CHAPTER 6 – MISSISSIPPIAN RESERVOIRS

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INTRODUCTION

No complete section of Mississippian Period strata remains in the Western Canada Sedimentary Basin, as a result of four periods of erosion, following widespread uplift which began in late Pennsylvanian and ended in Early Cretaceous (MacAuley et al., 1964). The thickest remaining section (> 1600 m) is found in the Peace River area of northern Alberta and northeastern British Columbia. It is completely eroded throughout much of the Western Canada Sedimentary basin (Fig. 6.1).

Primarily deposited in a shallow-marine environment, Mississippian rocks can be separated into two lithologic units (MacAuley et al., 1964). The lowest is mainly shales and calcareous shales and may include siltstones, sandstones and argillaceous carbonates. The earliest of these formations (Table 6.1) is the Bakken Fm of southern Alberta, Saskatchewan and southwestern Manitoba, a fine-grained sandstone sandwiched between two shales and its western Alberta equivalent, the Exshaw Fm. The Banff Fm in the west and Souris Valley or Lodgepole Fm in the east mark the upper limit.

The upper unit is predominantly limestones and dolomites with some shales and evaporites present and occasionally minor amounts of clastics. Included are the Mission Canyon Fm to Charles Fm in Saskatchewan, the Pekisko to Turner Valley formations (Rundle Gp) in Alberta and the Debolt Fm of northern Alberta and northeastern British Columbia.

In addition, the Mississippian formations are further defined by geographical areas. In southern Saskatchewan and southwestern Manitoba, carbonates form the major rock type. The bedding is relatively uniform, thinning to the north and east (Fig. 6.1) and is overlain by a thick Jurassic section. The second area includes southern Alberta and southeastern British Columbia. Carbonates still dominate but are more argillaceous and interbedded with shales. The siltstone of the Bakken is displaced by the Exshaw Fm shale. The overlying beds are thin Jurassic clastics or Cretaceous sediments often tightly cemented. Closer to the Rocky Mountains, the original structural relationships and to some extent, lithology, of the rocks have been altered by thrust faulting. Mississippian rocks outcrop along much of the length of the Rockies.

In northern Alberta and northeastern British Columbia, where the nomenclature changes, the section is thickest. Carbonates have significant shale content and interbedded shales are thicker and more common. Thrust faulting is present but is less severe than in southwestern Alberta.

The eight examples of Mississippian pools in this chapter have been selected to provide a representative sample of these different lithologies and areas. Some combine more than one aspect. All except one, Seal, have been significant producers of oil and/or gas.

The majority of Mississippian fields are erosional features, both as outliers, entirely overlain by dense cemented clastics or shales and as subcrop edges. Three examples, Alida, in southeastern Saskatchewan and Harmattan-Elkton and Alexis of southwestern and central Alberta are in this category. Alexis is an outlier of dolomitized Banff carbonate, the others produce from subcrops.

Tectonic movement and faulting are the major components creating the traps for Blueberry (northeastern British Columbia) and Turner Valley (southwestern Alberta). Both produce from subcrop of the Rundle Gp; Turner Valley from the Turner Valley Fm and Blueberry from the Debolt Fm. Faulting is relatively simple at Blueberry compared to the complexity found at Turner Valley.

Another type of structure found from southwestern Manitoba to southeastern Alberta is caused by salt dissolution, of which the Hummingbird field is an example. It was the first such field in Canada proved to have been formed by multiple stage salt removal.

Two fields (Viewfield and Seal) represent unusual or uncommon Mississippian features. Both are structurally controlled. The Viewfield example is a structure originally thought to be associated with salt dissolution. Although salt loss may have contributed to the structure, there are many other conditions present indicating a meteorite impact origin (Donofrio, 1981). Seal is comprised of Pekisko Fm carbonate mud mounds. These mud mounds grew, reef-like, on a carbonate bank in a shale basin and are the only known reef-type structure in the Mississippian.

The seismic lines which illustrate these eight fields range from early 1970's data (Viewfield) to mid-1980's (Blueberry). The sources are both surface (Vibroseis and Airgun) and subsurface (dynamite). All are multi-fold data. All sections were processed using a conventional sequence which included instrument and geophone dephasing, zero-phase deconvolution, elevation and first break statics (for surface and sub-surface sources), surface consistent statics and correlation trim statics. Some exceptions to this processing were necessary. Seal required a minimum phase spiking deconvolution to improve coherency of the data. Four examples Blueberry, Turner Valley, Viewfield and Seal with significant structure were migrated. The other four were not, although it is now becoming standard practise to migrate even apparently flat data. Finally, continuity of reflections on three examples, Viewfield, Harmattan-Elkton and Alexis, was enhanced by the use of mild post-stack F/K filtering.

Interpretation based on one or two seismic lines is, at best, somewhat arbitrary but the extensive well control in these fields has significantly helped. All the examples are interpreted structurally, no attempt was made to interpret porosity based on wavelet character other than in a subjective sense. However, one of the examples, Alexis, includes a description of the effect that gas in a reservoir has on seismic reflections.

Because Mississippian reservoirs are primarily associated with the subcrop, they are often difficult seismic targets. The target is frequently a structure but the many different lithologies of the overlying beds can either mask or exaggerate the identification of the unconformity. Deeper within the Mississippian strata, reservoirs are apt to go undetected seismically because adequate acoustic contrast is lacking.

Thus despite the apparent ease with which seismic can be used to map structural rather than stratigraphic features, the search for Mississippian reservoirs has been and continues to be a very challenging use of seismic techniques.

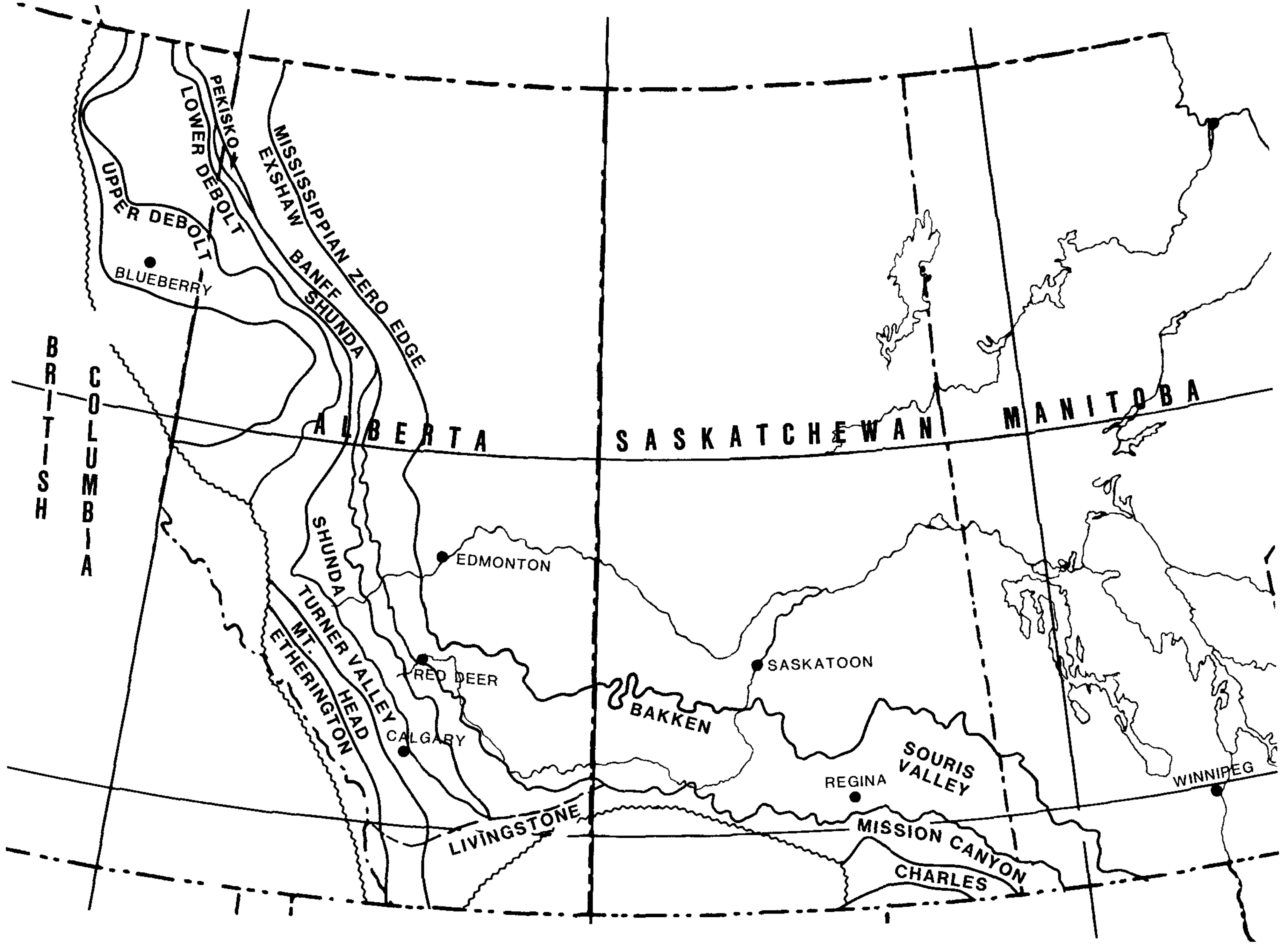


Figure 6.1. Regional geology of the Carboniferous.

ALEXIS FIELD

INTRODUCTION

Situated 65 km northwest of Edmonton, Alberta, the Alexis field (Fig. 6.2) is one of several similar fields which produce oil and gas from local Mississippian erosional highs. With an area of less than 800 ha, the Alexis pool is small compared to the much larger Cherhill field.

Production is from an extensively dolomitized carbonate of the Banff Fm, which has been partially eroded leaving remnant structural highs. Overlain by lower velocity sandstones and shales of the Lower Cretaceous, the erosional contact is seismically visible and allows geophysics to be a valuable tool in mapping the pool.

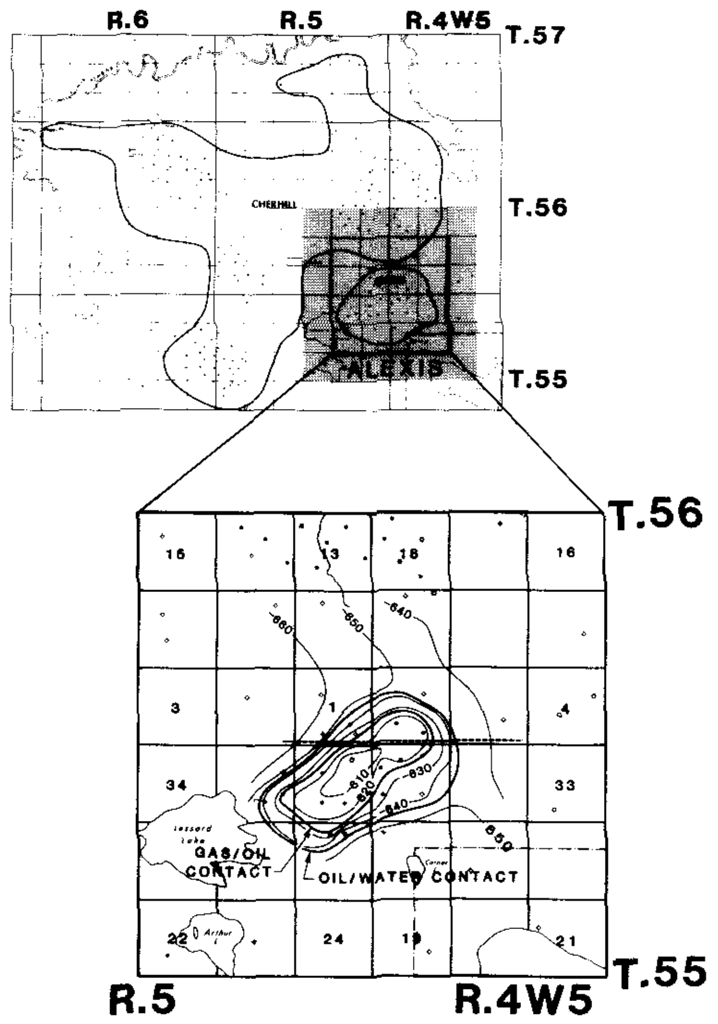


Figure 6.2. Location and structure of the Alexis field adjacent to the Cherhill field. Production is from a structurally high remnant of dolomitized carbonate of the Banff Fm. Gas/oil and oil/water contacts are shown (Contour interval 10 m).

The first Alexis well, 15-36-55-5 W5M, was drilled in 1968. Since then 14 more wells have been drilled, 10 of which were in production in 1987. Typical porosity is 13%. Horizontal permeability, based on cores, is as high as 245 md. Original estimates of recoverable reserves were 7 580 x $10^3 m^3$ oil in place (O.I.P). (with 15% recovery) and 267 400 x $10^3 m^3$ gas in place (G.I.P.). To date, (December, 1987), 405 889 m^3 of oil and 292 829 x $10^3 m^3$ of gas have been produced.

GEOLOGIC CROSS-SECTION

The eastern limit of the Banff Fm lies several kilometres east of the Alexis pool. There is a thick Banff section at the Alexis pool, composed predominantly of shales, calcareous shales and shaly and clean carbonates. The reservoir rock is a dolomitized carbonate, frequently referred to as the Clarke's Mbr. It was extensively and differentially eroded and is overlain by sediments of the Mannville Gp. The combination of structurally high, porous Banff dolomite and overlying impermeable Lower Mannville Gp shales has formed the reservoir and trap respectively for this field. The structural configuration of the Mississippian in this area is illustrated in Figure 6.3 with the Alexis pool as the centre structure.

A structure map of the top of the Mississippian is included in Figure 6.2. Maximum relief is more than 55 m. Approximate gas/oil

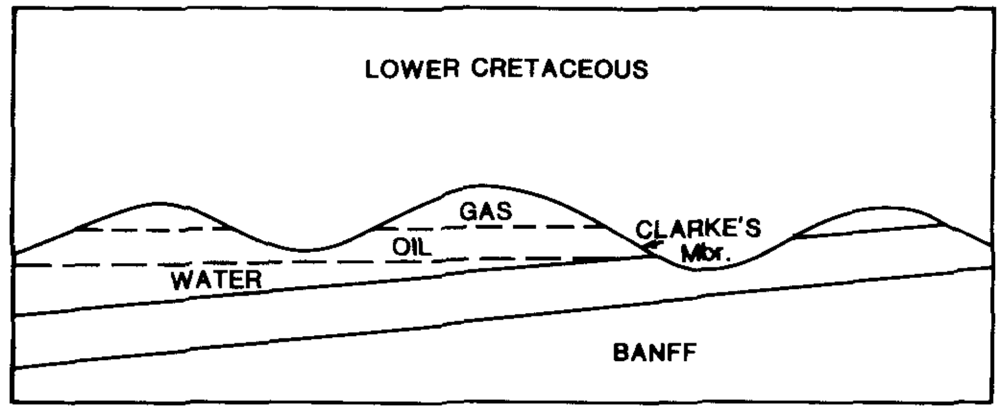
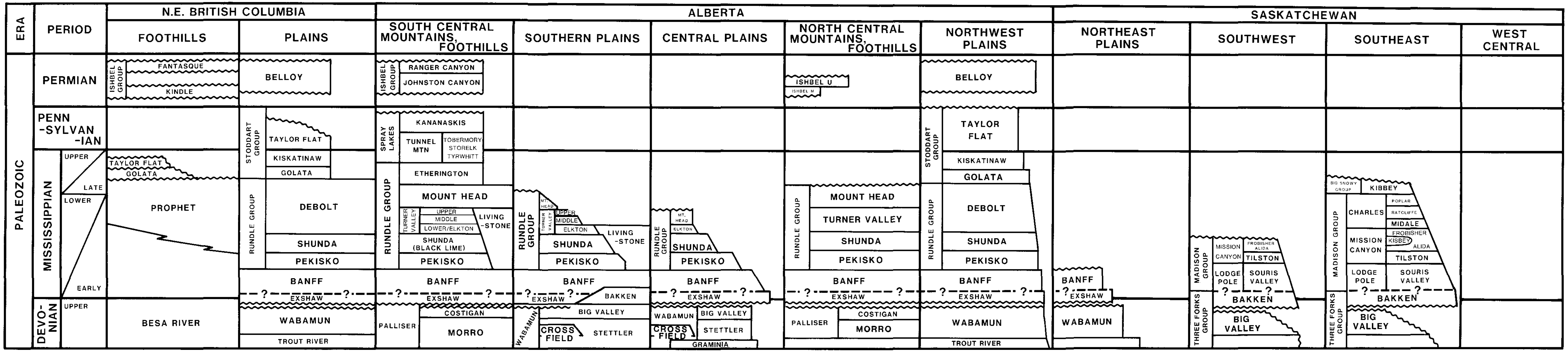


Figure 6.3. Erosion left remnants of porous Clarke's Mbr (Banff Fm) and subsequent burial under basal Mannville Gp shales provided the trap and seal at Alexis.

Table 6.1. Correlation chart of Upper Paleozoic (Late Devonian-Permian) formations (Modified from Western Atlas Int. Correlation chart)



and oil/water lines are indicated by heavy contours at -625 m and -645 m subsea respectively.

Figure 6.4 is a geologic cross-section which illustrates the structural features of the Alexis pool. The 3-1-56-5 W5M well lies outside the field and the Mississippian is 50 m lower than in the 15-36 discovery well. Well 7-5, at the eastern edge of the structure, is over 25 m lower. The porosity of the Clarke's Mbr is particularly well-developed in the three wells 15-36, 14-31 and 15-31. There is a strong gas effect on the 14-31 sonic. The 7-5 well, although structurally high enough to be above the water line, is stratigraphically too low as the Clarke's Mbr has been eroded.

Differential compaction of the thicker Lower Mannville sediments in the 3-1 well results in a Mannville isopach that does not represent true Mississippian structure. This has implications to seismic interpretations which are often based on isochron rather than time structure mapping.

SEISMIC SECTION

The location of the east-west seismic line (Fig. 6.5) is shown as a dashed line in Figure 6.2. This line was recorded in 1979 using a dynamite source, single hole, 4.5 kg charge size at 18 m depth, a 1617-m split spread, 132-m source interval and 33-m group interval. Geophones were 30 Hz.

Figure 6.6 is a suite of logs from the 1-1-56-5 W5M well, including a segment of the seismic section. All logs are displayed on a time scale equal to the synthetic seismogram. Key formations and their associated seismic reflections are the Joli Fou Fm shale, Mannville Gp top, the Mississippian subcrop, and the Ireton Fm shale. Also noted are the Viking Fm, Wabamun Gp and Graminia Fm tops.

Two wells, 3-1-56-5 W5M and 15-36-55-5 W5M are compared in Figure 6.7. The Mississippian Clarke's Mbr is eroded in 3-1 and is 50 m and 25 ms deeper than in 15-36. The reflection character changes significantly from a strong low frequency trough-peak sequence with a very weak upper peak (3-1) to a higher frequency, medium amplitude peak-trough-peak sequence (15-36). This change in 15-36, is caused, first, by structure on the Banff Fm and by the gas effect referred to in the geology discussion. Gas in a reservoir impedes the transmission of seismic compression, or P-waves and the result is an apparent reduction in velocity and density of the rocks, similar to the effect caused by porosity. Even very small volumes of gas can have this effect. In this example, it produces the trough below the Banff Fm peak in 15-36 and serves to push the maximum amplitude of the peak in the section higher in time than expected. Thus the Banff seismic event in 3-1 is picked as a maximum (peak), whereas it becomes a lower cross-over (below peak) in 15-36.

The example seismic section (Fig. 6.5) traverses the field, east to west. Reflections identified are a strong trough corresponding to the top of the Ireton Fm shale, the Banff Fm subcrop (a peak), the top of the Mannville Gp (a somewhat broken peak) and the strong trough associated with the Joli Fou Fm shale.

Outside the Alexis pool, the Banff event is a strong peak, but within the field, (traces 60 - 120) it moderates in amplitude then splits into a doublet in the presence of a sufficiently thick gas zone (e.g. 15-36 at trace 112). Structural closure is 20 to 25 ms in time.

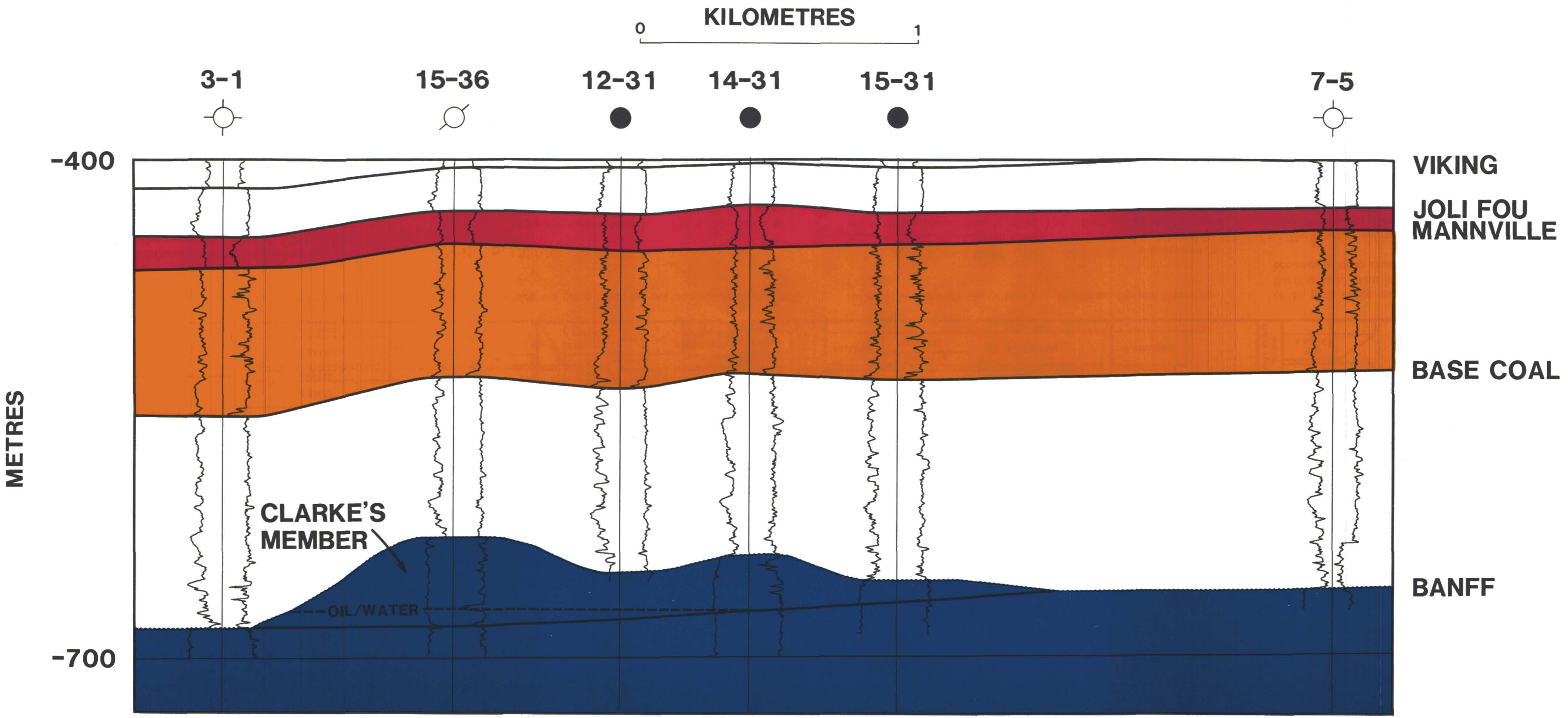


Figure 6.4. Geological cross-section of the Alexis field.

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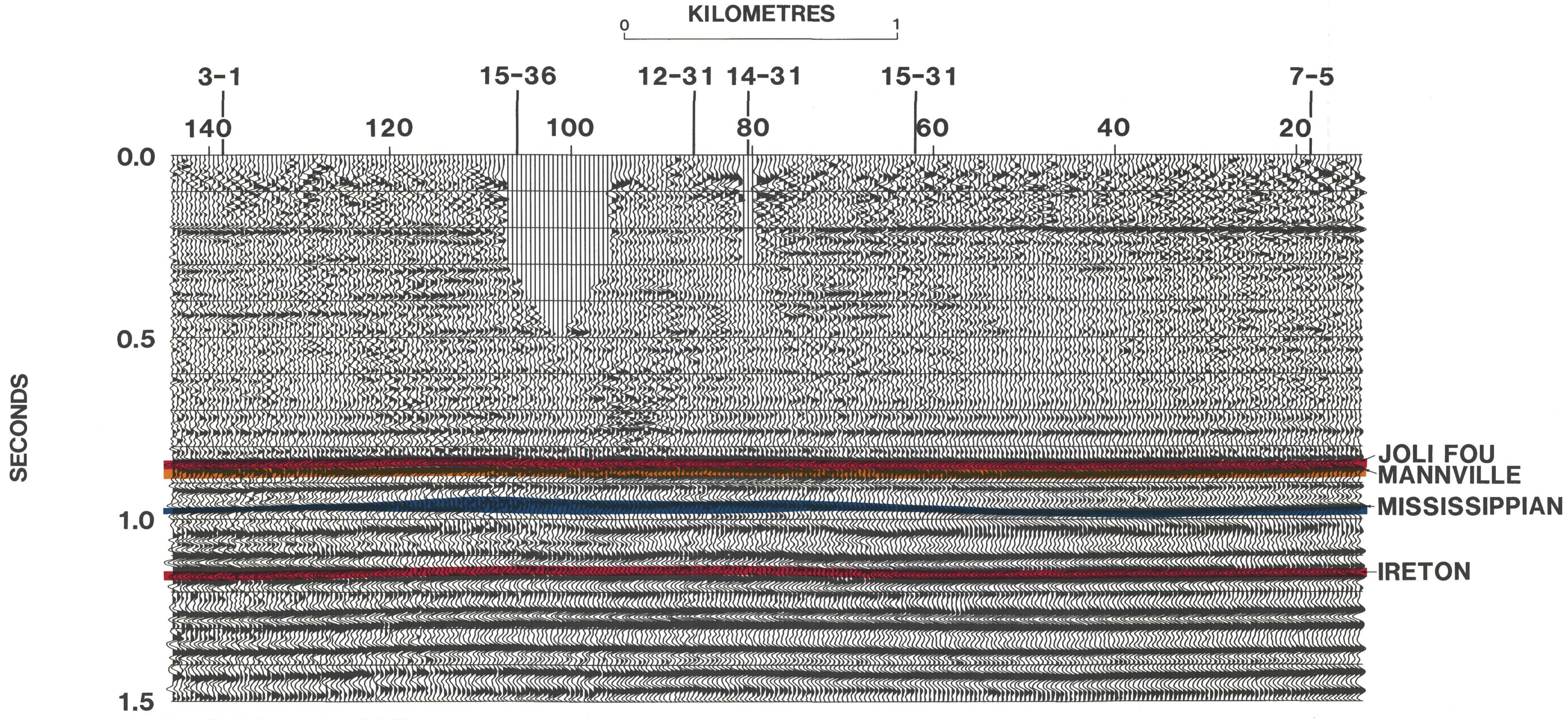

Figure 6.5. Seismic section of the Alexis field.

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Isochron mapping is frequently used to infer structure on one of two events with the other event assumed to be flat or regionally dipping. For the Joli Fou to Banff Fm isochrons, the Joli Fou is assumed to be flat. However, differential compaction of Mannville sediments introduces local structure on the Joli Fou. In addition, the velocity is higher and density is greater in the more compacted rocks. The time between the two events is correspondingly reduced. Consequently, the Joli Fou to Banff Fm isochrons observed on seismic show smaller variations (as little as 5 ms) and a calculated Banff structure based on a regionally dipping Joli Fou Fm may show less than actual closure.

CONCLUSION

The Alexis pool is one of a number of seismically visible Mississippian pools which have been developed or found by seismic analysis. The structural component is evident on the example seismic section as a time structure change and a Joli Fou-Banff Fm isochron thinning. Porosity and gas in the reservoir are indicated by character changes in the Banff seismic event which is altered from a strong peak off-structure to a doublet over the porous zone.

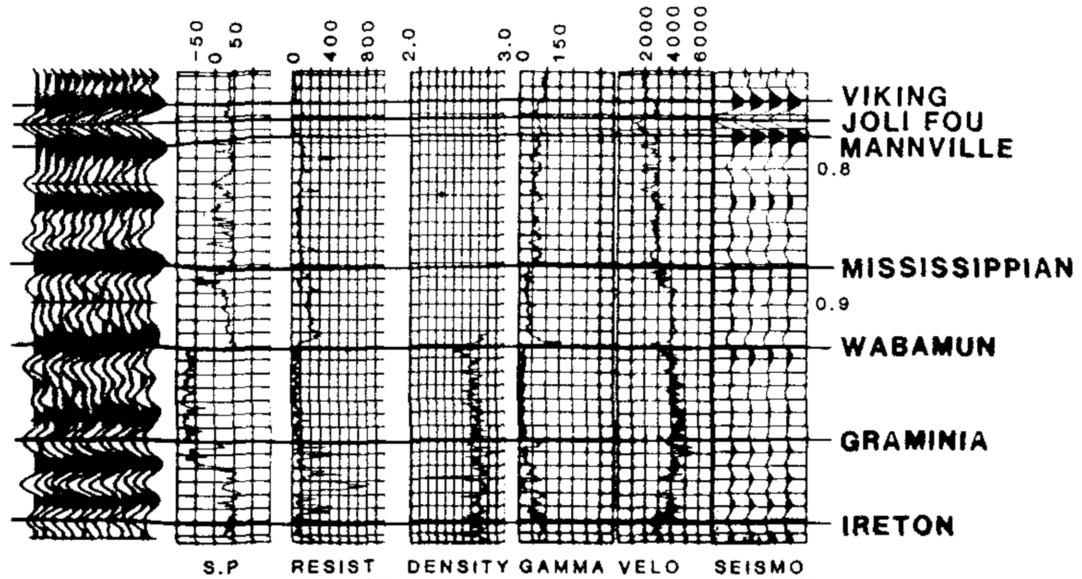

Figure 6.6. Suite of logs from the 1-1-56-5 W5M well indicating correlation to the seismic section.

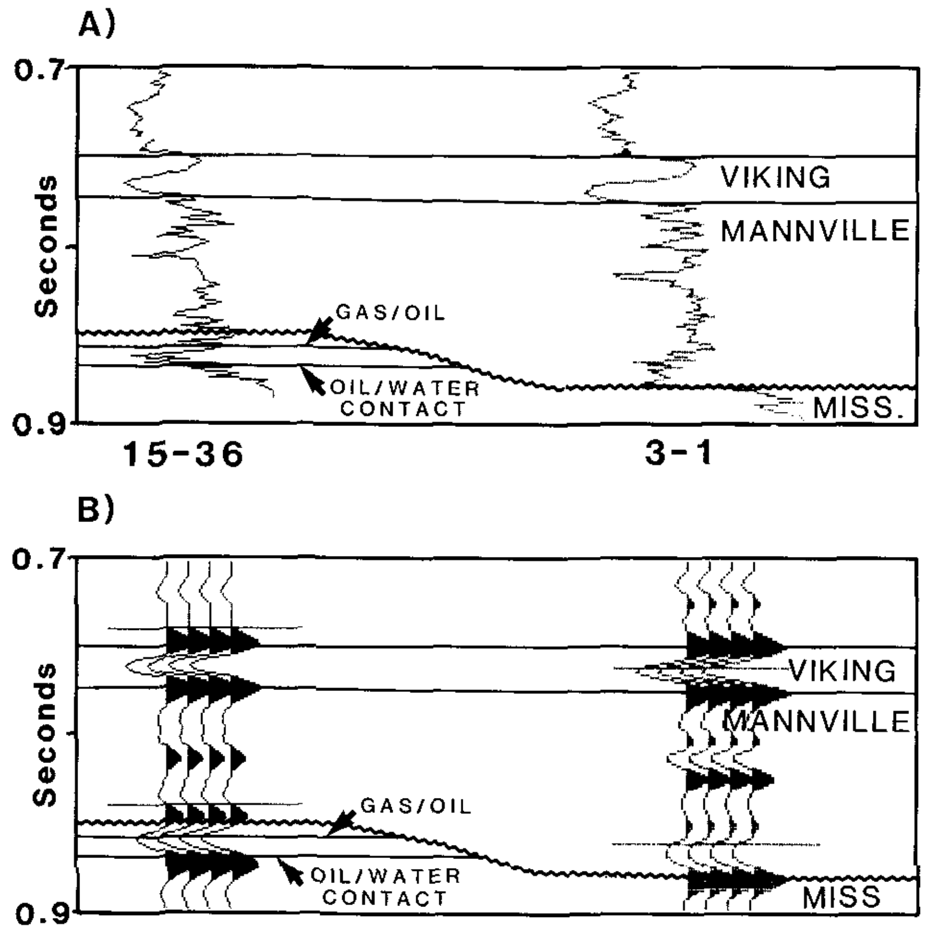

Figure 6.7. In A) the sonic logs show 50 m of the Clarke's Mbr in 15-36 eroded in 3-1. In B) the Mississippian event is a medium-amplitude peak over a strong, deeper peak.In 3-1, the upper peak disappears and the lower peak shifts deeper in time. Both figures use a Viking Fm datum.

HARMATTAN-ELKTON FIELD

INTRODUCTION

The Harmattan-Elkton field, as designated by the Energy Resources Conservation Board, covers an area in excess of 10,000 ha. However, the major oil production, which this paper will discuss, occurs in a long and narrow pool that trends north-south along the west side of the Little Red Deer River and covers less than half of the field area. Geophysics is useful for mapping the structural component of this field. It also yields some porosity information.

Discovered initially in 1954 as a gas field, it wasn't until the end of 1955 that the first commercially successful oil well was drilled. More than 120 wells have been drilled to date and the field has accounted for 39 x $10^6 m^3$ gas and 9535 x $10^3 m^3$ of oil.

The field, which has a large gas cap with a relatively thin oil column, is underlain by a limited aquifer (Donohue and Bohannan 1965). It produces gas and oil from a porous dolomite of the Elkton Mbr of the Turner Valley Fm. Early in the development phase, the presence of this large gas cap and the absence of gas markets put future production in doubt. However, in 1960, the field was unitized into a two-equity unit and plans were devised to introduce a scheme of gas cycling which would conserve the gas and improve oil recovery. The extent of the gas cap is one of the factors that allows this field to be seismically visible.

The areal extent of the field is estimated at 4,491 ha for oil and 7,020 ha for gas with an average pay thickness of 9.56 m for oil, 21.2 m for gas (Virtual Computing Services Ltd). Porosities average 10.5% for gas and 12.8% for oil, permeabilities are, respectively, 125.8 md and 113.3 md (arithmetic average). The western limit of the field is defined by the oil-water line. In the south the reservoir rocks are dolomite but the limestone content increases to the north and east where several wells encountered dense limestone. This change from a dolomite to a limestone facies reduces reservoir porosity considerably for many wells.

GEOLOGIC CROSS-SECTION

The Elkton Mbr, the lowest member of the Turner Valley Fm (Rundle Gp Fig. 6.8), is a dolomite with some interbedded dense limestone facies. The zero edge of this member lies east of the Harmattan-Elkton field. However, the Elkton Mbr may be absent locally due to post-Mississippian channelling. Two wells, 9-31-32-4 W5M and 16-29-32-4 W5M, are channel wells with the Elkton Mbr entirely eroded and infilled with clastics. Although the beds overlying the Mississippian in Harmattan-Elkton are also clastics, there are several occurrences where a dense Jurassic lithology is remnant (partially eroded) and is sufficiently hard that it affects the seismic interpetation.

The main trap for the oil pool is stratigraphic. Porosity of the dolomite is reduced by secondary calcite cementation of the pores and intercrystalline spaces. Oil with a high gas/oil ratio fills the porous dolomite. The limestone facies to the north and east has reduced reservoir porosity and permeability and is produced as a gas reservoir. This facies change is evident in several wells along the eastern edge of the oil pool such as 7-17-32-4 W5M.

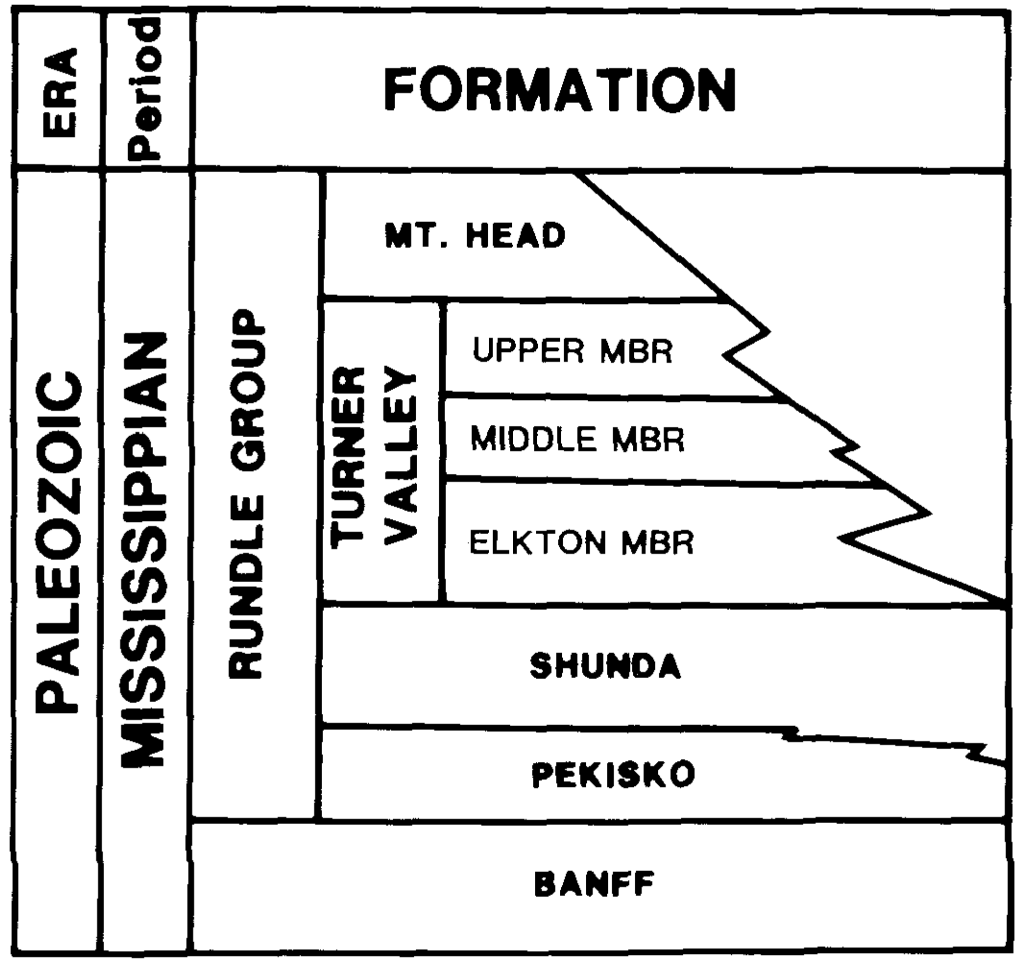

Figure 6.8. Mississippian stratigraphic correlation chart.

The Mississippian surface dips westward at about 20 m/km across the field (Fig. 6.11) which accounts for the narrowness of the productive area. Through much of the field, the Elkton Mbr is the sub-cropping unit and is overlain by clastics of the Lower Mannville Gp. In some areas these clastics include a dense Nordegg Fm (Jurassic) chert which can generate a strong seismic reflection and mask the actual top of the Mississippian.

Figure 6.9 is a representative geological cross-section which corresponds to the location of the example seismic section. Because these wells were drilled in the late '50's and early '60's, neutron logs were run as the main tool for porosity determination.

SEISMIC SECTION

Corresponding to the geological cross-section, the seismic section in Figure 6.10 is a north-south line which templates the north half of the Harmattan-Elkton oil pool. Seismically, the field is primarily visible as a structural prospect and to a limited extent, stratigraphic. Because of the proximity to the steep sided valley of the Red Deer River, good seismic information is difficult to obtain close to the up-dip edge of the field.

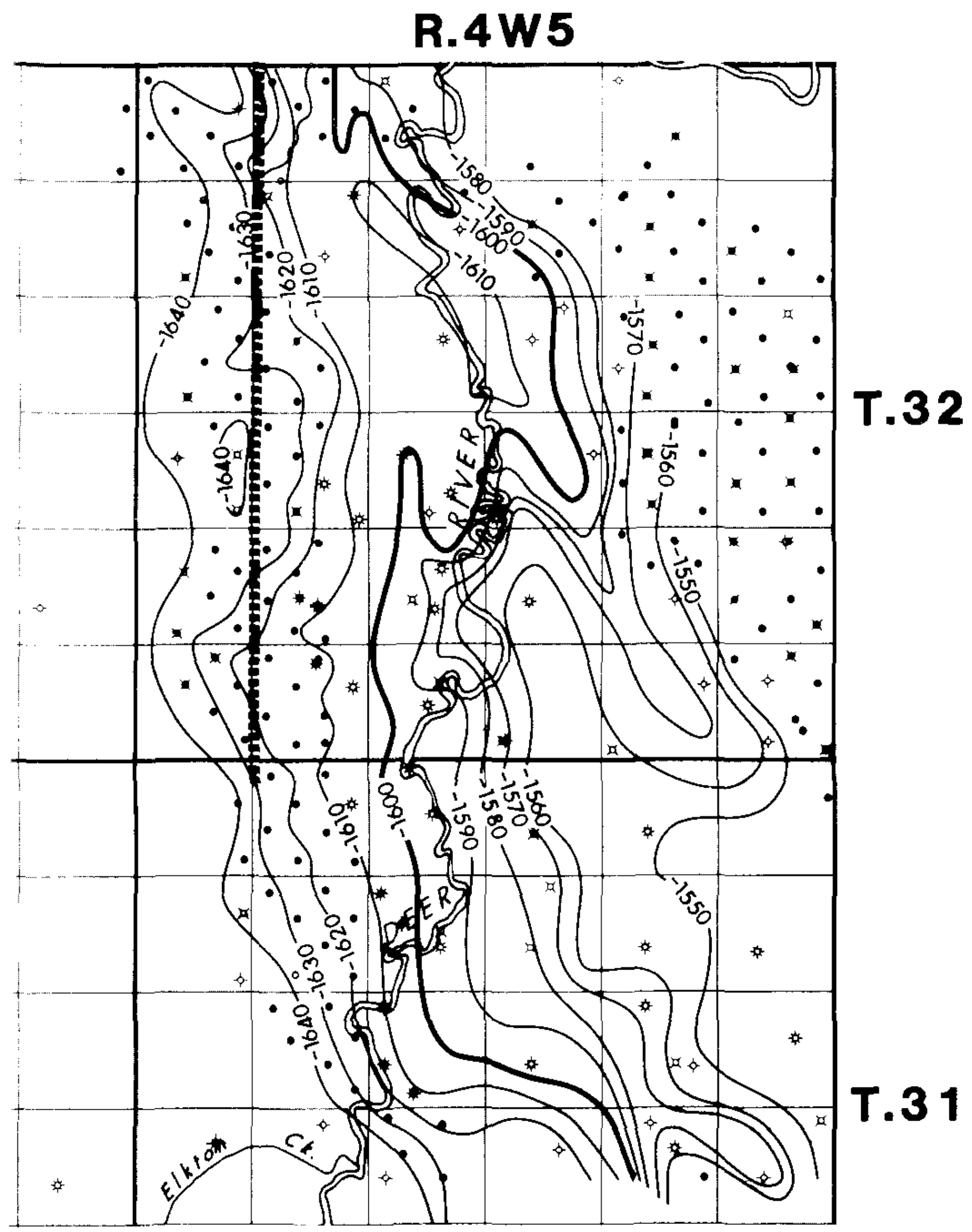

Figure 6.11. Mississippian structure map of the oil-bearing Harmattan-Elkton pool (Contour interval 10 m).

The example line was recorded, 12 fold, in 1983 using a Vibroseis source. A 7-second 56-14 Hz downsweep was input as 12 sweeps over 100 m. Near and far offsets were 300 and 2600 m respectively. A 60 Hz notch filter was used to allow the crew to monitor data quality. This did not affect the data as the sweep was already limited to 56 Hz.

The seismic reflections identified correspond to the Ireton shale (a trough), the Mississippian sub-crop (peak), the base of a Middle Mannville Gp sandstone (trough) and the Viking Fm (a peak).

The Mississippian structure map (Fig. 6.11) outlines an undulating surface with a low in the middle of Twp 32, a rise of 20 m through Section 6 and a more rapid drop to the south. The seismic line corroborates this structure which exists on many of the later Cretaceous events. When a surface source such as Vibroseis is used, the lack of refraction shots may limit static control during processing. Consequently, there will be less confidence in time structure maps and isochron mapping will normally be done as well. On this example line, thickening of the Mississippian-Ireton isochron is interpreted to indicate Mississippian structural highs and thus corroborates the highs identified by time structure alone.

The presence of gas in this reservoir affects the seismic reflection as it did in the previous Alexis pool example. At the north end of the field, the poor porosity of the Elkton Fm limestone facies coupled with the thin dense Nordegg chert immediately above produces a significant positive acoustic impedence at the interface with the overlying clastics. This produces the strong Missippian event at the right of the section.

However, gas in the reservoir, even as little as 5%, will reduce the interval velocity of a rock. There is considerable gas in the Elkton Fm, particularly to the south, where porosity is greater. This gas effect is observed when the high amplitude peak in the north (right) begins to lose amplitude at trace 135 and finally breaks up completely across the best part of the reservoir, left of trace 170. Gas/oil ratios are extremely high in the southern part of this field, for example, the 6-8-32-4 W5M well has a gas/oil ratio of 400 compared to 176 in 9-30-32-4 W5M. Another factor at Harmattan-Elkton which affects the seismic interpretation is the occasional presence of a thin dense Nordegg Fm chert layer overlying the Mississippian subcrop. Normally, the acoustic impedence at the boundary of the basal Mannville Gp sandstones and shales and the Mississippian carbonates and dolomites is a significant positive value and produces a high amplitude seismic event. When present, this dense chert layer generates a low- to moderate-amplitude seismic reflection and because it is thin, it masks the top of the Mississippian due to the destructive interference common with thin bed seismic resolution.

The wavelet maximum represents the time of the Nordegg Fm event, and the Mississippian time is deeper in the section corresponding to the slope or zero crossing of the seismic wavelet. In this example the weaker reflection may be incorrectly interpreted to infer Elkton Mbr porosity and the inaccurate timing of the data leads to uncertainty in predicting the Mississippian structure.

CONCLUSION

Several problems are associated with a seismic evaluation of this pool. The proximity to surface topography provided by a major steep-sided river valley prevents the recording of good data. The seismic contrast between the Mississippian subcrop and the overlying strata is often blurred due to the presence of an overlying dense Jurassic layer and the seismic event is accordingly "blurred" in amplitude strength and in time. Finally, the presence of gas affects the reflection character, changing it from a single, low-frequency peak to a high-frequency doublet, which dims over the better part of the reservoir.

Not all of these are negative conditions, but a good interpretation must recognize and compensate for all of these. Fields similar to Harmattan-Elkton are comparatively easy to discover seismically because of their obvious structural features but are much more difficult to develop with seismic and provide an exciting challenge to modern development geophysics.

ALIDA EAST

INTRODUCTION

The Alida East field is one of a series of elongate fields in southeastern Saskatchewan which produce gas-saturated oil from the Frobisher or Alida beds of the Mississippian Mission Canyon Fm (Fig. 6.12). Located approximately 230 km southeast of Regina, Saskatchewan, T. 6, R. 33 W1M, the field takes its name from the nearby town of Alida.

The reservoir at Alida East is a porous Alida limestone of low permeability overlain by a thin anhydrite zone which serves as a seal.

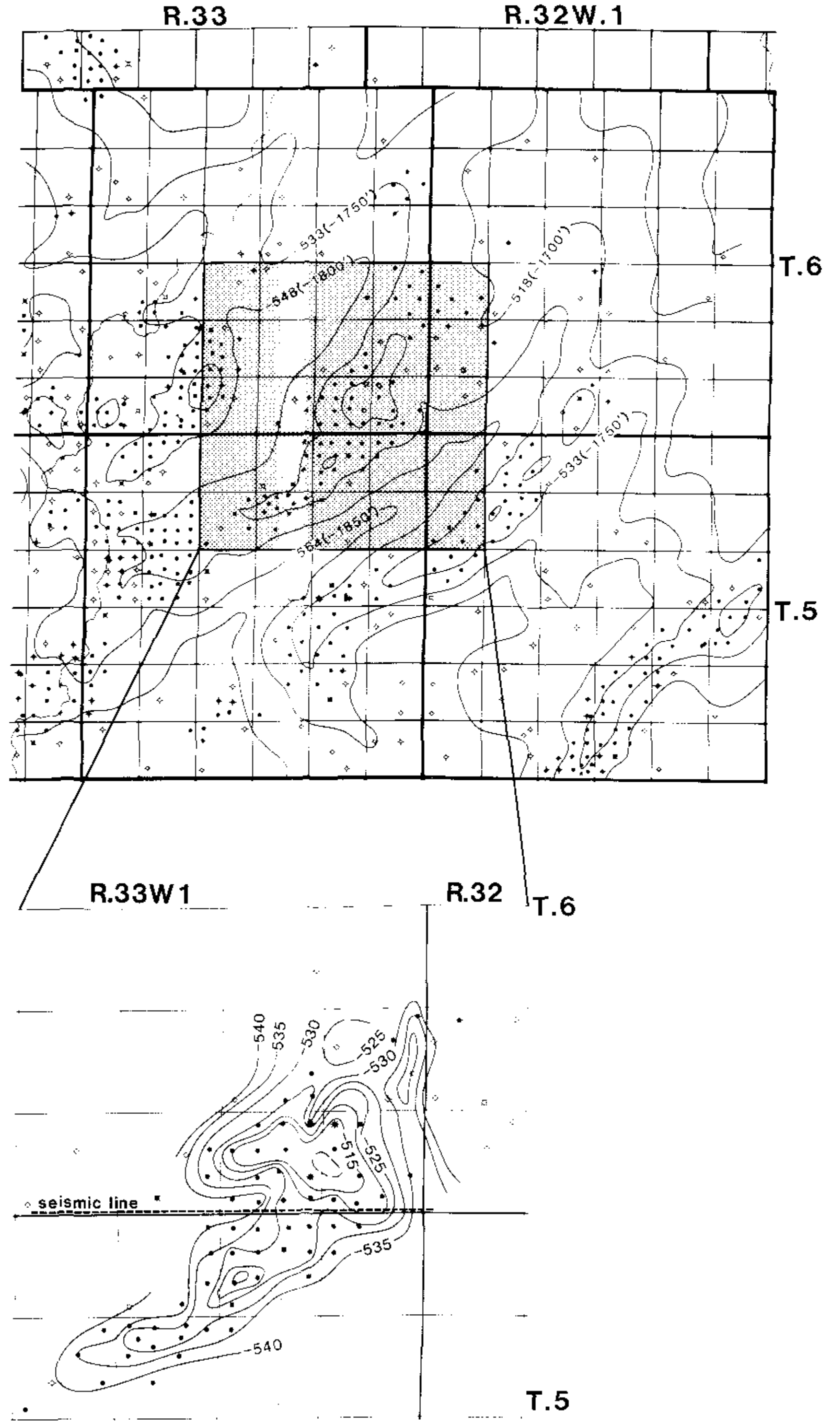

Figure 6.12. One of a series of elongate fields in southeastern Saskatchewan, Alida East produces from the Mission Canyon Fm (Coutour interval 5 m).

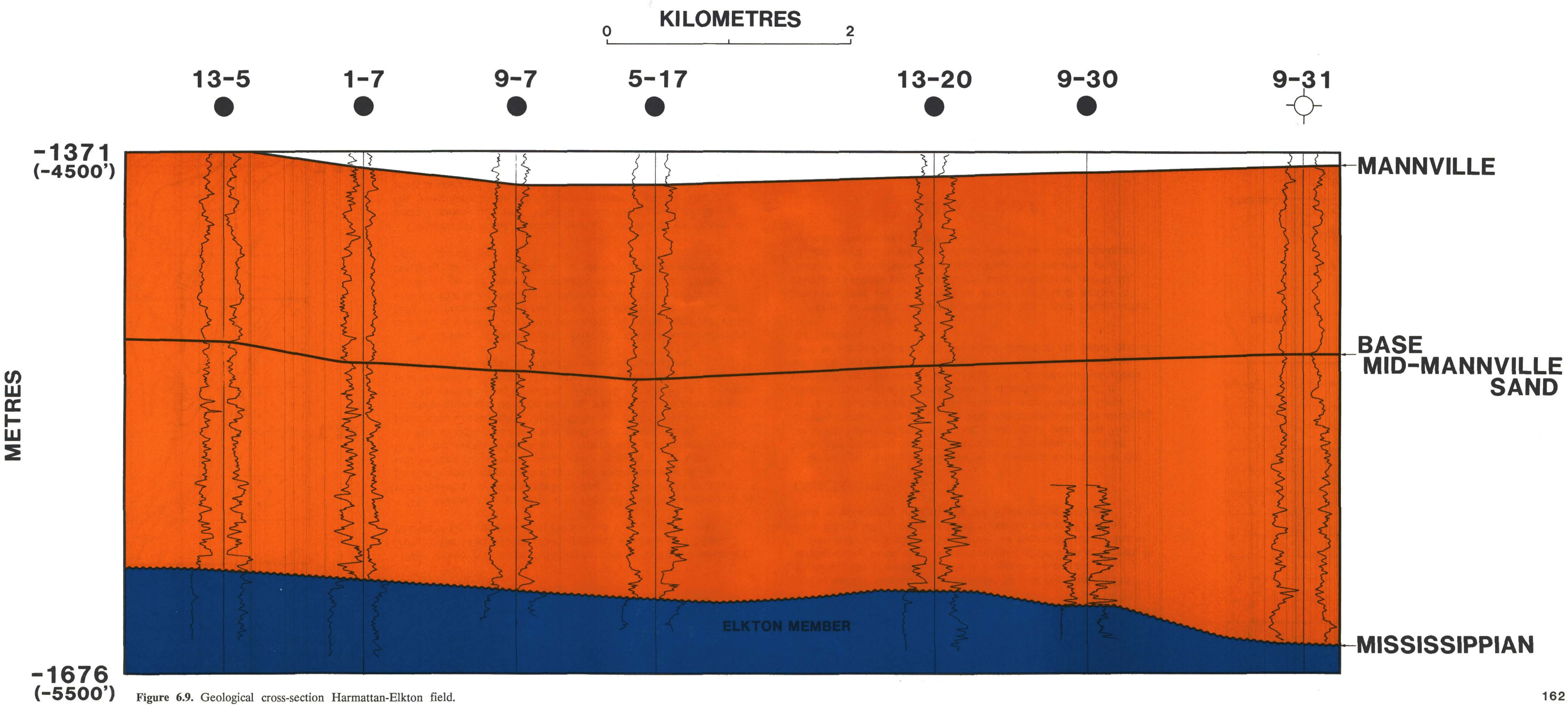

Figure 6.9. Geological cross-section Harmattan-Elkton field.

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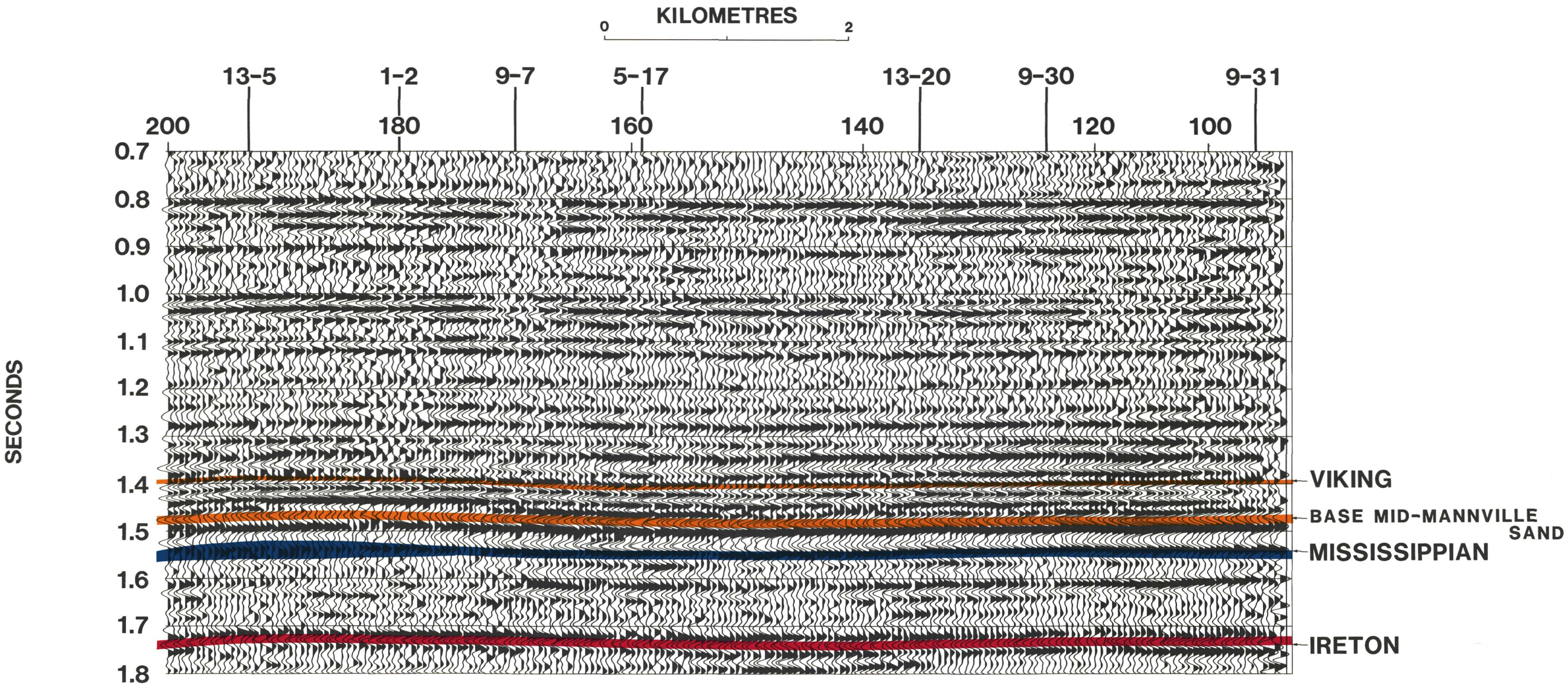

Figure 6.10. Seismic section Harmattan-Elkton field.

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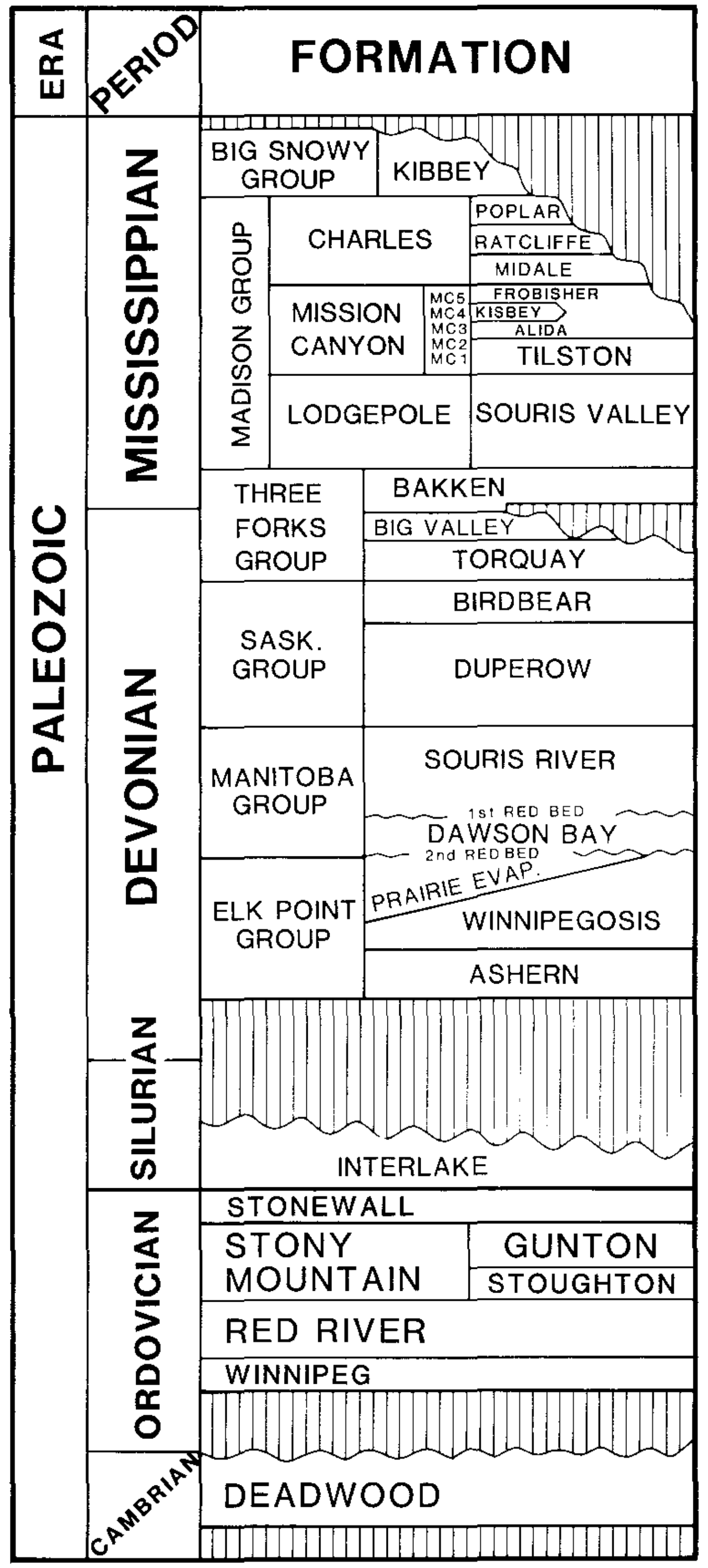

Figure 6.13. Stratigraphic column S.E. Saskatchewan (from, Dept. of Mineral Resources, Petroleum and Natural Gas Branch, Regina, Sask. Drawing No. G-193, October 1963).

Both structural and stratigraphic components are pertinent to this field, but geophysics is useful for the structural aspect only.

The earliest wells were drilled in 1954. Production began in early 1955 and continues to the present time. To date (December, 1987) oil production has been 1 944 860.8 m^3 and gas 7 892 856 x $10^3 m^3$.

GEOLOGICAL CROSS-SECTION

The Mississippian Mission Canyon Fm has been subdivided into five sub-units (Fig. 6.13), only one of which, Mission Canyon 3, is productive in this area. Where the sub-units are less distinguishable, the upper Mission Canyon is divided into two members, Frobisher (eroded in Alida East) and Alida (equivalent to Mission Canyon 3).

Originally deposited as limestone along the eastern side of the Williston Basin, probably in a shoal environment, the Alida beds thin to a zero edge a short distance east of this field. During post-Mississippian erosion, a diagenetic change occurred to the uppermost Mississippian whereby limestone was replaced by anhydrite to a depth of several metres. This provided a dense unit which acts as a seal and is recognizeable as a geological marker horizon. Figure 6.14 is a schematic diagram of this condition. In map view (Fig. 6.14A), the dotted line indicates the limit of anhydrite replacement, anhydrite to the east (right) and limestone to the west. Some anhydrite was eroded (dashed line), removing the seal. The solid line is the Mission Canyon erosional edge. Figure 6.14B is a sketch of the geology, both in the dip (A-A') and strike (B-B') direction.

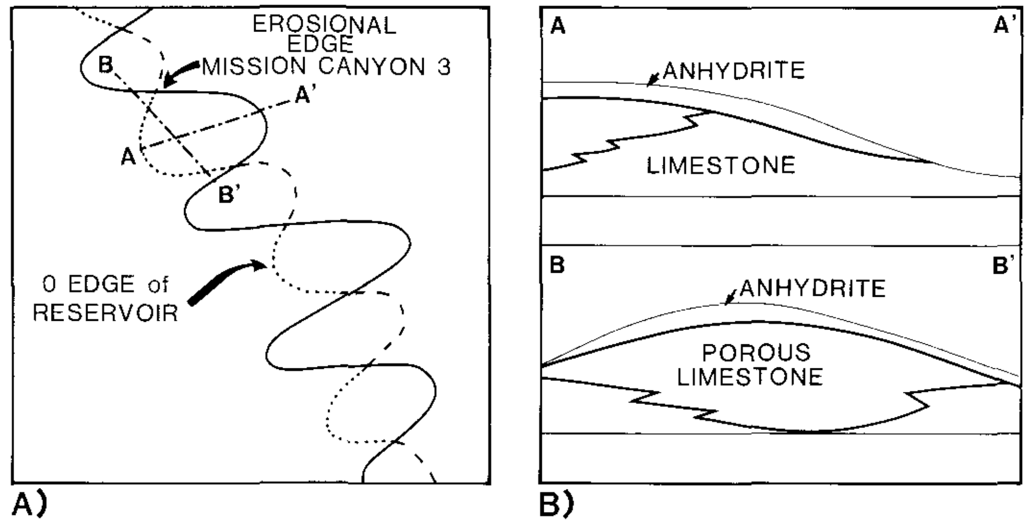

Figure 6.14. A) Erosional edge (solid line) with limit of anhydrite replacement (dotted line). Anhydrite absent west (left) of this line. Prior to erosion, anhydrite was present to the east (right) of the dashed line; B) Schematic cross-sections A-A' and B-B' illustrate the lithology.

Below the anhydrite, the limestone is porous, but has low permeability. For this reason, the Alida zone was normally cored and perforation points determined based on core oil saturation.

A map of the Mississippian structure (Fig. 6.12) shows closure to the northeast, but such closure is deceptive because the Alida Mbr thins north-eastward by erosion and becomes unproductive before reaching its erosional edge due to diagenetic loss of porosity.

The geological cross-section in Figure 6.15 crosses the Alida East field in an east-west direction. The deepest formation penetrated by drilling is the Mississippian Mission Canyon Fm with the Alida Mbr uppermost. Overlying the anhydrite, marking the pre-Jurassic unconformity, are the radioactive sandstones of the Watrous Fm Red Beds (Jurassic). Other horizons are the Shaunavon Fm (Jurassic) and the top of the Mannville Gp (Lower Cretaceous).

There is a significant velocity contrast between the Red Beds and the underlying anhydrite, a factor which is important geophysically. The porous Alida limestone and the Red Beds have similar velocities and the top of the unconformity would be difficult to identify seismically without the anhydrite.

SEISMIC SECTION

The example seismic section (Fig. 6.16) starts within the field at the east edge, crosses it and ends just outside its western limit (Fig. 6.12). Recorded in 1984 with an air gun source, the line parallels the geologic cross-section. Three guns of 60 cu. in. each were used in a linear pattern over 17 m, with 4 pops per gun. The split spread had far offsets of 1225 m, near offsets of 50 m, a group interval of 25 m and source interval of 50 m. Geophones were 28 Hz, 9 over 25 m. Field filters were set at 18-128 Hz with a notch filter applied during recording.

Figure 6.17 is a suite of logs for one of the wells in Figure 6.16, 1-2-6-33 W1M, displayed in time to match the synthetic seismogram. It is representative of many wells in Alida East. The strongest seismic event corresponds to the Lower Shaunavon top.

Figure 6.18A compares the synthetic seismograms of wells 10-4, 3-1, 3-2 and 1-2 from Figure 6.15. Figure 6.18B is a diagram of the feature using the Red Beds as a datum. The anhydrite gives rise to the Mississippian seismic marker horizon which is present across the section but changes character, depending on lithology and thickness. A strong positive peak corresponds to a thick (9 - 10 m) anhydrite zone (10-4 well). As both the anhydrite and the Red Beds thin and streaks of unaltered carbonates appear in the anhydrite, the peak dims (3-1, 3-2). In 3-2 the Red Beds are thicker and the peak is

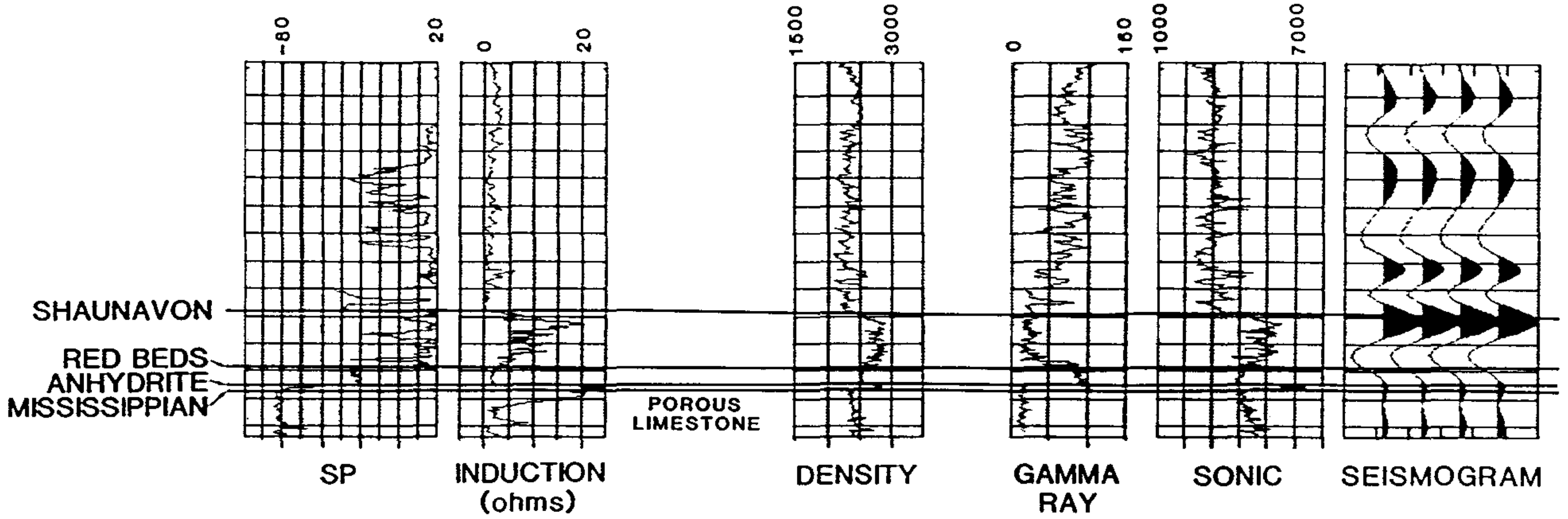

Figure 6.17. Correlation of a suite of well logs with synthetic seismogram from well 1-2-6-33 W1M.

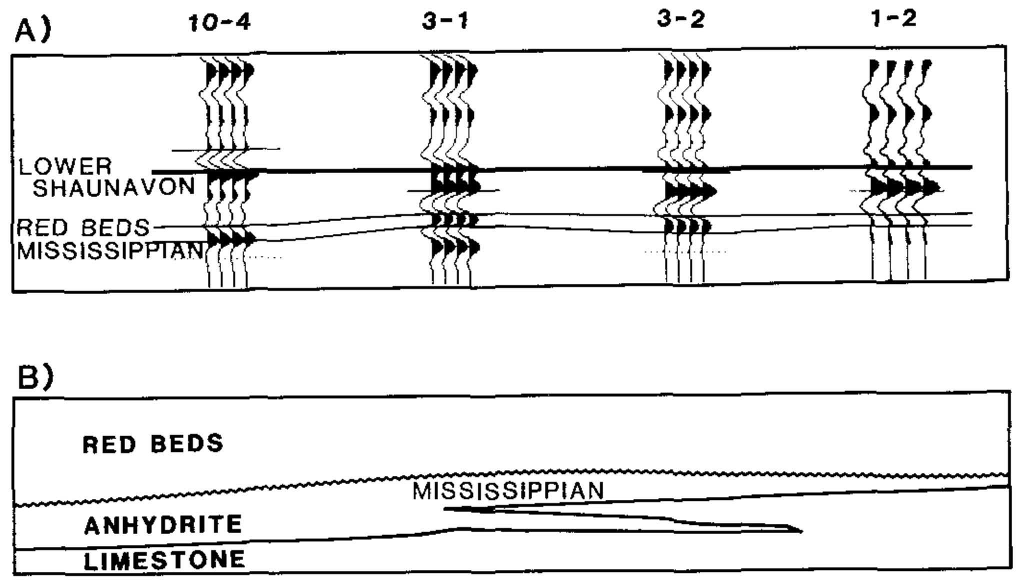

Figure 6.18. Comparison of synthetic seismograms of wells 10-4, 3-1, 3-2 and 1-2 (Fig. 6.18A) and schematic of the Mississippian seismic marker datumed on the Red Beds (Fig. 6-18B).

stronger than 3-1. Finally the anhydrite thins to 3 to 4 m, and results in a seismic wavelet that is a weak, low-amplitude peak (1-2 well) and the Red Beds event is part of a broad low frequency trough.

Events identified on the seismic line (Fig. 6.16) correspond to the geologic horizons of top of the Mississippian (peak), the Watrous Red Beds (strong trough), the Lower Shaunavon (peak) and the Mannville (peak). Change in Mississippian structure is noticeable both as a time structure change and as an isochron change, using the interval from Mississippian to a deeper event just below 1.1 sec. The structure can be mapped using either of these criteria.

In addition to a structure change, the thinning of the Red Beds over the highs and the varying anhydrite isopach produce character changes similar to the seismograms in Figure 6.18. The Mississippian seismic response is a strong low frequency peak where both Red Beds and anhydrite are thick (at the west end near the 10-4 well). Within the field (traces 880 - 1000), the wavelet becomes higher frequency and changes to a doublet in several places (e.g. traces 892 - 912) indicative of thinning Red Beds and anhydrite. Porosity in the Alida Mbr limestone is indicated by the development of a trough under the Mississippian peak. Where this dims (traces 940 - 958) reduced porosity is suspected.

CONCLUSION

The structure of the Mississippian at Alida East and similar fields can be mapped relatively easily as a time structure. Porosity may also be predictable, based on seismic character However, the critical factor in development is permeability and for this reason, geophysics can be only partially successful in locating productive wells.

Development of such a field today depends on an interdisciplinary approach between geophysics and geology. First, geology and geophysics are used to locate and delineate the field configuration, and then petrophysics and engineering to determine the most effective drilling and testing techniques and to optimize recovery methods based on detailed knowledge of the reservoir rocks.

TURNER VALLEY FIELD

INTRODUCTION

Although not the earliest field drilled in the Canadian Rockies, Turner Valley is, perhaps, one of the best known. The oilfield, the nearby town and, eventually, the formation all took their name from local settlers, James and Robert Turner, who ranched in the area in the early 1900's.

The discovery well, Royalite No. 1 (originally Calgary Petroleum No. 1) 14-6-20-2 W5M, spudded in 1913 and was completed in 1916 as a Lower Cretaceous gas well. It was located on an anticline next to a gas seep which still bubbles away on the outskirts of Turner Valley about 40 km southwest of Calgary (Gallup, 1975). The well was produced for local needs until suspended in 1927.

It wasn't until 1924 when Royalite No. 4 was drilled in 12-7-20-2 W5M that gas was found in the Mississippian Rundle Gp. This led to the development of the Rundle pool. Six years later, the 8-22-20-3 W5M well tested the same zone and found hydrocarbons with a much lower gas-oil ratio than had been found previously (Gallup, 1975). With this discovery, the potential for oil in the Turner Valley field became a reality.

Production is from structurally trapped, dolomitized limestones of the Turner Valley Fm and is currently 21 969 124 m^3 of oil and 31 395 208 x 10^3m^3 of gas (Dec. 1987). Oil in place has been estimated at nearly 160 x 10^6m^3 but barely 15% of this is expected to be recovered because so much of the gas cap was removed by both production and flaring.

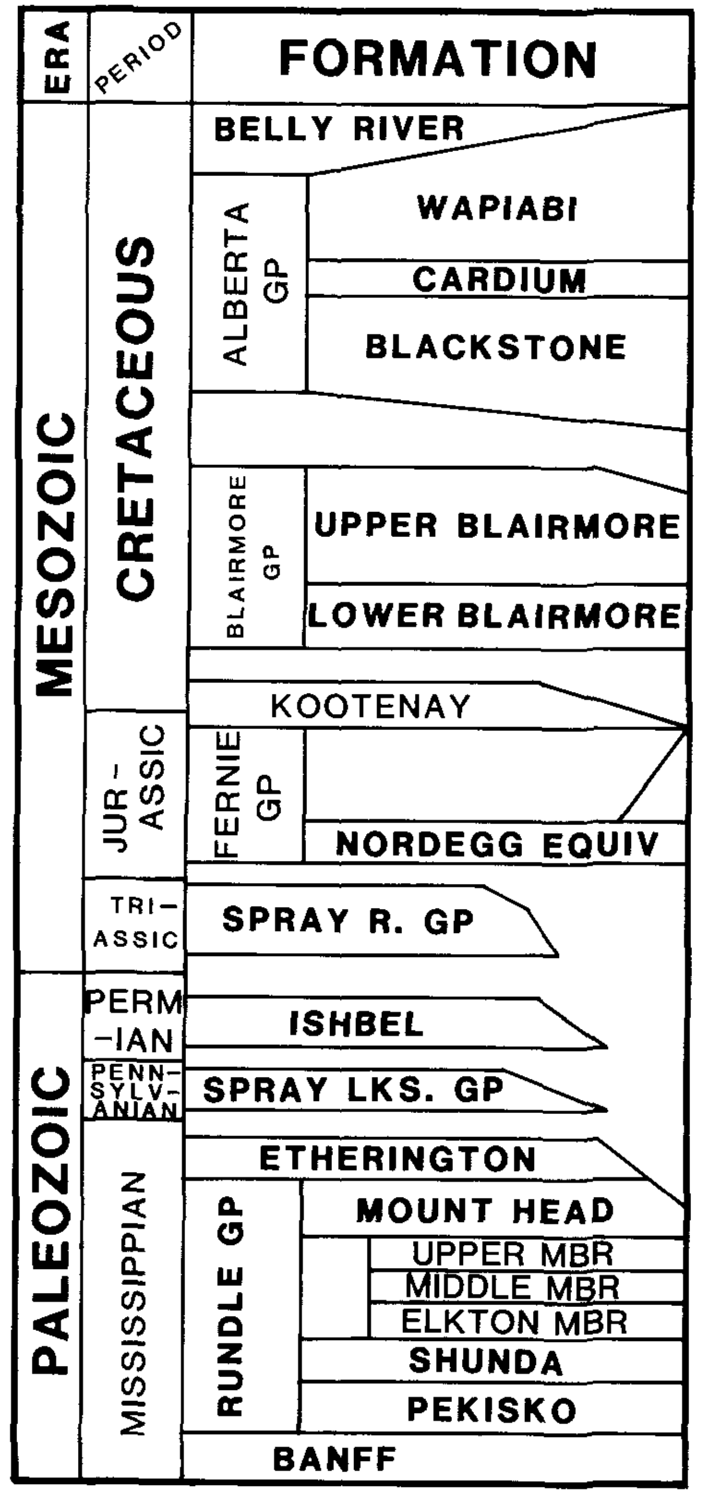

Figure 6.19. Stratigraphic Column of south-central Alberta Foothills (modified from AGAT Laboratories Table of Formations of Alberta).

Seismic played no part in Turner Valley's development, but the field became a geophysical model in the subsequent search for similar sub-surface Mississippian structures.

GEOLOGICAL CROSS-SECTION

Turner Valley lies at the eastern edge of the Foothills Belt (Jones, 1982). Early drillers looked for surface anticlines, postulating co-incident deep structure. Fortunately, Turner Valley fit this criterion, though many other fields do not.

The structural framework of the Foothills is a series of folded thrust faults with steepest dips to the west. Many of these thrusts are sole faults which follow shale or coal beds and periodically rise sharply through the denser limestones and sandstones. Deformation is attributed to the Laramide Orogeny. The Turner Valley field, like many other Foothill structures, may have had a degree of folding prior to faulting and, as well, has since had folding imposed on these faults. Thus the reservoirs formed as anticlines, rather than fault traps.

The Turner Valley Fm occupies the upper part of the Rundle Gp (Fig 6.19) and may be either medium- to coarse-grained crystalline, crinoidal limestone or medium-grained crystalline silty dolomite. Original sediment was most commonly an echinoderm - bryozoan limestone. Biostratigraphy of the zone is difficult to identify due to subsequent dolomitization and re-crystallization (MacQueen et al., 1972). The formation was originally separated into three informal members, Upper Porous, Middle Dense and Lower Porous. The Lower Porous is now designated the Elkton Mbr and is the major gas producer in the Foothills fields (MacQueen et al., 1972).

Porosity and permeability information for the field is limited. Very few logs were run as the earliest drilling pre-dated well logging and later (1940's) electric logging tools were primitive. Few cores were cut and in some of the earlier wells, no samples were recorded. Development had to depend on information derived from these sparse samples. Although the Elkton Mbr is generally porous, it is not necessarily permeable and it became evident that fracturing was also an important factor in producing the reservoir.

Figure 6.20 is a Mississippian structure map with a 500 ft (152 m) contour interval. It shows how great the relief is on the structure. The major thrust faults are indicated by wavy lines. Minor faulting is not shown.

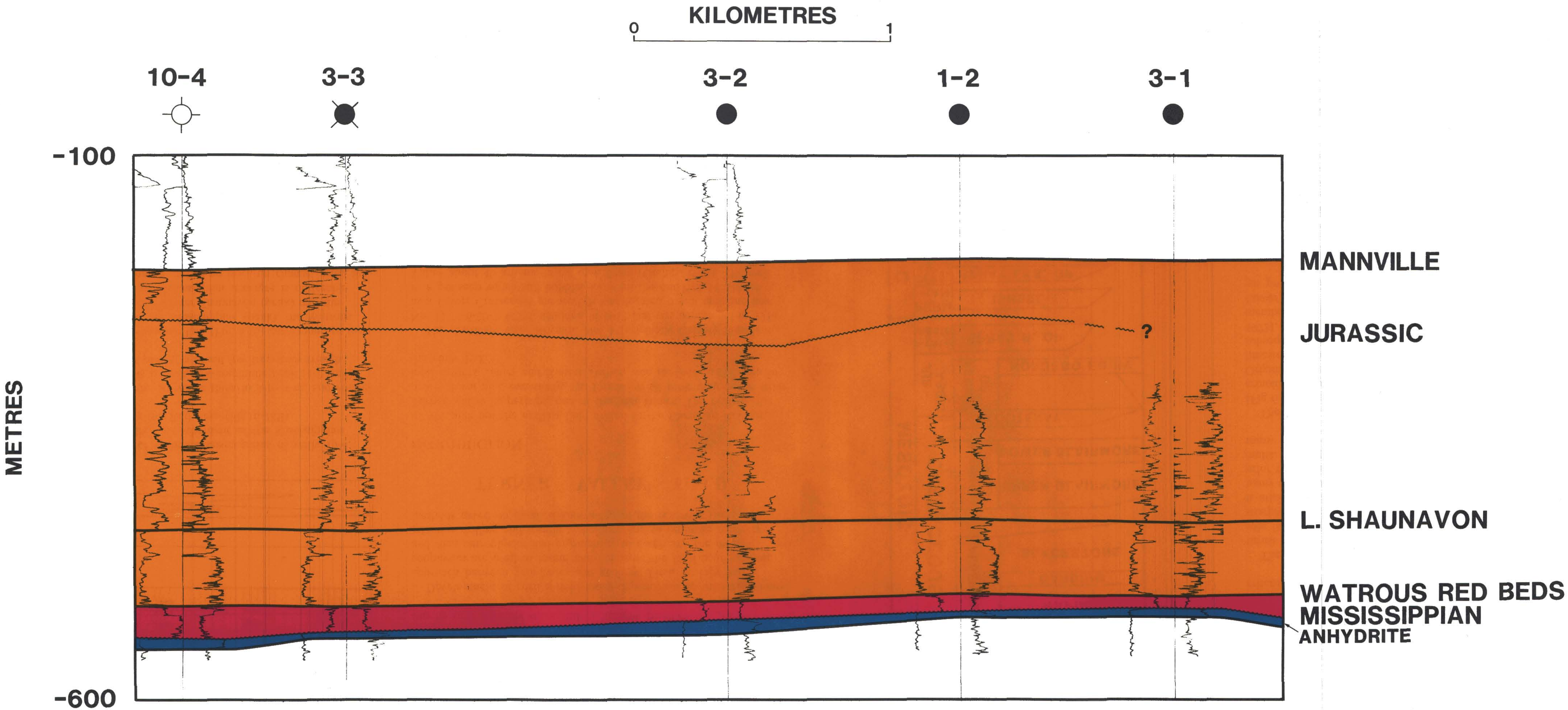

Figure 6.15. Geological cross-section Alida field.

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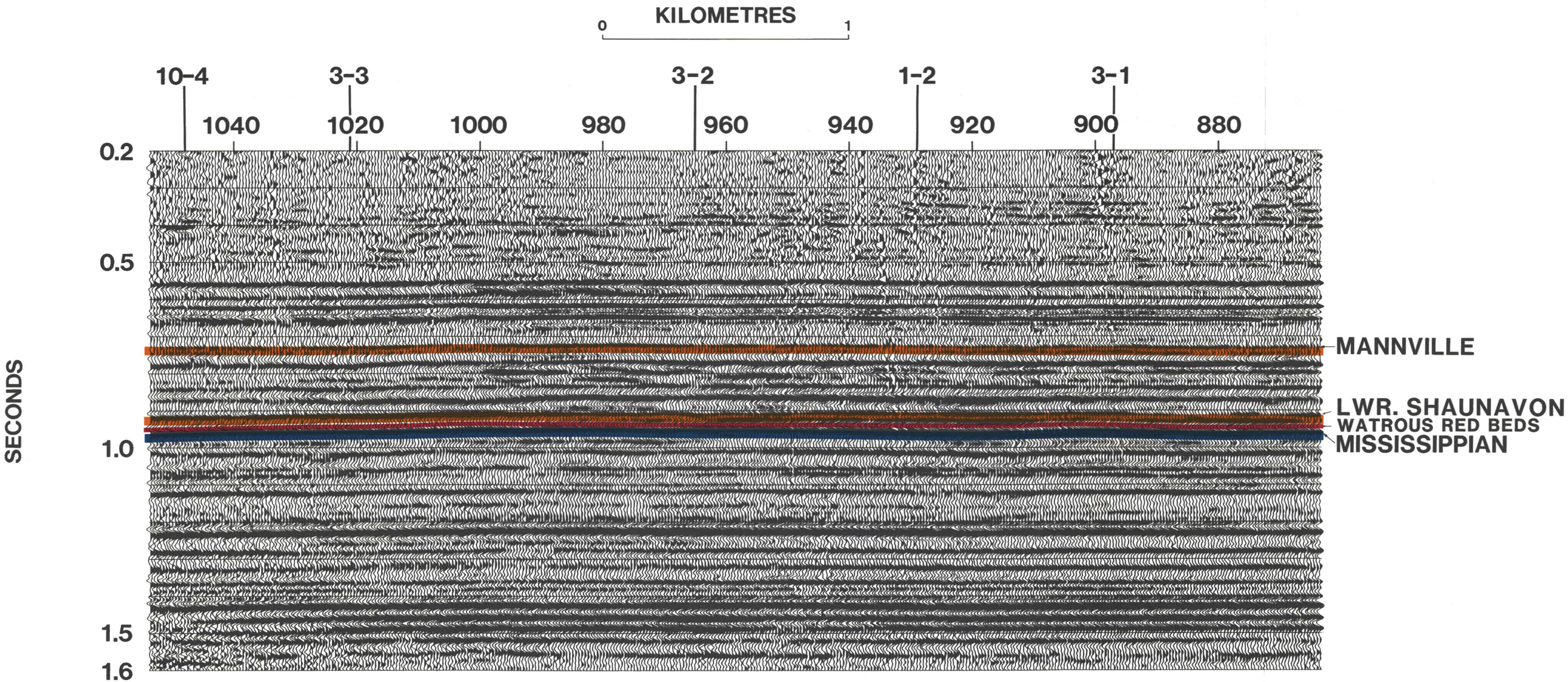

Figure 6.16. Seismic section Alida field.

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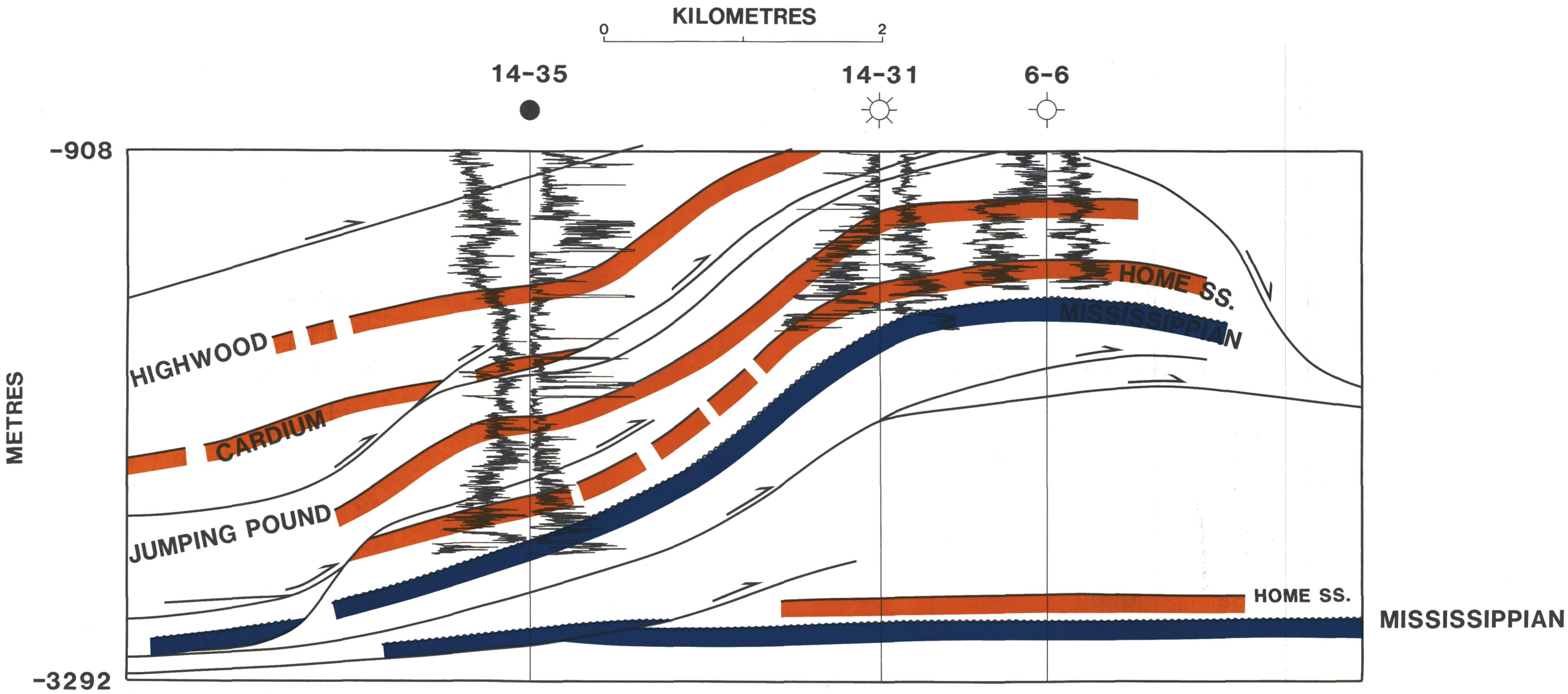

Figure 6.21. Geological cross-section Turner Valley field.

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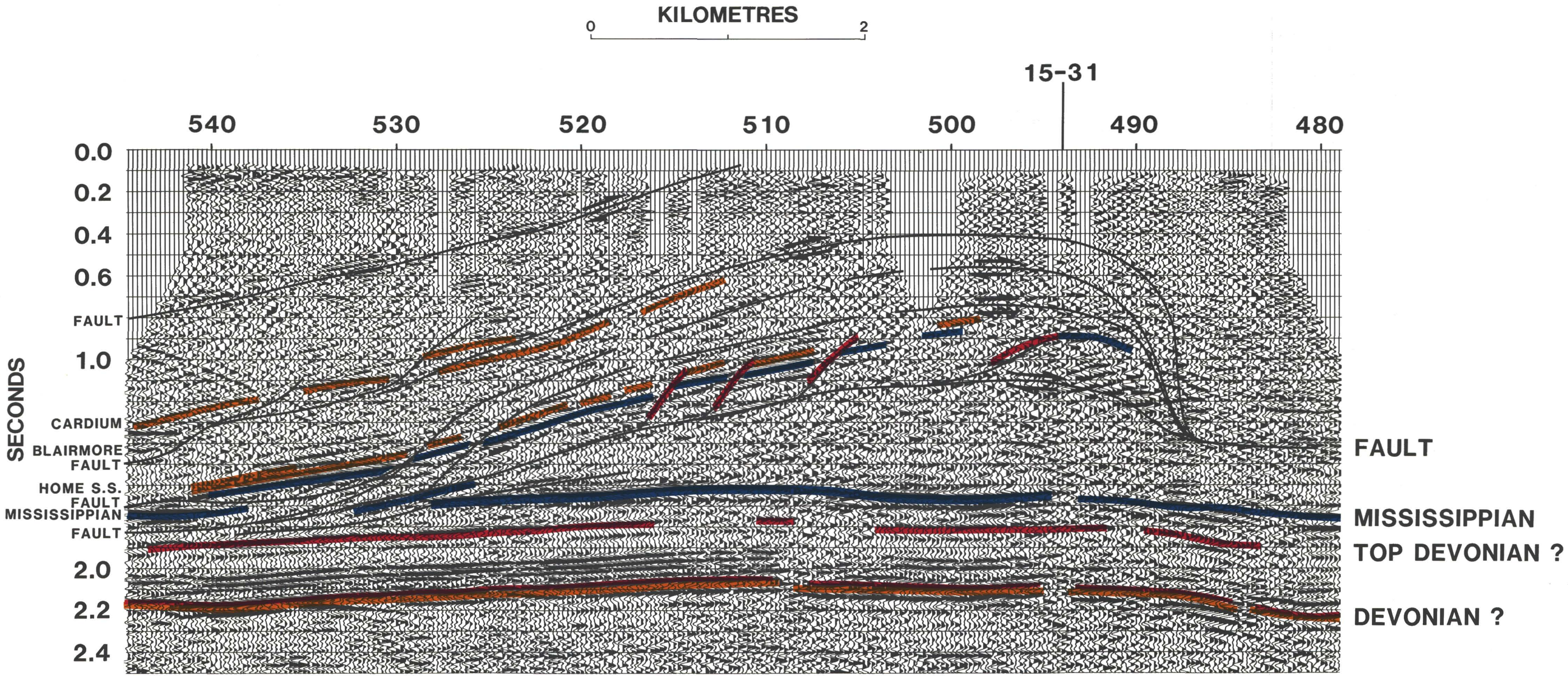

Figure 6.22. Seismic section Turner Valley field.

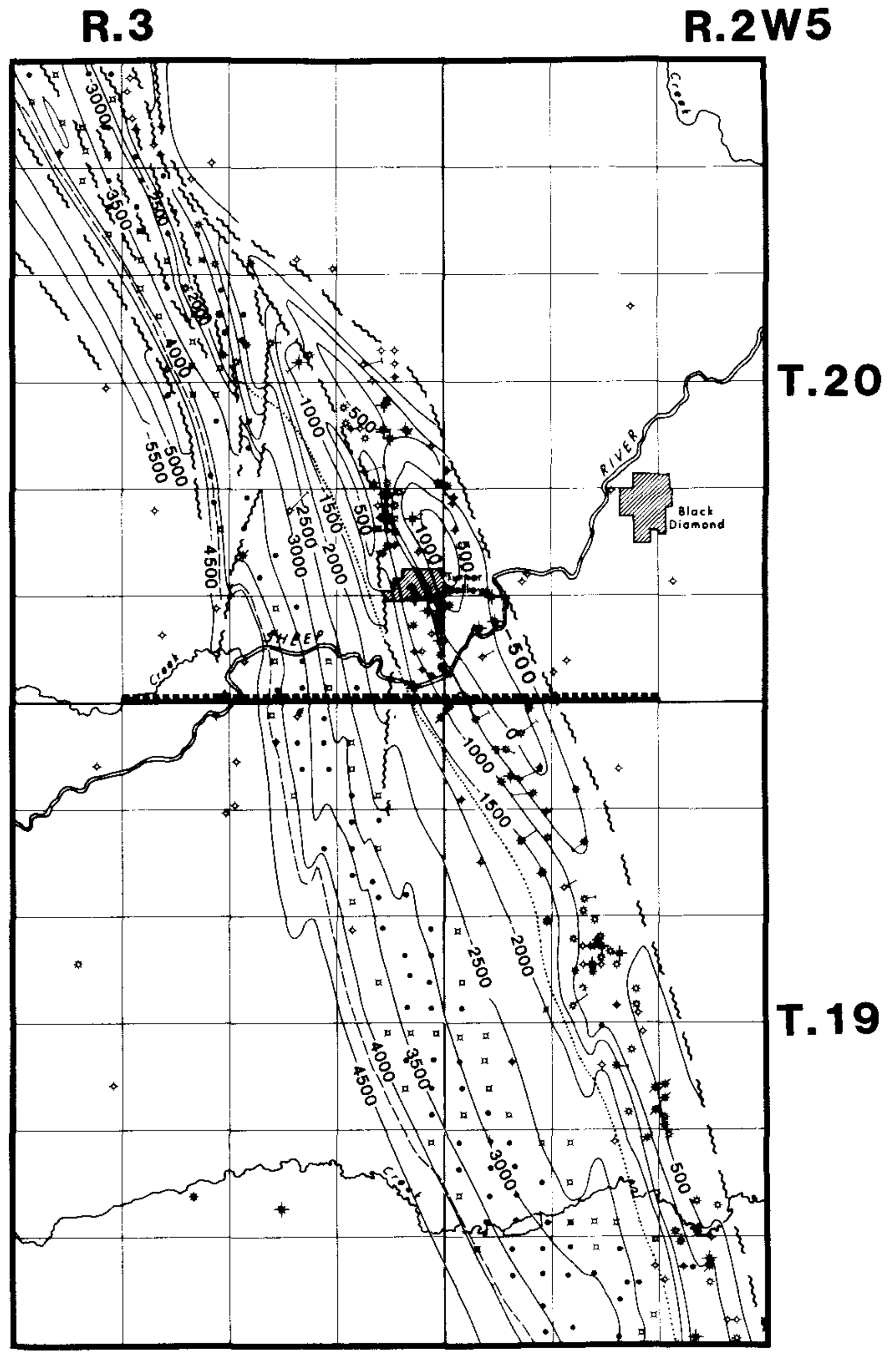

Figure 6.20. Mississippian structure map (after Gallup (1975) contour interval 500 ft, wavy lines indicate faults).

Figure 6.21 is a west to east geologic cross-section through the mid-point of the field. The interpretation is based on the three logs included, but also incorporates data from several wells which had samples only. In addition, the seismic section (Fig. 6.22) was used to aid in extrapolating beyond well control and in identifying fault planes.

SEISMIC SECTION

The earliest seismic recorded in Turner Valley was refraction data. It continued to be favoured over reflection data into the late 1960's. The geology was so complex that energy was returned only from major horizons; i.e. the top of the Blairmore Gp and the top of the Mississippian (Keating, 1966). Eventually reflection seismic techniques improved and it became the more popular method.

The example seismic line (Fig. 6.22) parallels the geological cross-section and crosses the Turner Valley field, oblique to the dip (Fig. 6.19). It is 12 fold reflection data, recorded in 1975 with 5 lb (2.2 kg) dynamite source in single, 50 ft (15 m) holes. Group and source intervals are 220 and 440 ft (67 and 134 m) respectively, spread is symmetric with near and far offsets of 330 and 5390 ft (100 and 1643 m). Geophones were 8 Hz. Field filter was 12/18-124 Hz.

Several important factors were considered when interpreting this seismic data. First, the wells should tie. Since there were no sonics from adjacent wells, a 1971 well, 15-11-20-3 W5M, 3 km to the northwest, was correlated first to the wells along the seismic line and then to the seismic section. The deeper horizons tie at trace 515. The shallower events do not tie as well because faulting has affected the two locations differently. The sonic and synthetic seismogram for 15-11 are shown in Figure 6.23.

Secondly, the strength of the reflections is a guide to identifying the seismic events. Thus the strongest reflections come from the Mississippian surface. The Home sandstone (Blairmore Gp) and Cardium Fm also generate strong reflections. Occasionally the fault planes themselves give rise to moderate amplitude reflections. Finally it was assumed that one or more of the thrust faults could be significantly folded (Jones 1982).

On the example line, the change from Cretaceous clastics to Mississippian carbonates produces the high amplitude seismic event between 1.65 and 1.75 sec. to the right of trace 528. Similarly the strong event which starts at about 1 sec. at trace 505 and dips to the west is also interpreted as Mississippian. The Home sandstone produces a good reflection as does the Cardium Fm. The shallowest Mississippian event is segmented which may be the result of fracturing or of inadequate migration of the seismic data due to the complexity of the overlying strata. The deeper events between 2.0 and 2.2 sec. are unidentified, but are assumed to be Devonian in age.

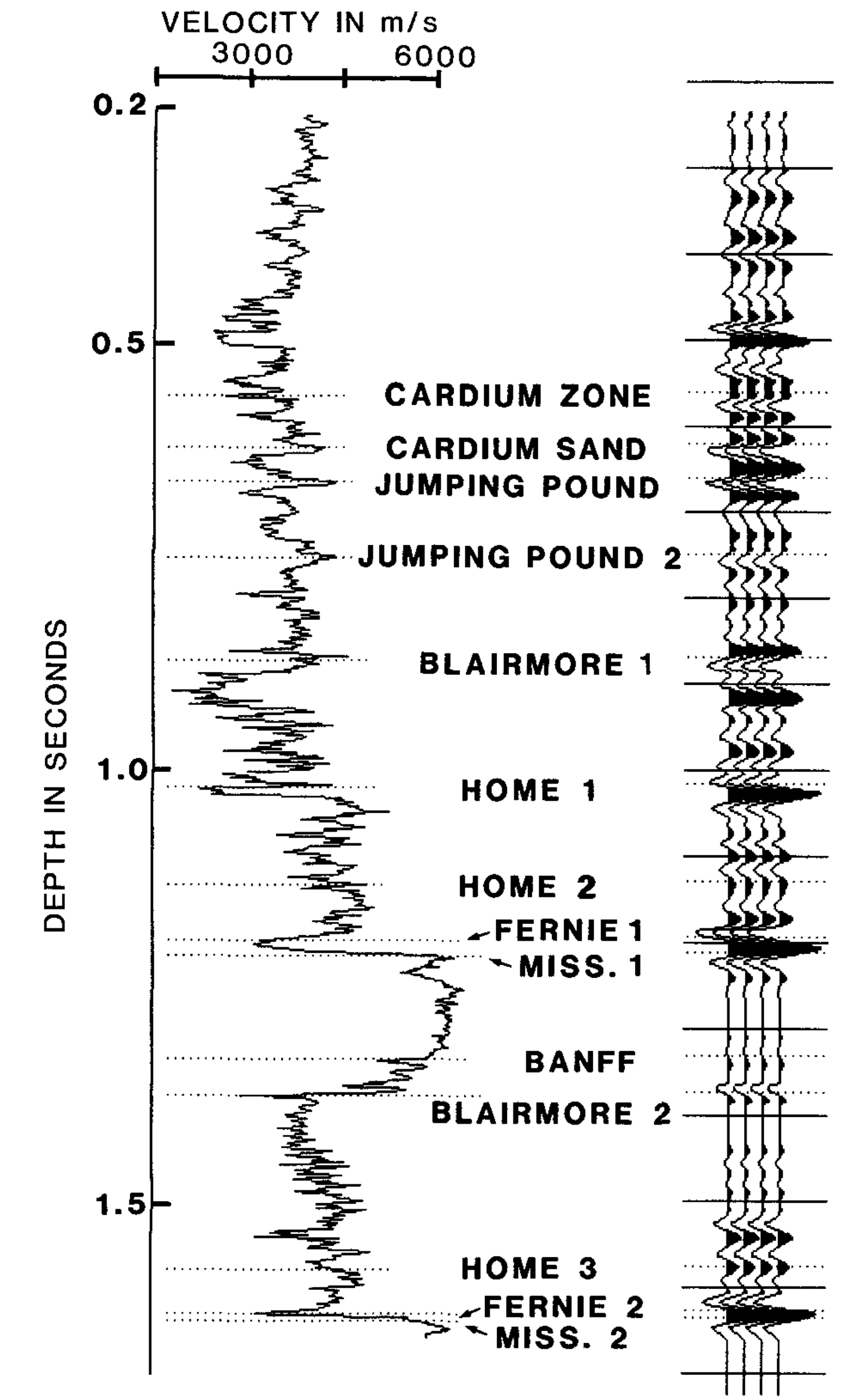

Figure 6.23. Sonic and seismogram for the well 15-11-20-3W5M, displayed in time. The strongest seismic events are generated by the Mississippian at 1.2 and 1.63 seconds.

Apparent pull-up on the deeper Mississippian event (trace 485 - 525) is caused by the thick, high velocity Mississippian section present above. Outside these limits, the equivalent upper sequence is lower velocity clastics and the event appears in its correct structural position.

Because the structure is complex, energy is reflected from outside the line (side-swipe) or from other than the common mid-point. Migration can help with in-line diffractions, but can do little for side-swipe. Consequently, psuedo events will break up otherwise flat reflections or give rise to erroneous interpretations if mistaken for valid reflectors.

CONCLUSION

Though not discovered seismically, the Turner Valley field nevertheless became important in the development of both refraction and reflection seismic techniques. Template lines such as the example in Figure 6.21 were recorded by many companies in an effort to achieve two goals. Firstly, to find similar structures, with the result that fields including Jumping Pound, Quirk Creek and Pincher Creek were either discovered or developed utilizing seismic. Secondly, seismic data has been valuable in unravelling some of the complexities of the thrusting and folding of Foothills strata. It is evident, in Turner Valley, that the main trap is the anticline formed of folded Mississippian rocks either subsequent to or concurrent with the thrusting. When geophysics and geology are used to complement each other as has been done in this and other fields along the thrust belt, it leads to a far greater understanding of the complex features being found by today's explorationists.

BLUEBERRY FIELD

INTRODUCTION

Discovered in the late 1950's, the Blueberry field is located in northeastern British Columbia, approximately 80 km northwest of Fort St. John near the Alaska Highway. Production is from a dolomitized carbonate of the Debolt Fm (Mississippian Rundle Gp).

The Blueberry Field is long and narrow (20 by 2 km) and is structurally controlled by a major thrust fault (one of many such faults in the general area) on its northeast up-dip edge. Vertical displacement on these faults is 100 m or more. The western edge of the field is limited by the oil/water contact, a feature which changes from south to north, indicating separation of the field into more than one pool. Seismic data recorded in the early 1960's defined the major fault and indicated the presence of several others which are probably the reason for the different oil/water contacts.

Both oil and gas are present with most gas found in a gas cap in wells nearest the main fault. Earliest oil production was seriously hampered by high gas/oil ratios in some wells. Porosities range from 9.5 to 11%, average horizontal permeability is 26.96 md. Net oil pays are from 6 to 37 m. Production to December, 1987, was 906 519 800 m^3 of gas and 2 195 127 m^3 of oil.

GEOLOGIC CROSS-SECTION

The subcropping Mississippian unit in the Blueberry field is the Debolt Fm (Fig. 6.26) , time equivalent to the Turner Valley and Mount Head formations of southwestern Alberta. It is comprised of carbonates interbedded with shales. At Blueberry, the reservoir rock is a microcrystalline dolomite with fine, vuggy and intercrystalline porosity. Production is from the top of the zone.

Where the rock is not dolomitized, the limestone facies is non-porous. Overlying the dolomite is a massive 6 to 10 m thick chert, which forms an effective seal against upward loss of hydrocarbons. Cores show minor vertical fracturing and stylolites within the Debolt Fm.

Faulting and differing water lines effectively separate the Blueberry field into at least four pools, one of which is mapped in Figure 6.27. The Mississippian structure contours are based on well control, whereas the main thrust fault location is defined by seismic data recorded in the early 1960's.

Since the faulting occurred too late in time to create an effective trap, it is postulated that the structure was anticlinal prior to thrust faulting and that these faults served both to enhance permeability and prevent further migration of gas and oil.

No wells in this pool penetrate beyond the first 100 m of Mississippian and very few have been drilled off-structure. An exception was b-100-K 94-A-12, which was drilled east of the fault in a more regional position and encountered a porous but wet Debolt at 1251 m sub-sea. Structure on the shallower horizons tends to be sub-parallel to the Mississippian.

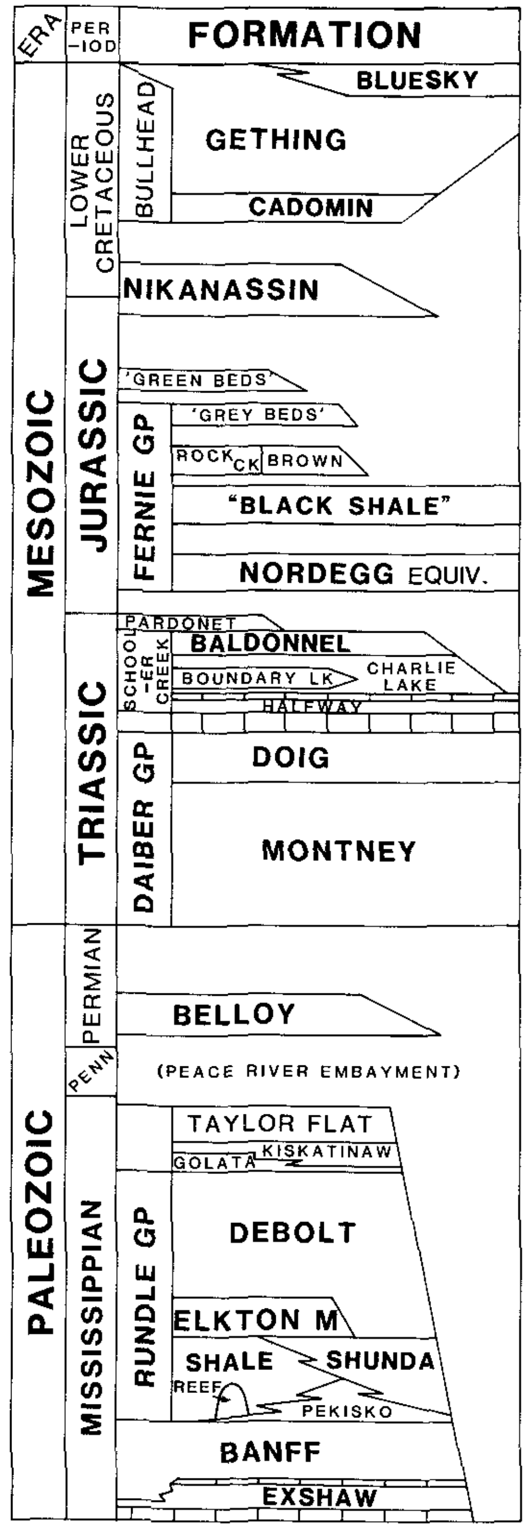

Figure 6.26. Stratigraphic column, Blueberry field, northeastern British Columbia.

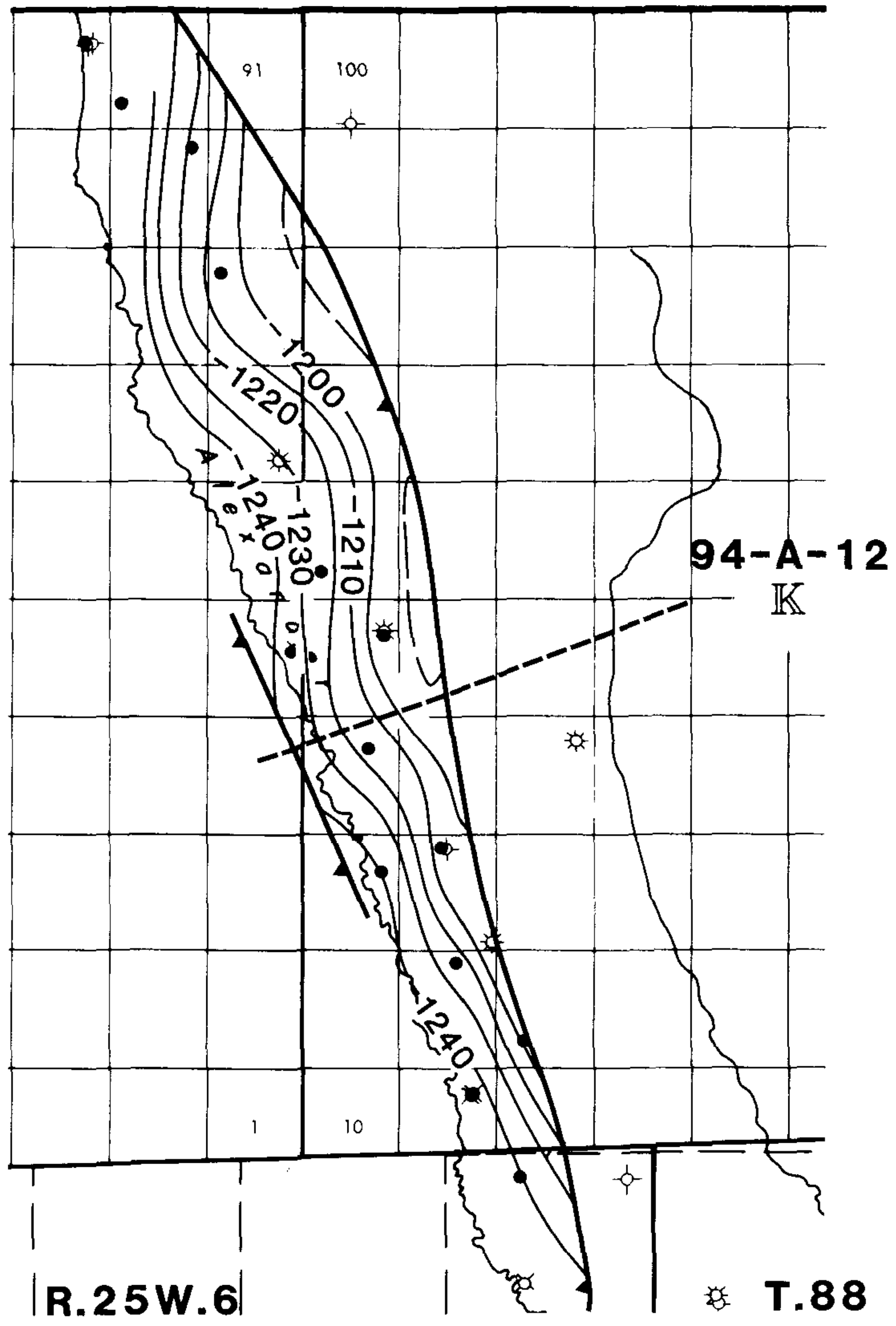

Figure 6.27. Mississippian structure, 10 m contour interval. Location of 2 faults is based on seismic. Dashed line indicates position of seismic line (Fig. 6.28).

The wells in Figure 6.24 illustrate the geology along the example seismic line. The d-50-K well lies close to the crest of the up-thrust Debolt, whereas d-40-K is downdip to the southwest, and has less gas. The d-38-K well, a shallow Dunlevy (Cadomin) gas producer, does not penetrate the Mississippian and is downdip from the off-structure well to the east, b-100-K. Structure on the Fernie and Nordegg in d-38-K indicates a return to the more regional conditions east of the thrust.

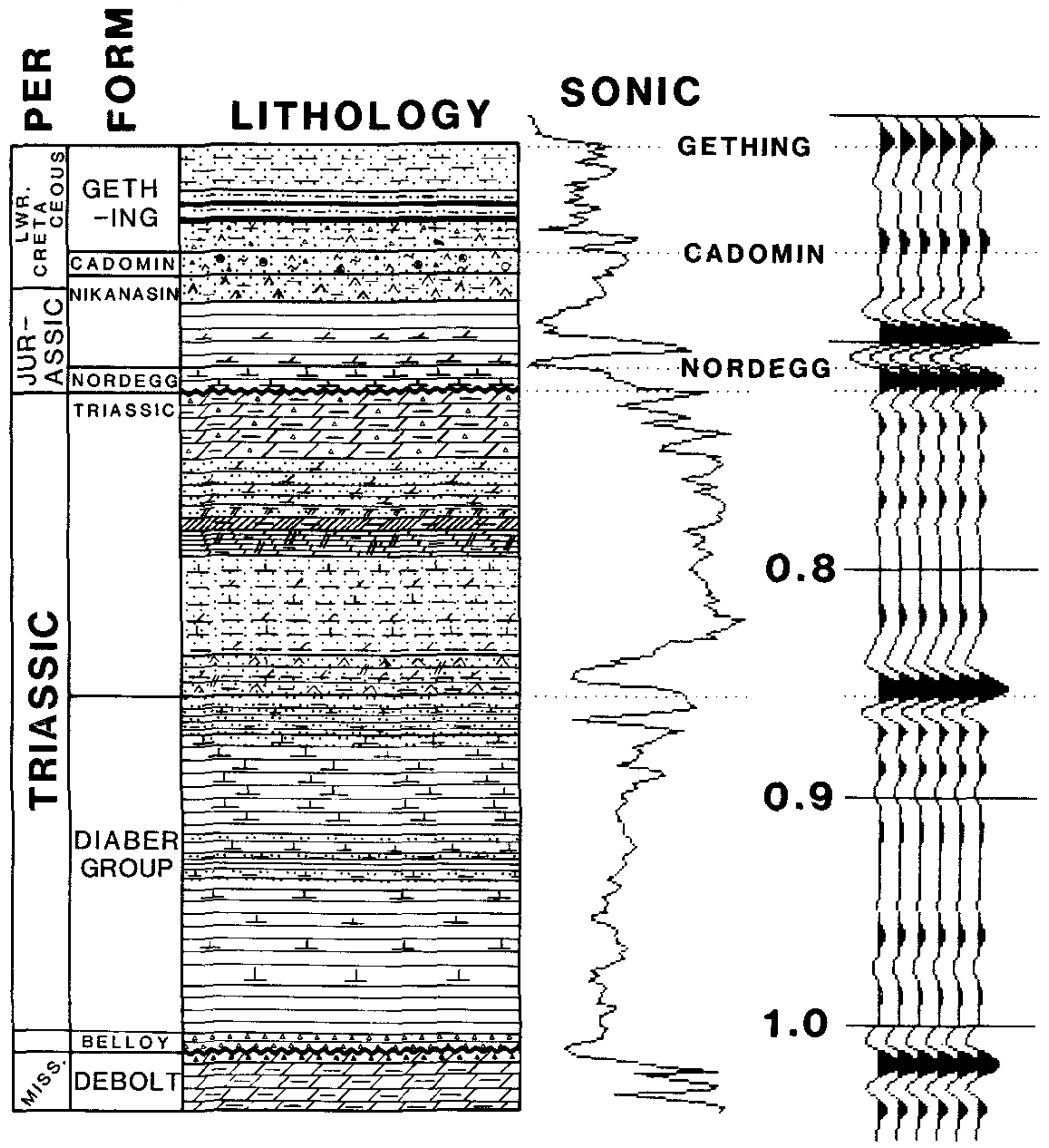

Figure 6.28. Relationship of lithology to sonic log and synthetic seismogram d-40-K94-A-12 well.

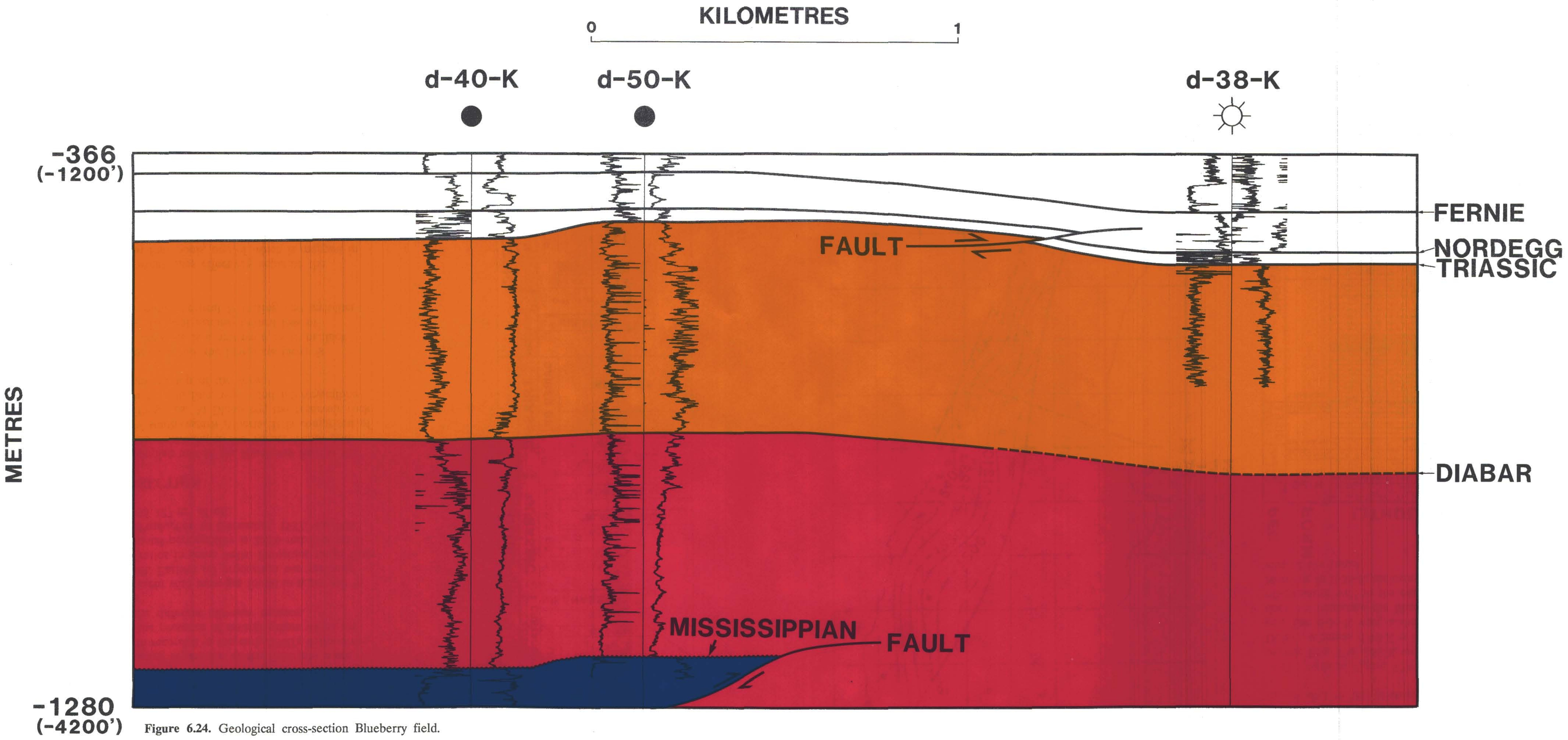

Figure 6.24. Geological cross-section Blueberry field.

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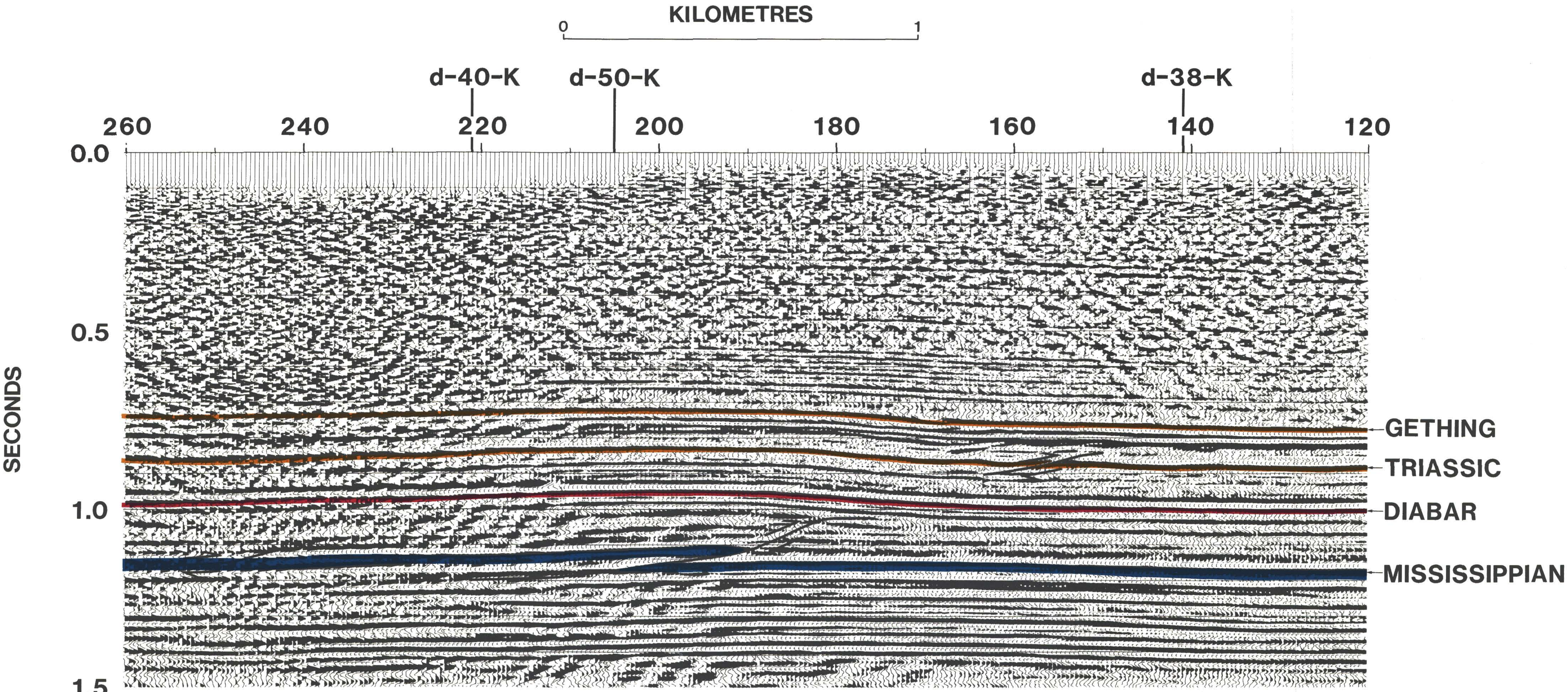

Figure 6.25. Seismic section Blueberry field.

DONOR: SUNCOR INC., GENERAL AMERICAN OILS LTD., CANADIAN RESERVE, PETRO CANADA INC. | PROCESSOR: SEIS-PRO AND CONSULTANTS LTD. | AUTHOR: DOROTHY-ANN REIMER

SEISMIC SECTION

Seismic data played a prominent part in the development of this field. Although the main thrust fault edge was defined within a narrow zone by 1960's data, the location of minor faults controlling the oil-water line and a more precise positioning of the main fault required further work. Consequently, seismic was recorded in the late 1970's and again in the mid 1980's.

The lithology of the d-40-K 94-A-12 well is related to the seismic response in Figure 6.28. On the left, the lithology log is drawn to match the sonic and synthetic seismogram, displayed in time on the right. The major seismic events correspond to the Gething Fm Sands (peak), the Cadomin conglomerate (peak), a Triassic dolomite (peak), the Diabar Gp (peak) and the Debolt Fm chert over dolomite sequence (a peak). The porosity in the Debolt Fm appears as low-velocity zones on the sonic and as a strong trough on the seismogram.

The seismic line (Fig. 6.25) recorded in 1986 crosses the field in the dip direction, northeast to southwest. It is an example of the improvement in seismic quality in the intervening 25 years since discovery of the field. It was recorded with 2 kg of dynamite in single, 18 m deep holes, a split spread with a 1500 m far offset, 25 m group interval amid 100 m source interval to produce 15 fold coverage. Receivers were Mark Products 10 Hz geophones, 9 in-line over 25 m. This example has been processed using a spiking deconvolution with an 80 ms long operator. A post-stack dip filter was applied prior to migration.

Events identified on the seismic section are the Debolt Fm, Diabar Gp, top of Triassic and Gething Fm. All are strong peaks. Thrust faults occur both in the Mississippian to the left of trace 180 and in the Triassic near trace 150.

In the example, the Debolt Fm is cut by the main thrust at trace 202 and two separate Debolt events appear to the right of the break. The Debolt event on the left side of the section rises 35 ms, 2 way traveltime, to where it terminates at trace 190. The lower Debolt event is 55 ms deeper. At an estimated interval velocity of 5500 m/s, this displacement is in the order of 150 m.

Between trace 207 and 212, the character of a deeper event (at 1.18 sec.) shows break-up of the single peaks on either side suggesting the trace of the main fault as it dips into the section.

Further west, between traces 246 and 260, changes to the Debolt Fm reflection indicate another thrust fault. Evidence of earlier thrusts are observed in the shallower zones where the Triassic is cut by a minor fault between traces 151 and 156.

The loss of reflections in the upper half of the section to the left of trace 210 is caused by the dispersion and diffraction of energy both by fracturing in the rocks during tectonism and by the poor near-surface ground conditions. Because the far offsets are least affected, the deeper horizons are still interpretable.

Because the field is structurally controlled, no effort is made to predict porosity. However, the trough below the Mississippian peak does indicate porosity. The reduction in amplitude of this trough to the right of trace 155 indicates that the dolomitized zone may thin considerably to the northeast.

CONCLUSIONS

As a thrust fault controlled field, Blueberry is the type of prospect that has benefitted from the use of the seismic technique. Both discovery and extension of this field have relied on seismic as the major exploration tool. The field lies far enough east of the major thrust deformation belt to permit acquisition of good quality seismic data.

Several faults, not suspected on earlier interpretations, can now be identified and faults can be determined with a high degree of accuracy. Amplitudes of the peak and underlying trough of the Debolt event can be mapped and used to help predict the presence of porosity and/or gas in the formation.

HUMMINGBIRD FIELD

INTRODUCTION

Situated approximately 70 km southwest of Weyburn, Saskatchewan, the Hummingbird field is a multi-pool gas and oil producer first drilled in 1966. Initially identified seismically as a structurally closed Paleozoic feature in 1963, it now produces from three zones; the Devonian Birdbear Fm, and the Mississippian Bakken Fm and Ratcliffe Mbr (Charles Fm). This paper will discuss only the Bakken Fm and Ratcliffe Mbr (Fig. 6.13)

Smith and Pullen (1967) described the evolution of the geological structures as multiple stage salt dissolution and collapse. The resultant features became the structural traps for hydrocarbons.

The field is small, barely 250 ha in size, but has been quite prolific. The Bakken Fm produces from an argillaceous fine-grained sandstone. The producing zone of the Ratcliffe Mbr is a porous dolomitic bioclastic limestone. Production (to December, 1987) from the Bakken Fm, includes 27 638 m^3 oil and 1 714 300 m^3 gas and from the Ratcliffe Mbr is 565 209 m^3 oil and 23 594 800 m^3 gas. Porosity and permeability within the Bakken Fm and Ratcliffe Mbr are 6% and .3 md, 14% and 7.5 md respectively.

Other similar features in the area, smaller than Hummingbird, have also been identified and successfully developed. Thus, Hummingbird became one of the key geological and geophysical models for multi-stage salt dissolution features in the Paleozoic.

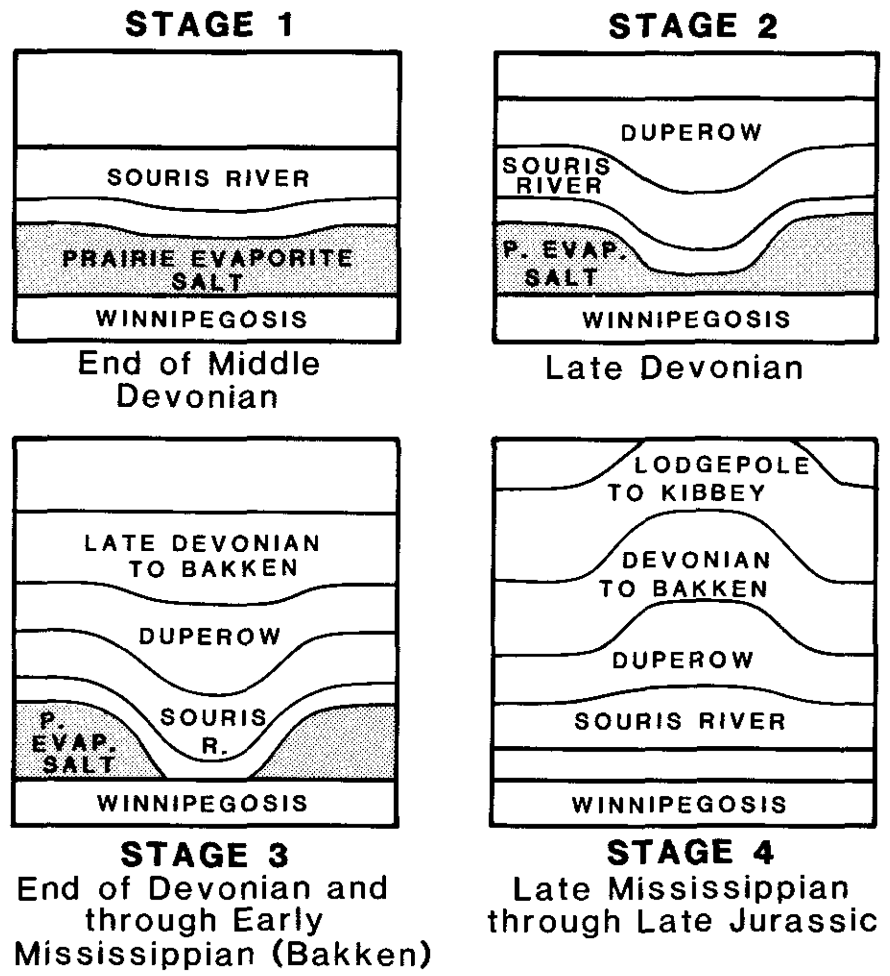

Figure 6.29. Stages of differential salt dissolution.

GEOLOGICAL CROSS-SECTION

Hummingbird field lies in the northwest quadrant of the Williston Basin, an ancient structural low more than 600 km in diameter. The Williston Basin was the site of active subsidence during Ordovician and Silurian time, remained relatively flat during Devonian and then

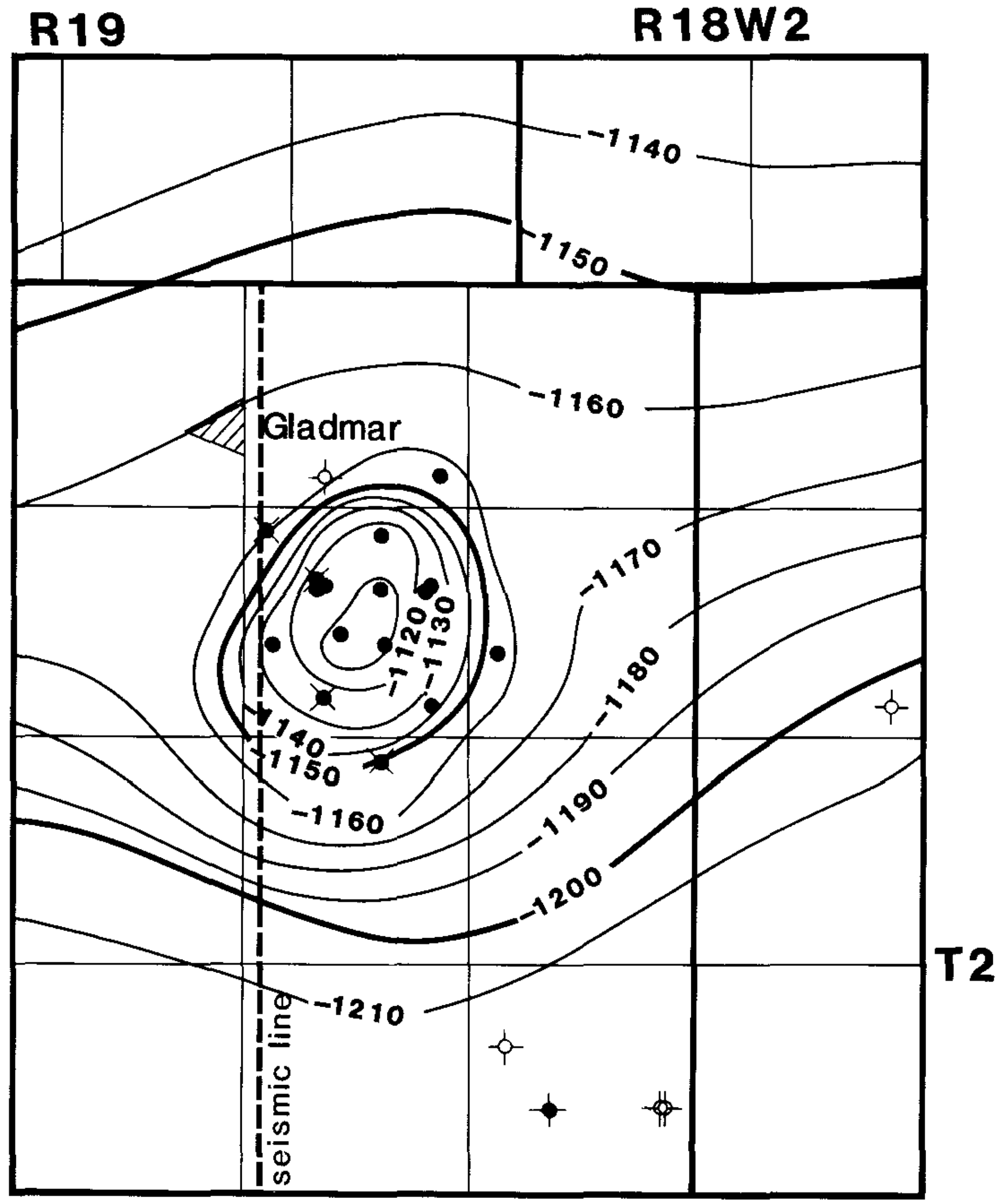

Figure 6.30. Structure contour map of the Ratcliffe Mbr, Hummingbird field. Seismic line (dashed) lies along the west flank of feature (contour interval 10 m).

began to subside again through the remainder of Paleozoic time, continuing until Late Jurassic (Smith and Pullen, 1967).

During Devonian time, the Prairie Evaporite Fm salt was deposited in a large part of the basin. It is not known how much salt was originally present at Hummingbird, but evidence suggests that over 90 m has been lost. The nearest well with salt is over 6 km to the northeast (9-9-3-18 W2M) and has 85 m of Prairie Evaporite Fm. Of the deep wells drilled in Hummingbird, including the 10-26 discovery well, none encountered salt, thus supporting a salt dissolution origin.

Differential dissolution of salt began near the end of Middle Devonian time with most loss occurring in Late Devonian. (Fig. 6.29). During Bakken Fm deposition, further salt was removed with as much as 20 m of additional Bakken sandstone accumulating in the lows created by salt dissolution. Continued dissolution during Jurassic meant that the thicker sections, such as those of Bakken Fm sandstone, were left structurally high. The overlying beds were deformed to conform to the altered structure and became traps for hydrocarbon accumulation.

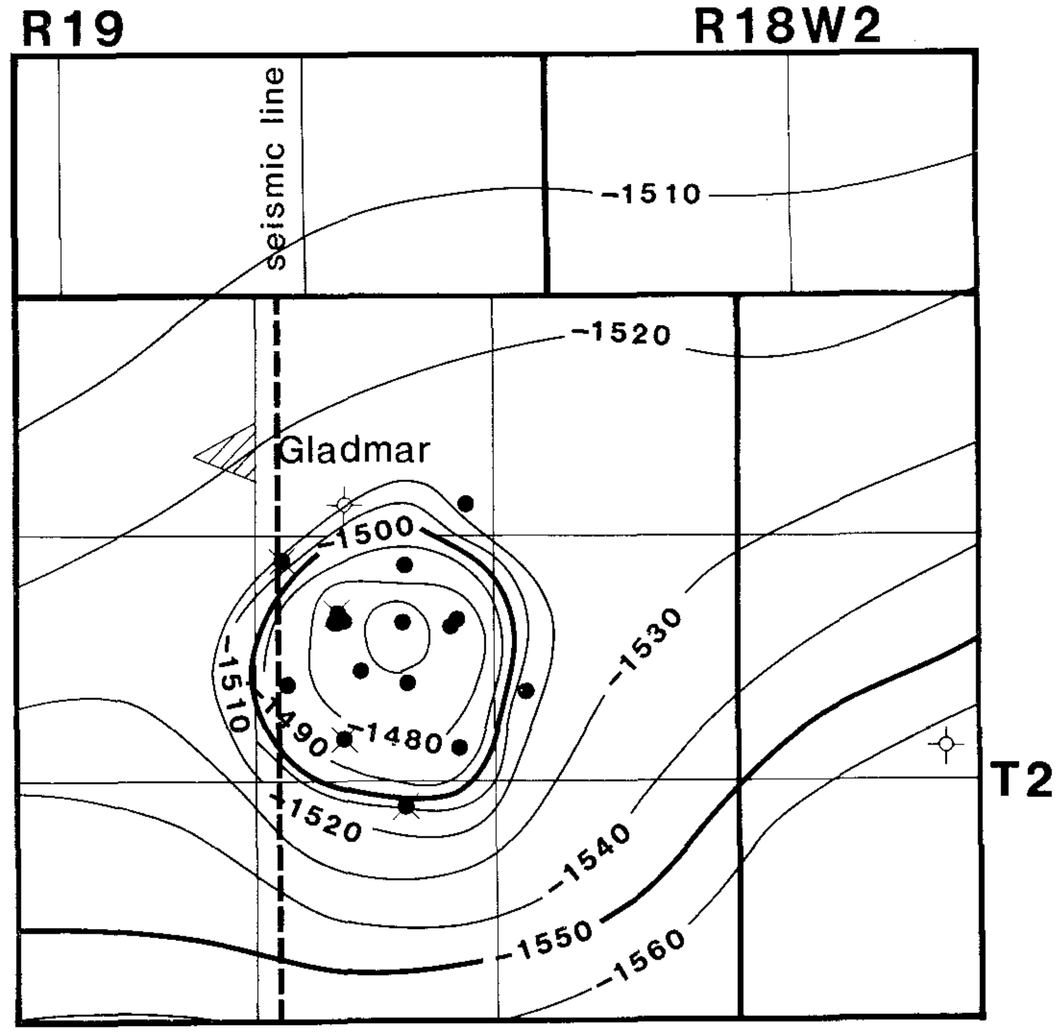

Figure 6.31. Structure contour map Bakken Fm, Hummingbird field. Structure is steep-sided relative to the Shallower Ratcliffe Mbr structure (contour interval 10 m).

Structure maps of the Ratcliffe Mbr (Fig. 6.30) and Bakken Fm (Fig. 6.31) show the similarity of the two subcrop surfaces. Both have 50 m of closure with the later Ratcliffe being less steep-sided.

The discovery well, 10-26-2-19 W2M, was drilled to the Ordovician Winnipeg Fm and logged to a depth of 10 124 ft (3 523 m). Hydrocarbons were tested in several Mississippian zones and the Devonian Birdbear Fm. It was completed as a Birdbear well. Several subsequent wells were twinned to produce from both the Birdbear Fm and Ratcliffe Mbr. Beginning in 1985, the Birdbear zone was abandoned in some wells and production began from the Bakken Fm sandstone.

The geologic cross-section in Figure 6.33 parallels the seismic line in Figure 6.34 over the Hummingbird field. Structure is evident on all horizons below the pre-Jurassic unconformity. The Mississippian top is relatively flat due in part to subsequent erosion as well as to salt dissolution. Horizons identified are the Birdbear Fm, Three Forks Fm (both Devonian in age) the Bakken Fm, the base of a deep Mississippian shale marker, the Oungre (an informally named zone within the Ratcliffe Mbr) and the Ratcliffe Mbr and the top of the Mississippian.

SEISMIC SECTION

The example seismic section (Fig. 6.34) lies along the west flank of the Hummingbird field (Fig. 6.31) and parallels the geological cross-section. This line was recorded, 12 fold, in the winter of 1983 using a dynamite source of 2 kg in single 18 m deep holes, source interval of 132 m and group interval of 33 m. A nest of 9 14-Hz geophones with 4-m separation was used. It is interesting to compare this survey to the 1963 discovery seismic data printed in earlier literature, recorded singlefold with a dynamite source of 4.5 to 9 kg in 46 to 60 m deep holes. Although in the old data reflections are broken into short, slightly curvilinear events as a result of single fold acquisition and inadequate data processing, it is still more than adequate to identify the feature. This success must partly be credited to the fact that this area has excellent ground coupling conditions for recording seismic. The main improvements are in the higher-frequency content and the ability to migrate the data to better define the limits of the structure.

The display is reverse polarity which shows the low velocity producing zones as peaks. Events identified correspond to the following; the Winnipegosis Fm (a strong peak), the Bakken Fm (a peak), the Ratcliffe Mbr (a moderate-amplitude peak), the top of the Mississippian (a trough), and the Jurassic Shaunavon Fm (a trough).

Structure is evident on all the Mississippian events. In addition, the Bakken Fm reflection changes from a low-frequency peak to a high-frequency doublet, the result of a thicker sandstone between traces 305 and 350. At its thickest, the sandstone gives rise to a reflection from both its top and base.

The Ratcliffe Mbr also shows character change as it dims over the structure. This is attributed to its greater thickness off structure and is the effect of tuning whereby the velocity-frequency content of the seismic interfere constructively in the thicker beds but destructively in the thinner beds. The top Mississippian event is nearly regional, dipping from north to south. The isochron from top Mississippian to Ratcliffe Mbr is much thicker off the Ratcliffe structure. This isochron change indicates that much of this zone was eroded in the vicinity of the anomaly. The Shaunavon Fm has only minor structure.

CONCLUSIONS

Until the Hummingbird structure was tested, multi-stage salt dissolution had not been proven in Western Canada. The discovery and development of this feature became one of the more exciting success stories of the early 1960's where geology and geophysics were used to complement each other.

VIEWFIELD FIELD

INTRODUCTION

Identified by seismic and developed in the early 1970's, the Frobisher Beds pool of the Viewfield field in southeastern Saskatchewan is not only fascinating to earth scientists for its scientific value but also for its economic potential as well.

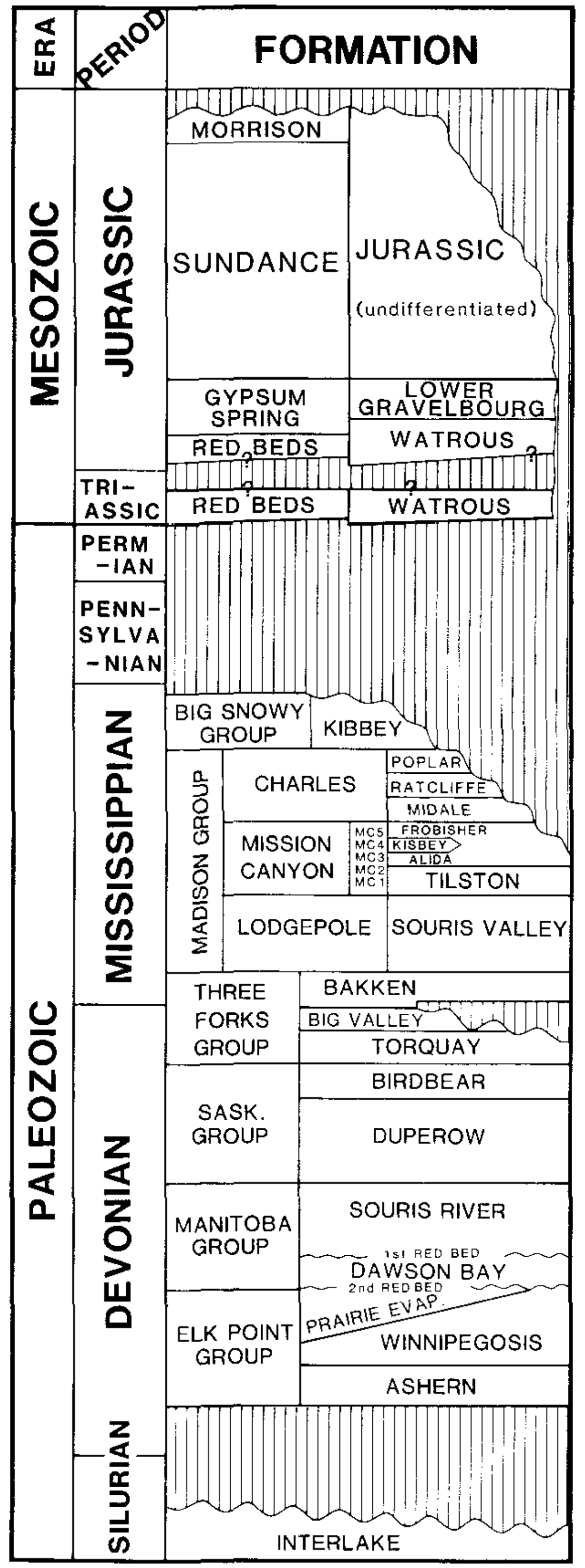

Figure 6.34. Stratigraphy southeastern Saskatchewan.

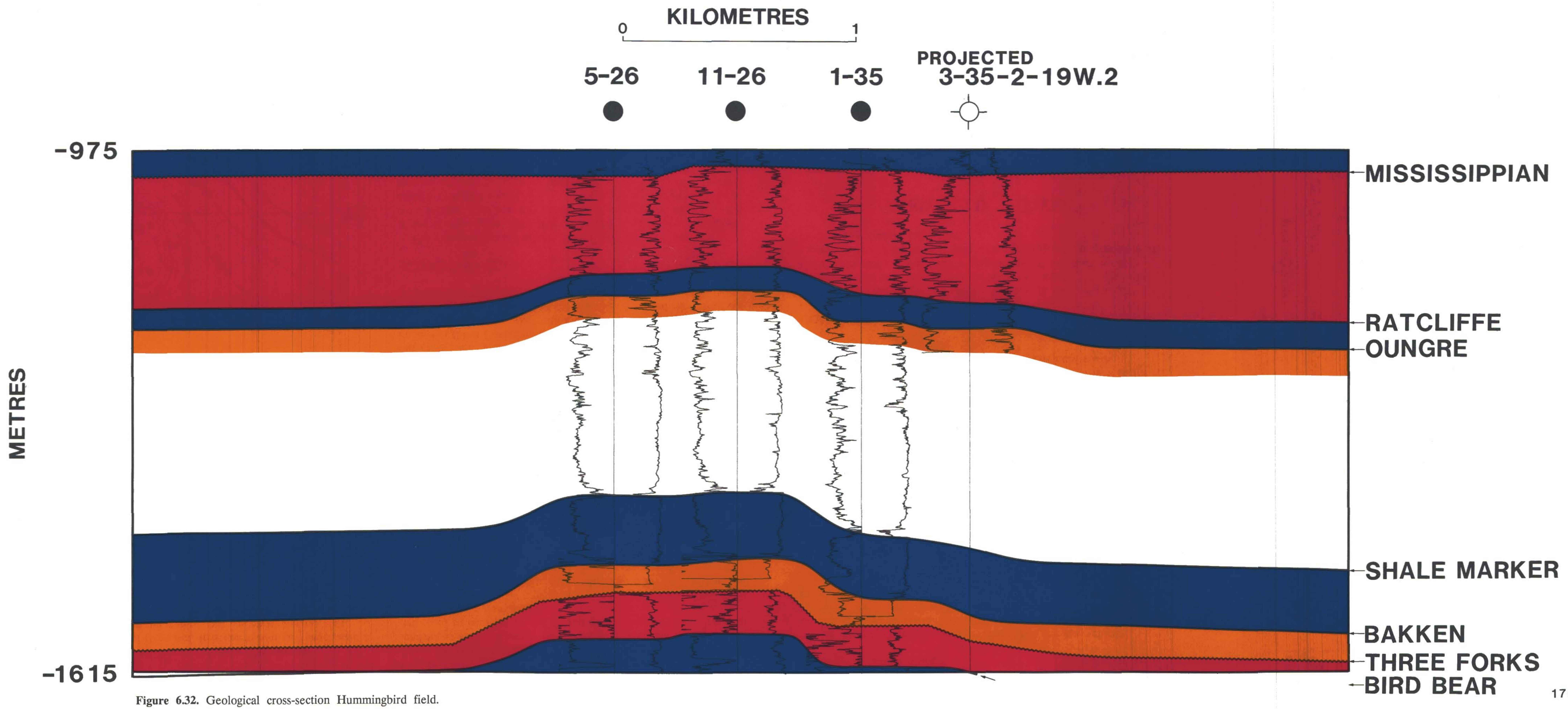

Figure 6.32. Geological cross-section Hummingbird field.

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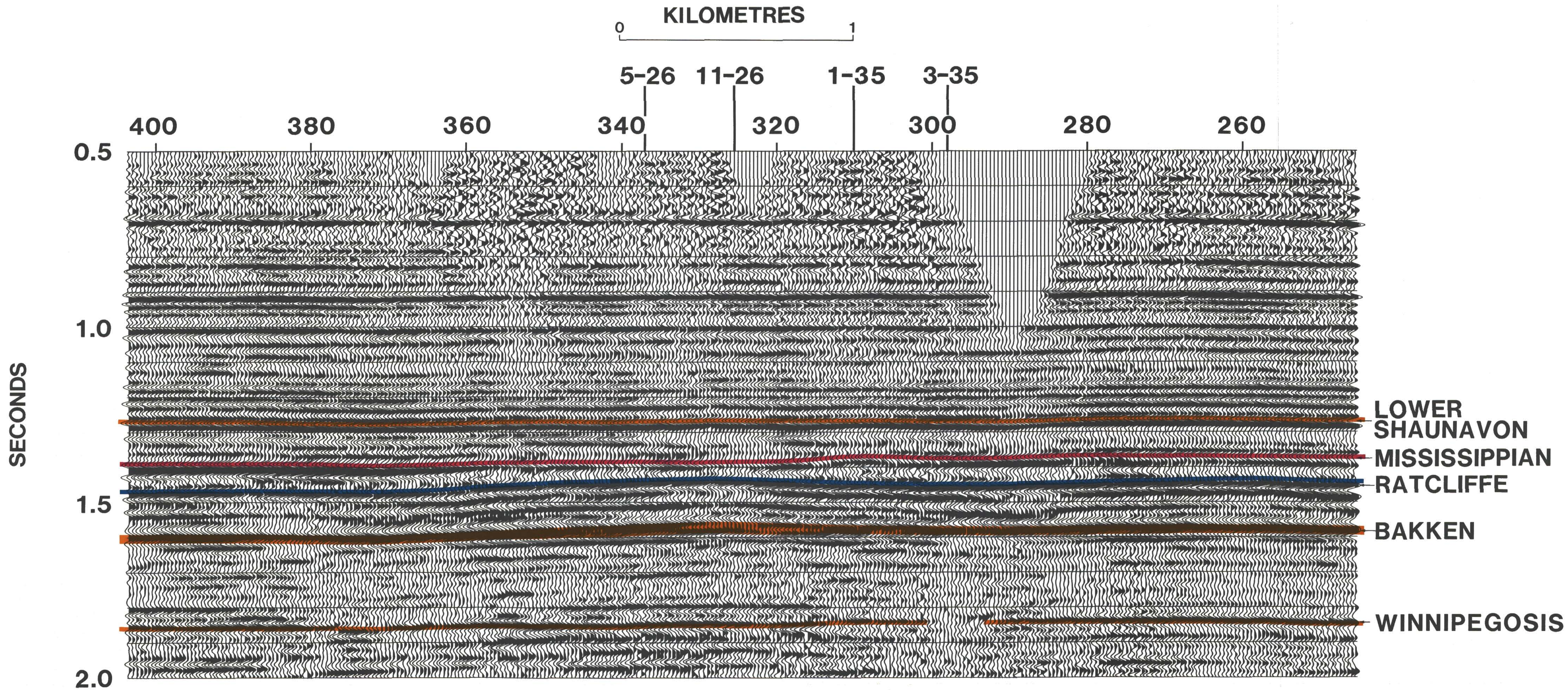

Figure 6.33. Seismic section Hummingbird field.

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Situated in the Williston Basin amid many fields created by salt dissolution, this field is difficult to explain solely by salt tectonics. An alternate origin was postulated by Sawatsky (1972) in which the structure was described as a small post-Mississippian impact crater or astrobleme which was subsequently modified by erosion and by later dissolution of Devonian salt. The lack of meteorite particles or shock features in core prevents a conclusive classification, but there is still sufficient evidence to warrant a 'possible' classification as an impact crater (Donofrio, 1981).

Viewfield production is from the Mississippian Frobisher beds of the Mission Canyon Fm and from an overlying breccia identified as Mississippian in origin, and often referred to as the "Rim" facies. To date (December, 1987) 1 417 832 m^3 of oil and 115 407 400 m^3 of gas have been recovered. Seismic was used to map the Mississippian structure and the majority of wells were drilled on seismically determined highs.

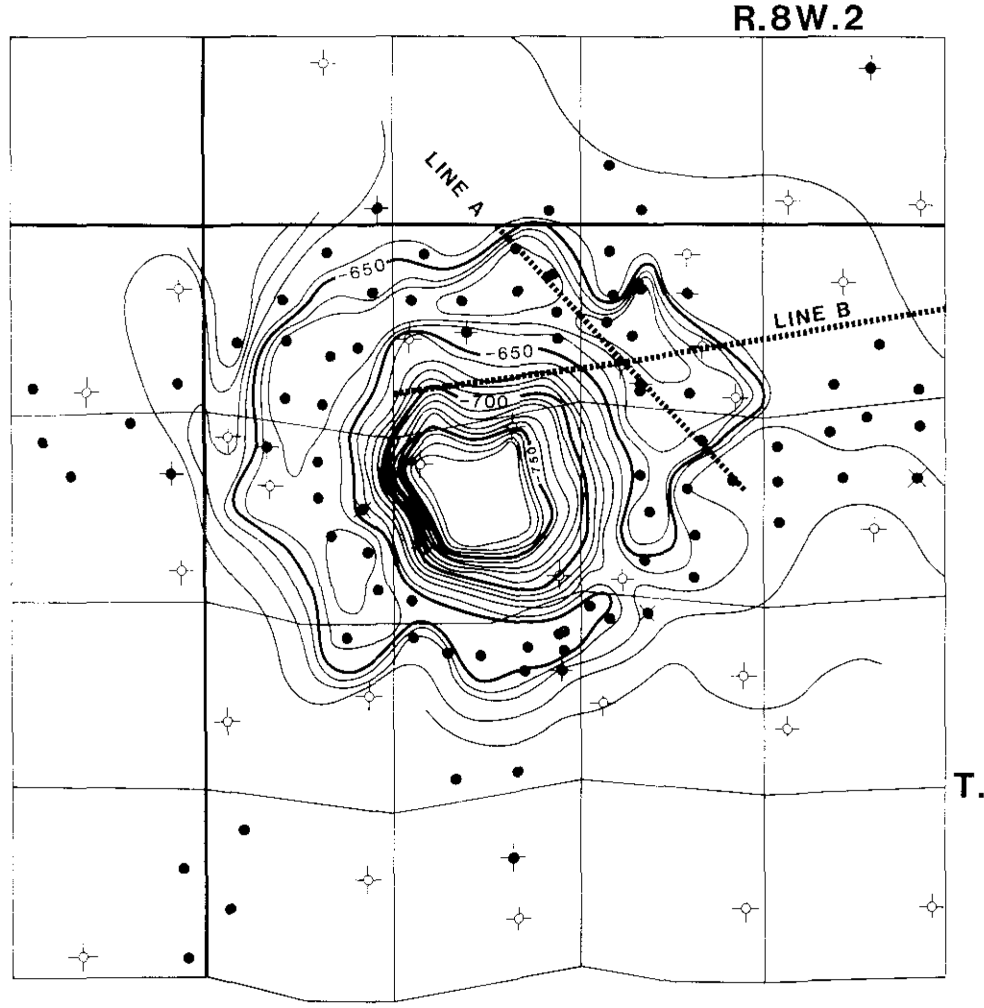

Figure 6.35. Structure contour map Viewfield field and location of geological cross-section and seismic section.

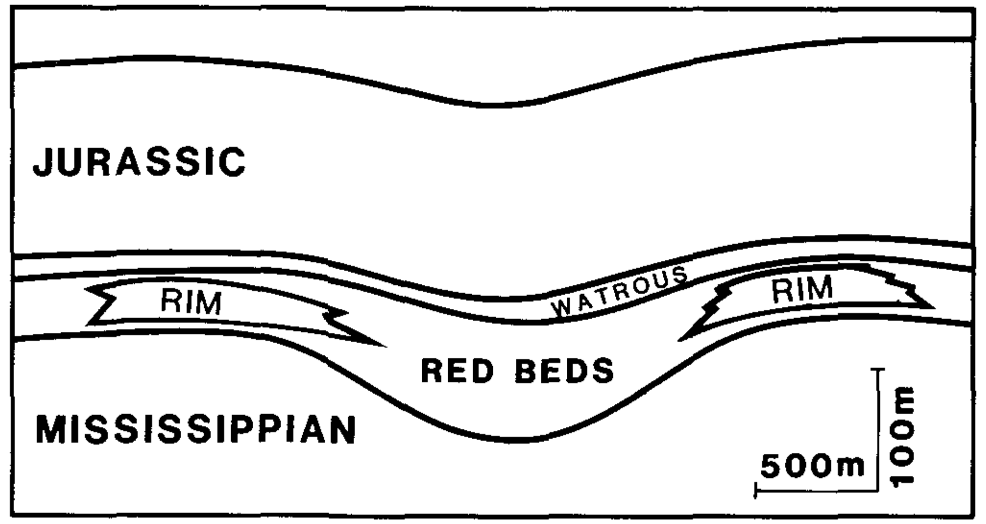

Figure 6.36. Schematic of geological structure and stratigraphy Viewfield field.

GEOLOGICAL CROSS-SECTION

One of the earliest wells drilled in Viewfield was Shell's 1957 Viewfield 'B' 13-30-7-8 W2M. It was abandoned after testing oil- and gas-cut mud. It wasn't until early 1969 when the United Canso Viewfield 8-30 well was drilled and tested oil that development of the field began.

The normal stratigraphic sequence shown in Figure 6.34 is interrupted in many of the Viewfield wells. The Lower Watrous Fm (Triassic), composed of red to reddish-brown shales and siltstones, is encountered both above and below varying thicknesses of Mississippian sediments. These Mississippian sediments, highly brecciated carbonates, are described as the "Rim" facies.

Figure 6.35 is a map of the Mississippian structure and includes the "Rim" facies where present. The feature is that of a large ring with a high circular ridge surrounding a deep depression. Three wells (5-29, 13-29, 15-29-7-8 W2M) confirm this deep feature. The deepest well, 13-29, was drilled to 788 m subsea without finding Mississippian strata, a full 100 m below regional. The diagram in Figure 6.36 is a cross-sectional sketch of the feature.

The presence of Mississippian rocks over later Red Beds sediments, the brecciated condition of the "Rim" facies rocks and geometric configuration of a raised rim around a central cavity are considered indicative of an impact origin.

The geological cross-section, A-A', (Fig. 6.37) follows the northeast rim of the feature and parallels the seismic line labelled A. Underlying the Watrous Fm is a very thin Red Beds section ranging from less than a metre in 9A-32 to several metres in 10-28. These separate the Watrous Fm from the "Rim" facies below. This "Rim" unit is the reservoir rock in most wells. At the base of the brecciated rim, a second, thicker Red Beds section is encountered.

The second cross-section B-B' (Fig. 6.37) traverses the south slope of the feature's north rim, crosses the crest and extends beyond the field. It parallels the example seismic line B. The "Rim" facies is evident in three of the wells. The 5-32 well has a thick, but low rim section between two Red Bed units. The Rim facies is absent from the regional 11-34-7-8 W2M well.

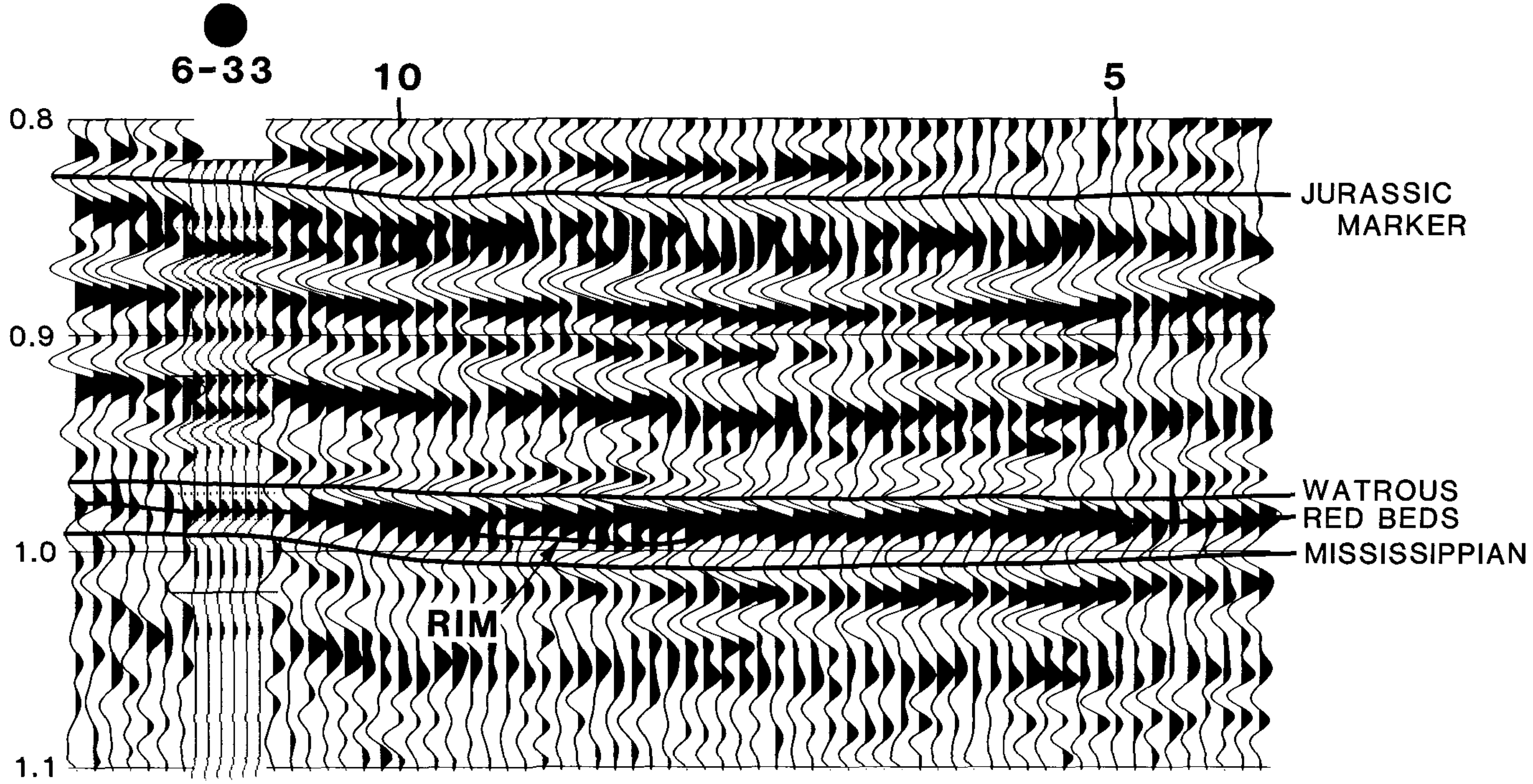

Figure 6.39. Enlarged view of Line B between the 11-34 and 6-33 wells. Display is reverse polarity. The higher frequency content to the right of trace 10 and around the 6-33 well indicates the "Rim" facies.

SEISMIC SECTION

The first indication of a geophysical anomaly and a possible support for the impact origin theory in Viewfield is the aberration in survey grid lines (Fig. 6.35). The east-west lines, which should be straight and parallel show major deviations due to compass deflections during the survey. Such deflections can be attributed to the presence of other than sedimentary rocks such as plutons. In this example, the cause may be a buried meteorite or rock that was heated and altered during impact with a meteor.

Development of this field benefitted greatly from two relatively new technologies, common depth point seismic recording and the sonic tool. Though the early sonics were often full of cycle skips, they still yielded valuable information both for geologist and geophysicist.

The two example seismic lines (Fig. 6.38) were recorded in 1970 using a dynamite source of 1.1 kg in 18 m holes. The recording system was a 24-channel DSF III, and a sample rate of 2 ms was used at a time when most seismic was still being recorded at 4 ms.

Near and far offsets for the split spread were 33.5 and 771 m respectively, coverage was 300%. Coupled with the excellent ground conditions of southeastern Saskatchewan, these recording parameters allow current processing capabilities to bring out the high frequency content and coherency of the data.

The seismic events identified correspond to a Jurassic marker horizon (a strong peak), the Watrous Fm (a peak) and Lower Watrous Red Beds (trough), the Mississippian subcrop, including the "Rim" facies (a peak), the Alida (a low-amplitude peak), the Lower Bakken shale (a strong trough), the top of the Prairie Evaporite Fm salt (a trough) and the Winnipegosis Fm (an intermittent peak). Correlations are based on the deep 8-30-7-8 W2M well, drilled 2255 m and into Silurian strata. This well encountered over 150 m of Prairie Evaporite Fm. Salt in this well supports the possibility of salt dissolution as a factor in the creation of the Viewfield structure.

Both lines A and B have thickened Mississippian sections and a loss of reflection strength over the rim crest. The trough associated with the Red Beds diminishes in amplitude and disappears at the crest, corresponding to a thinning of the geological section. Structure on the deeper horizons coincident with the rim, may be pull-up caused by the thickened Mississippian, salt dissolution in one or more stages, or tectonic movement, or some combination of these three.

Figure 6.39 is an enlarged segment, reverse polarity, from line B between the 11-34 and 6-33 wells. On the right, a low frequency peak represents the thick Red Beds section of the 11-34 well. The Rim facies is seen, seismically, as a change in frequency content of the underlying Mississippian event where the trough splits to form an incipient doublet. On the left, the reflections break up totally. This loss of reflections corresponds to the 6-33 well (Fig. 6.37) where there is negligible velocity contrast from the top of the Watrous Fm down through the Mississippian for over 130 m. A synthetic seismogram for the 6-33 well, filtered with a 35 Hz Ricker wavelet, is shown on the left of the diagram.

CONCLUSION

The origins of Viewfield field are certainly complex. Because of its relatively small size, (about 2 km in diameter) the original crater would have been considerably eroded before it was fully covered and preserved by later sediments. In addition salt dissolution has most likely affected the structure. The salt itself may have fractured and dissolved as a result of fracturing of the upper zones. Regardless of its origin, however, Viewfield must be considered an excellent example of a geophysically defined field.

SEAL

INTRODUCTION

In the early 1970's, several wells were drilled in the Seal area, approximately 300 km northwest of Edmonton, Alberta. The targets were oil in the Devonian Slave Point Fm and gas in the Mississippian Debolt Fm.

Considerable seismic had been recorded as an aid in positioning these wells. Several reef-like features within the Mississippian Pekisko Fm were evident in what was believed to be a low relief, 10 to 15 m thick carbonate platform. In January 1984, Pembina Resources tested the first of these seismic anomalies and encountered 58 m of Pekisko Fm carbonate now identified as a carbonate 'mud mound'.

Core analysis and testing indicated a reservoir containing heavy oil (11.7° API). Subsequently, several other structures have been drilled, based on seismic data, and have found Pekisko carbonate build-ups ranging from 34 to 50 m thick. Unfortunately the oil is too heavy to be produced economically at the present time.

Porosity ranges from less than 6% at the base of the mound to 25% in the mound core. Permeability also ranges from very low, less than 1 md at the base, to very good, 1 to 10 in the core. In-place oil reserves for the discovery well, 7-6-82-12 W5M, are estimated to be between 2 and 5 x 10^6 bbls. Since these mounds are seismically similar to pinnacle reefs, they are ideal geophysical targets.

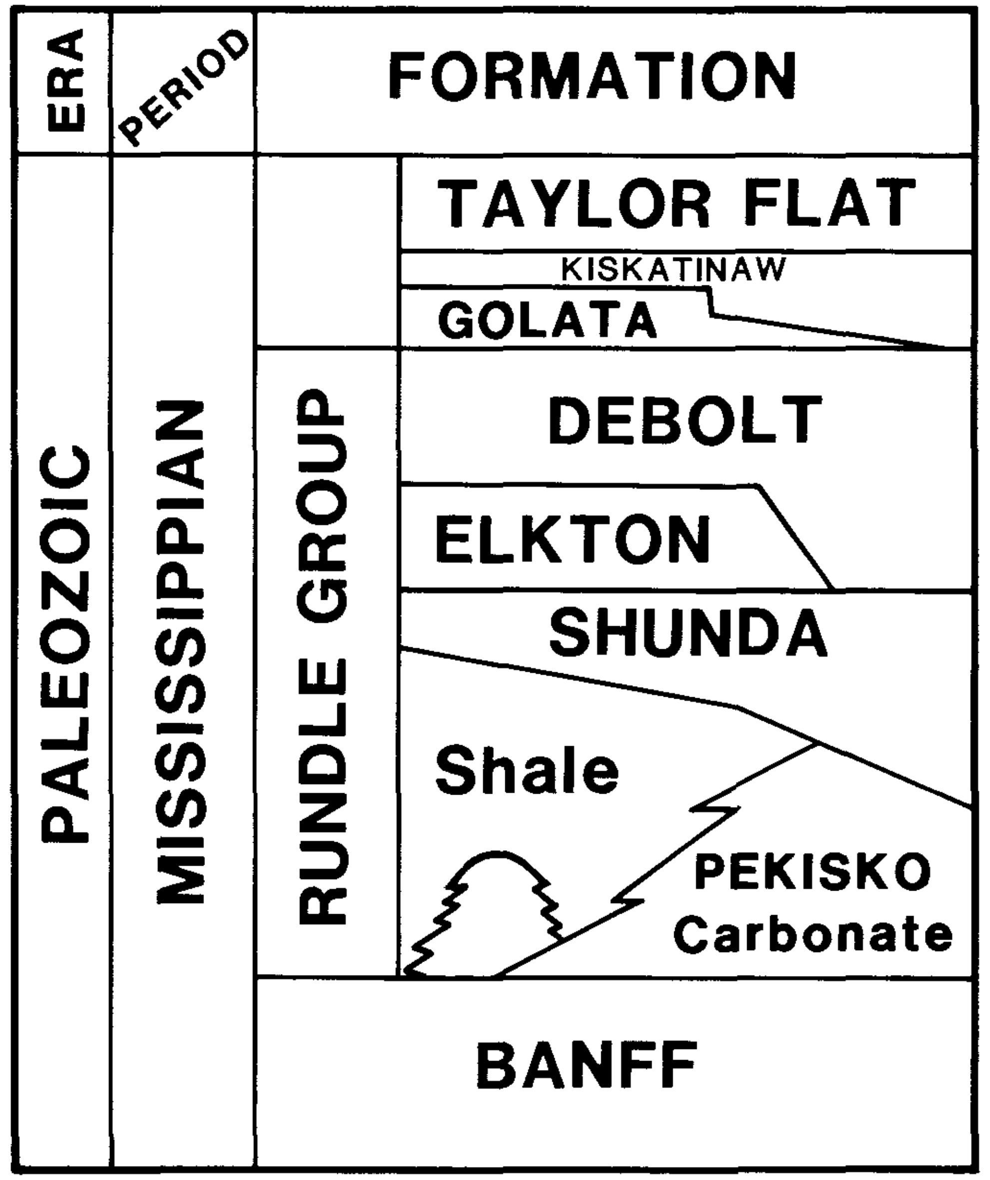

Figure 6.40. Mississippian stratigraphy, northcentral Alberta.

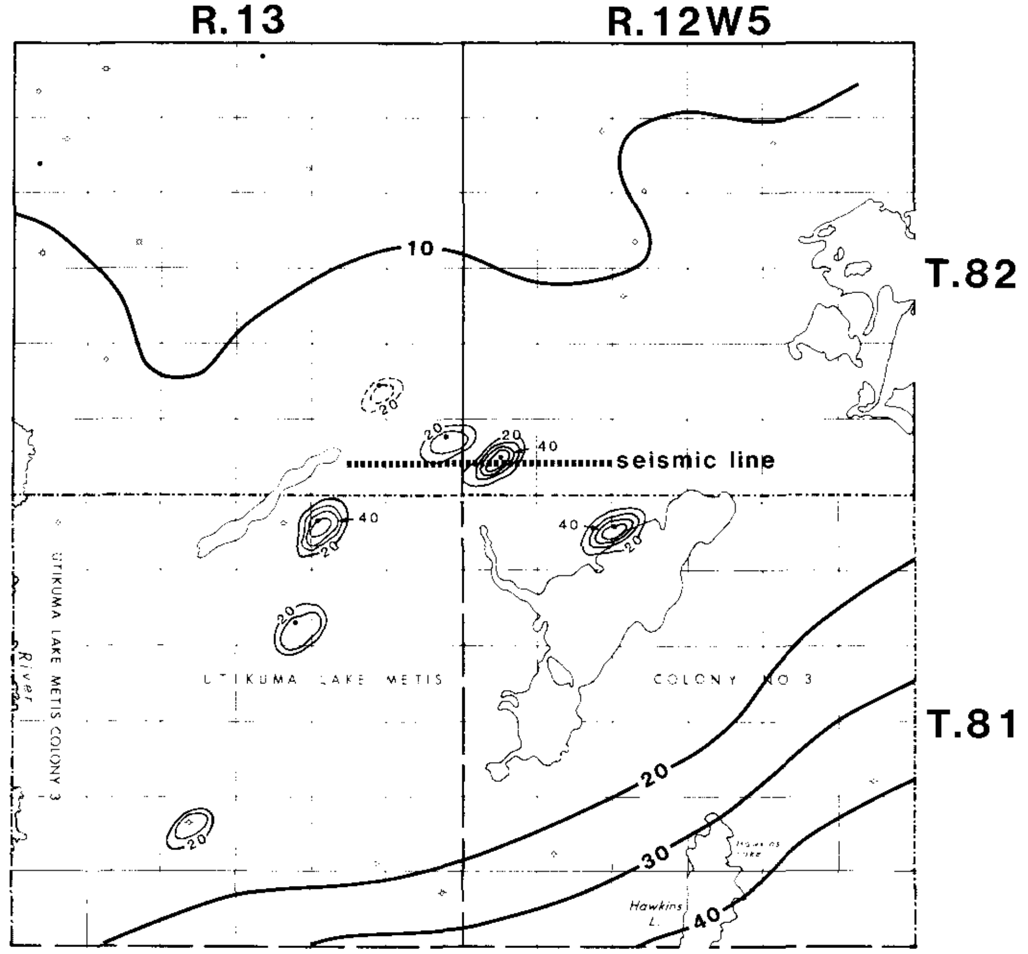

Figure 6.41 Isopach map Pikisko Fm carbonate, Seal Area, (Contour interval 10 m).

GEOLOGICAL CROSS-SECTION

The Pekisko Fm is the lowermost unit of the Rundle Gp. Overlying the Banff Fm (Fig. 6.40) it exhibits both carbonate and shale facies. In the Seal area, the basal unit of the Pekisko Fm is a thin platform-type carbonate overlain by thick shales. Arising from the platform are a series of small carbonate mud build-ups identified as "Waulsortian" mounds (Edwards, 1986), which range from 20 to nearly 50 m in thickness. Figure 6.41 is a map of the Pekisko Fm carbonate isopach. The broad low platform on which these mounds develop is more than 10 km wide. To the southeast, this platform thickens rapidly to 30 m over a distance of three kilometres.

The Banff structure (Fig. 6.42) is generally regional, but a minor low extends northeastward along the southwest edge of the field and may have affected deposition of the Pekisko Fm, favouring growth of the mounds on the updip flank of this depression.

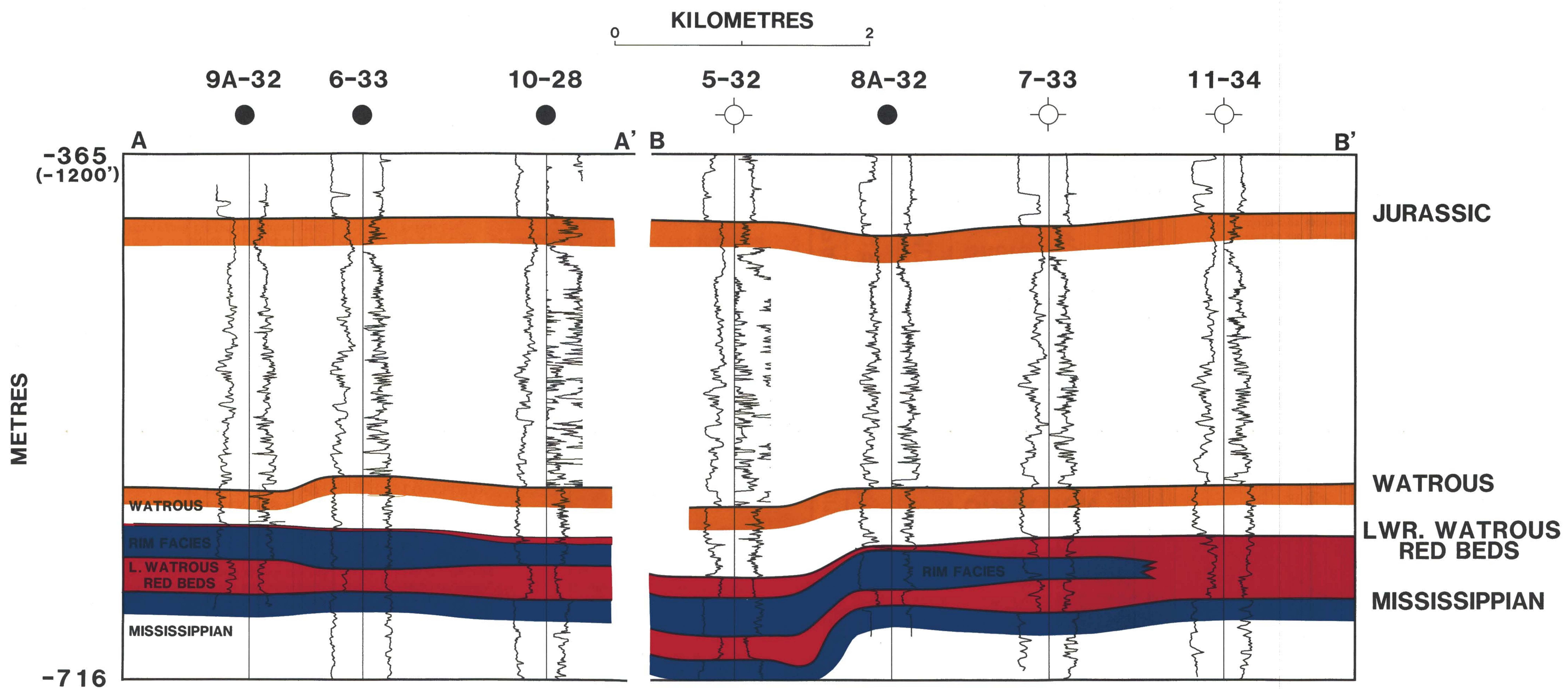

Figure 6.37. Geological cross-section Viewfield field.

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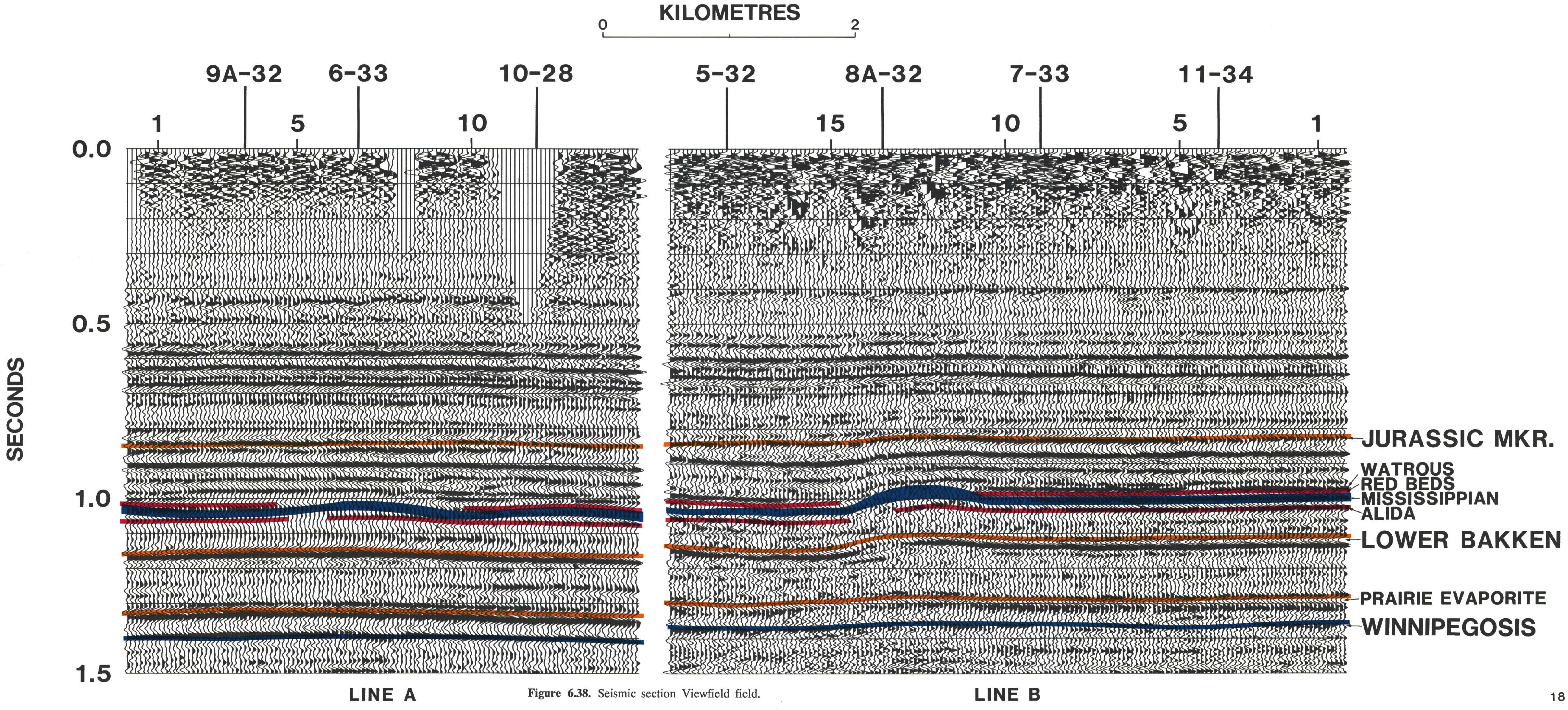

Figure 6.38. Seismic section Viewfield field.

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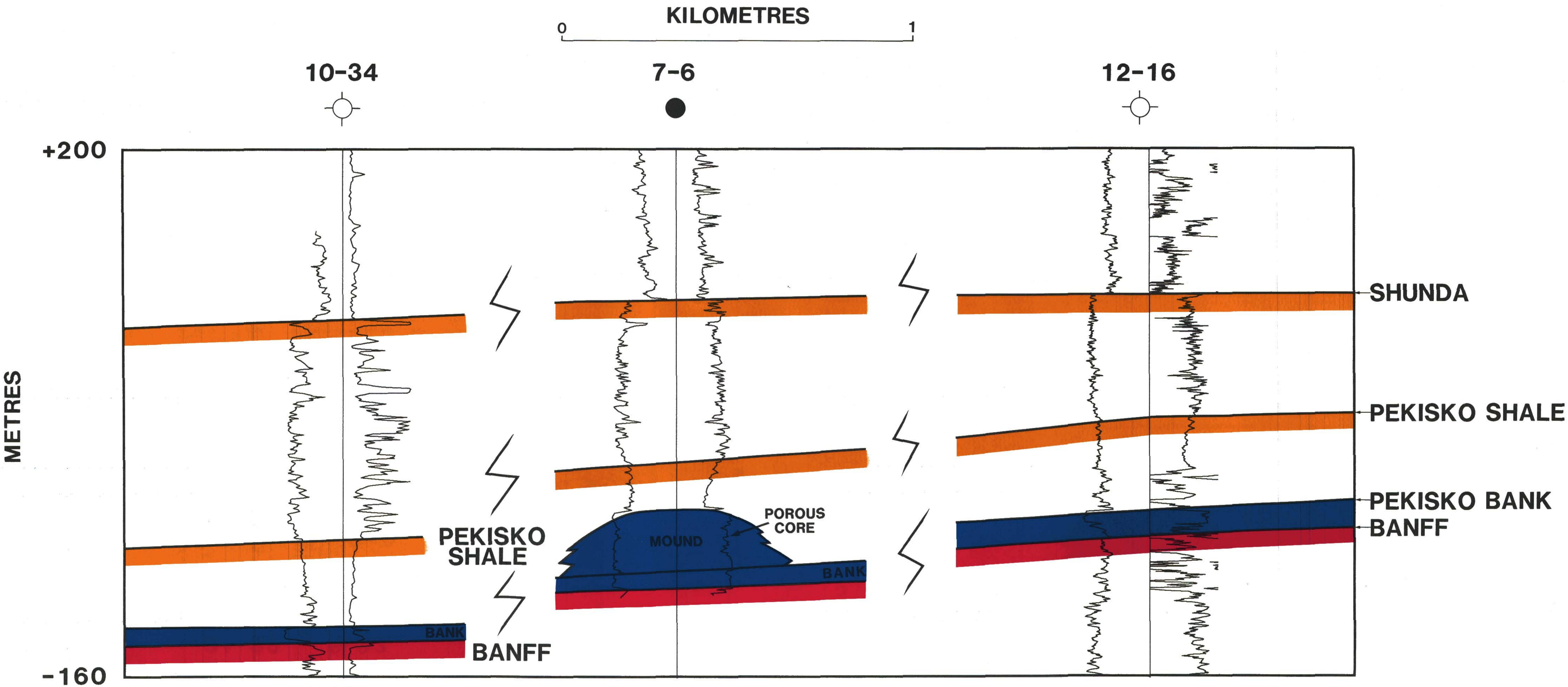

Figure 6.43. Geological cross-section Seal area.

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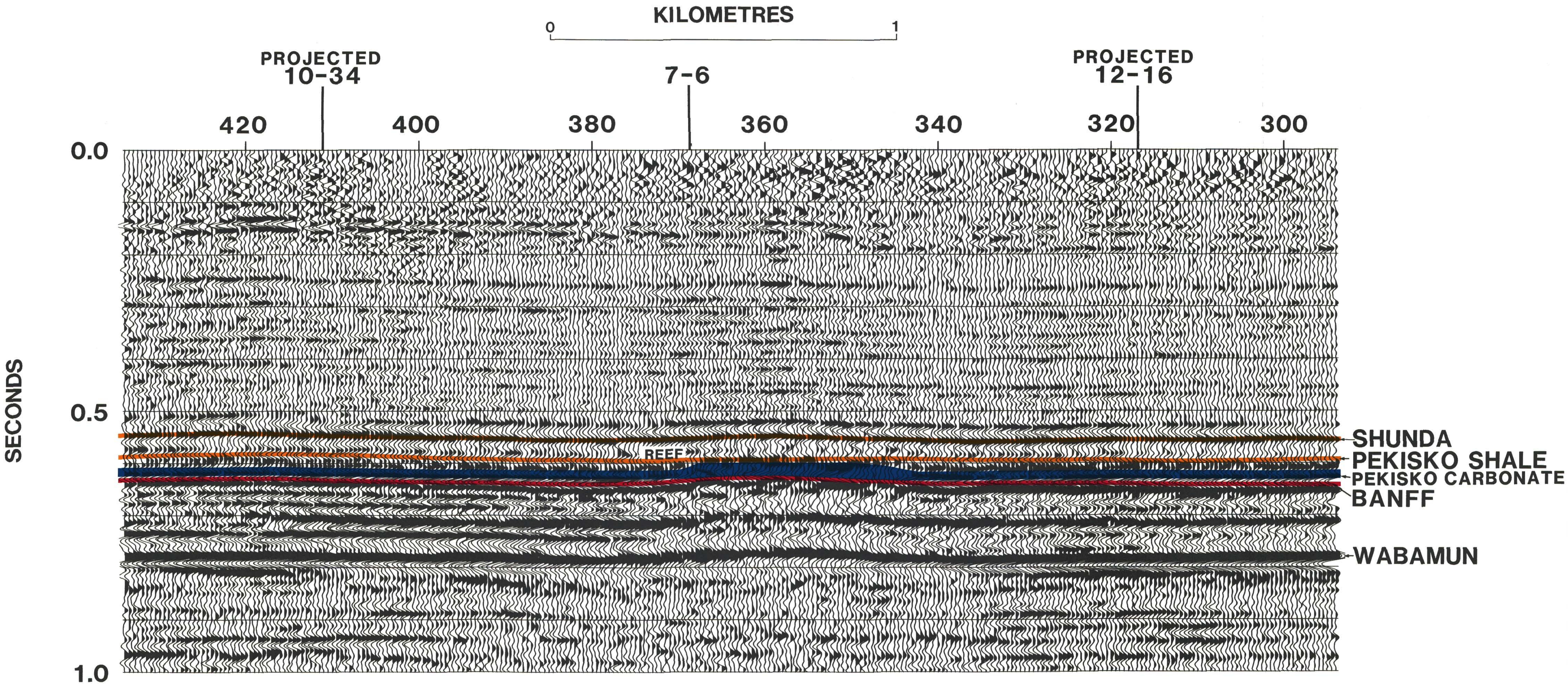

Figure 6.44. Seismic section Seal area.

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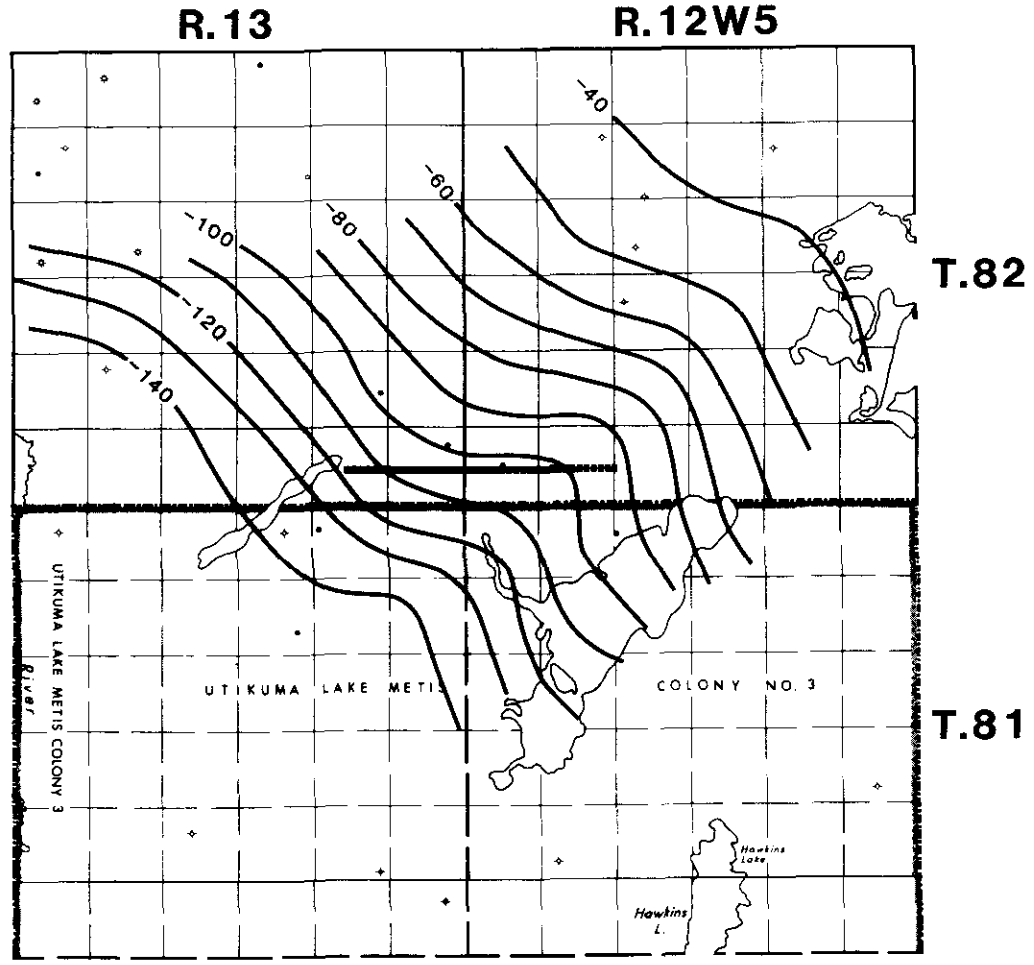

Figure 6.42. Banff structure contour map, Seal area, (Contour interval 10 m). Dashed line is location of example seismic line (Fig. 6.44).

Fragments of marine fossils including bryozoans and crinoids, form the thin base of these mounds. The mound core, 30 m or more in thickness, is also fossilliferous with interbeds of lime mud. Draped over this core is a thin layer of crinoidal debris (Edwards 1986). Much of the mound has been significantly altered by diagenesis. Stylolites are found mainly in the base and sometimes in the mound core. There has been extensive recrystallization and infilling with sparry calcite, reducing the porosity and permeability. However, some fracturing is present, enhancing porosity and permeability.

The geological cross-section (Fig. 6.43) is representative of the Mississippian geology in the Seal area. Two wells, 10-34-81-13W5M and 12-16-82-12W5M, are regional, whereas the third, 7-6-82-12W5M, is the discovery well. The logs shown are gamma ray-sonic pairs with the exception of a gamma ray-resistivity pair for 10-34.

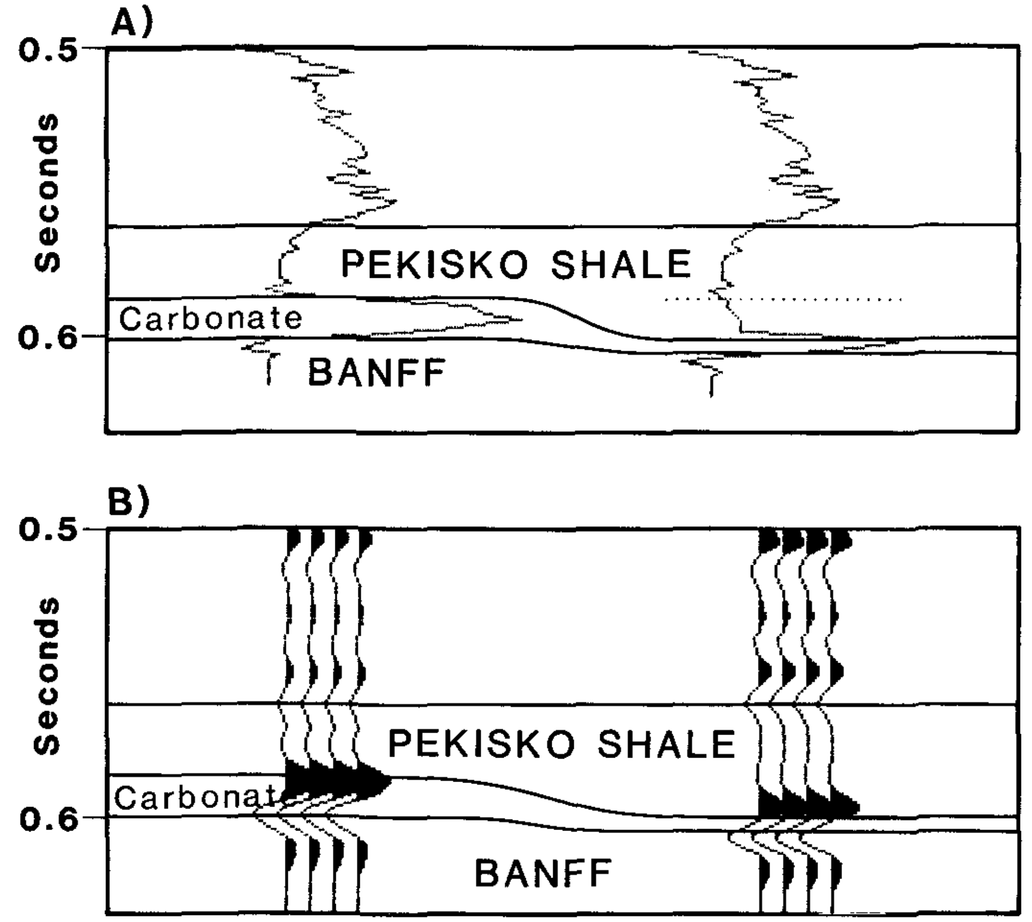

Figure 6.45. The sonic log curve (Fig. 6.45A) from 16-1-82-13W5M on the left has 23 m of Banff Fm carbonate which is replaced by shale to the right. In the corresponding seismic response (Fig. 6.45B) the Banff is "pulled-up" on the left and the carbonate event is a broader peak.

The Debolt Fm is present in the 10-34 well but absent in the other 2 wells. A thin Pekisko Fm carbonate bank is present in all wells. In the 7-6 well, there is about 45 m of mound. The sonic indicates the better porosity of the mound core compared to the zones above and below. The underlying Banff Fm is a low-velocity shale.

SEISMIC SECTION

The seismic section (Fig. 6.44) is an east-west line which templates the discovery well 7-6-82-13 W5M. It was recorded in 1982 using a dynamite source of 0.5 kg in each of a 2-hole pattern. Coverage was 1200%, group interval, 25 m and near and far offsets were 25 and 1200 m respectively.

The reflections identified on the seismic section correspond to the Shunda Fm carbonate (a peak), Pekisko Fm shale (trough), Pekisko Fm carbonate (a peak), a Banff Fm shale (strong trough) and Wabamun Gp carbonate (peak). It should be noted that unless it is built up in thicker mounds, the Pekisko Fm carbonate, at 10 to 12 m thickness, is generally too thin to be seen seismically.

Figure 6.45 compares the seismic response between regional carbonate bank and build-up. In Figure 6.45A the sonic from 16-1-82-13 W5M, with 35 m of Pekisko Fm carbonate, appears on the left. On the right, 23 m of carbonate are replaced by low velocity shales. The depth to the Banff Fm is constant. The corresponding synthetic seismograms are shown in Figure 6.45B. The Banff Fm event is pulled-up by the higher velocity mound carbonates, the time of the carbonate event changes from a cross-over to a peak and the peak above the Banff Fm trough becomes broader and stronger (lowered frequency).

Several changes are observed between traces 340 and 375, which is the location of a Pekisko mound (Fig. 6.44). The most noticeable is the poor coherency at all levels below the Shunda Fm, which is attributed to reduction and dispersion of energy within the mound. Pull-up between 10 and 15 ms is observed on the Banff event. There is dimming of the Pekisko Fm shale event as it thins over the mound and the Pekisko carbonate event rises, merging with the peak above it.

Of the wells, only 7-6 lies on the seismic line. The 10-34 well is southwest of the line and 12-16 is approximately three kilometres to the north. These latter two wells have been projected into the line to illustrate the regional geology beyond the mound drilled in 7-6.

CONCLUSIONS

Until the Seal wells were drilled and analyzed, reefing in the Pekisko Fm was considered unlikely or, at most, quite rare. Although these structures are mounds not reefs, their porosity and permeability make them viable exploration targets. Their seismic expression is similar to that of reefs hence the criteria used for reef-finding is valid for these features. Seismic is currently the only tool being used to locate these mounds. They vary in size and shape, but all are small, probably not more than 400 to 500 m long and up to 50 m high. Since the mound core is the reservoir, it is necessary to drill the highest point of these features as was done for the 7-6 well where the seismic data indicated rapid thinning to the east and a sharp drop-off to the west. At present only 2-D seismic is being recorded, but if any of the features encounter lighter oil, 3-D seismic may be justified and better delineation will be possible.

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