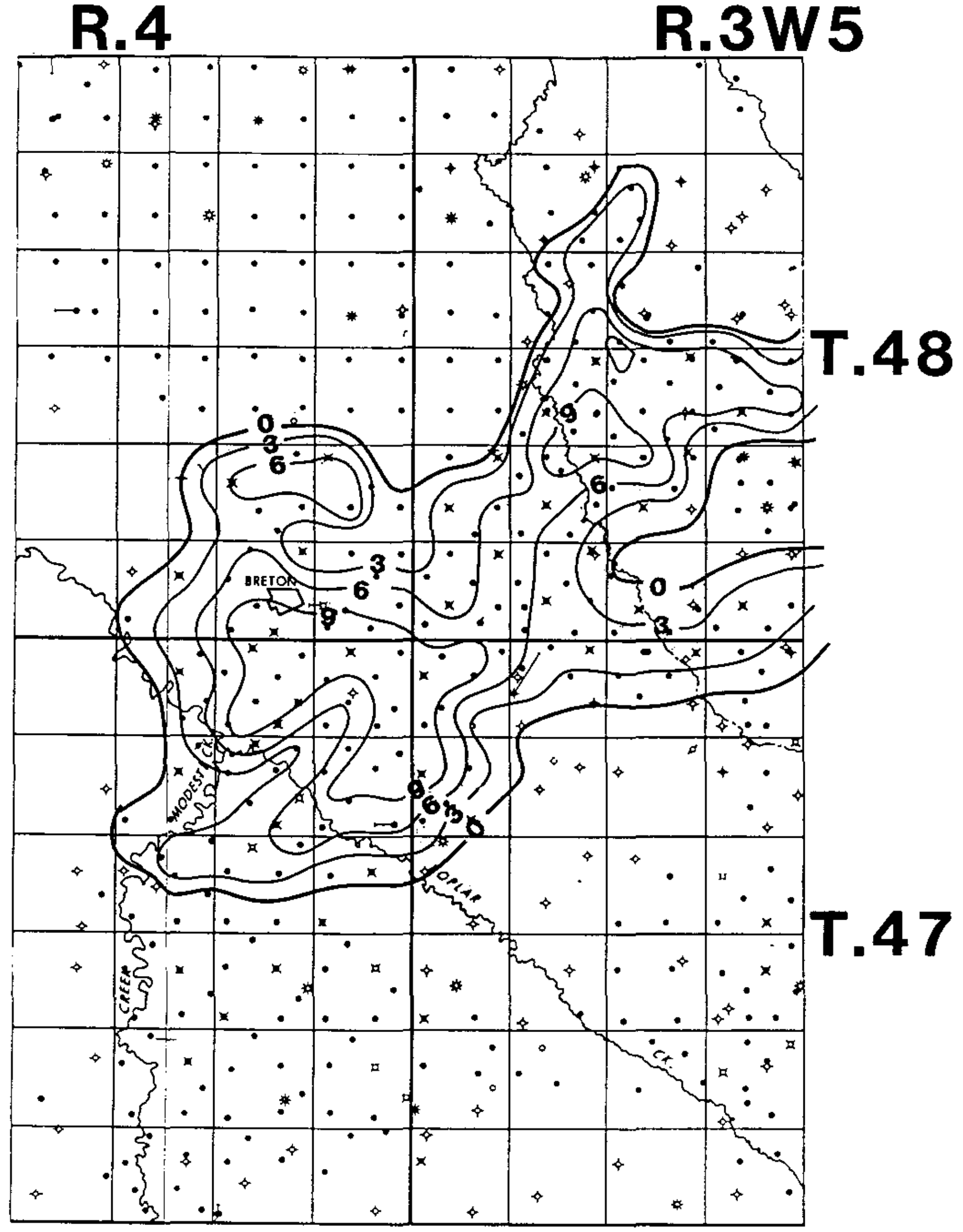


Figure 9.13. Isopach of the Belly River B pool (contour interval 3 m).

Belly River CC pool (Fig. 9.8). The very silty sandstones or sandy siltstones at 10-24-47-4W5 form a cut-off between the Belly River CC and the Belly River B pools in Pembina Keystone.

From 10-24 to 10-25-47-4W5M the lowermost sandstone increases in thickness from 3 to 11 m. The thin shale wedge which separates the two sandstones at 10-24, disappears and one massive sandstone approximately 15 m thick is present at 16-25-47-4W5M. This sandstone thins to 11 m at 8-36 and then thickens to 14 m at 16-36. It is productive in the Belly River B pool and thins to the north, to 7 m at 8-1, 4 m at 16-1 and 7 m at 8-12-48-4W5M. The basal sandstone undergoes a facies change between wells 8-12 and 8-13, and the former represents the northern limit of the Belly River B pool.

The following depositional sequence may be postulated for the geological cross-section. Following deposition of the Lea Park Fm shale deposition of the Belly River Fm resulted in regression with the basal Belly River Fm being deposited in a transitional environment along a very shallow basin or low lying coastal plain (Lerbekmo, 1963; Storey, 1982). As sediments prograded into the area, the center of sand deposition shifted continuously. Thus, there is no major center of deposition but rather numerous pods of sandstone varying laterally and vertically within the lower Belly River Fm (Fig. 9.16).

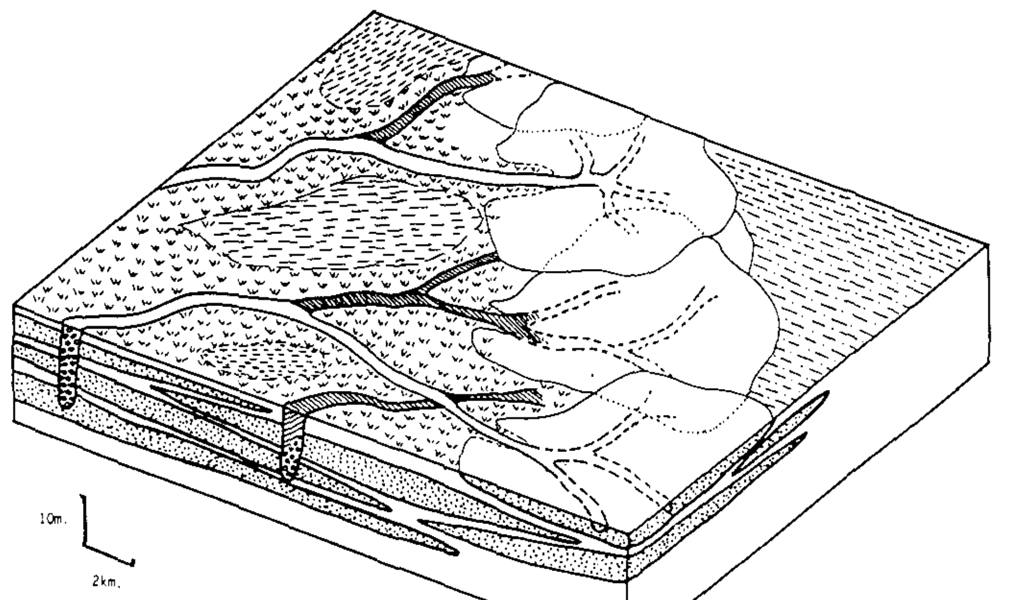


Figure 9.16. Shallow lobate delta model (after Storey, 1982).

The lower two sandstones of the CC and B pools are probably wave-formed or delta margin sheet sandstones. Production in the CC pool is obtained from the basal sandstone. A shale found at 1037-1041 m at 8-13, and at 1058-1061 m, at 10-13, is probably the cap rock for this reservoir. In addition, Storey (1982) gives pore filling cement (calcite/siderite) an important role in Belly River pools.

The Belly River CC sandstone which is productive at 10-13-47-4W5M is overlain by over 12 m of shale followed by 15 m of sandstone. This upper sandstone is not observable at 10-24-47-4W5M which is south of the producing limits of the Belly River B pool.

The base of the producing sandstone of the Belly River B pool is at the top of the Lea Park shale at 10-25-47-4W5M. At the 8-36-47-4W5M well the base of the producing sandstone is 9 m above the Lea Park shale. Such variance indicates support for Storey's conclusion that lower Belly River sandstones result from "stacking of thin, aerially limited, lenticular depo-units produced by progradation of a shallow lobate delta." (Storey, 1982, p. 5).

The stacking of such units results in the presence of over 12 m of sandstone at 16-36-47-4W5M. North of section 36-47-4W5M there is no apparent stacking of the sandstones, but there are four separate sandstones from 1.5 m to 6 m in thickness in the lower Belly River section. Each of these sandstones is separated by shale or mudstone ranging from 3.5 m to 8 m in thickness.

The rapid lateral variations in the depositional sequence, as shown on the geological cross-section, makes correlation of geological markers above the lower Belly River very difficult.

SEISMIC SECTION

The seismic section runs north-south over the Pembina Keystone Belly River B pool, (Fig. 9.12). These data were acquired in 1978 using a vibroseis source and DFS IV instruments. The group interval was 67 m which, with a source interval of 134 m on 48 trace instruments produced a 1200% seismic section. Eighteen, 10 Hz geophones were spaced, in line, 3.9 m apart in each group. Three vibrators were used, making six, 11 second sweeps at each source point, with a total move-up of 13.4 m. The sweep was from 12 to 85 Hz non-linear. The response of the geophones was recorded through a 12/18 - 72/124 filter, with a 4 ms sample rate for 14 seconds.

Table 9.3: Data processing sequence

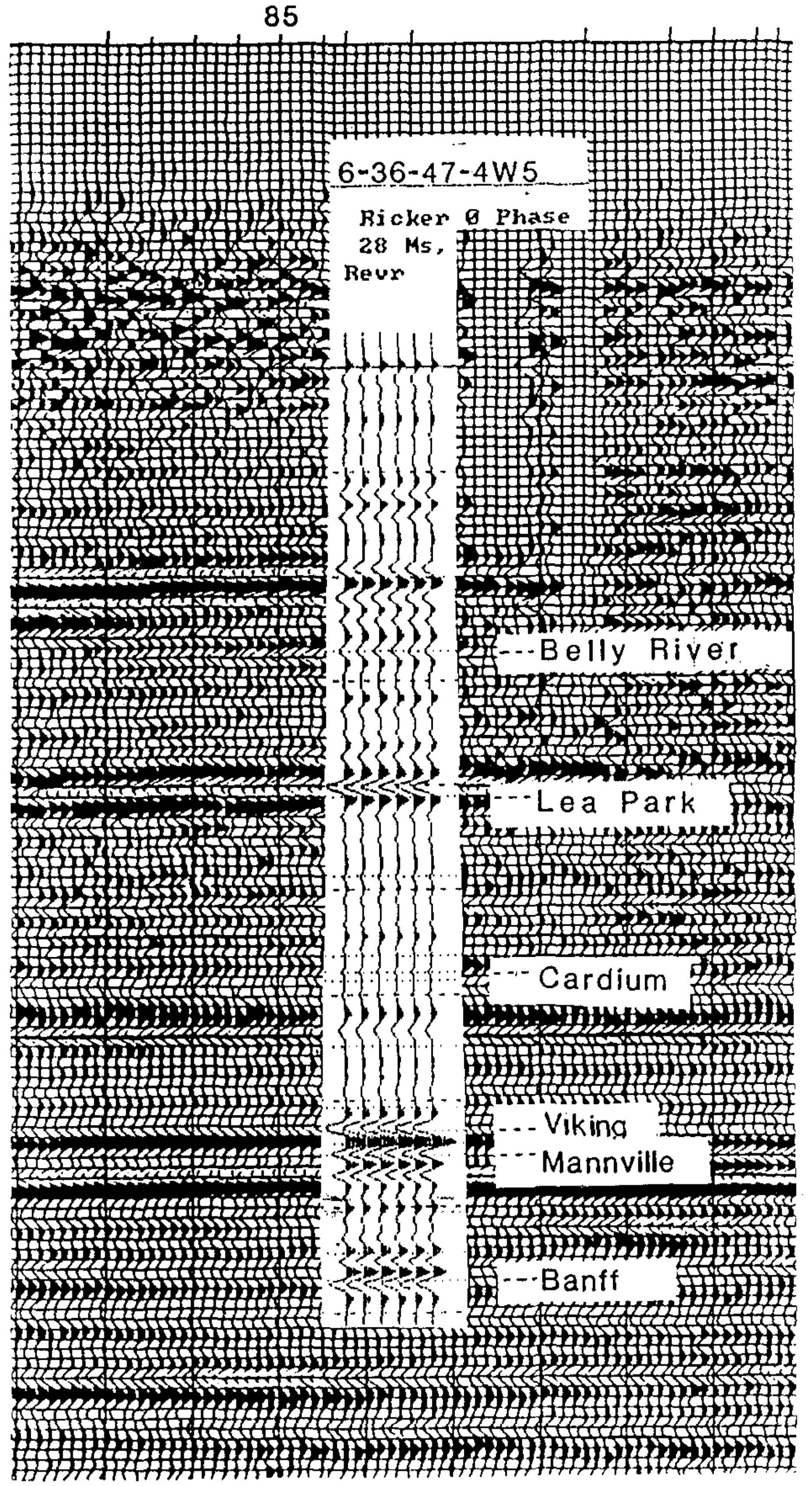
Demultiplex				
Amp. Rec.				
Dephase Instrument and Geophone				
Gather				
Spiking Deconvolution 0.5% Pre-whitening, 80 ms operator				
Velocity Analysis				
NMO Prelim.				
Structural Corr.;	Elev. Weathering, Drift Datum 915 metres			
Datum Velocity 3353 m/s				
Trace Equalization Window 500 - 1800 ms				
Surface Consistent Auto Statics				
NMO Final				
Trim Statics				
Mute	0	400	600	1000 ms
Distance	335 m	402 m	1006 m	1744 m
Stack (1200%)				
Filter 12/18 - 60/70				
Trace Equalization - 500 - 1800 ms				
Amplitude Coherency Filter				

Note that the seismic section (Fig. 9.12) has been interpreted as a log inverse section, ie., an acoustic impedance decrease at an interface presents a peak on the seismic section.

The sonic log from the 6-36-47-4W5M well, was used to identify the seismic events on the cross-section. A good match of the frequency content of the section was obtained using a 28 ms, zero phase Ricker wavelet. The tie of the synthetic for 6-36 made at trace 85 required a stretch of 5% (Fig. 9.14). The tie at the end of the log may be inaccurate, but this is believed due to structural relief on the Mississippian surface as well as end of log effects on the synthetic.

The lower Belly River sandstones in the Pembina Keystone area have an average transit time of 255-262 μs/m. This transit time is less than the transit times for the underlying Lea Park Fm shales which is 295-302 μs/m. The shales above and between the lower Belly River sandstones have transit times from 295-312 μs/m. Wherever there is a well-developed sandstone there is a well-devel-

Figure 9.17. (right) Identification of seismic events and tie of synthetic to trace 85.



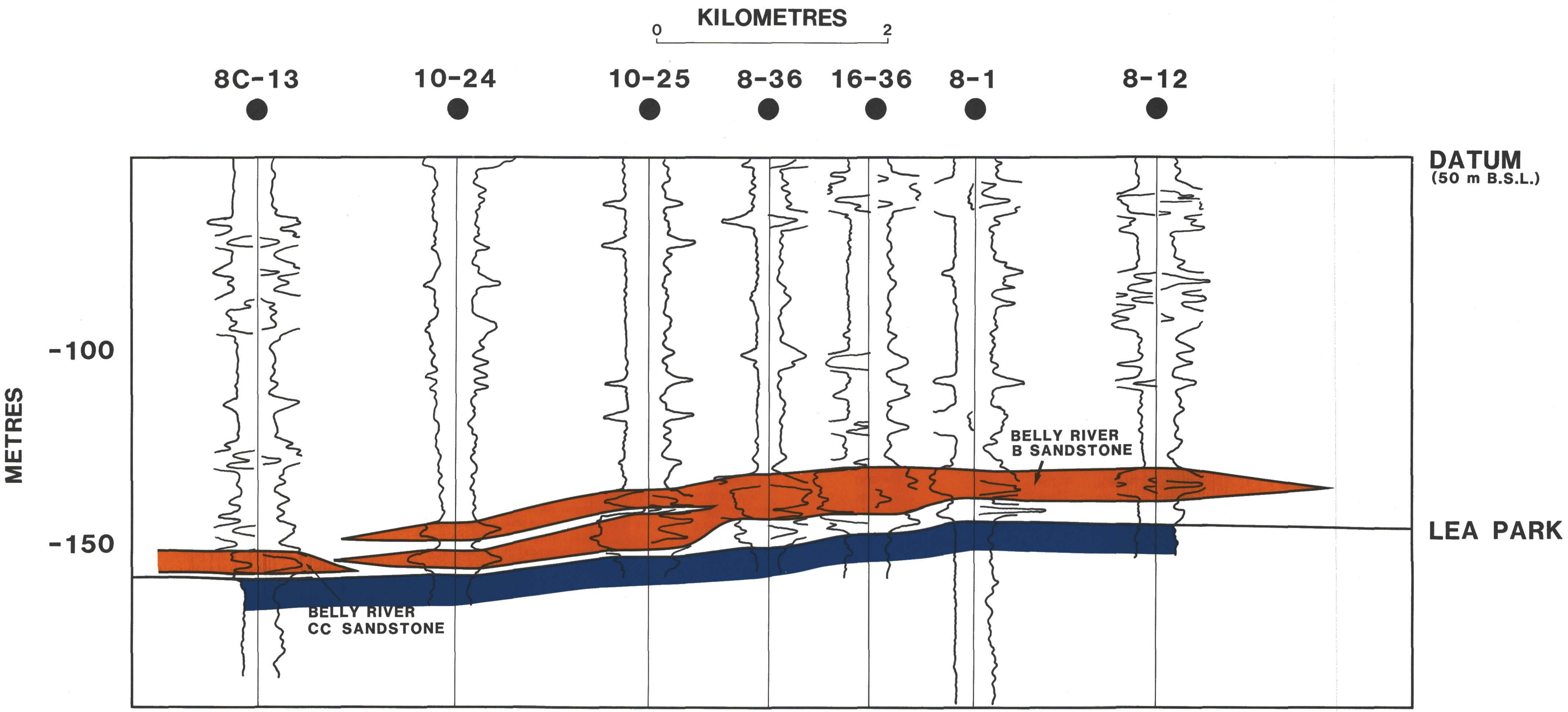


Figure 9.14. Geological cross-section Pembina Keystone Belly River B Pool.

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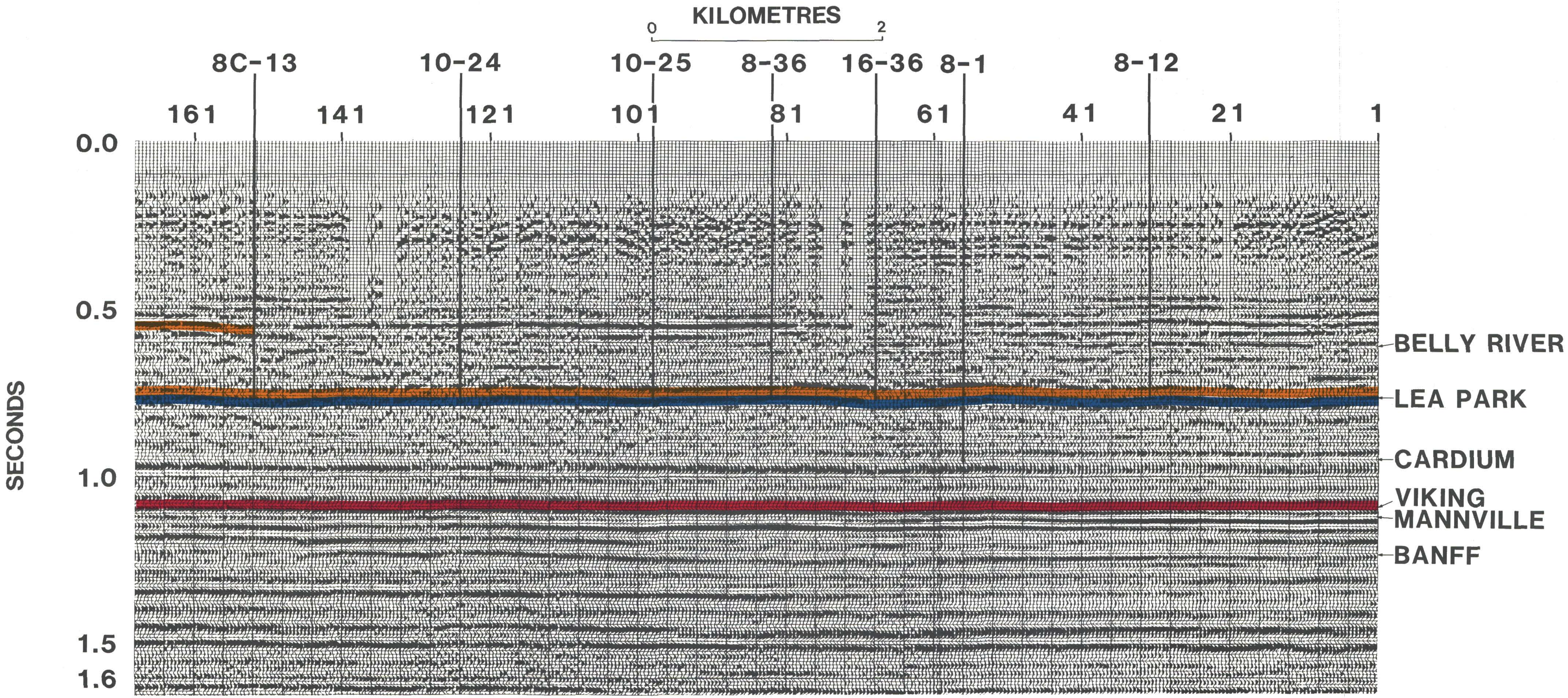

Figure 9.15. Seismic section Pembina Keystone Belly River B Pool.

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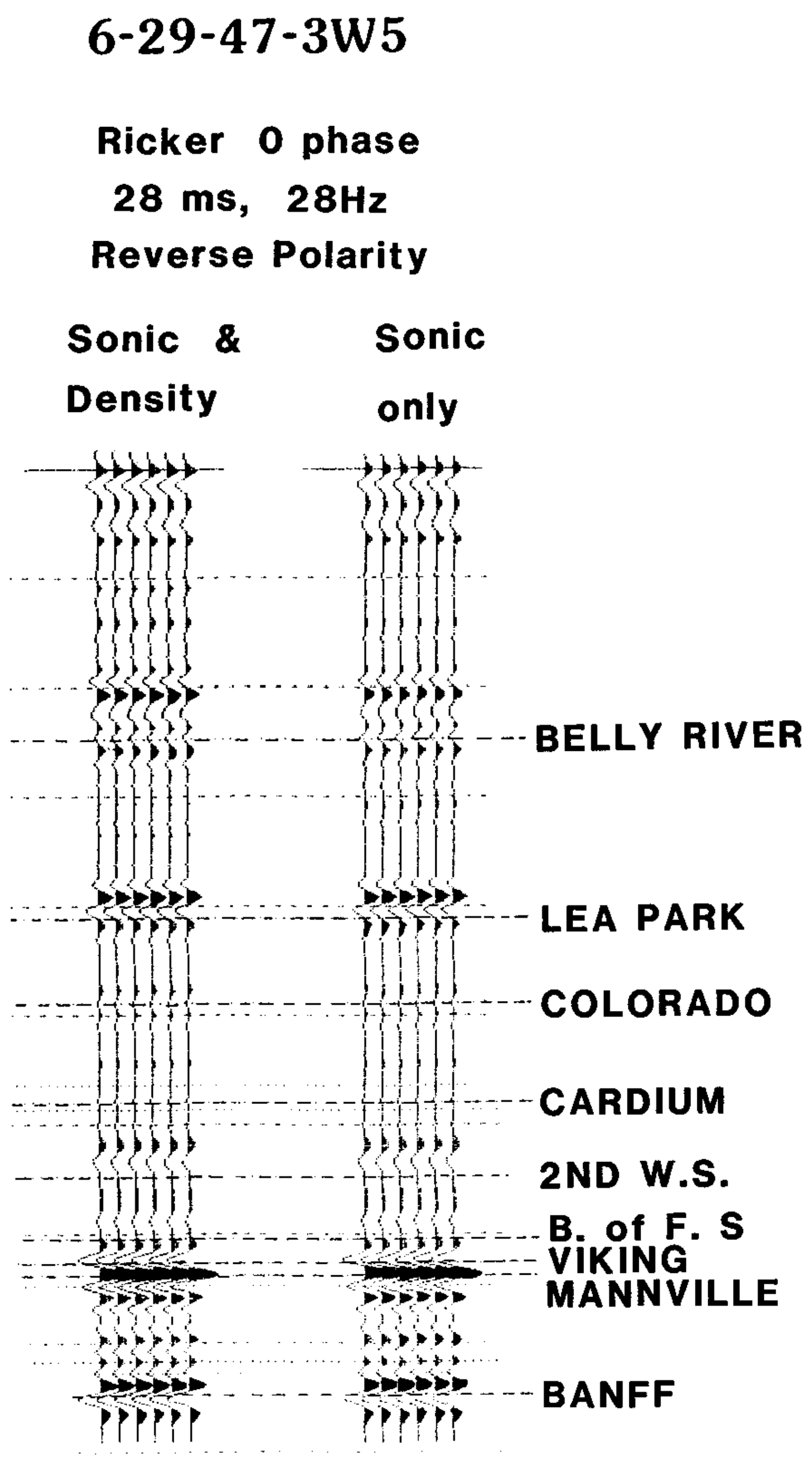

Figure 9.18. Synthetic seismogram for 6-29-47-3W5M.

oped event from both the top and the base of the sandstone. Due to the varying nature of the shales overlying the Lea Park, there can be a fairly strong Lea Park event where there are thin or no basal sands. The density of the sandstones in the lower Belly River section are quite variable. In 8C-13-47-4W5M, in the CC pool, the underlying Lea Park Fm has a density of approximately 2.50, the basal sandstone has a density of approximately 2.45, and the overlying shales a density of 2.47. In 16-36-47-4W5M the basal sandstone has a density of approximately 2.38 and the Lea Park Fm 2.50, whereas that of the overlying silty shales is 2.47. The effect of density is not believed to have a major effect on the seismic reflection associated with the Belly River sandstones, (Fig. 9.9). Figure 9.15 contains synthetic seismograms for the 6-29-47-3W5M well. Though this well is not productive from the same reservoir sandstone found in the B pool, there are sandstones in the lower BellyRiver Fm. The incorporation of the density log into the synthetic seismogram is seen to have only a marginal effect. For example, note the rounding of the trough above the Lea Park event. This event is associated with a Belly River Fm sandstone which lies 52 m above the Lea Park Fm.

An evaluation of the effect of varying thickness of the Belly River sandstone was made using the synthetic from the 16-25-47-4W5M borehole. To eliminate end of log effects the lower section of the 6-36-47-4W5M sonic log was spliced onto the 16-25-47-4W5M test at 1015 m. To compensate for the changing thickness of the Belly River sandstones, 5 m adjustments were made in the interval between 853-884 m. Compensation was made in this manner so that any change in the seismic character in the zone of interest (975-1006 m) would be the result of the variation in thickness of the Belly River Fm sandstone. Using this extended log, the thickness of productive Belly River Fm sandstone in the B pool was decreased by 15 m in 5 m increments. The resulting synthetics demonstrate the decrease in amplitude that accompanies a decrease in thickness of this sandstone (Fig. 9.19).

Using the criteria established above, an interpretation of the seismic line was developed. At the north end of the line, trace 1-10, the weak amplitude of the Belly River event indicates the presence of little or no sandstone. The minor amplitude change indicated could be the event generated by the interface of the basal Belly River Fm shale and the Lea Park Fm.

At the north end of the line the amplitude of the Belly River event is very weak. From the structure map (Fig. 9.12), it is apparent that little or no structure will be evident on the seismic data. The amplitude of the Belly River event increases slightly from trace 20 to trace 25, corresponding with the development of the productive sandstone. This increased amplitude deteriorates from trace 45 to trace 50 but increases again at trace 50. Further increase in amplitude occurs at trace 90 and continues to trace 100, and marks the thickest producing section in the Belly River B pool. The amplitude of this Belly River event gradually decreases from trace 100 to trace 120. From trace 120 to trace 140, the amplitude of the Belly River Fm sandstone event deteriorates completely. This region represents the very silty sandstones or sandy siltstones that separates the Belly River B pool from the Belly River CC reservoir.

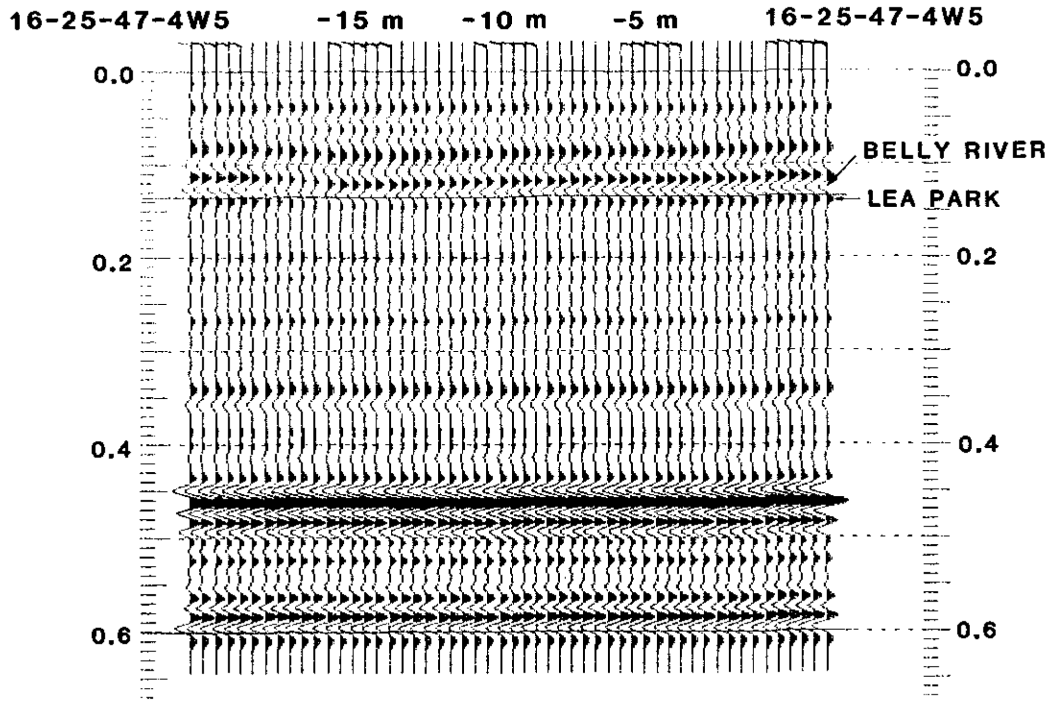

Figure 9.19. Effect of bed thickness on Basal Belly River seismic event.

TINDASTOLL BELLY RIVER A POOL

INTRODUCTION

The Tindastoll Belly River A pool lies in southcentral Alberta approximately 30 km southwest of Red Deer, (Fig. 9.17). The pool was discovered in 1980 and covers approximately 900 ha. At the present time, there are four designated Belly River pools in the Tindastoll area, (Fig. 9.20). Also indicated on Figure 9.20 is the location of the seismic line used in this example. Figures 9.21 and 9.22 show the structure and the thickness of the sandstone associated with the Belly River A pool at Tindastoll. Note that both the structure and the isopach maps have values outside the outline of the Belly River A pool. These maps were constructed in this manner to show the general structural and isopach trends of the non-reservoir sandstones regarded as laterally equivalent to the producing sandstone of the Belly River A pool. The pools in the Tindastoll area appear to be controlled both by structure and the stratigraphic changes that occur within the sandstones of the basal 50 m of the Belly River Fm. The producing wells on the geological cross-section (Fig. 9.23) produce from the A sandstone. Across the geological cross-section, a distance of 2.80 km, there is 18 m of west dip on the A sandstone. The well at 14-9-36-1W5M is marginal at best, having produced 1525 bbl. since 1983, and currently listed as producing 3.5 bbl/day. The well at 12-11-36-1W5M is a dry hole. The Basal B sandstone is not productive at any of the wells on the geologic cross-section, though it is productive at 14-4-36-1W5M approximately 0.8 km south of production in the A pool. This separation between the producing B sandstone at 14-4 and the laterally equivalent sandstone at 14-9 indicates the role of stratigraphic change in the formation of these pools.

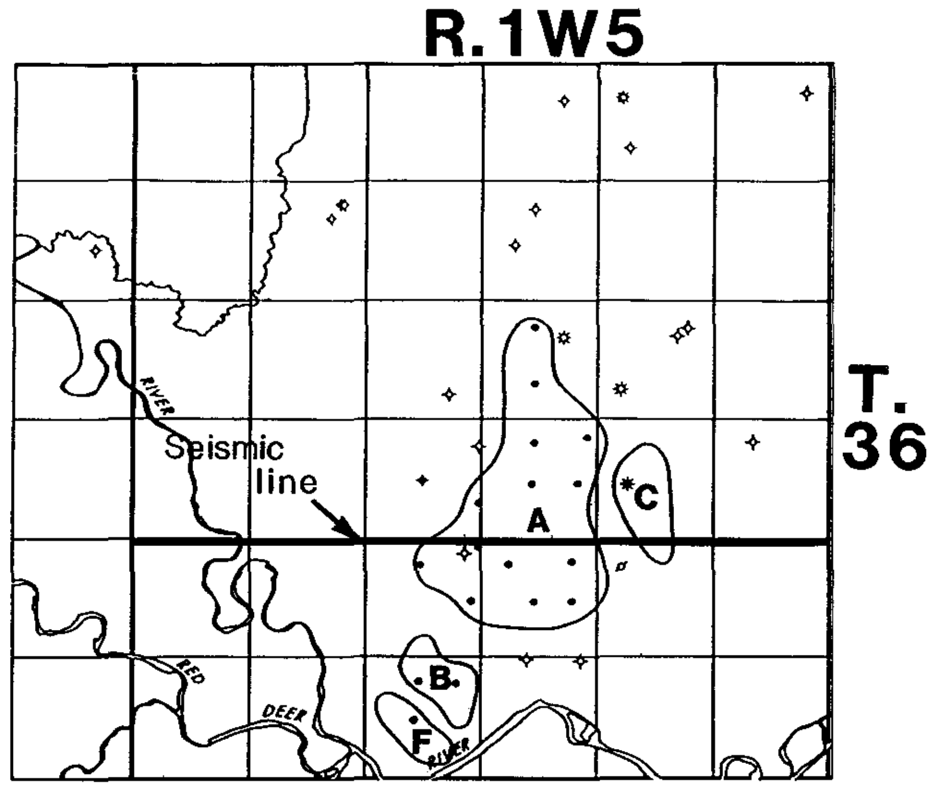

Figure 9.20. Location and outline of Figure 15 and 16, Tindastoll Belly River pools and location of seismic line.

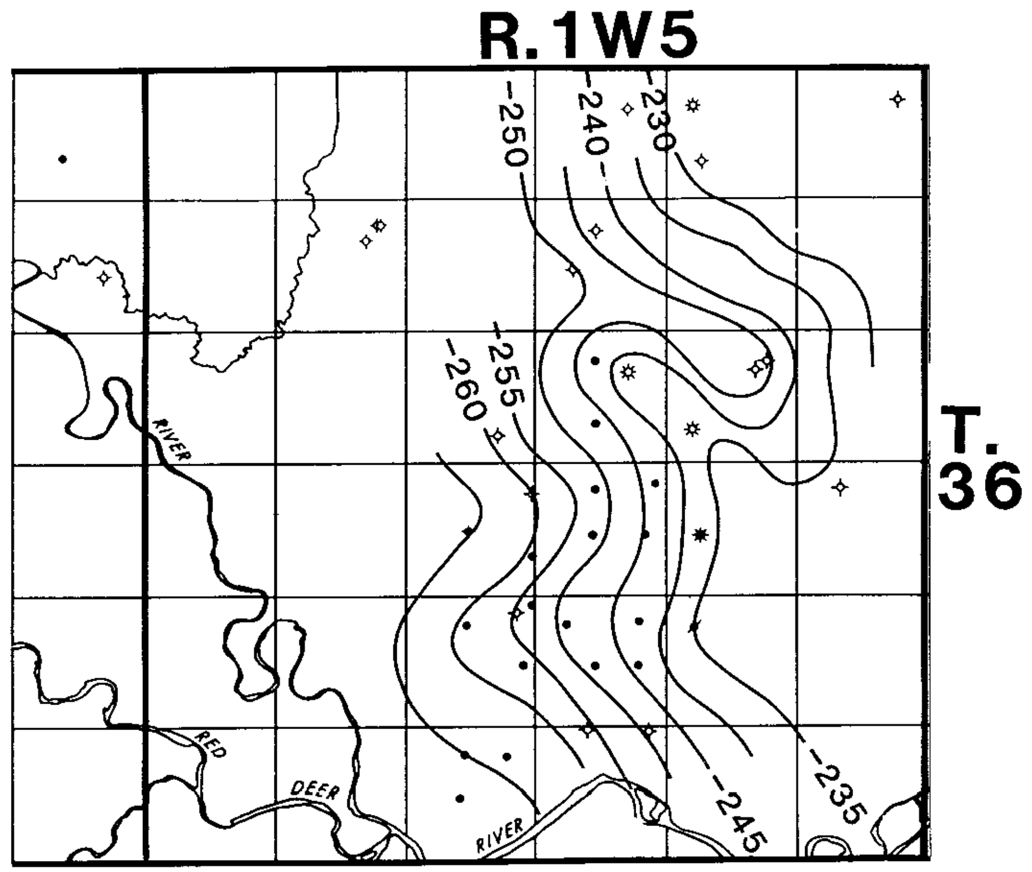

Figure 9.21. Regional structure Tindastoll Belly River A sandstone.

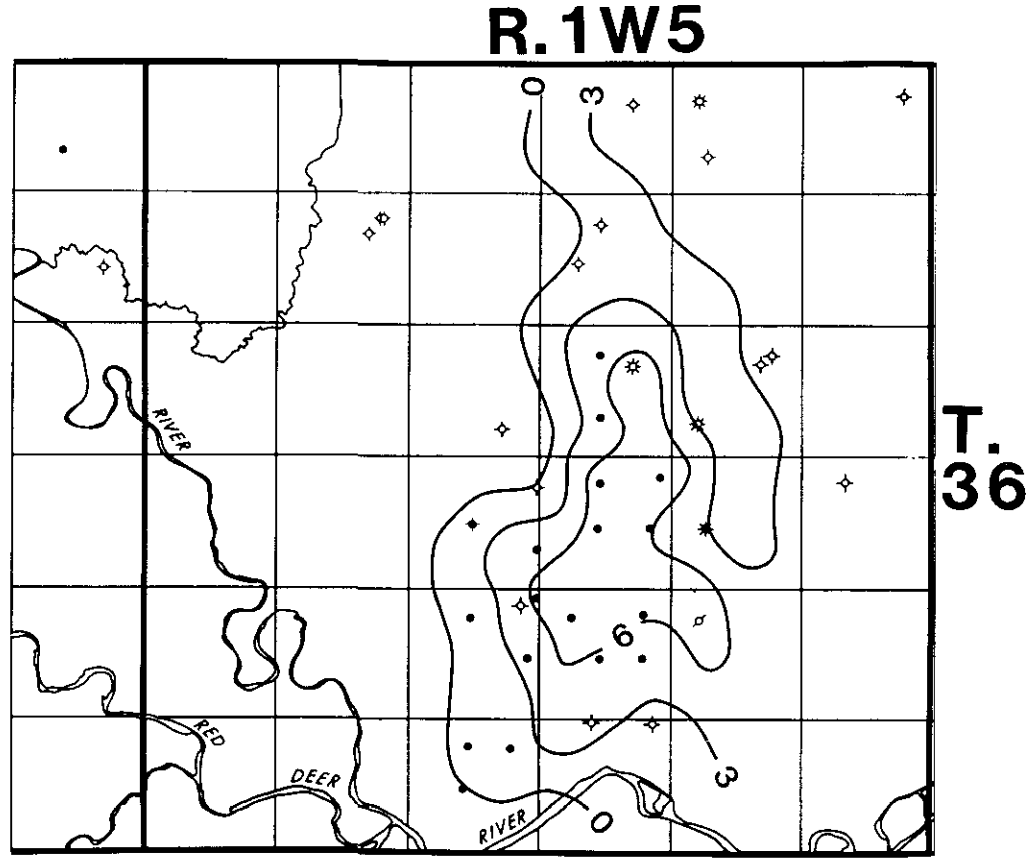

Figure 9.22. Sandstone thickness Tindastoll Belly River A sandstone.

GEOLOGICAL CROSS-SECTION

The depositional environment at Tindastoll is believed similar to that described by Storey (1982) for the Pembina-Keystone area where basal Belly River sandstones occupy the transitional zone between underlying marine shales and overlying coals and coastal plain mudstones and thus represent a progradational shoreline.

Deposition of the lower Belly River Fm in the Tindastoll area is regarded as having occurred in a delta plain cut by a distributary channel system. The discussion that follows describes the basal 50 m of the Belly River Fm. In this paper this interval will be termed the lower Belly River Fm. The correlations on the geological cross-section Figure 9.23 show the rapid variations that can occur in the lower Belly River Fm. These correlations are duplicated on Figure 9.25, a stratigraphic cross-section which shows the variations in density within the lower Belly River Fm.

At the beginning of Belly River time, sands were being deposited over much of the area covered by the cross-section. The basal Belly River sandstone, identified as the Basal B sandstone on Figure 9.20 is fairly uniform over the area covered by the cross-section. The B sandstone contains tight streaks at various levels across the area, which could be due to diagenetic cementation and carbonate replacement as concluded by Iwuagwu and Lerbekmo, (1982) for the basal Belly River sandstones of the Pembina-Keystone Belly River B pool. Deposition of the 13 m thick B sandstone at 14-9 was terminated by the deposition of 6 m of shale which is covered by 2 m of the A sandstone. This cycle repeats, there being 6 m of shale above the A sandstone with a 1 m thick sandstone deposited on that surface.

At 16-9, the 13 m thick B sandstone has three tight streaks each 1 to 2 m thick within the sandstone (Fig. 9.23). A 5 m thick shale above the B sandstone is overlain by 6 m of the A sandstone. The A sandstone is divided by a tight streak 1 m in thickness. Above the A sandstone is what is regarded as a delta plain succession. To the east at 14-10 and 16-10 the sequence is similar to that at 16-9. The number of tight streaks in the B sandstone goes from three to one. At 16-10 the B sandstone, consists of a coarsening-upward sequence followed by a fining upward sequence. This results in the development of 17 m of B sandstone. The shale break between the B and the A sandstones in 2 m thick at 16-10. The 7 m thick A sandstone is overlain by a delta plain sequence within which are two thin sandstones, 14 m and 20 m above the A sandstone.

At 12-11-36-1W5M both the A and the B sandstones appear tighter than they are to the west, especially in the upper section of each sandstone (Fig. 9.25). The sequence above the A sandstone is similar to that at 16-10, with a sandstone 5 m thick approximately 18 m above the A sandstone. The interval from the top of the A sandstone to the Lea Park marker varies by only 3 to 4 m along the line of the geological cross-section.

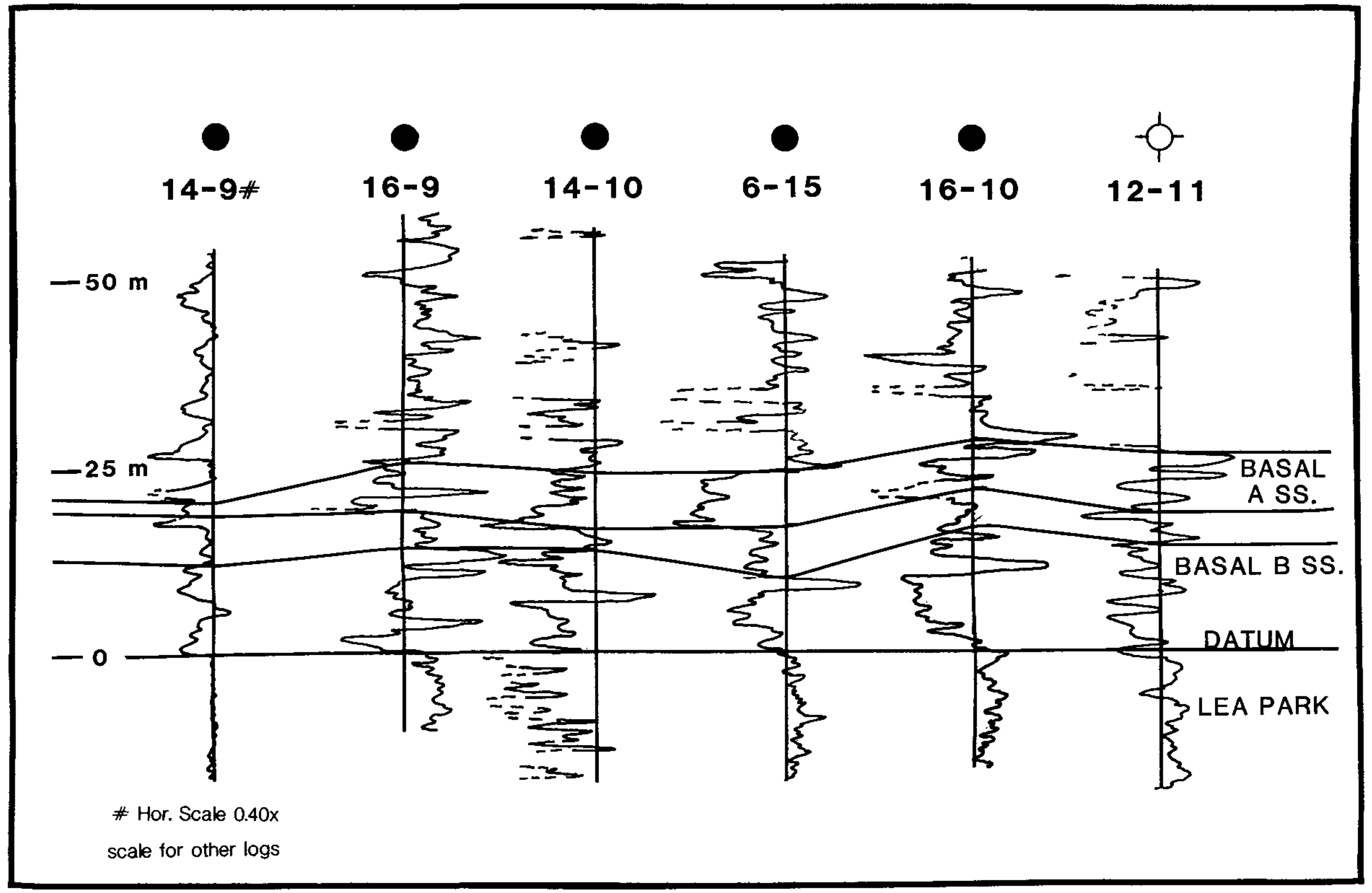

Figure 9.25. Stratigraphic cross-section illustrating variations in density within the lower Belly River Fm.

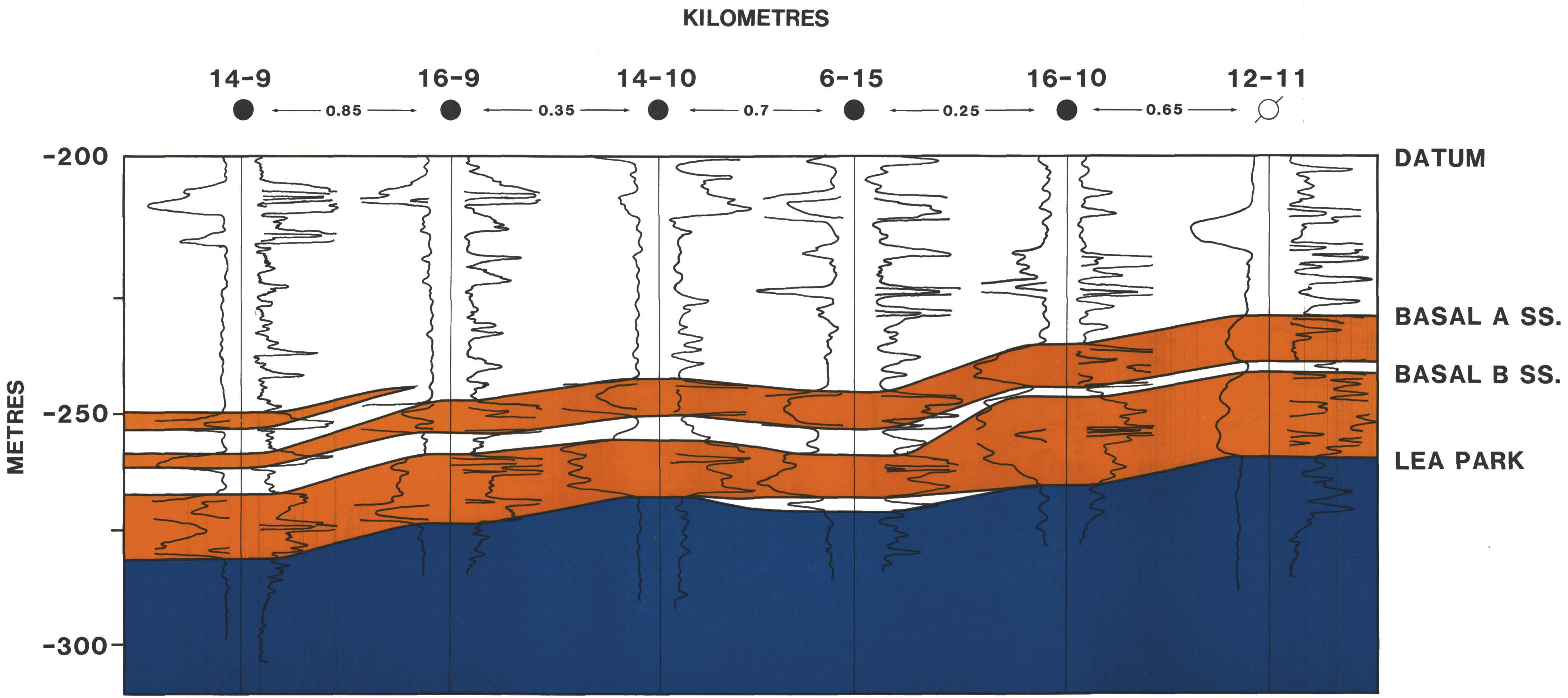

Figure 9.23. Geological cross-section, Tindastoll Belly River A pool.

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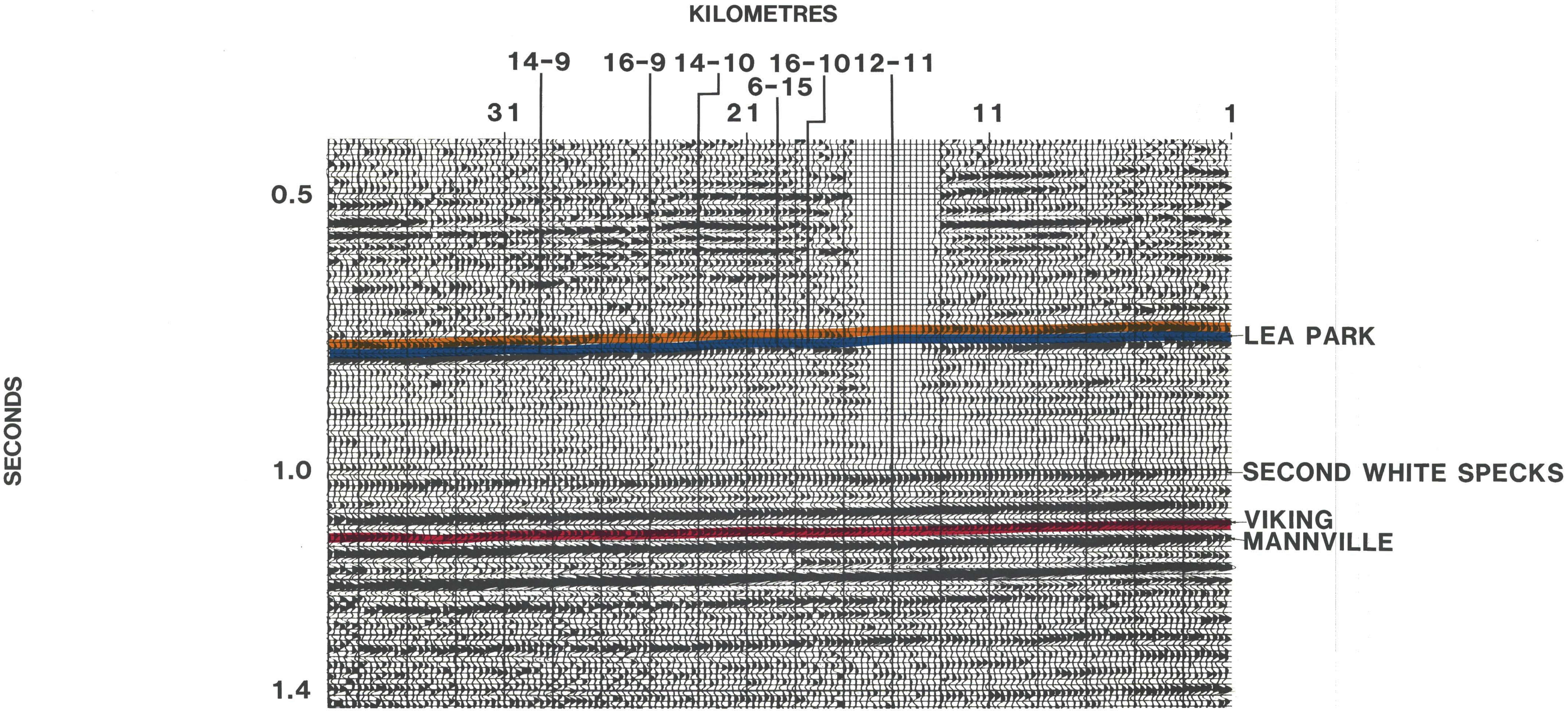

Figure 9.24. Seismic section Tindastoll Belly River A pool.

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SEISMIC SECTION

The seismic section (Fig. 9.24) as presented here is log normal polarity, ie., an acoustic impedance increase at an interface is represented by a peak on the section.

From the description of the geological cross-section above, it is apparent that the seismic method would be unable to resolve the interfaces associated with the A and B sandstones, yet there is a seismic response to the Tindastoll Belly River A pool. Resolution of beds giving a seismic response is dependent on the thickness of the beds and the frequency content of the seismic energy that produces that response. Using the criteria of Kallweit and Wood (1982) resolution of seismic events of the same polarity would require a time interval of 11 ms, assuming 60 Hz data. For the A and B sandstones this would imply an interval of at least 22 m. The maximum interval between the A and B sandstone is 14 m+. Therefore, for this data in this area, matched to a 28 ms, 28 Hz Ricker, resolution of the stratigraphic changes that occur in the lower Belly River section is not possible. The seismic response may well detect changes, but it cannot resolve them.

The development of the seismic signature package that covers the Belly River-Lea Park interface is dependent on the sequence of sandstones and shales in the lower Belly River as well as the nature of the upper section of the underlying Lea Park shale. Modelling the changes that occur in the section was begun by comparing the available sonic density and dual induction logs for 14-4, 14-9 and 16-10. From analyses of these logs a synthetic sonic log was created for 16-10-36-1W5M. The synthetic seismogram that results from this sonic log, gives a quite acceptable match to the seismic section at trace 18, (Fig. 9.26).

The sandstones in the lower Belly River section in the Tindastoll area are extremely variable in average transit times. In 14-9-36-1W5M the transit time for the B sandstone ranges from 256 to 210 µs/m, reflecting the cementation or pore infilling that appears to be present. In the 14-9 well the transit times for the A sandstone range from 255 to 262 µs/m indicating possibly a homogeneous sandstone. The transit times for the underlying Lea Park shale are variable near the Belly River-Lea Park interface. At 14-4, slightly south of the seismic line, the transit time is 270 µs/m, at 14-9, 255 µs/m. This transit time tends to stabilize at approximately 290 µs/m, 10-15 m below the Belly River Lea Park contact. This transition in transit time within the upper section of the Lea Park Fm creates the pronounced trough that is the Lea Park event.

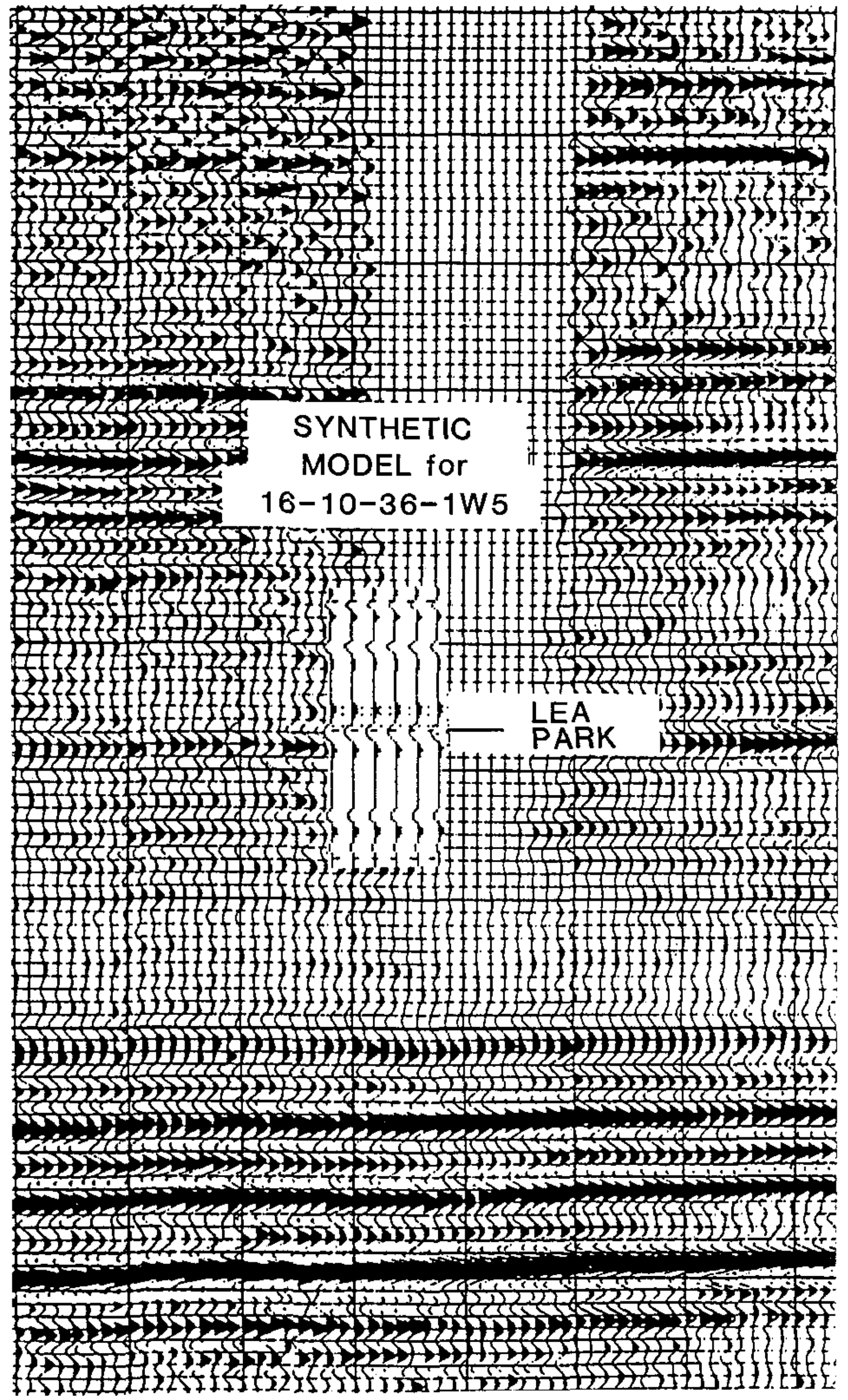

Figure 9.26. Synthetic seismic section match to seismic section (16-10-36-1W5M).

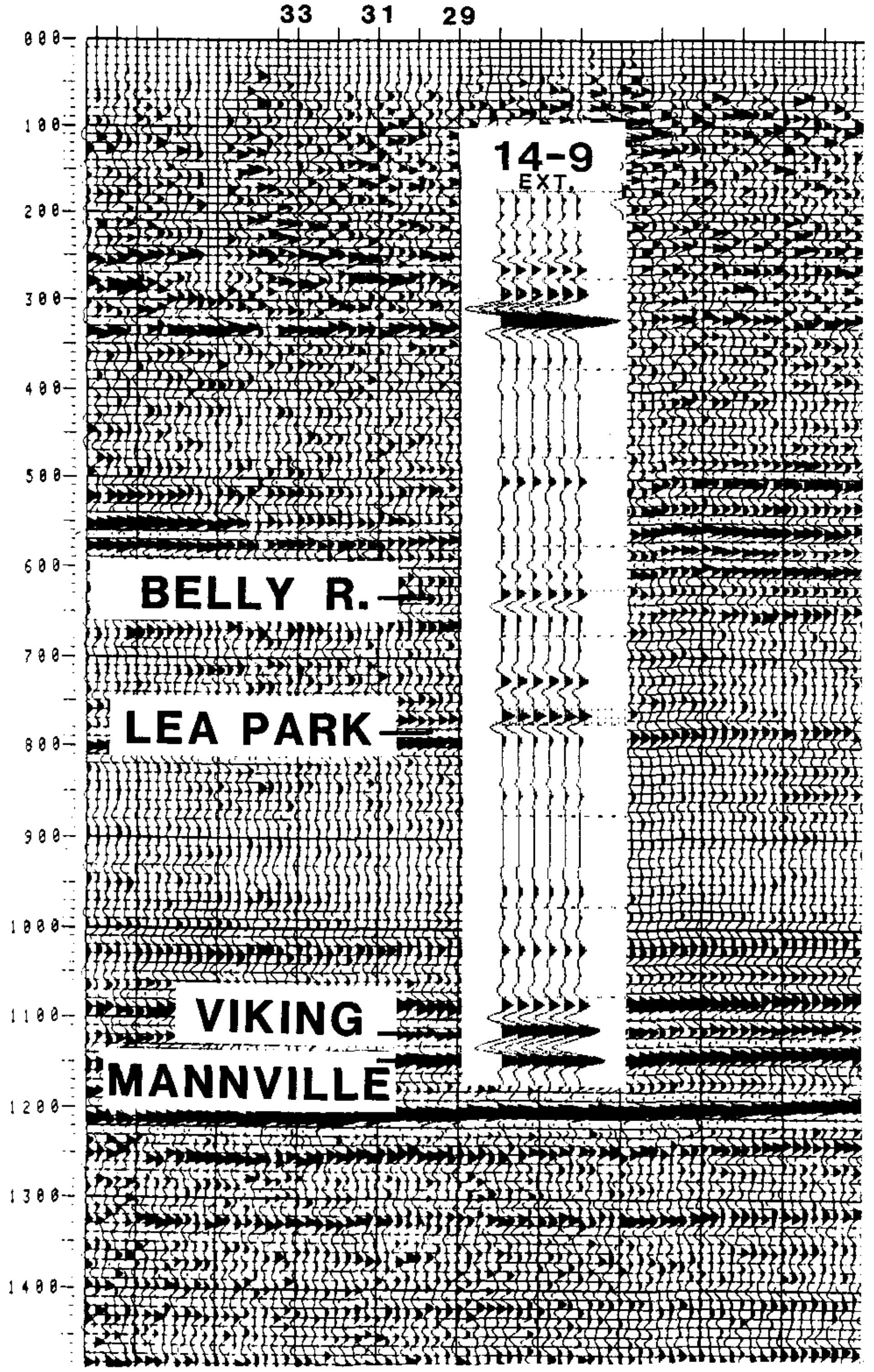

Figure 9.27. Synthetic seismogram for 14-9 and identification of seismic events.

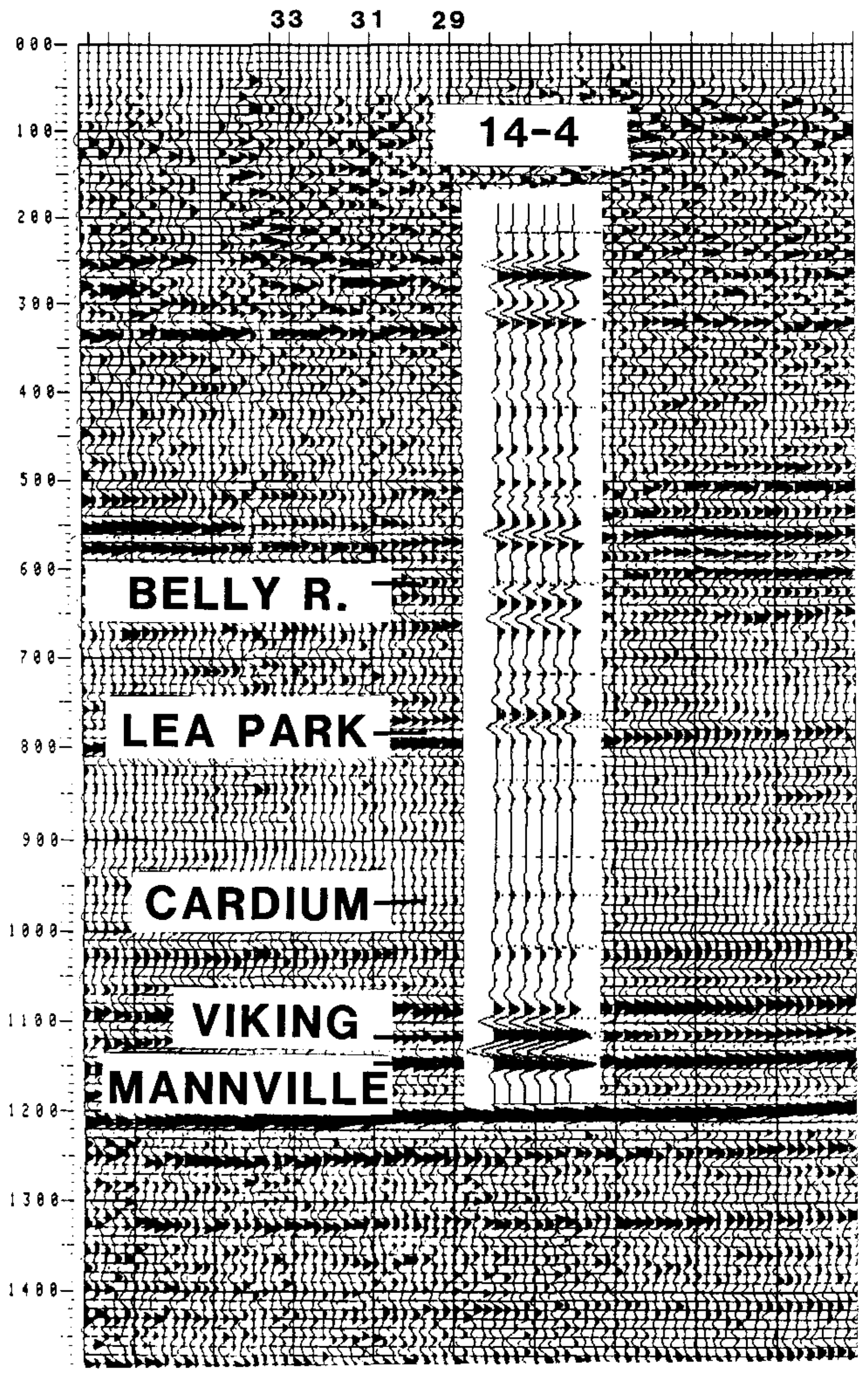

Figure 9.28. Synthetic seismogram for 14-4 and identification of seismic events.

The density of the sandstones and shales in the lower Belly River Fm are quite variable (Fig. 9.21). This variability in density does not appear to have a major effect on the reflection package at the lower Belly River level. Note the dramatic effect density has on the trough 60 ms above the top of the Belly River Fm.

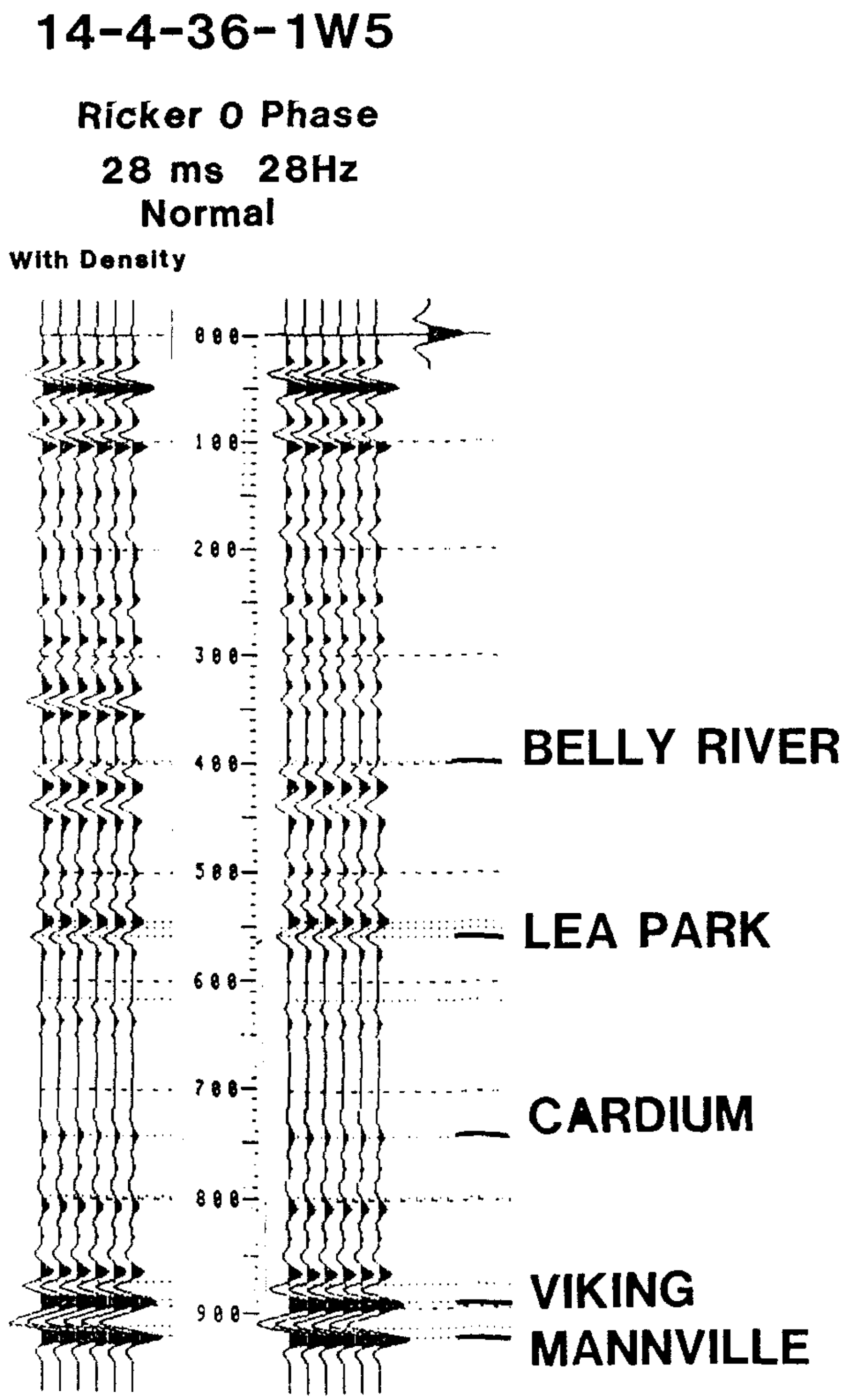

Figure 9.29. Seismic model for 14-4.

The seismic events on the section were identified using synthetics from both 14-4-36-1W5M and 14-9-36-1W5M. A 28 ms zero phase Ricker wavelet, dominant frequency 28 Hz, gives a synthetic that matches the data quite well (Figs. 9.27 and 9.28). Note: the 14-4 synthetic was extended to the Mannville Gp by splicing in the 14-4 sonic log 16 m below the top of the Lea Park Fm.

The acceptable identification of events and the model for 16-10-36-1W5M indicated a seismic model along the line of the geological cross-section should be made. The sonic logs for the wells used were extended 300 m below the Lea Park using the sonic log from 14-4-36-1W5M to eliminate end of log effects in the model.

The seismic model used are the sonic logs from 14-4, 14-9, 16-9 and the modelled log for 16-10. The resultant section, flattened at the top of the Belly River Fm, is shown in Figure 9.29. On the modelled section the Lea Park trough carries across the section with varying amplitude. Note that the trough associated with the Lea Park event is 4-5 ms below the geological correlations for the Belly River-Lea Park boundary. The greatest variation in this model occurs in the events above the Lea Park trough. The peak above the Lea Park trough moves up in the section, from 14-9: 2 ms at 16-9; 5 ms at 16-10. Accompanying this shift up in the section is a decrease in amplitude of the peak-trough-peak sequence above the Lea Park event. This model does not allow resolution of the events that are associated with changes in the stratigraphy in the lower Belly River Fm, but indicates that changes in the seismic signature for the section under discussion may be correlative with changes in the geology of the interval.

The seismic section presented is log normal. The spread lengths used in acquisition yielded a maximum of 6-fold coverage at the depth of the Lea Park seismic event (Table 9.4).

Table 9.4: Reserves and significant reservoir parameters of the Tindastoll Belly River A pool.

Original Oil in Place	2.800 x $10^6 m^3$
Primary Recovery	10%
Primary Reserves	2.80 x $10^5 m^3$
Area	904 ha
Average pay thickness	3.5 m
Porosity	5%
Water Saturation	33%
Shrinkage	0.88
GOR	50 m^3/m^3
Density of Oil	827 kg/m^3
Initial Pressure	5951 k Pa
Mean Formation Depth	1175.8 m
Discovered	1980
Total wells in pool	14
Wells currently producing (June, 1988)	10

The trough associated with the Belly River-Lea Park interface correlates easily across the section, Figure 9.30, with considerable variation in amplitude. The peak above the Lea Park is the seismic event identified with the basal Belly River B sandstone. The amplitude of this peak at trace 35 indicates the presence of a thick B sandstone. At 14-9, 13 m of basal Belly River sandstone is deposited above the Lea Park marine shale. The amplitude of the B sandstone peak decreases beginning at trace 27. Accompanying this loss of amplitude in this peak is the formation of a doublet peak above the Lea Park trough. The formation of this doublet peak indicates either a change in stratigraphy or an earlier onset of the peak of the Belly River B sandstone. An earlier onset of the peak associated with the Belly River B sandstone event decreases and there is an earlier onset, the interpretation is that there has been development of a sandstone above the B sandstone. As the B sandstone is productive at 14-4-36-1W5M, build-up of a sandstone immediately above the B sandstone could also be productive. This doublet gradually becomes a front-loaded doublet, trace 24, 23. The time interval from the Lea Park trough to the peak above the Lea Park trough has increased from 11 ms at trace 35 to 18 ms at trace 23. At trace 21 the section now shows the lower part of the doublet peak to be dominant. From trace 21 to trace 19 there is almost complete cancellation of the peak above the Lea Park trough. At trace 18 the event correlated with the B sandstone is re-established and leads into the trough of the Lea Park event. East of the gap, the section has a slightly lower frequency. The time interval from the Lea park trough to the peak above remains at approximately 18 ms. The width of the Lea Park trough and the amplitude of the peak above indicates the presence of a well-developed basal Belly River sandstone on the Lea park surface, with little or no development of a sandstone above the B sandstone.

Table 9.5: Acquisition and processing parameters for the seismic line

48 trace SN 338 B instrument				
101 m group interval				
9, L-10 8 Hz phones per group over 61 m				
Field Filter 10-125 Hz, notch in				
Energy Source Dynamite:				
2.3 kgs @ 18 m				
Shotpoint spacing 202 m				
Acquired 1976				
Reprocessing sequence:				
Demultiplex				
Amplitude recovery				
Trace gather				
Instrument - geophone dephasing				
Deconvolution: spiking, 1% prewhitening				
Velocity analysis				
NMO				
Structural corrections				
Trace equalization				
Statics	- surface consistent cross-correlation			
Mute	0	550	900	1200 ms
	453	654	1358	2465 m
Stack	1200%			
Filter	12/15 - 60/72			
Equalization				
Amplitude Coherency	Enhancement			

CONCLUSION

In the two examples of the lower Belly River Fm, two very different seismic responses have been observed. These responses were obtained on data that was acquired with, what might now be termed, less than sufficient parameters for detection of shallow, stratigraphic objectives. Both of these pools were probably discovered in drilling for deeper objectives, but this should not deter the explorationist from analyzing carefully shallower events on the seismic section that might in conjunction with careful geological analysis lead to the discovery of similar pools in the Upper Cretaceous section.

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