CHAPTER 7 – TRIASSIC/JURASSIC FIELDS

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INTRODUCTION

The stratigraphy, geological history and morphology of the Triassic and Jurassic systems are briefly discussed in the introduction to this Atlas. Generally, Triassic strata are far more prolific hydrocarbon bearing reservoirs than are Jurassic strata. Based upon volume of oil per volume of rock the Triassic section is the richest within the Western Canada Sedimentary Basin. Triassic reservoirs account for approximately 94.4 x $10^6 m^3$ of recoverable oil reserves, approximately 4% of the total within the entire basin (Podruski et al., 1987). This fact combined with the very subtle nature (from a seismic viewpoint) of producing Jurassic reservoirs and the relative unavailability of pertinent seismic data underlies the strict focus on Triassic reservoirs in this chapter (Fig. 7.1). Within the Alberta Basin, subsurface expression of the Triassic System consists of a thick sediment wedge within the confines of the Peace River Arch and in a northwest-southeast trending band preserved along the Foothills Belt of the Rocky Mountains. Triassic strata of the Absaroka sequence outline the final stages of cratonic carbonate sedimentation which dominated the Paleozoic. Carbonates within the Triassic are numerous but clastics dominate this part of the section. Provenance of Triassic sediments consisted mainly of Permian and Carboniferous sediments from a shoreline on the eastern and northern flanks of the emergent craton (Podruski et al., 1987). The westward thickening wedge (1300 m max.) contains sediments representative of more open marine conditions on the shelf/slope of the craton. The distribution of Jurassic reservoir quality rock is limited in the Peace River Arch area and southwestern Saskatchewan due to erosion and/or nondeposition.

The Triassic is bounded above and below by unconformities. The lower contact lies disconformably upon rocks of either Permian or Mississippian age. Although the Jurassic, where present, itself rests upon the Triassic disconformably, a larger regional unconformity bevels both the Jurassic and Triassic beds in such a manner that successively younger beds are absent toward the northeast, possibly due to uplift and subsequent erosion.

Tectonic activity that produced the collapse of the Peace River Arch in the upper Paleozoic remained active, albeit to a lesser degree, through the Mesozoic (Williams, 1958). Syn- and post-depositional movement along pre-existing faults warped and fractured Mesozoic sediments and in conjunction with pre-existing Carboniferous and Permian lows, produced anomalously thick Triassic sediments.

Three major transgressive-regressive shoaling upwards cycles occurred during Triassic time in the Peace River Arch region. Podruski et al. (1987) suggest depocentre preservation within the cratonic embayment indirectly supports epeirogenic movement during Triassic time. During the transgressive stage of the Early Triassic, thin-bedded calcareous shales and argillaceous siltstones (Barss et al. 1964) of the lower Montney (Griesbachian to Dienerian stage) accumulated within the depocentre. Eastward toward the shelf limit (Podruski et al. 1987), glauconitic sandstones occur with interbedded shales in northwest-southeast trending lineations parallel to the present Montney subcrop edge. Reservoir quality of these sandstones is poor with no known producing examples to date although oil-staining is prevalent.

Middle to upper Montney (Smithian and Spathian Stage) sediments which follow represent a much thicker regressive phase of the Early Triassic cycle. They consist of thick dolomitic to calcareous siltstone units with some limestone and sandstone. Porous sandstone and coquina deposits represent marked progradation of shoreline facies onto the shelf. The Sturgeon Lake South Triassic "A" pool produces from delta lobes, which prograded westward from a shoreline located east of the present subcrop edge (Miall 1976). Deeper structure influenced formation, placement and preservation of these lobes as inferred on the example seismic line Figure 7.30. This is outlined in detail in the Sturgeon Lake South field example.

The second transgressive-regressive cycle represents sediment progradation and shoreline migration to the west. Initially a phosphatic lag was deposited on the stratal disconformity separating the Montney and lower Doig (Anisian Stage) of the Daiber Gp. Thick clastics of the lower Doig Fm overlie this hiatal surface (Podruski et al., 1987). Regressive near-shore sands of the upper Doig and Halfway formations (Ladinian Stage) were subsequently deposited. Production from the Doig Fm occurs mainly from sand-filled estuarine channels and Doig drape features. Unfortunately no seismic data addressing Doig Fm production was available. The Halfway Fm predominantly produces from stratigraphic traps which consist of sandstones and coquinas which generally trend northwest-southeast, parallel to the paleo-shoreline. The Wembly seismic example illustrates production from a relatively broad nearshore to shoreline complex of prograding barrier bars and migrating tidal inlets. The Valhalla seismic example, on the otherhand, characterizes the less complex, isolated barrier bars which are narrower and more linear. The seismic response of these two reservoirs is quite different; the Wembley field shows a very subtle response at the Halfway level whereas the Valhalla field exhibits a strong amplitude anomaly. In both examples, however, deeper structure, apparent on the seismic data, probably influenced deposition of the Halfway Fm.

Halfway production also occurs in dolomitic coquinoid sandstones. These sandstones consist of quartz grains and pelecypod, brachiopod and crinoid fragments in a crystalline dolomite matrix (Cant, 1986). The Spirit River field produces from Halfway coquinoid sandstone and the example seismic line illustrates the basement influenced syn-depositional hinge-line platform where the sediments were deposited and preserved.

The Kobes field is a disturbed-belt expression of a Halfway reservoir. Here the reservoir consists of porous Halfway sandstones trending northwest-southeast on imbricate Laramide thrust-sheets with updip structural closure. The structural trapping also accounts for the Charlie Lake gas production in the same area.

The second cycle of Triassic sedimentation is terminated by interbedded evaporites, red beds, sandstones, siltstones, dolomites and limestones of the Charlie Lake Fm (Carnian stage). These sediments are indicative of a pronounced regression in the Peace River area and accordingly display abrupt lateral and vertical variations (Podruski et al., 1987). Production occurs from isolated sandstone lenses and dolomitized algal mat outliers. Generally seismic analysis cannot resolve these units nor is any deeper structuring evident. The Kobes Charlie Lake gas field is a notable exception.

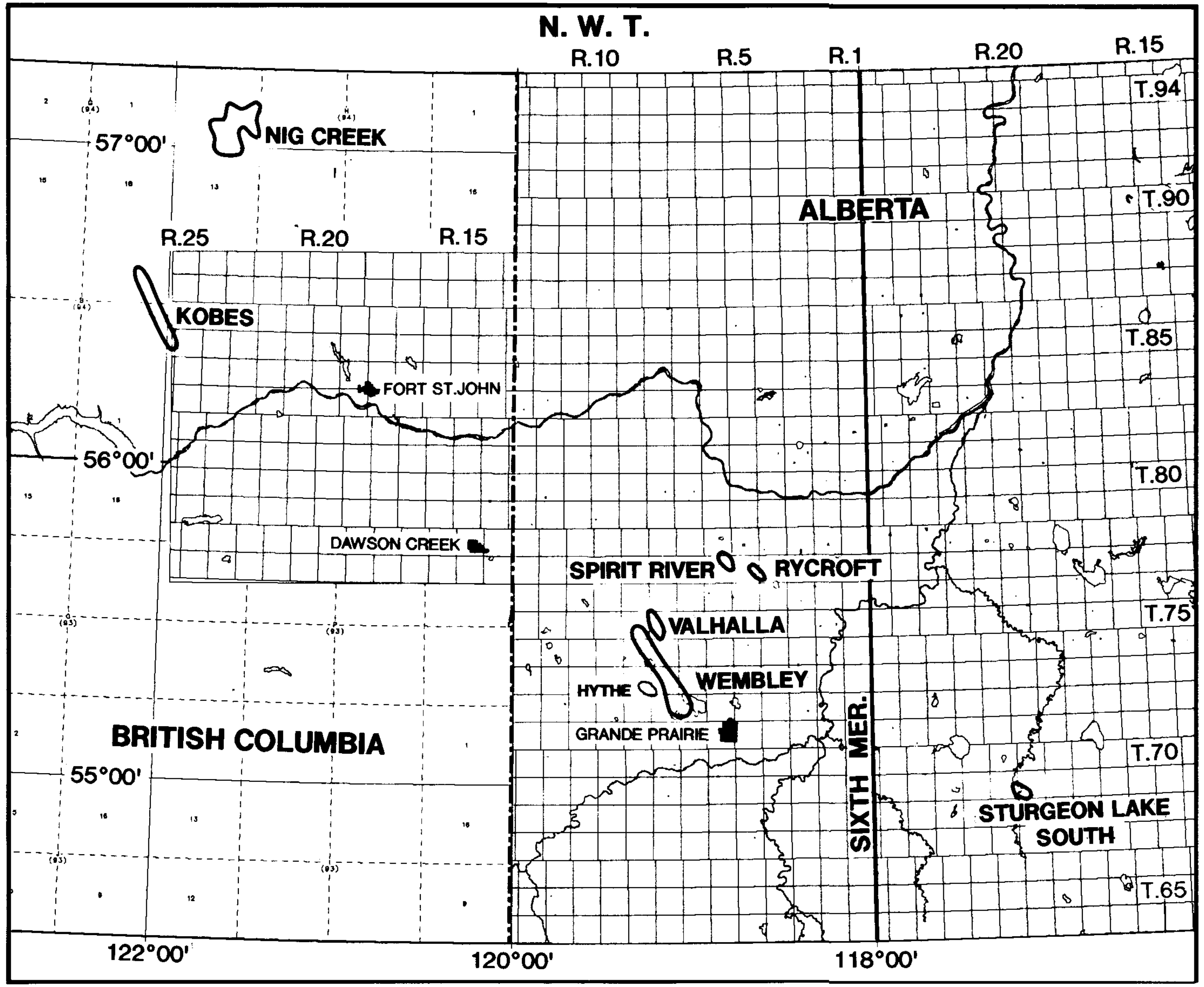

Figure 7.1. Location of Triassic reservoir examples.

The third cycle of Triassic deposition is dominated by carbonates and represents a return to shallow marine conditions (Podruski et al., 1987). Transgressive lower Baldonnel (Carnian) siltstones, dolomites and limestones form the base of this unit and are succeeded by upper Baldonnel and Pardonet (Norian) carbonates. Production occurs from residual structures and subcrop edges of the aforementioned units with the Nig Creek field being a prime example. A dolomitized crinoidal zone within the Baldonnel is the productive unit at Nig Creek. As illustrated in the example seismic section the trapping mechanism consists of northwest-southeast trending post-Triassic Laramide structures. Pre-Laramide structure may have influenced the Baldonnel subcrop edge alignment.

Although definitive dating of the Worsley/Tangent member has not been performed the dolomitized algal nature of the member compares favorably with older Charlie Lake members indicating a Triassic age. The reservoir quality of the member has been enhanced by the overlying disconformity and the member is widespread throughout the Peace River Arch area. Production occurs from the dolomitized algal mat in two separate trapping situations. The Worsley field produces from the Worsley Mbr on an upthrust horst block near the Worsley subcrop edge. Unfortunately no seismic data was available over the field itself. The Rycroft Charlie Lake "A" field produces from the Worsley/Tangent dolomite in a basement influenced erosional outlier encased in shales above (Nordegg) and below. The example seismic section once again illustrates the importance of identifying basement structure in deducing reservoir presence and structurally favorable reservoir position.

NIG CREEK FIELD

INTRODUCTION

The Nig Creek field is located in northeastern British Columbia, and was discovered in 1953. The field consists of two assigned Triassic pools, containing hydrocarbons in the Baldonnel and Halfway formations. Nig Creek field was selected as an example for the Triassic Schooler Creek Gp reservoir because:

1) the Baldonnel 'A' pool at Nig Creek is a significant reservoir from an economic perspective, with reserves of 16 559 x $10^6 m^3$ (587.8 Bcf) of gas and 22.1 x $10^6 m^3$ (138 x 10^6 bbls) of oil; and

2) the structural element in the Nig Creek field is well illustrated in the example seismic line.

The 'A' pool and other Baldonnel pools in the area are located close to the western edge of the Baldonnel Fm erosional limit. As a consequence of proximity to the subcrop, the Baldonnel Fm ranges from 0 to 100 m in thickness depending on the amount of post-Triassic erosion.

The reservoir in the Nig Creek field is a 10m thick, widespread zone of shelly crinoidal carbonate and is situated stratigraphically 10 to 15m below the top of the Baldonnel Fm. Hydrocarbons in the Baldonnel Fm are trapped by a combination of three factors:

1) Stratigraphy - where porous Baldonnel Fm is preserved on erosional highs and sealed against the tight carbonates and shales of the Jurassic Nordegg Fm or against sandstones and shales where the pre-Cretaceous unconformity incises deeply into the Baldonnel Fm;

2) Structure - Minor Laramide structural closures trending north-west-southeast have been influenced by deep seated basement structures and control the distribution of the reservoir fluid phases; and

3) Reservoir diagenesis - Calcite infilling and replacement cause porosity reduction on a local scale and can affect reservoir fluids.

GEOLOGICAL CROSS-SECTION

Figure 7.2 gives the locations of the four wells incorporated into the geological cross-section (Fig. 7.3) and the seismic line (Fig. 7.4). This map also shows the topography on the top of the Baldonnel unconformity. As illustrated, the seismic and the geological cross-sections extend across a major structural high on which some smaller structural features are present. These smaller features are difficult to identify based on well data alone.

The lowest labelled horizon on the cross-section is the Charlie Lake Fm which underlies the Baldonnel Fm and is primarily composed of carbonate, siltstones and anhydrite. It has an uniform thickness of 100m in the study area. In contrast, the thickness of the Baldonnel Fm changes rapidly in the area, due to post-Triassic erosion. The amount of erosion is illustrated in the cross-section by well b-50-A/94-H-4. Well b-50-A has the entire Nordegg and Baldonnel formations removed, with a thick section of Cretaceous sandstone and shale infilling the erosional low. The erosional edge of the Baldonnel Fm is illustrated in Figure 7.2. The irregularity of this edge could provide numerous opportunities for stratigraphic traps as displayed by the 'A' pool.

The Nordegg Fm shale in this situation provides both a seal and source. Also evident is the Laramide low amplitude folding which strikes in a northwest - southeast direction. The reservoir facies within the Baldonnel Fm is very close to the erosional unconformity. The shelly crinoidal zone has porosities in the range of 10-12% and can be correlated over a wide area by gamma-ray logs. The shelly crinoidal zone has been interpreted as being deposited during a stillstand of the main Norian transgression.

SEISMIC SECTION

The example seismic line is shown in Figure 7.4. These data were recorded in 1982 using a dynamite source (single charge of 2.25 kg at 23 m depth), a 2400-m split spread, 300-m shot spacing and a 100-m group interval. This particular arrangement gave a coverage of 400%. Although this coverage is considered low with respect to the present industry standard, the data are fairly good in quality.

Identification of seismic reflections below one second are difficult because most wells in the Nig Creek area are quite shallow, usually bottoming in the Triassic sediments. To assist the interpretation, the well a-12-G/94-H-4 located approximately 5.5km to the northwest was projected into the line. The synthetic seismograms, in normal and reverse polarities, created by a 30 Hz Ricker wavelet are shown in Figure 7.5. Several large velocity contrasts are clearly shown on the sonic log. Large amplitude reflections are anticipated at the Bluesky, Baldonnel, Debolt, Banff, Kotcho, Tetcho and Utahn (or Jean Marie) interfaces. The normal polarity synthetic seismogram was used to interpret the seismic data.

The two parallel seismic reflections at approximately 1.48 and 1.57 seconds are the upper Devonian Kotcho and Utahn (Jean Marie) events. These show strong amplitude reflections, which can be attributed to the sharp positive impedance contrast between shale and limestone. The time structure (30 to 40 ms anomalies) defined by these reflections is thought to be related to deeper structures, possibly associated with normal faulting and/or basement topography. It is difficult to evaluate these structures since wells penetrating beyond the Triassic are scarce in the area. However, to the southeast of the Nig Creek field normal faulting is common. The Banff event is identified at 1.25 seconds in the seismic section. The event is picked as a peak, resulting from a positive impedance contrast between a unit of interlayering shale and limestone layers at the top and a clean limestone at the base. The Banff event shows less time structure than the Kotcho event. This may suggest that the structuring below 1.4 seconds in the seismic is pre-Mississippian in age and the majority of the tectonic movement took place after the deposition of the Kotcho Fm.

The next event identified on the example seismic section is the Shunda. From the synthetic seismogram in Figure 7.5, the Shunda is anticipated to have a poor quality reflection due to the lack of a good impedance contrast. The thin shale-limestone beds cause destructive interference, resulting in a low amplitude reflection on the seismic section. In contrast, the erosional top of the Debolt Fm produces a reflection event which is clearly visible both in the synthetic seismogram and seismic section (near 1.1 seconds). The Debolt event is interpreted as a positive amplitude resulting from a sharp positive change in impedance, from a low-velocity shale to a clean higher velocity limestone.

Isochron changes are observed between the Debolt and Banff events. These changes in isochron may be the result of tectonic activity and/or erosional effects on the Debolt surface. Located at approximately 0.95 - 0.99 seconds on the seismic section are the Halfway and Doig events. The Halfway Fm is interpreted to have been deposited as a blanket sandstone approximately 10 to 12 m thick.

Porosity and permeability are generally good in the area and some gas production has been discovered to the west of the Nig Creek field. Structural closure of the Halfway Fm is considered to be the main trap type for hydrocarbons. Doig Fm channel sandstone, when present, can also be prospective in the vicinity. However, the Doig Fm in the Nig Creek field generally consists of shale and siltstone.

The seismic image of the Baldonnel Fm is dominated by high amplitude (peak) events. The reflection amplitudes are caused by sharp changes in impedance (shale to dolostone) as illustrated in the synthetic seismogram in Figure 7.5. Gas may partly contribute to the high amplitude reflections. It is interesting to note that the Baldonnel event dims at well location b-50-A, where the post-Jurassic erosional channel has removed the entire Nordegg and Baldonnel formations, leaving behind a thick consolidated sandstone and shale sequence. The structure on the top of the Baldonnel Fm is

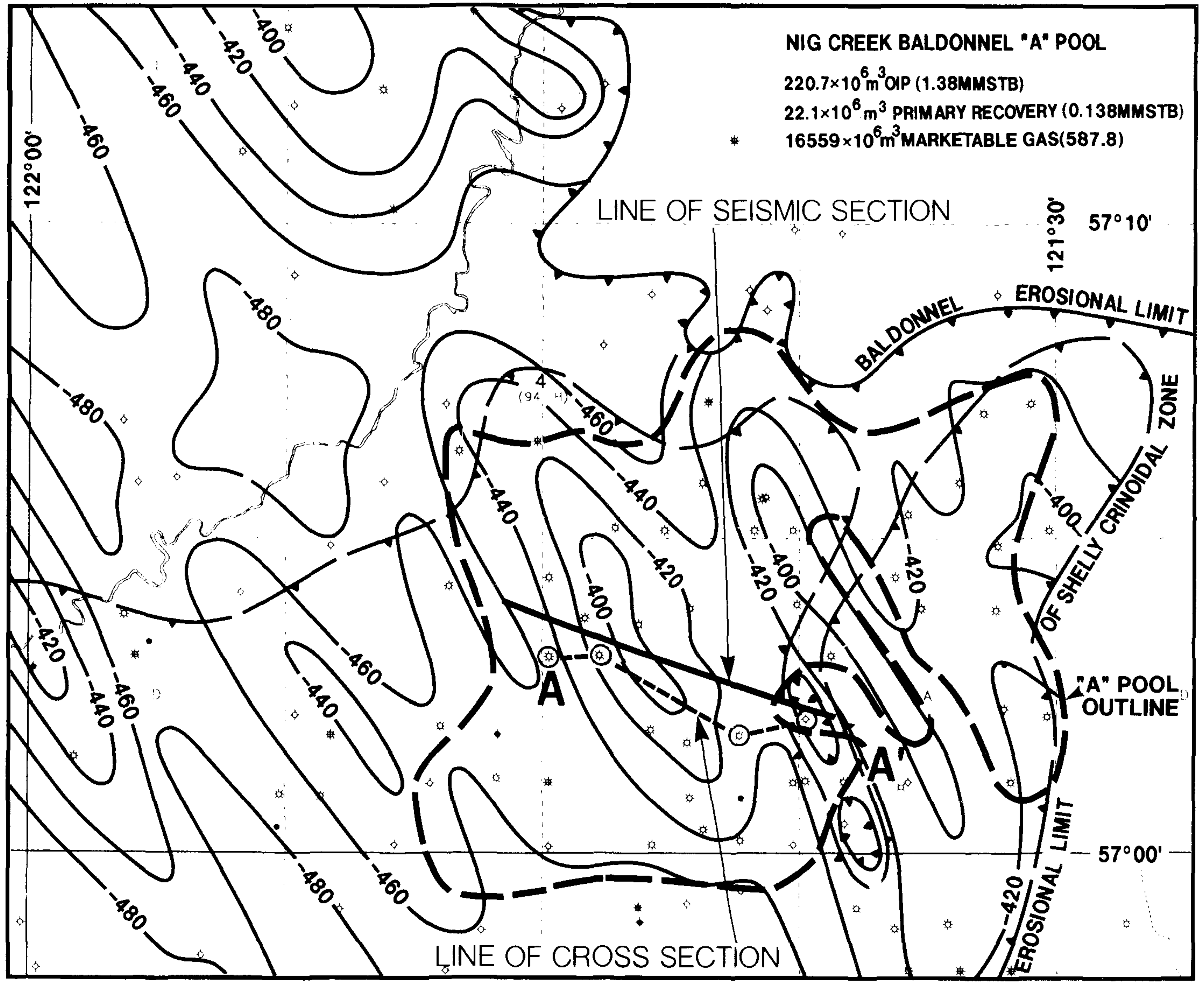

Figure 7.2. Nig Creek Baldonnel A pool and position of geological cross-section and seismic section.

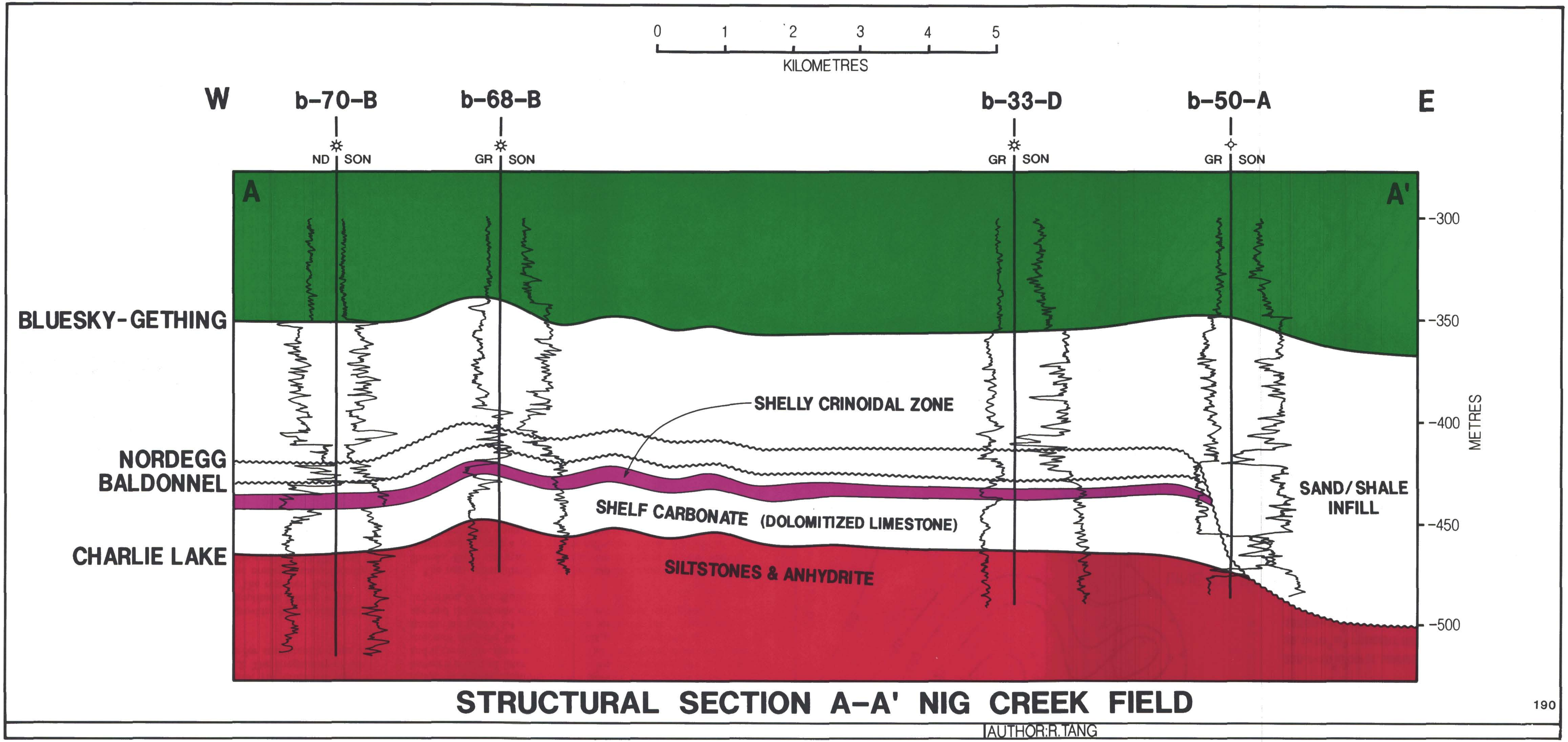

Figure 7.3. Geological cross-section, Nig Creek Field.

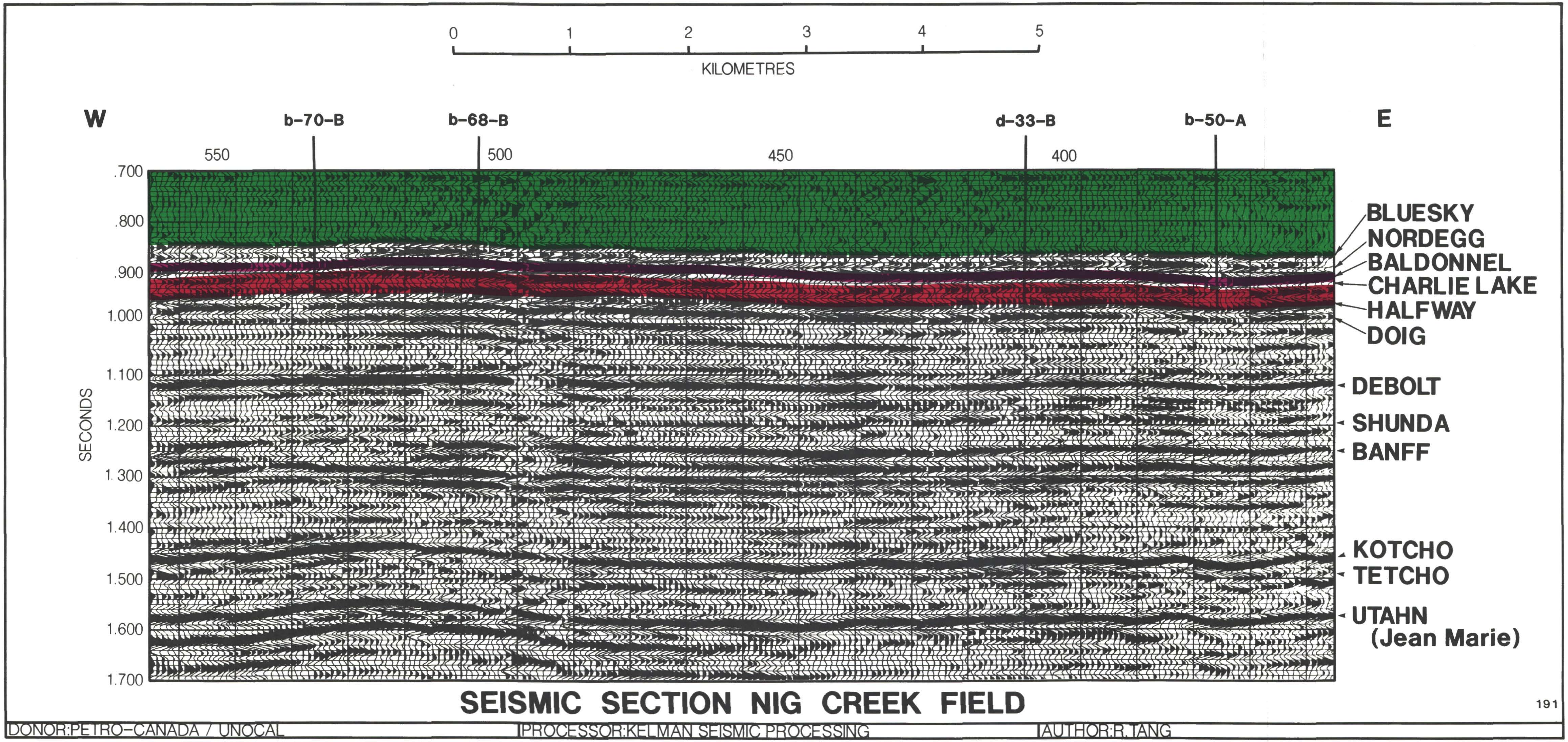

Figure 7.4. Seismic section, Nig Creek Field.

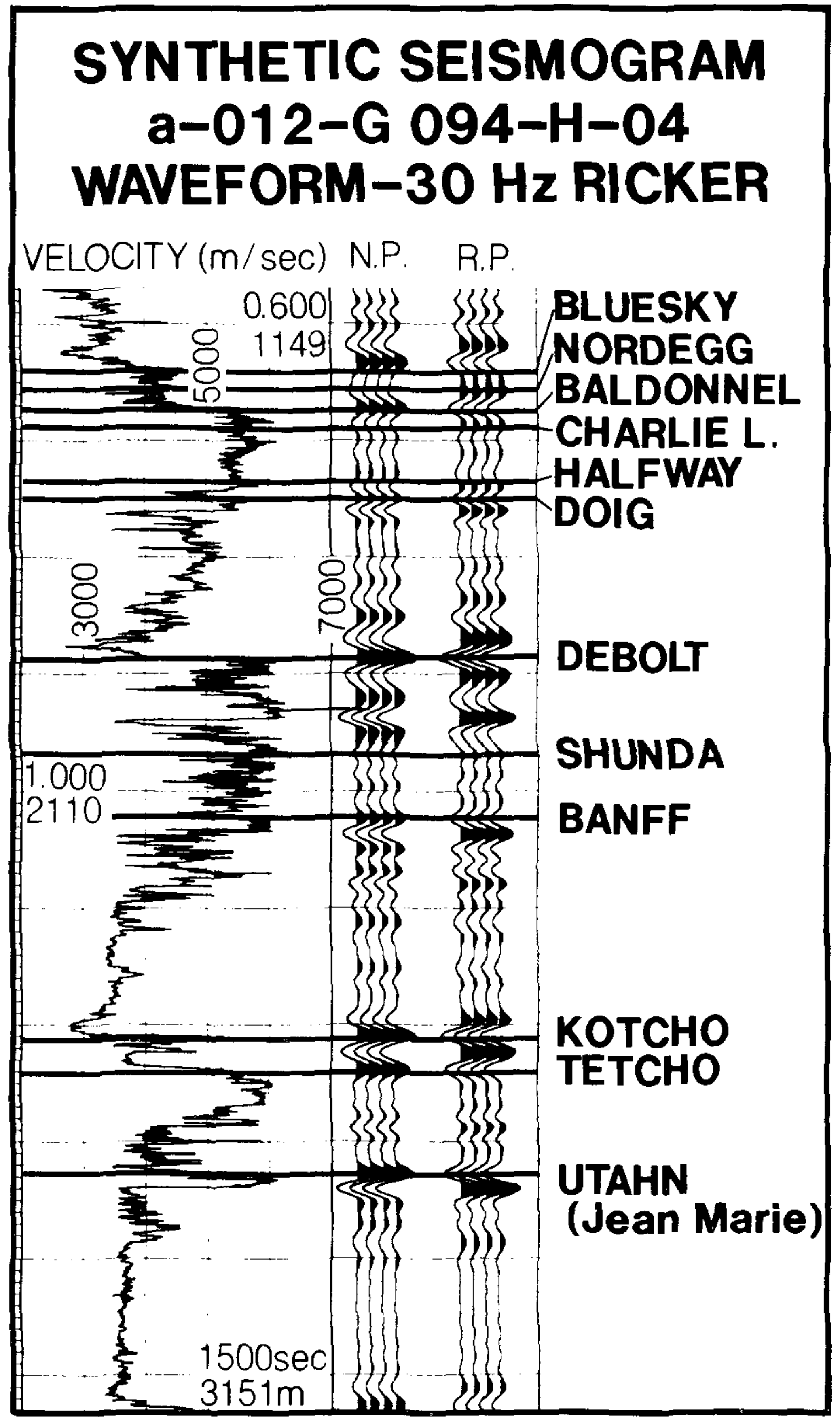

Figure 7.5. Synthetic seismogram for well a-012-G 094-H-4.

primarily caused by drape over deep-seated structures. There is Laramide structuring to the west of the Nig Creek field but its influence on highs within the field is subtle at best.

It is important to map both the location of the post-Triassic channels and the relative structural highs in exploring and developing Baldonnel Fm reservoirs. Since the porous shelly crinoidal zone is not seismically visible, geological mapping is critical to the prediction of the hydrocarbon trap.

The last two events identified on the example seismic section are the Nordegg and Bluesky formations. The Nordegg, in general, is a poor quality reflection due to the lack of impedance contrast. A clearly identifiable Bluesky event can be seen on the seismic section due to the contrast between the overlying Mannville Gp shale and the Bluesky Fm sandstone. Both the Nordegg and Bluesky events show structure on the seismic section due to drape over deep-seated structures and post-Triassic infilled topography. Also note that the Nordegg event completely dims out at location b-50-A where the entire Nordegg has been eroded and replaced by a Cretaceous age sandstone and shale unit.

SUMMARY

The three major factors which control the trapping of hydrocarbons in the Nig Creek field are erosional topography on the top of the Triassic surface, minor Laramide related structure, and reservoir diagenesis. Present seismic techniques can only provide images of the structural element. Occasionally, where post-Jurassic erosion has incised into the Baldonnel Fm and juxtaposed Baldonnel Fm carbonate laterally against Cretaceous age clastics, a change in seismic response may be detected. However, geological mapping remains critical to the prediction of hydrocarbon traps in the Nig Creek field.

KOBES FIELD

INTRODUCTION

The Kobes Halfway "A" gas field is located in northeastern British Columbia approximately 75 km northwest of Fort St. John. The field was discovered in 1956 by Phillips Petroleum with the drilling of d-94-I/94-B-8 which tested 402 x $10^3 m^3$ (14.2 MMcf) of gas per day from the Halfway Fm. The Kobes field also produces from the Debolt Fm, five zones in the Charlie Lake Fm and from the Dunlevy

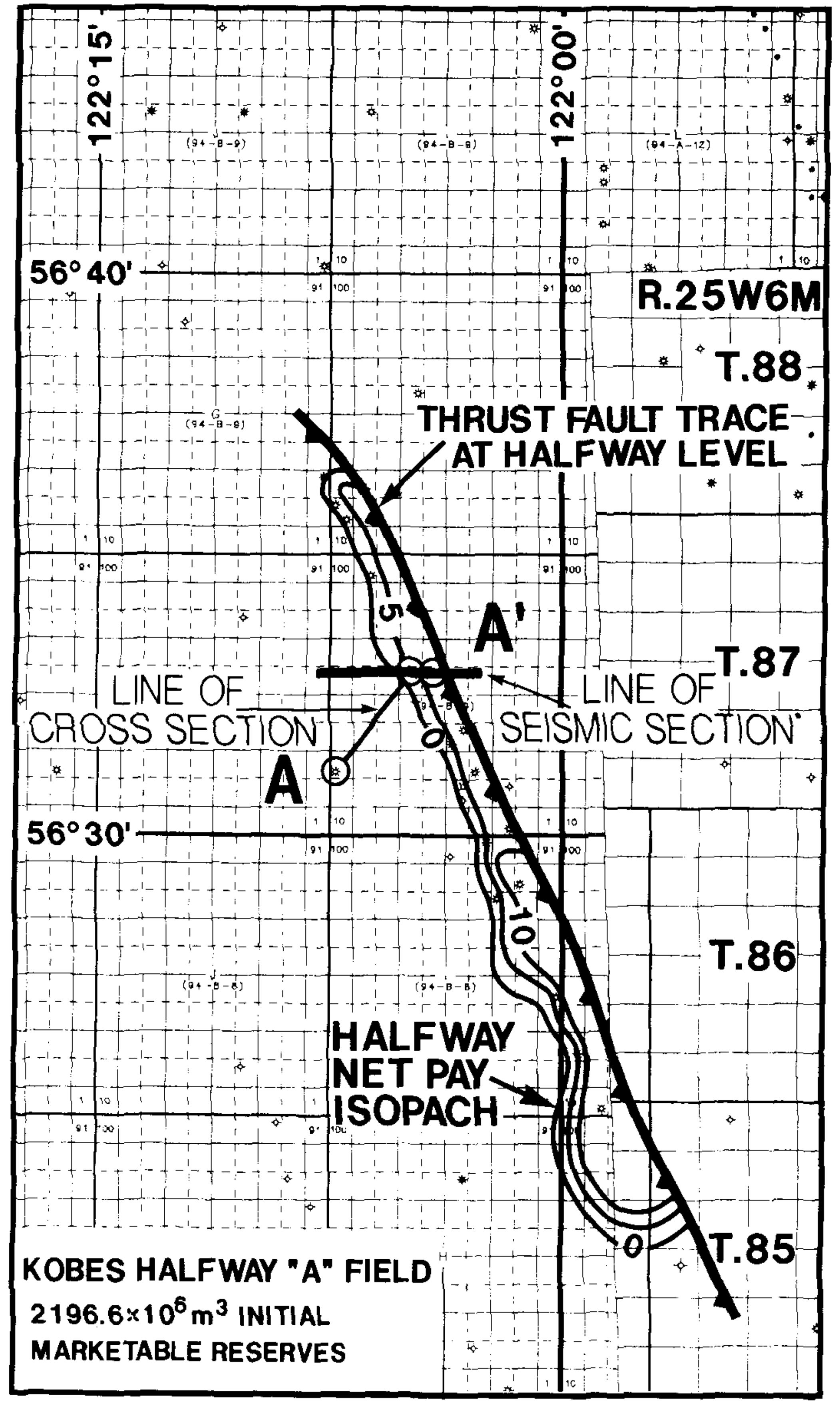

Figure 7.6. Kobes Halfway A field and position of geological cross-section and seismic section.

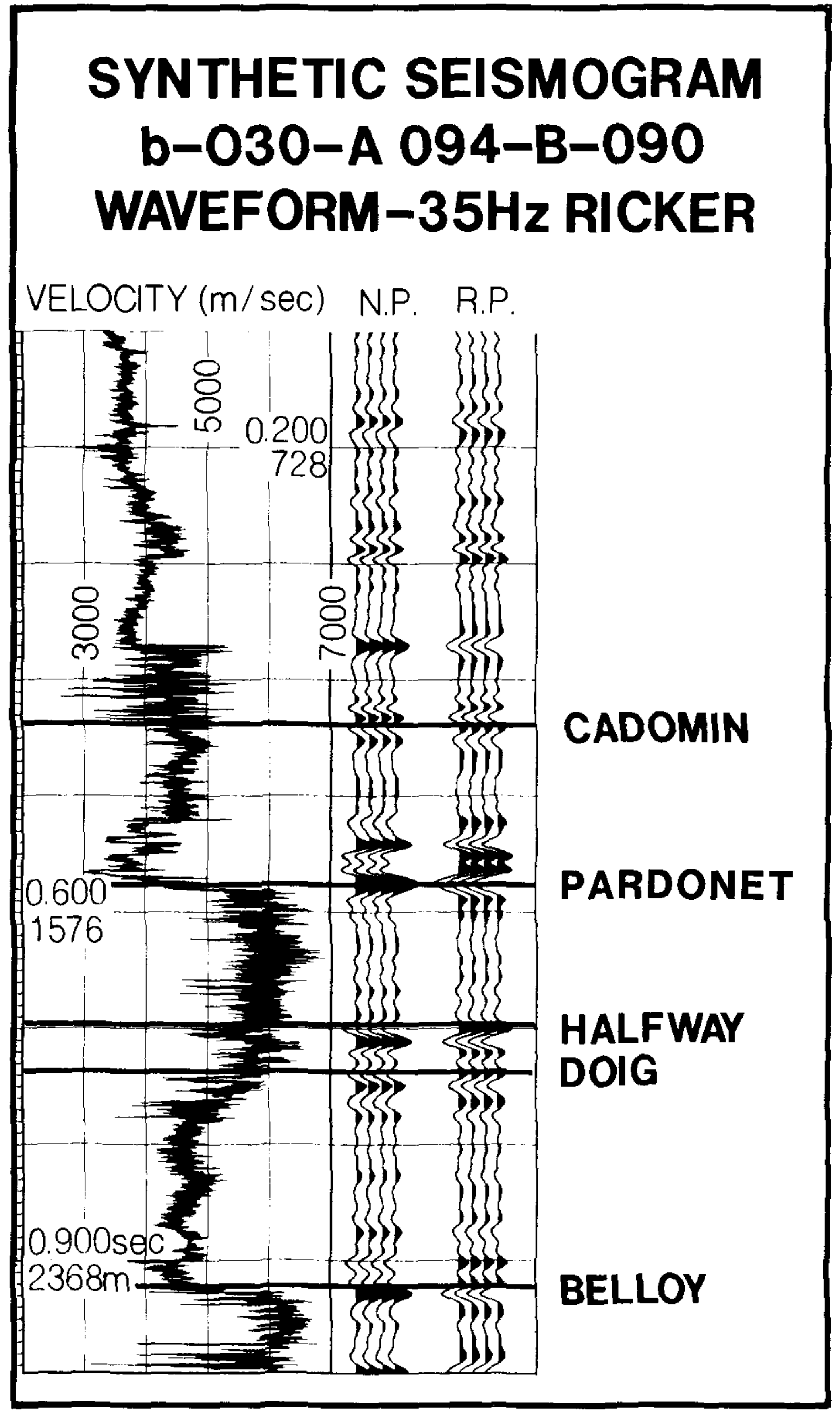

Figure 7.9. Synthetic seismogram well b-030-A 094-B-090.

Fm (Cadomin equivalent). Reserves in the Halfway Fm are greater than the combined reserves of the other zones and for this reason the other zones will be addressed only briefly.

The Triassic sequence in the Kobes area is bounded above and below by unconformities and increases in thickness from about 850 m in the northwest to 950 m in the southeast. Triassic sediments exhibit a generally regressive nature from the basal Toad-Grayling Fm to the top of the Charlie Lake Fm. The Toad-Grayling Fm consists of marine shales and siltstones which unconformably overlie the Belloy Fm. The Doig Fm conformably overlies the Toad-Grayling Fm and consists of siltstones and fine-grained sandstones. The Halfway Fm is comprised of shoreline sandstones, siltstones and minor dolomite units. The overlying Charlie Lake Fm grades from shoreline sandstones to supratidal anhydrites and dolomites. The Baldonnel Fm carbonates conformably overlie the Charlie Lake Fm and mark the return to more open marine conditions. The youngest Triassic unit preserved in the area is the Pardonet Fm. It conformably overlies the Baldonnel Fm and is unconformably overlain by the Nordegg Fm.

A plan view map of the Kobes Halfway "A" field is shown in Figure 7.6. The Halfway "A" net pay isopach is contoured at five metre intervals. The approximate location of the thrust fault trace at Halfway level is also shown. This information was obtained from a gas field map published by the Province of British Columbia Ministry of Energy, Mines and Petroleum Resources: Energy Resources Division.

The Kobes Halfway "A" field is approximately 30 km in length and 2 km in width and trends northwest-southeast. The Halfway Fm reservoir consists of porous sandstone which ranges in thickness from 0 to 15 m. The top seal is provided by tight facies of the Charlie Lake Fm.

The field is located in the foothills of northeastern British Columbia. The primary geological feature in the subsurface is a series of southwest dipping thrust faults. These faults flatten and converge into the Banff Fm and appear to be absorbed in the Lower Cretaceous units. This faulting has resulted in the formation of an anticlinal trap for Halfway Fm hydrocarbons.

Initial volume of gas in place for the Halfway "A" is estimated to be 2,858 x $10^6 m^3$ (101 Bcf). Marketable gas reserves are estimated to be 2,197 x $10^6 m^3$ (77.7 Bcf). The reservoir has an average porosity of 6.5% and an average water saturation of 25%.

The seismic method is extremely useful in identifying Triassic anticlinal traps associated with the Laramide Orogeny. However, since the quality of the Halfway Fm reservoir is quite variable, geological mapping is necessary in order to predict where, along the anticline, the best reservoir may be encountered.

GEOLOGICAL CROSS-SECTION

The location of the geological cross-section, Figure 7.7, is shown on the map of the Kobes field (Fig. 7.6). The cross-section is oriented roughly perpendicular to the trend of the field and parallel to regional dip. It incorporates one dry and abandoned well which was drilled to the Debolt Fm, one Triassic gas well drilled to the Doig Fm and one Cretaceous gas well drilled to the Fernie Fm. Log traces for the above wells are not illustrated due to the highly compressed vertical scale. The geological horizons which are labelled on the cross-section correspond to correlative seismic horizons on the example seismic section.

The Banff Fm is the lowest identified horizon on the cross-section. Depth control on this horizon is inferred from deeper wells outside the area and is therefore only approximate.

The next labelled event, the Belloy Fm, is roughly 25 m in thickness and consists of calcareous siltstone, chert and shale. It unconformably overlies the Debolt Fm and is unconformably overlain by the Toad-Grayling Fm. The Belloy to Banff isopach is shown to thin slightly to the east to correspond to the isochronal thinning evident on the seismic section. This thinning is a reflection of the angular nature of the Mississippian unconformity.

The Doig and Halfway formations are the next labelled horizons on the cross-section. The Doig Fm conformably overlies the Montney Fm and consists of fine-grained, subangular to subrounded, medium-sorted calcareous or dolomitic siltstone. The contact between the Doig Fm and the underlying Montney is placed at the base of the phosphatic Black Shale Mbr of the basal Doig Fm (Barss and Montandon, 1981). The contact between the Doig Fm and the overlying Halfway Fm is difficult to define in this area but may be made at the base of a massive fine-grained sandstone. There is also an increase in grainsize associated with the Halfway Fm which consists of calcareous, dolomitic and quartzitic nearshore marine sandstone. It is conformably overlain by the predominantly supratidal sediments of the Charlie Lake Fm.

The Charlie Lake Fm is conformably overlain by the Baldonnel Fm which consists primarily of dolomite with minor amounts of siltstone and marks the return of more open marine conditions. The Baldonnel is conformably overlain by the Pardonet Fm which is the next labelled event on the cross-section and consists of a dolomitic siltstone. Contact between the Pardonet Fm and the overlying Fernie Fm is erosional and is placed at the base of the Nordegg Mbr shale.

The last labelled horizon on the cross-section is the Cadomin Fm which unconformably rests on the Nikanassin Fm and is conformably overlain by the Gething Fm. The Cadomin Fm consists of a coarse-grained, conglomeratic sandstone with abundant chert.

The geological cross-section illustrates the structural aspect of the Kobes field. Compressive forces exerted during the Laramide Orogeny resulted in eastward translation of the sedimentary package along listric thrust zones. A series of these thrust faults have been interpreted from the seismic section and are illustrated. The age of the faults decreases downwards, that is, the lowest fault is also the youngest. These faults are interpreted to sole out in the Banff Fm to the west and to step-up through the overlying sediments in the area of the Kobes field. The result of this translation was the formation of an anticlinal trap in the Halfway Fm. The other producing zones also rely on this structure for the trapping of hydrocarbons. The faults themselves do not seem to supply an updip seal since the vertical displacement of the Halfway Fm across these faults is not sufficient to juxtapose non-reservoir rock and reservoir rock.

SEISMIC SECTION

The example seismic section shown in Figure 7.8 is 12-fold dynamite data acquired in February, 1981. A single 10 kg charge of dynamite at a depth of 15 m was used as the source. The shot interval was 100 m. The receiver array consisted of nine 10 Hz geophones over 50 m with a group interval of 50 m. Data were recorded from a split-spread configuration (near offset 100 m, far offset 1250 m) at a 2 ms sample rate utilizing a DFS-5 instrument. An 8-128 Hz field filter was used.

The seismic section is displayed (Fig. 7.8) as a normal polarity section. Standard processing was applied except for the application of a pre-stack migration algorithm. Events were correlated with the aid of several synthetic seismograms, one of which is illustrated in Figure 7.9. A zero phase Ricker wavelet having a dominant frequency of 35 Hz was used to generate the b-30-A synthetic.

The Banff event is the lowest identified event on the seismic section. This peak originates from the base of a 10 to 15m thick shale which overlies a relatively clean carbonate. The top of the Banff Fm is placed at the top of the shale unit. The peak, therefore, represents an event near the top of the Banff Fm and was chosen over the leading trough due to its greater amplitude and continuity. It is below this event, within the less competent Banff Fm shales, that the thrust faults are interpreted to flatten out.

The next labelled event on the seismic section is the Belloy Fm. This peak is interpreted to originate at the positive impedance contrast between an argillaceous siltstone unit and an underlying calcareous siltstone unit within the Belloy Fm. This event is strong and continuous across the seismic section except in the zones bounded by the thrust faults where it is tentatively identified.

The Doig and Halfway are the next labelled events on the seismic section. The Doig is interpreted to be a trough originating at the negative impedance contrast between the calcareous shale at the top of the Doig Fm and the overlying Halfway Fm siltstone. The Halfway event is interpreted to be a peak originating at the positive impedance contrast between porous sandstone near the top of the Halfway Fm and underlying tight Halfway Fm sandstone. This event, therefore, approximately represents the base of Halfway Fm porosity. Both the Doig and Halfway events are strong and continuous from the western end of the seismic section to approximately trace 180. The strength and continuity of these events and events shallower in the section degrade between approximately traces 180 and 160. This loss in signal quality may be surface related or the result of physical deformation of the strata over the anticline. A loss of amplitude and continuity of the Halfway event is also seen in the zones bounded by the thrust faults and correlation, again, is tentative.

The next event labelled on the seismic section is the Pardonet. This peak is interpreted to originate at the positive impedance contrast between the dolomitic siltstone of the Pardonet Fm and the overlying Nordegg Mbr shale. Except for the zone over the anticline, this event is strong and continuous.

The remaining labelled event on the seismic section is the Cadomin. This trough is interpreted to originate at the negative impedance contrast between the porous Cadomin Fm conglomerate and the overlying Gething Fm siltstone and sandstone.

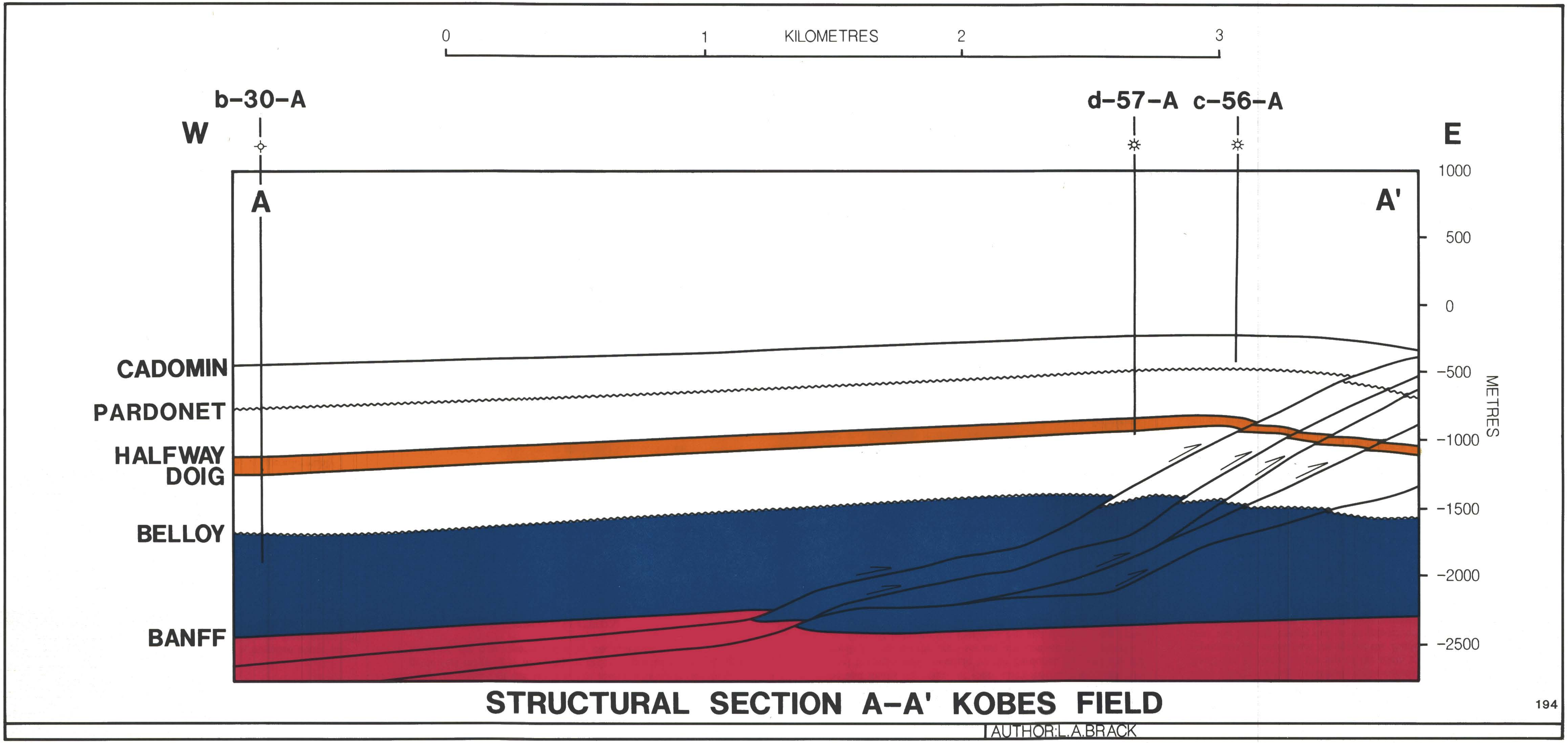

Figure 7.7. Geological cross-section, Kobes field.

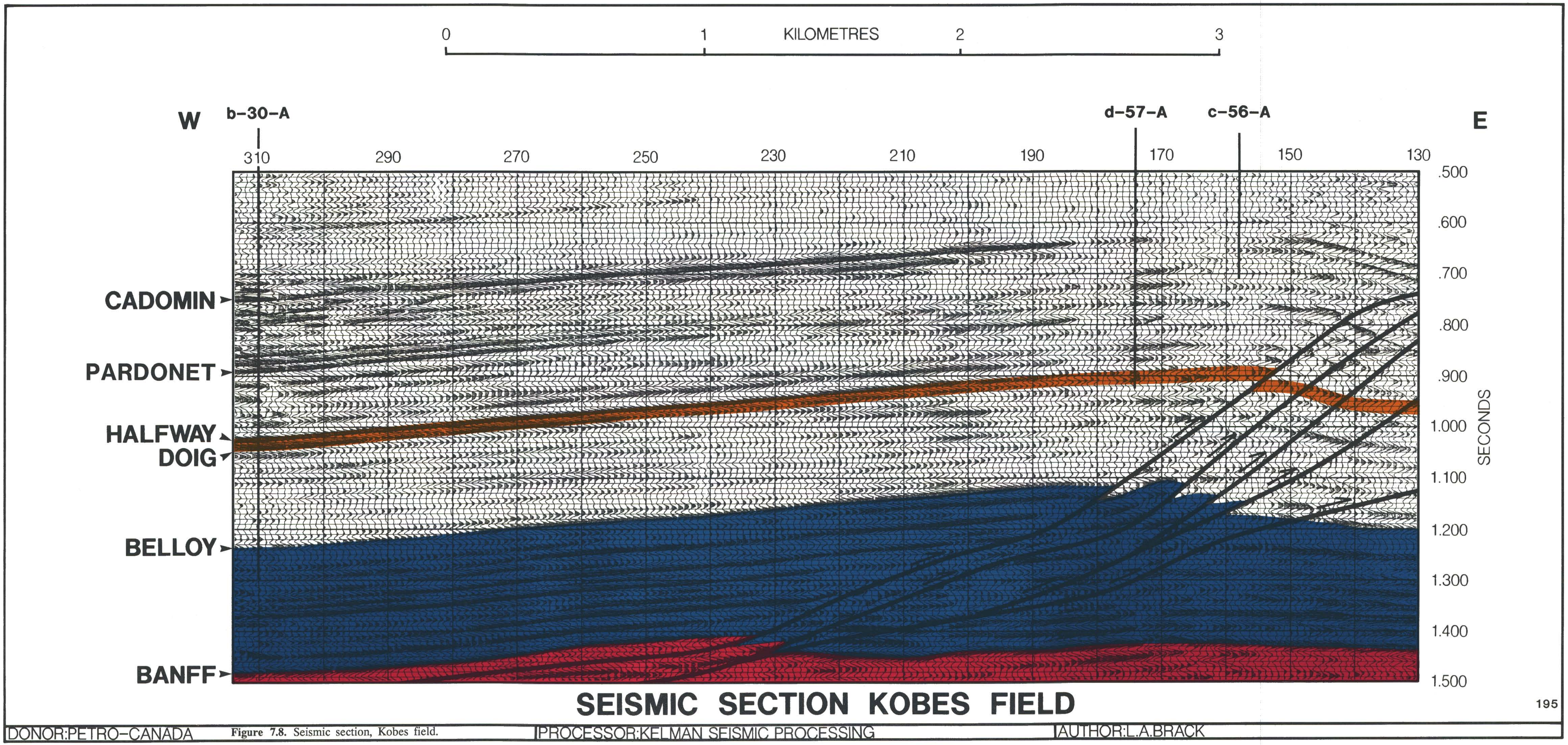

Figure 7.8. Seismic section, Kobes field.

SUMMARY

The Kobes Halfway "A" field produces natural gas from porous Halfway Fm nearshore marine sandstone. Net pay and porosity average 6.5 m and 6.5% respectively. Hydrocarbons are trapped structurally in an anticlinal trap which was formed by Laramide compressive forces. The presence of the structural trap is well-defined seismically, but due to the variability of reservoir quality geological mapping is necessary to identify areas along the anticline where superior reservoir rock may be encountered.

SPIRIT RIVER HALFWAY FIELD

INTRODUCTION

Production in the Spirit River Halfway field is mainly from clastic carbonate coquinas of the Halfway Fm and unconformably overlying carbonate algal mats of the Charlie Lake Fm. Both the Halfway and the Charlie Lake Fm are stratigraphic traps sealed by updip Halfway Fm anhydrites and overlying Charlie Lake anhydrites and siltstones.

The Spirit River Halfway field is located in north-central Alberta (Fig. 7.10) and is one of a series of northwest-southeast trending offshore bar sequences. The porous Halfway occurs on successive progradational hinge line platforms, which in the case of the Spirit River field, is apparent on the example seismic line. The Spirit River field, however, occurs very near the depositional/erosional edge of the Halfway Fm and the Schooler Creek Gp. It is because of this that the Halfway sequence is primarily comprised of dolomitic coquinas and stacked bar sequences which would indicate a very near shore subtidal environment. The geological cross-section through the Spirit River field shows the trap morphology, stratigraphy and facies relationships discussed above.

The Spirit River Halfway field is approximately 15 km long by 3.5 km wide and aligned northwest-southeast parallel to the paleo-shoreline. The unit, near the seismic line attains a gross thickness of 30 m with maximum oil pay of 15 m. The map view (Fig. 7.10) shows both the geological cross-section and the seismic line extending from the updip sabkha anhydrites through the intertidal algal mats and nearshore stacked bar sequence of the field into tighter offbar sandstones and siltstones. Production in the Spirit River/Rycroft field is primarily from the updip stacked bar. Porosities range from 10 to 30% in the stacked bar coquinas and from 3 to 22% in the tidal flat algal mats. Permeabilities in the

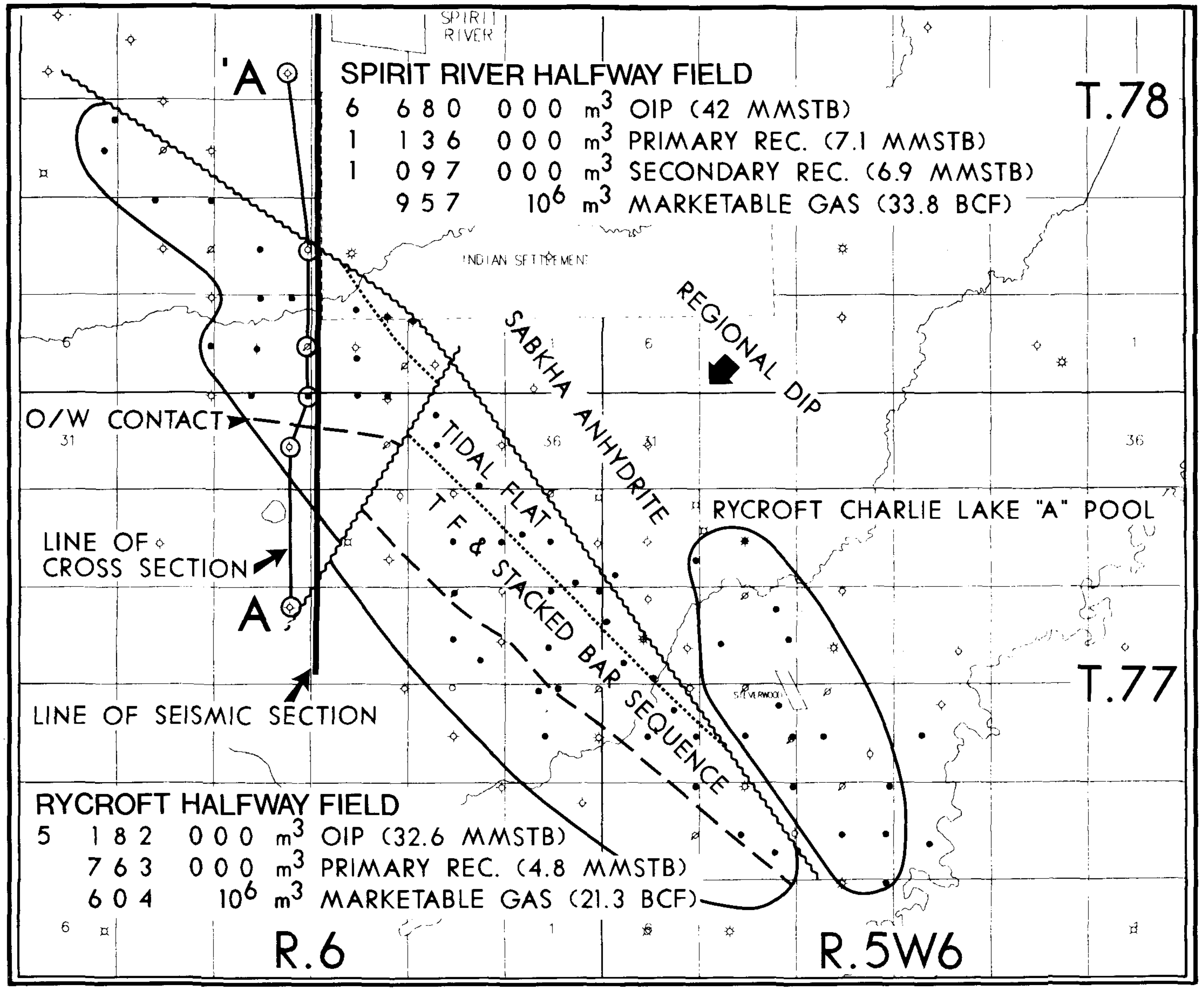

Figure 7.10. Spirit River Halfway field and the location of the geological cross-section and the seismic section.

stacked bar coquinas range from 0.5 md (anhydrite plugged) to 10 Darcies, whereas algal mat permeabilities range from 0.5 md (anhydrite plugged) to 200 md.

The Spirit River Halfway field was initially discovered in 1983 as was the associated Rycroft Halfway field which are separated by a southwest-northeast trending fault (Fig. 7.10). Both fields were fully developed by 1985 with secondary recovery water injection in place in the Spirit River field. Reserves and recoveries for the respective fields are annotated on the schematic map (Fig. 7.10).

GEOLOGICAL CROSS-SECTION

The geological cross-section (Fig. 7.11) parallels the example seismic line in a north-south configuration. The oblique orientation of the seismic line and cross-section to the northwest-southeast strike of the field helps portray field parameters over a wider area. The cross-section is hung on a structural datum which emphasizes the subtle field morphology.

Basement faulting occurred during Halfway deposition which directly influenced deposition of the shallow water algal mats and coquinas and ensured their subsequent preservation. A hingeline flexure occurs downdip of 7-21 marking the lateral boundary between the updip Halfway Sabkha anhydrite and the platform dolomitized algal mats and dolomitic coquinas. The algal mats disconformably overlie the stacked bar coquinas indicating a separate regressive stage. The algal mats are unconformably overlain by the Charlie Lake siltstones and anhydrites.

The platform depocentre extends from 8-9 to 16-33 where consistent thickness of both the stacked bar and the tidal flat are preserved as is the reservoir quality. Another more subtle flexure occurs updip of 8-33 where the Halfway has graded into siltstones and very fine-grained sandstones indicative of deeper water deposition. The general structural configuration of the field at the time of Halfway deposition has been preserved in a relative sense and is apparent on both the cross-section and the example seismic line.

SEISMIC SECTION

The orientation of the example seismic section (Fig. 7.12) is shown on the schematic plan view (Fig. 7.10). The example line was recorded in 1976 using a dynamite source (2 kg at 15 m), a 1575 m split-spread, a 134 m source interval, and a 33.5 m group interval.

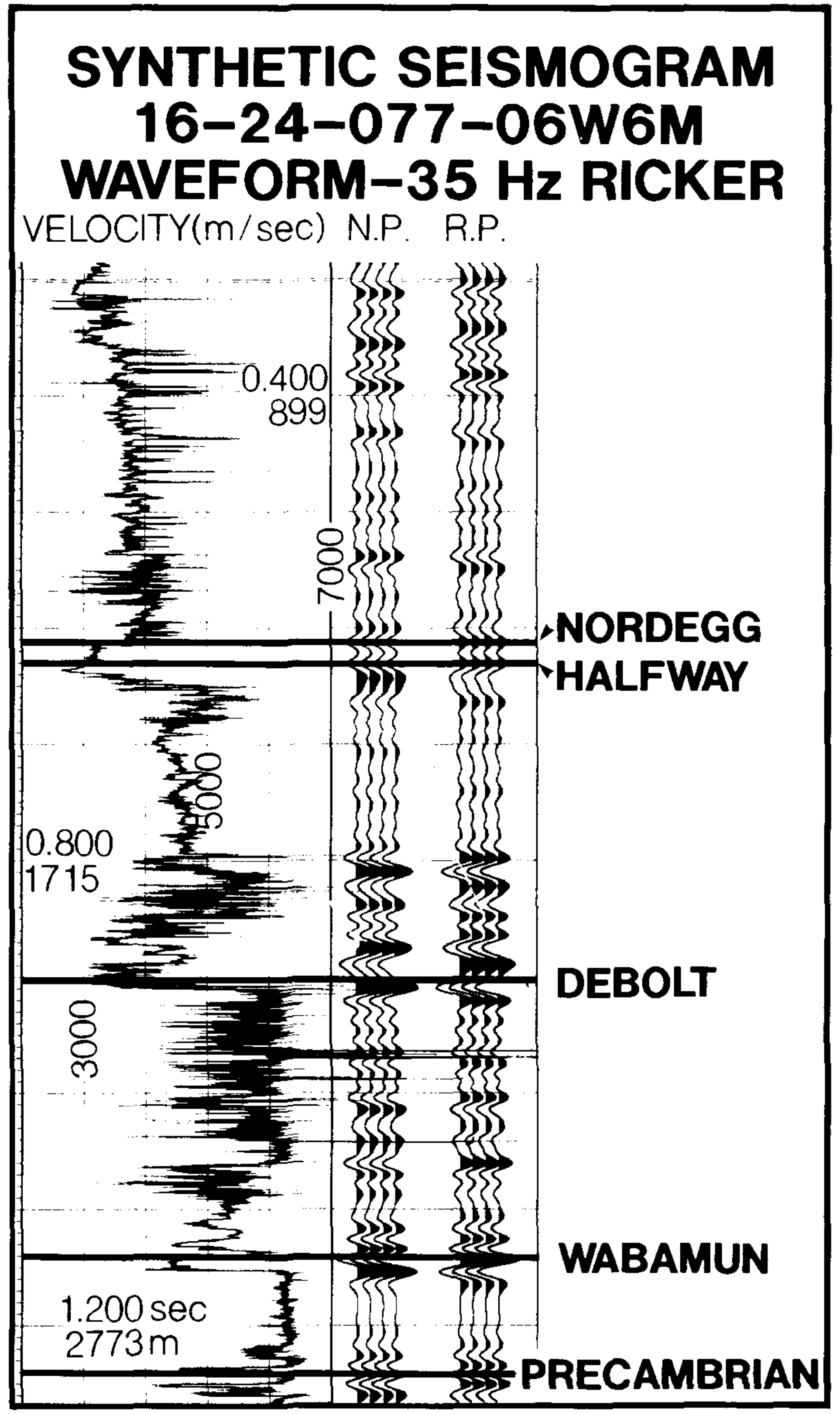

Figure 7.13. Synthetic seismogram well 16-24-077-06 W6M.

The seismic section was produced using conventional processing and is presented as a normal polarity section.

Deep well control is limited in the area with the example synthetic from 8-24-77-6 W6M (Fig. 7.13) being 5 km off the line to the east. The synthetic seismogram illustrates the horizons of interest which can be directly correlated to the seismic line. The synthetic was generated using a zero phase Ricker wavelet with a central frequency of 35 Hz. The Wabamun event is the lowest labelled event on the seismic section. This event corresponds to the peak resulting from the sharp positive impedance contrast between the Wabamun carbonate and overlying Mississippian shale.

The next event identified on the example seismic section is the Debolt Fm. It is interpreted to be the peak resulting from positive impedance contrast between the Debolt carbonate and the conformably overlying Golata Fm shale.

The uppermost event identified on the example seismic section is the Halfway Fm. It is interpreted to be a trough originating from the negative impedance contrast between the Halfway siltstones and sandstones and the underlying Montney shale.

The seismic section shows the relationship between basement structure and Halfway Fm facies and structure. Halfway Fm deposition was concurrent with basement faulting making basement identification a key interpretive parameter.

The deepest event discernible is the Wabamun at 1.21 secs at trace 560. Normal faulting is evident at the Wabamun level and was active up to Halfway time. Fault offset is apparent at the Debolt event and subtle drape is evident at the Halfway level. Halfway Fm facies can be applied directly to the seismic section as noted in Figure 7.12. Halfway Fm sabkha occurs at the northern end of the line from the basement rooted hingeline to trace 560. The Halfway Fm platform depocentre containing the tidal flat and stacked bar sequences can be observed downdip of the hingeline. The platform extends to the 16-33 well where another flexure is evident, downdip of this flexure the Halfway Fm grades into deeper water siltstones and sandstones.

SUMMARY

The Spirit River field produces from Charlie Lake dolomitized algal mats and Halfway coquinoid sandstones. Thickness ranges from 5-30 m with maximum oil pay of about 15 m. A tectonically influenced basement hinge-line provided for Halfway platform coquina deposition and ensured its subsequent preservation.

RYCROFT CHARLIE LAKE 'A' FIELD

INTRODUCTION

Production in the Rycroft Charlie Lake 'A' field (Fig. 7.14) emanates from erosional outliers of dolomitized algal mat. This member of the Charlie Lake Fm is known by various names within industry, the most common being the Worsley and the Tangent members. The Charlie Lake 'A' pool is a stratigraphic trap sealed by disconformably overlying shales of the Jurassic Nordegg Fm. The Nordegg Fm is a likely source due to its very high organic material content. Shales of the Charlie Lake Fm also underlie the Charlie Lake 'A' which itself grades into a burrowed intertidal channel shale surrounding the productive outliers. Exact dating of the Charlie Lake 'A' has not been conducted but it very closely resembles other productive algal members of the Charlie Lake, such as the Boundary Lake Member, and is most likely of Triassic age.

The Charlie Lake 'A' is the last depositional event of the Triassic and has been deposited over a wide geographic expanse in the Peace River Arch area. It unconformably overlies the red beds, anhydrites and sandstones of the Charlie Lake Fm.

The Rycroft Charlie Lake 'A' pools consist of a number of dolomitized algal mat outliers (Fig. 7.14). The largest and most prolific outlier trends northwest-southeast and is approximately 7 km long by 3 km wide and is 10 km east of the Charlie Lake 'A' regional subcrop edge. Both the seismic line and geological cross-section transect this pool.

Production in the Rycroft Charlie Lake 'A' pool is solely from dolomitized intertidal laminated algal mats. Porosities range from 10 to 25% and horizontal permeabilities range from 5 md to 1.5 Darcies with averages of approximately 20% and 250 md respectively.

The Rycroft Charlie Lake 'A' pool was initially discovered in 1983 and was fully developed by 1985. Secondary recovery waterflood is currently underway with the ERCB assigning a combined recovery of 45% of original oil in place. Reserve for the Charlie Lake 'A' pools are 2 500 x 10^3m^3 (15.7 MMSTB) OOIP with 295 x 10^3m^3 (1.8 MMSTB) for primary recovery and 718 x 10^3m^3 (4.5 MMSTB) for secondary recovery.

GEOLOGICAL CROSS-SECTION

The geological cross-section (Fig. 7.15) parallels the example seismic line (7.16) in a southwest - northeast alignment normal to the orientation of the pool. Rycroft Charlie Lake 'A' unconformably overlies the Charlie Lake Fm and is in turn overlain by the Triassic/Jurassic boundary disconformity which separates the Charlie Lake 'A' from the Nordegg shale.

The algal mat of the Charlie Lake Fm ranges from 0.5 to 5 m thick where present and lies conformably upon a burrowed intertidal shale. The cross-section shows the erosional edge of the outlier with erosion most likely taking place during, or immediately following deposition. The northeastern edge of the outlier could mark the shoreline/sabkha edge as there is no indication of Charlie Lake 'A' dolomite or shale deposition in the 7-22 well.

Basement faulting was subsiding during Charlie Lake deposition and directly influenced deposition and preservation of the Charlie Lake 'A'. The dip oriented cross-section suggests that the Charlie Lake 'A' outlier was preserved on a basement rooted paleo-high. Dip flexure can be noticed between the 6-16 and 7-22 wells and also between the 16-8 and 6-8 wells. Relative position with respect to mean sea level would directly influence deposition and preservation. Given the intertidal environment of algal mat deposition. Algal mat would be deposited within a tidal flat complex and barring sea level increase and associated high energy conditions, would be preserved on a structurally high position. The example seismic line (Fig. 7.16) further supports this interpretation.

SEISMIC SECTION

The orientation of the example seismic section (Fig. 7.16) parallels the cross-section in its dip orientation and is illustrated on the schematic plan view. The example line was recorded in 1980 using a dynamite source (2.2 kg at 20 m), a 134-m source interval, and a 33.5-m group interval. The seismic section was produced using conventional processing and is presented as a normal polarity section.

Deep well control is limited in the area with the shallow synthetic seismogram (6-8-77-5W6M) (Fig. 7.17) lying directly on the seismic line. The deeper synthetic (Fig. 7.13) from the Spirit River example lies 4 km off-line to the northwest and can be used for deep horizon correlation. The shallow synthetic (Fig. 7.17) was generated using a zero phase Ricker wavelet with a central frequency of 35 Hz.

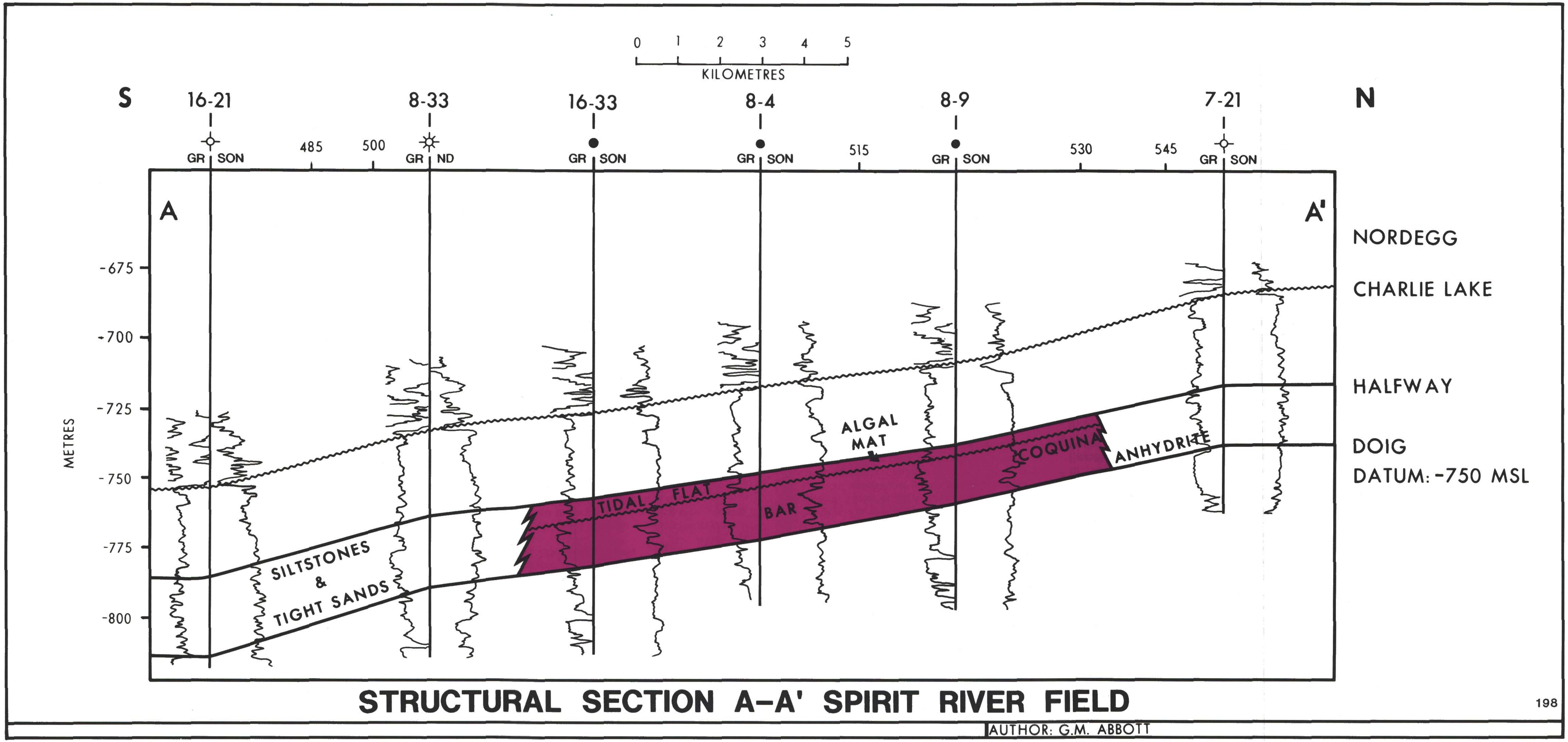

Figure 7.11. Geological cross-section of the Spirit River Halfway field.

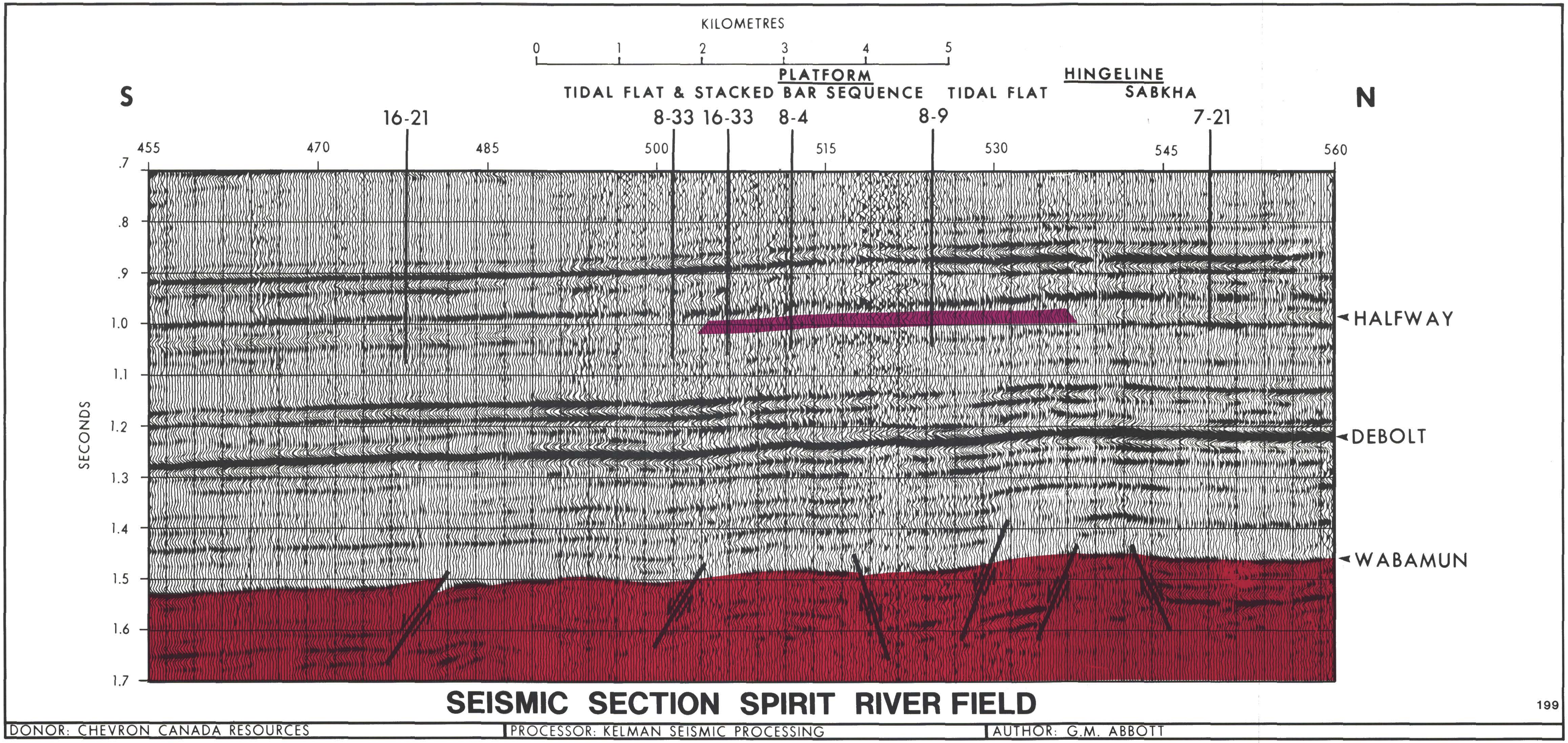

Figure 7.12. Seismic section of the Spirit River Halfway field.

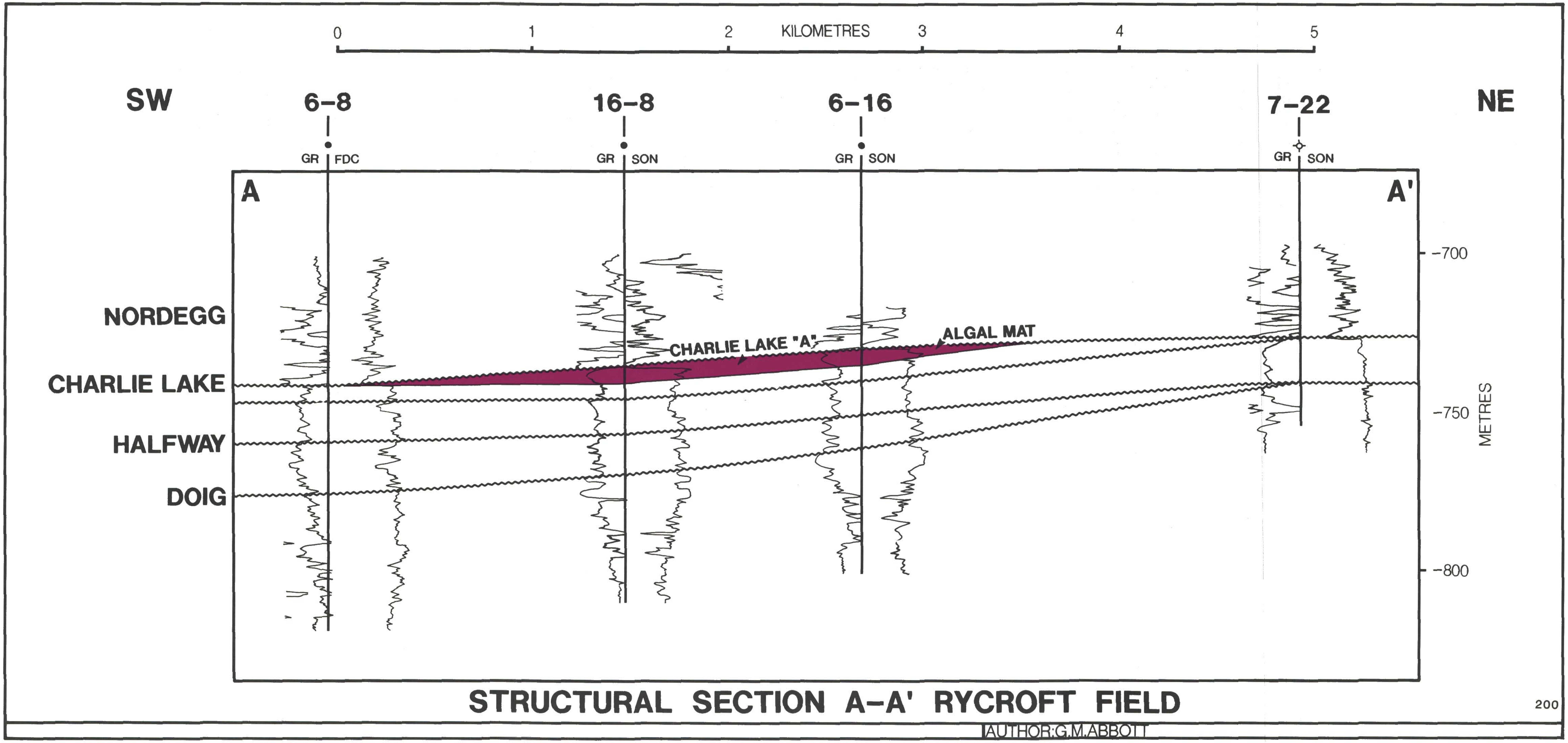

Figure 7.15. Geological cross-section, Rycroft Charlie Lake A field.

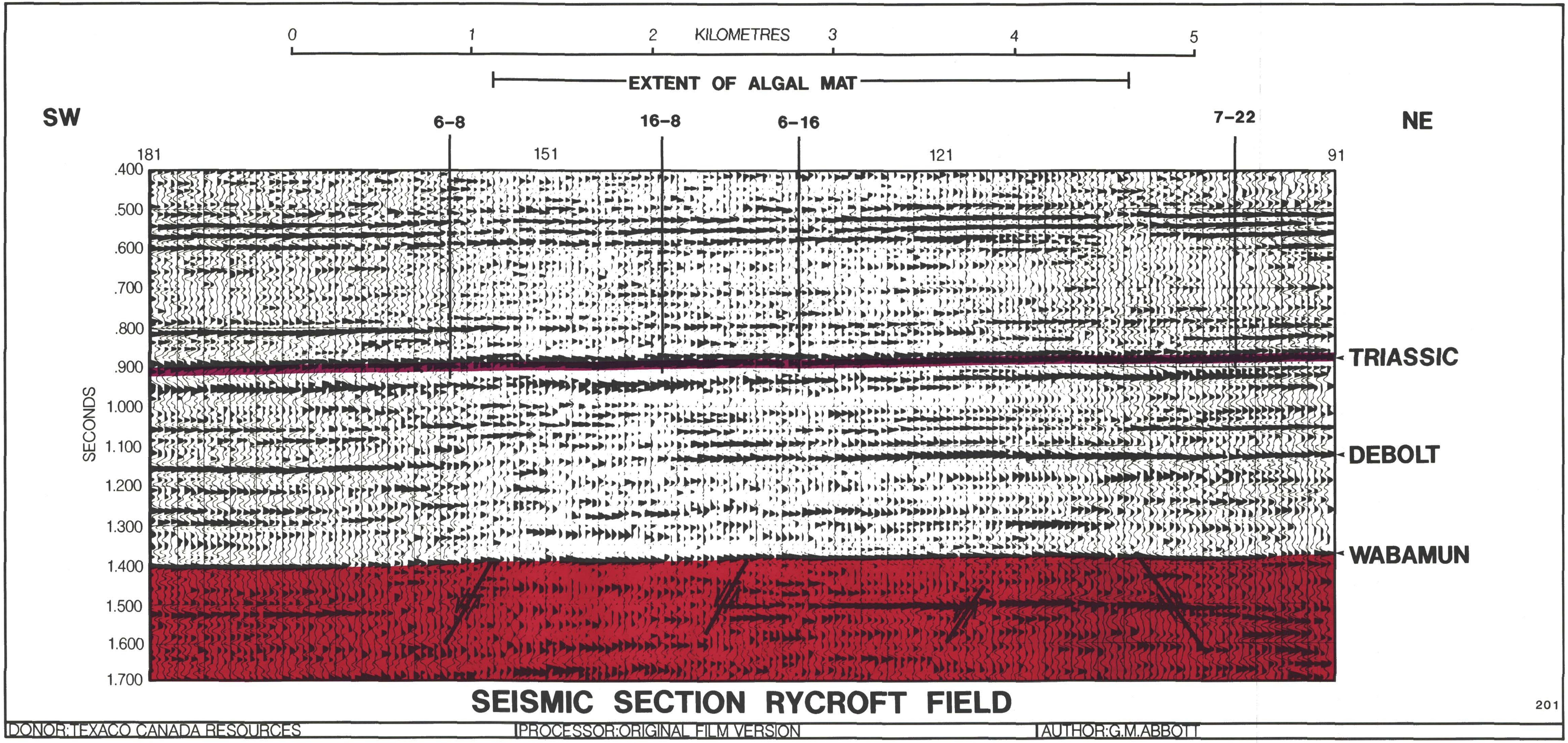

Figure 7.16. Seismic section, Rycroft Charlie Lake A field.

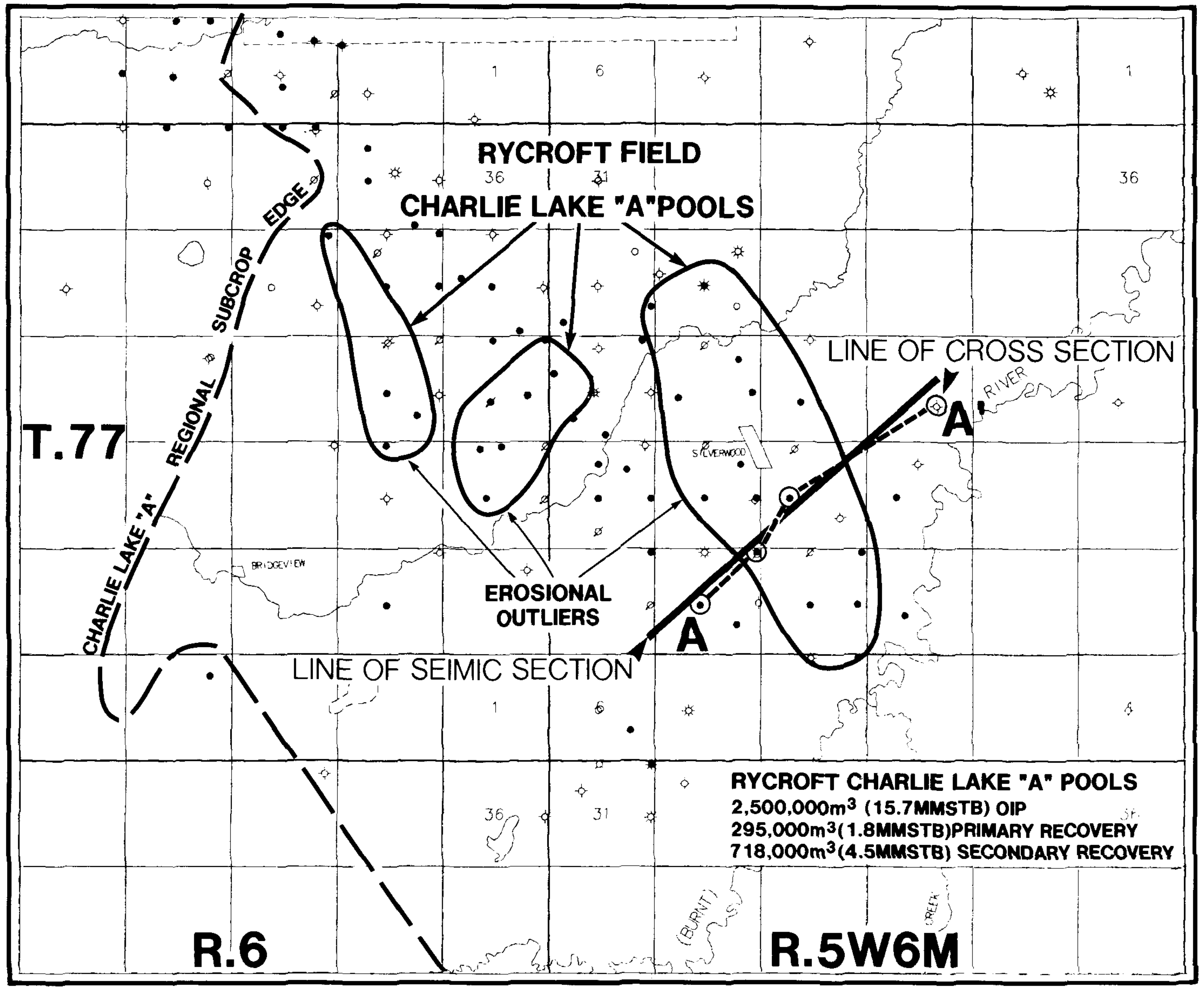

Figure 7.14. Rycroft Charlie Lake 'A' field and location of the geological cross-section and the seismic section.

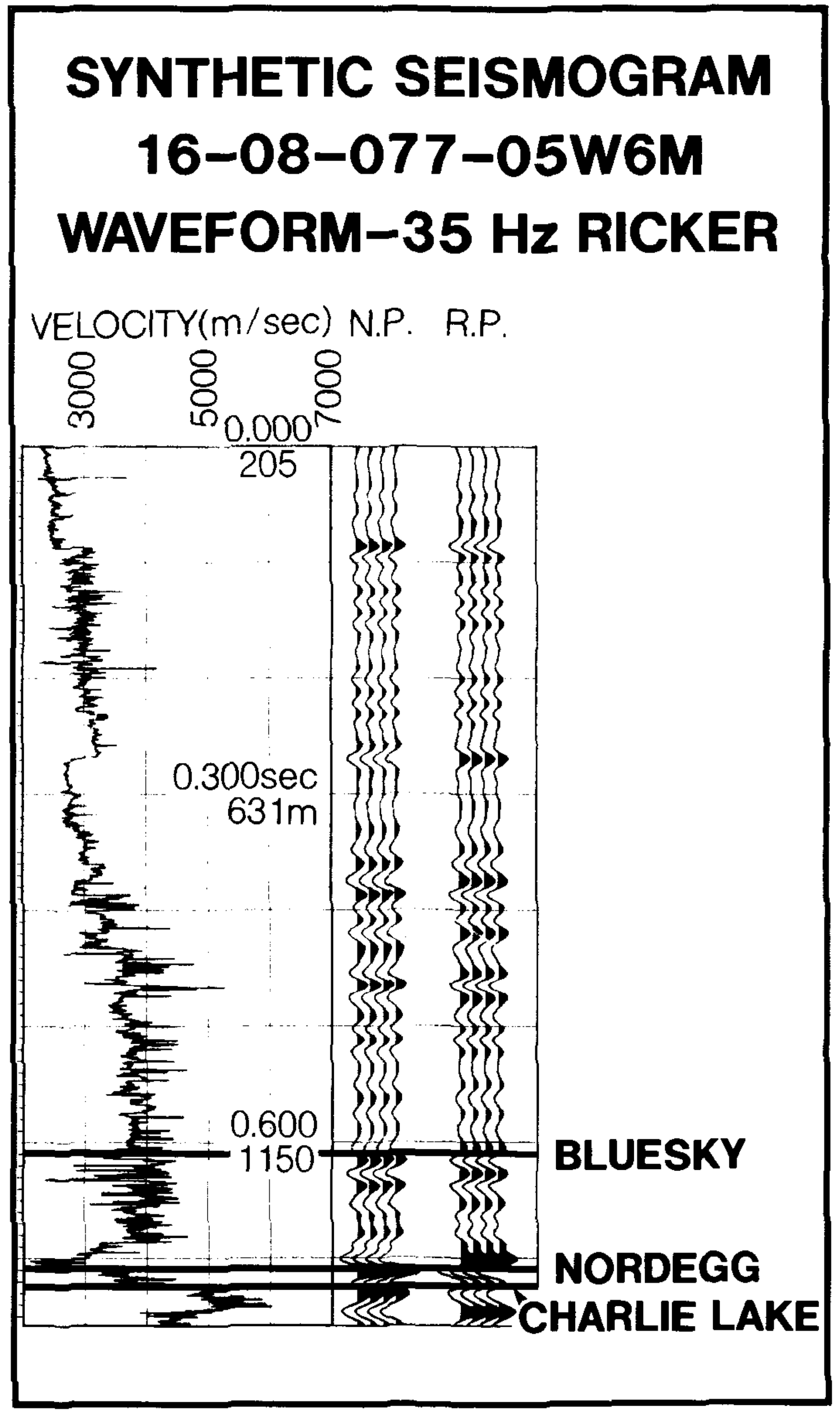

Figure 7.17. Synthetic seismogram for well 16-08-077-05 W6M.

The Wabamun event is the lowest labelled event on the seismic section. This event corresponds to the peak resulting from the sharp positive impedance contrast between the Wabamun Gp carbonate and overlying Banff Fm shale. The next event identified on the example seismic section is the Debolt Fm. It is interpreted to be the peak resulting from positive impedance contrast between the Debolt Fm carbonate and the conformably overlying Golata Fm shale. The next event identified on the example seismic section is the Charlie Lake. It is interpreted to be the peak resulting from the positive impedance contrast between the Charlie Lake Fm clastic/carbonate and the disconformably overlying Nordegg Fm shale.

The seismic section shows the relationship between basement structure and presence of Charlie Lake 'A' algal mat. Charlie Lake 'A' deposition was concurrent with basement faulting making structural interpretation of deep events an essential parameter in Triassic interpretation. Normal faulting is evident at the Wabamun level, producing a broad horst. Fault offset is apparent at the Wabamun event with flexure evident at both the Debolt and Triassic reflectors at traces 105 and 151.

Charlie Lake 'A' algal mat relates directly to the horst outlined by the normal faults identified at the reflector. The updip edge of the Charlie Lake 'A', which most likely represents the algal mat/shoreline transition, coincides with the normal fault southwest of the 7-22 well. The downdip edge of the outlier, which represents the erosional extent of the paleotide, coincides with the normal fault at trace 151. Triassic Charlie Lake 'A' algal mat has been preserved on a basement paleohigh.

SUMMARY

The Rycroft Charlie Lake 'A' pool produces from a dolomitized laminated algal mat ranging in thickness from 0.5 to 5 m. The stratigraphic trap was formed by algal mat deposition and preservation, directly over a paleohigh, with subsequent marine shale deposition forming the overlying and lateral seal.

VALHALLA FIELD

INTRODUCTION

The Valhalla Halfway "C" pool is located in west-central Alberta approximately 40 km northwest of Grande Prairie. It was discovered in 1980 by Petro-Canada Exploration Inc. with the drilling of 8-5-

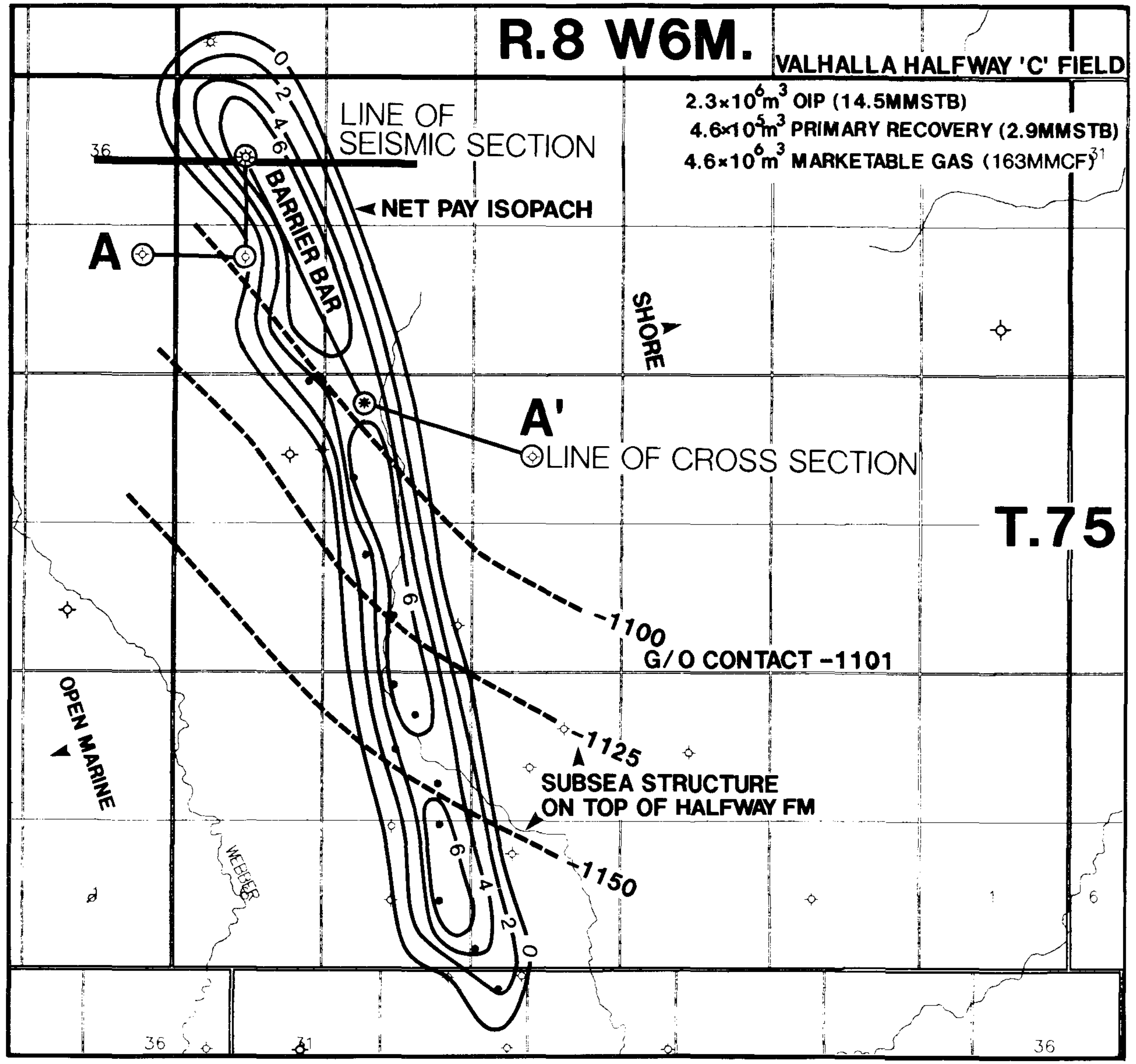

Figure 7.18. Valhalla Halfway 'C' field and location of the geological cross-section and the seismic section.

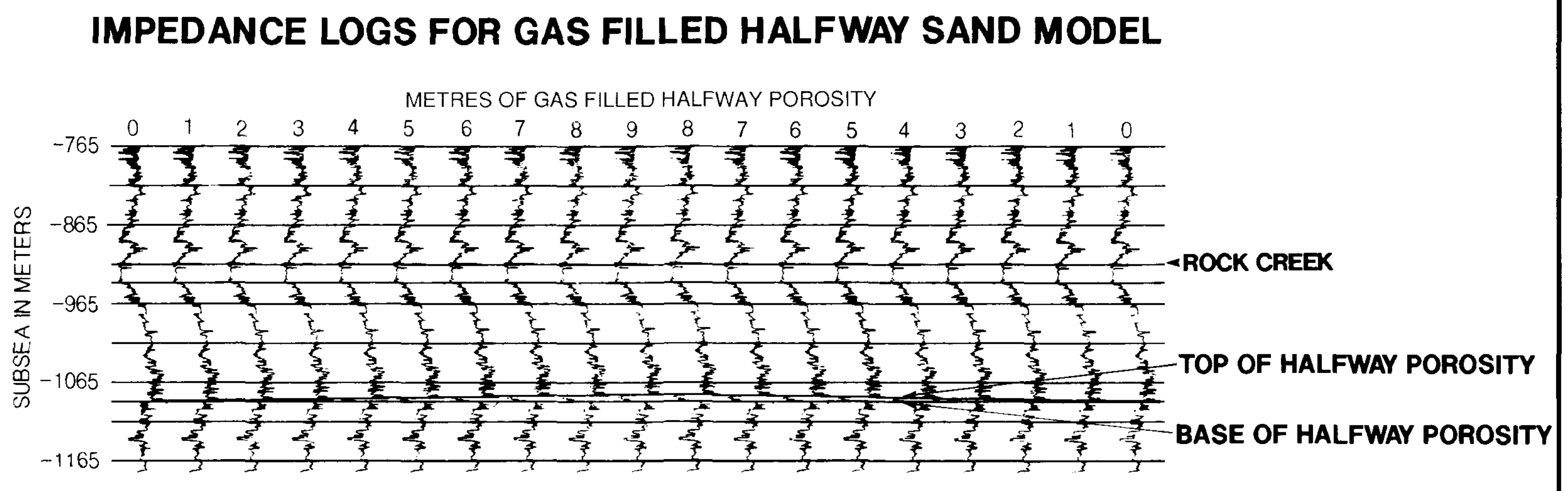

Figure 7.19. Impedance logs for gas filled Halfway sand model.

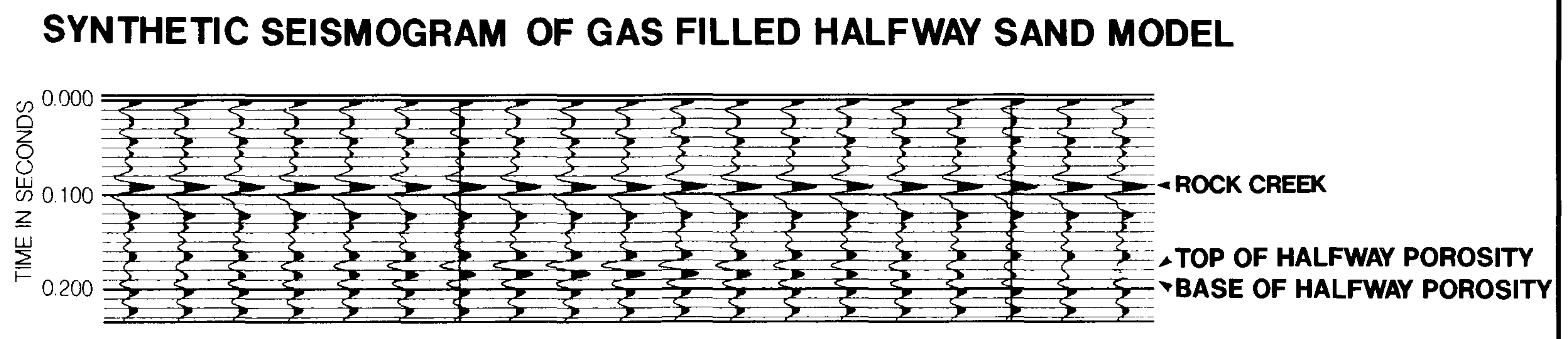

Figure 7.20. Synthetic seismogram of gas filled Halfway sand model.

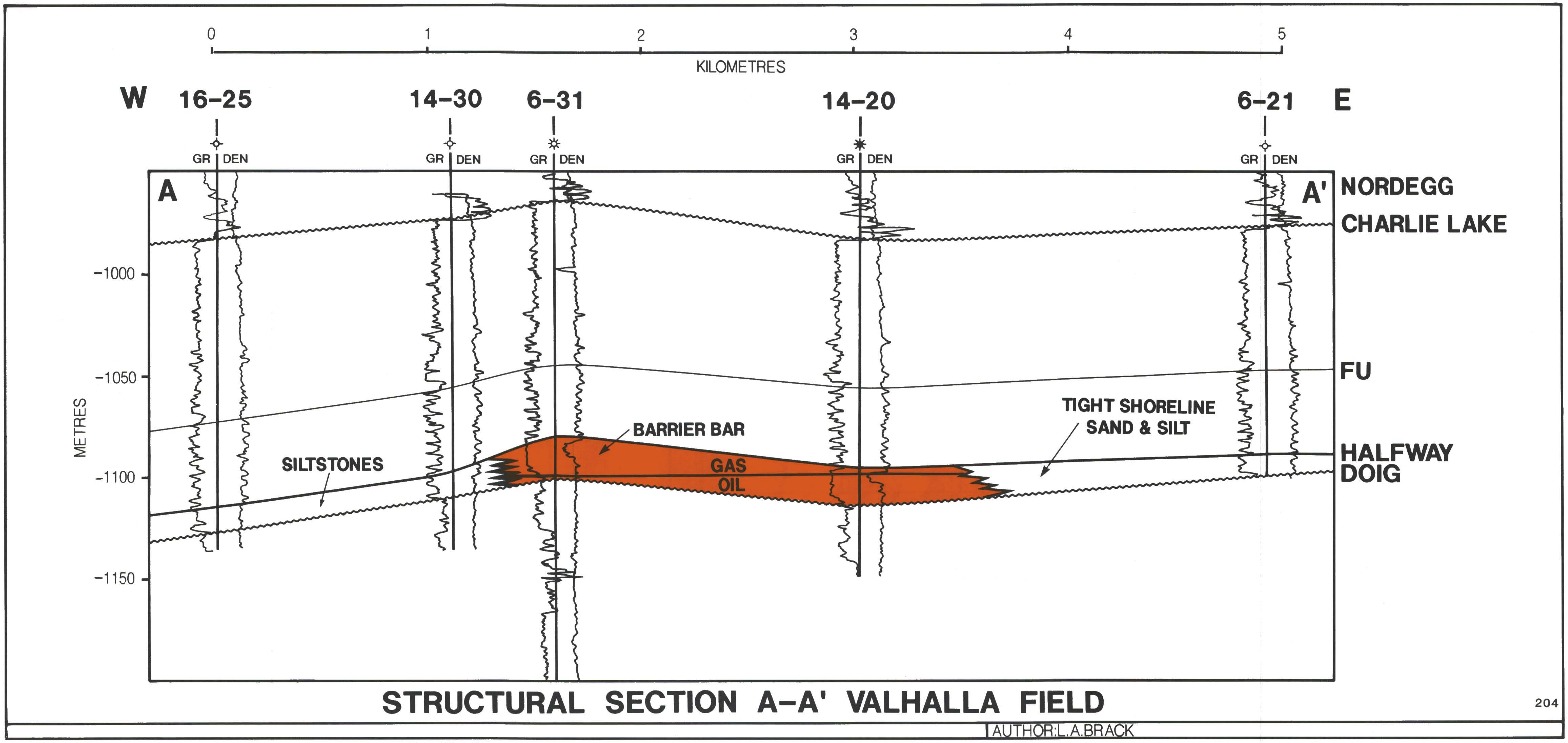

Figure 7.21. Geological cross-section, Valhalla Halfway 'C' field.

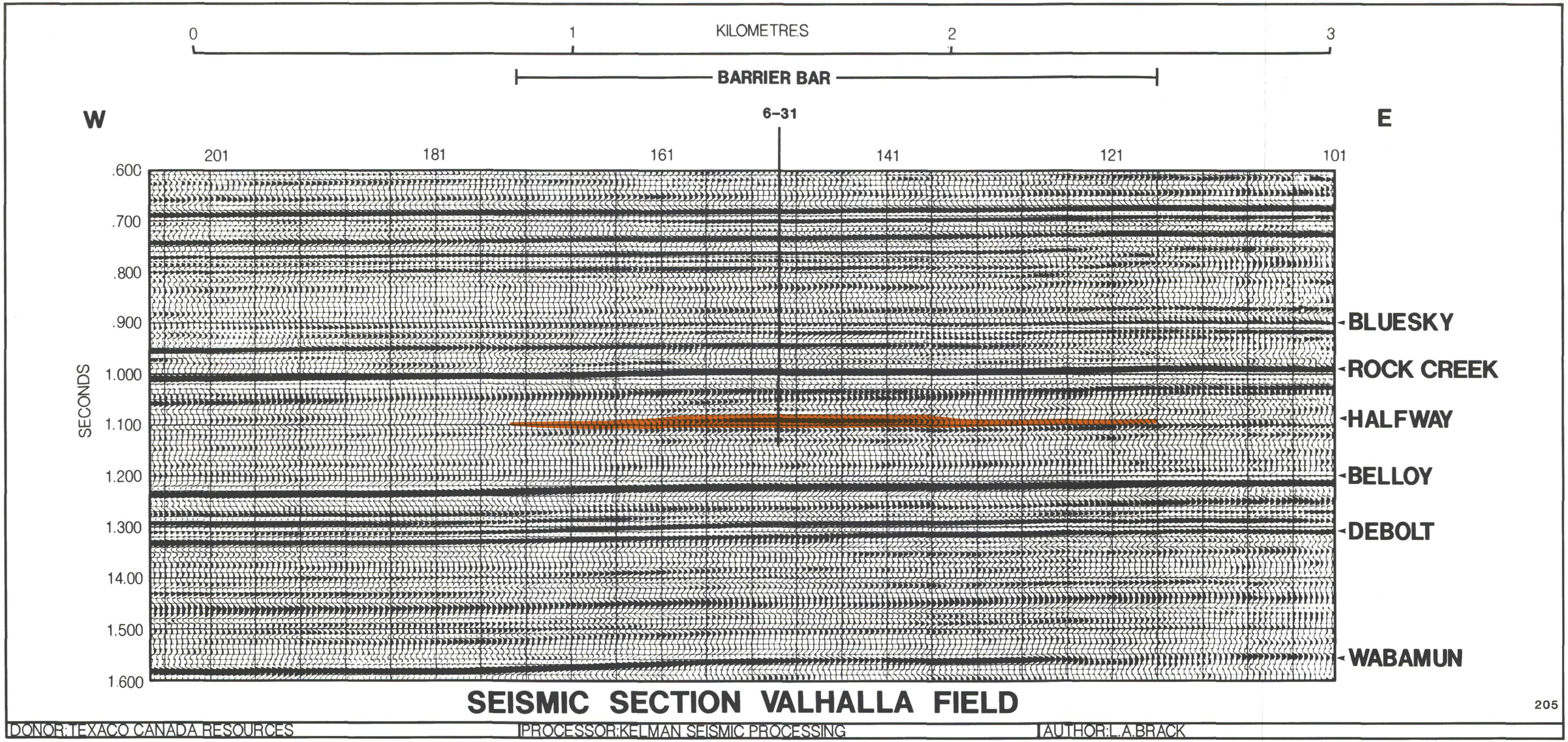

Figure 7.22. Seismic section, Valhalla Halfway 'C' field.

75-8 W6M. This well flowed light gravity crude oil (806 kg/m^3, 44° API) at a rate of 121.1 m^3 per day (765 BOPD) from 7.5 m of net pay.

The Halfway Fm unconformably overlies the Doig Fm and is conformably overlain by the Charlie Lake Fm. The Doig Fm is a regressive shale to sandstone unit in the Valhalla area. The top of the Doig Fm is marked by an erosional surface. This erosional event produced numerous channels which in some areas to the south and west of the Valhalla field incised deeply into the pre-existing Doig Fm clastics. These channels exhibit a sharp erosional base and are backfilled with a crossbedded fossiliferous marine sandstone. There is no evidence, however, of these estuarine channels in the Valhalla field area. The end of Doig Fm deposition is marked by a transgression and associated transgressive lag. This transgressive lag has been picked to represent the base of the Halfway Fm (Campbell and Horne, 1986).

The Halfway Fm is a predominantly regressive nearshore to shoreline complex of prograding barrier bars, tidal channels, shoreline sandstones and associated open marine siltstones and shales. The paleoenvironment during the Middle Triassic was arid and warm with low rates of sediment influx from the east (Campbell and Horne, 1986). This, combined with the low topographic relief, resulted in the deposition of contemporaneous Charlie Lake Fm sabkha facies in the supratidal area to the east of the shoreline. These evaporitic facies of the Charlie Lake Fm interfinger with and eventually conformably overlie the Halfway Fm due to the generally continuous regression of the Halfway sea.

A plan view map of the Valhalla field is shown in Figure 7.18. This map has been simplified by plotting only those wells which penetrated the Halfway Fm and by having the symbols reflect Halfway Fm status only. Net pay is contoured at two metre intervals and subsea structure on the top of the Halfway Fm is contoured at 25 m intervals. The gas-oil contact, at approximately -1101 m subsea, and the orientation of the field with respect to depositional setting are also shown. Note that a free water leg is not present in this reservoir.

The Valhalla field is located near the maximum eastward limit of the early Halfway transgressive shoreline and is interpreted to be a barrier bar, from its elongate shape and characteristic coarsening-upwards gamma-ray log curve. The reservoir commonly consists of fine-grained, well-sorted, subrounded and crossbedded quartz sandstone. There is no structural closure of the reservoir. It is sealed updip by a facies change; porous barrier bar grading to tight shoreline sandstones and siltstones. The top seal is provided by tightly cemented Halfway Fm sandstone and overlying Charlie Lake Fm evaporites.

The Valhalla Halfway "C" pool had an initial volume in place of 2.3 x 10^6m^3 (14.5 million barrels) of light gravity (785 kg/m^3, 49° API) crude oil. Recoverable reserves are estimated to be 460 x 10^3m^3 (2.9 x 10^6 bbls) from a mean formation depth of 1954 m. Marketable gas reserves are estimated at 4.6 x 10^6m^3 (163 MMcf). Average porosity and water saturation are 14% and 26% respectively.

The seismic section over the Valhalla field clearly shows direct evidence of the Halfway Fm reservoir by the presence of a "bright spot". Where sufficient thickness and porosity is present this direct hydrocarbon indicator may be used as an exploration tool. Subtle structural variations on underlying strata are also evident and may be used in conjunction with geological mapping to define favorable areas for Halfway Fm barrier bar development.

GEOLOGICAL CROSS-SECTION

The location of the geological cross-section (Fig. 7.19), is shown on the map of the Valhalla field. It is oriented roughly perpendicular to the strike of the field. Three non-productive wells, one well in which the Halfway Fm contains only gas, and one in which both oil and gas are present are incorporated into the cross-section. The log traces represented are the gamma-ray and bulk density curves.

The lowest identified horizon on the geological cross-section is the Doig Fm. As stated earlier, the Doig Fm is a regressive siltstone shale sequence, the top of which has been eroded.

The next horizon identified on the geological cross-section is the Halfway Fm. In the 16-25 and 14-30 wells it is interpreted to be offshore siltstones and shales adjacent to the clean sandstone of the barrier bar as seen in the 16-31 and 14-20 wells. The Halfway Fm thins towards the east where tight shoreline sandstones and siltstones are present. These tight facies act as the updip seal for this stratigraphic trap. A thin transgressive lag at the base of the Halfway is overlain by a coarsening-upwards sequence which is clean to the top of the Halfway in the area of the barrier bar, whereas in both the near-shore and off-shore positions it is comprised of alternating siltstones and shales, with infrequent clean sand lenses. Finely crystalline rhombic dolomite cement and early quartz overgrowths have occluded porosity in the lower Halfway Fm, whereas in the top few metres porosity is occluded by anhydrite cement, probably derived from the overlying Charlie Lake Fm evaporites.

The Charlie Lake Fm is comprised of alternating anhydrite and dolomite units with minor amounts of siltstone and sandstone, deposited in a sabkha environment. Several correlatable units exist within the Charlie Lake Fm one of which is a fining-upward sequence marked FU on the geological cross-section. The isopach from this fining upward unit to the top of the underlying Halfway Fm is fairly uniform across the geological cross-section with only minor thinning evident over the barrier bar. This implies that little structure was present at the end of Halfway deposition.

The top of the Charlie Lake Fm is marked by an erosional unconformity over which phosphates of the basal Nordegg Fm, the uppermost identified horizon on the geological cross-section, were deposited.

SEISMIC SECTION

Data for the seismic section (Fig. 7.20) were acquired in February 1988 utilizing a 120 channel DFS-5 instrument, a split-spread receiver configuration (near offset 30 m, far offset 1800 m), a 30 m group interval and a 120 m shot interval (1500% CMP data). The source array used was a three hole pattern (10 m spacing) with two kg of dynamite per hole at a depth of 15 m. The receiver array consisted of nine Mark L28 14 Hz geophones over 30 m. Data were sampled at two milliseconds on a three second record with a 12-128 Hz, notch out, field filter.

As shown on the map in Figure 7.18 the seismic section runs east-west, approximately perpendicular to the trend of the Valhalla field and at 45° to regional dip, which is to the southwest at approximately one degree. The seismic section is displayed as a normal polarity section. The seismic section was correlated with the aid of several synthetic seismograms, one of which is illustrated in Figure 7.23. This synthetic seismogram was generated using a zero phase Ricker wavelet having a central frequency of 35 Hz.

The Wabamun event is the lowest labelled event on the seismic section (Fig. 7.20). This event corresponds to the peak resulting from the sharp positive impedance contrast between the Wabamun Fm limestone and the overlying Banff Fm shale. The Wabamun is a high amplitude continuous event and is easily correlated from a Wabamun penetrating well (7-6-76-9 W6M) outside the area.

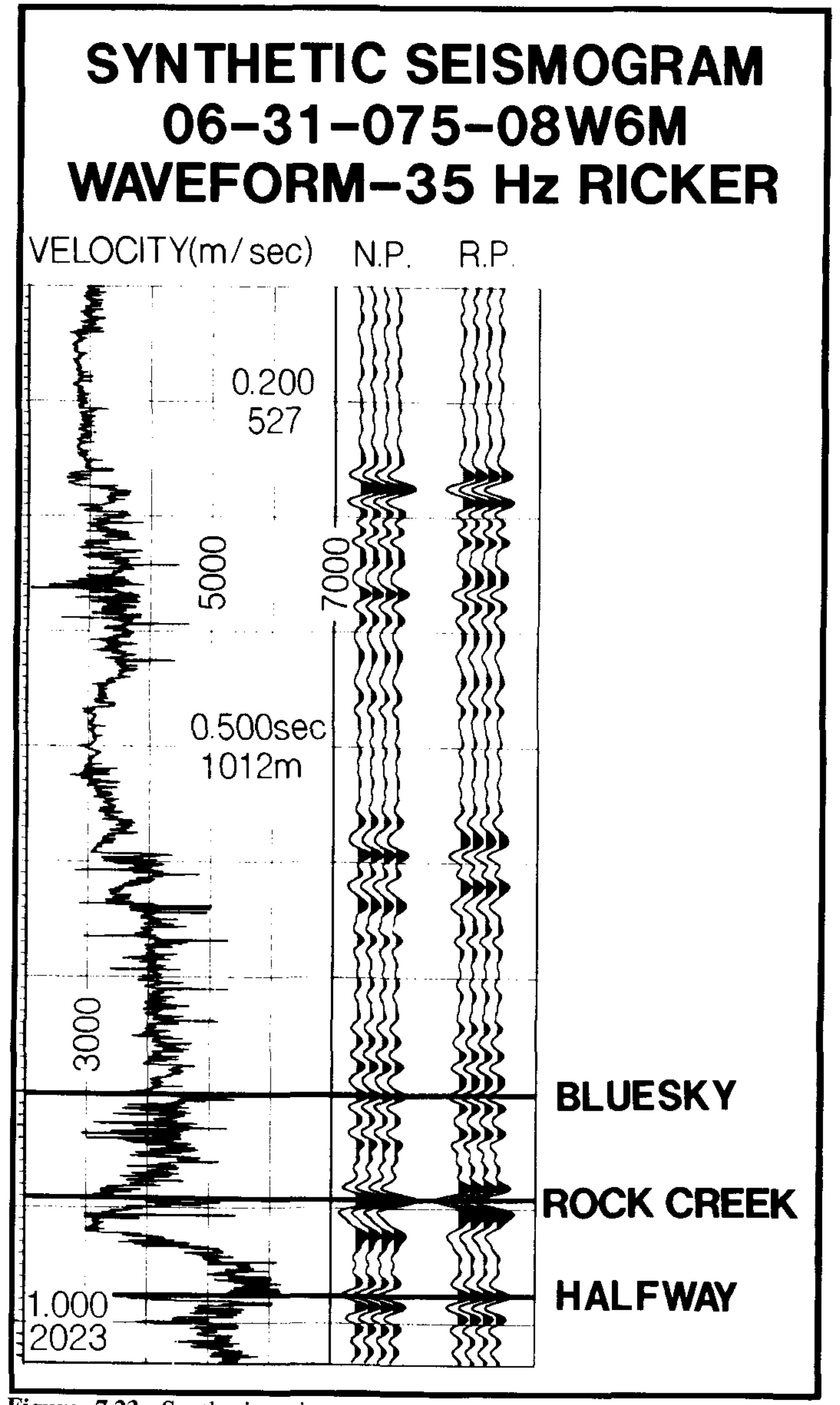

Figure 7.23. Synthetic seismogram 06-31-075-08 W6M.

The next event identified on the example seismic section is the Debolt Fm. It is interpreted to be the peak resulting from the positive impedance contrast between the Debolt Fm carbonate and the conformably overlying Golata Fm shale.

The Belloy is the next labelled event and is picked to be the trough originating from the negative impedance contrast between the clean sandstone at the top of the Belloy Fm and an underlying shale, approximately 6m below.

The next event labelled on the seismic section is the Halfway. This event is interpreted to be the trough originating at the negative impedance contrast between the top of the porous Halfway Fm sandstone and the conformably overlying tight Halfway Fm sandstone and Charlie Lake Fm evaporites. This event ranges in amplitude from very strong to non-existent. This amplitude anomaly is related to the presence of porous gas filled Halfway Fm sandstone.

The synthetic seismic response from a symmetrically thinning gas filled Halfway Fm sandstone is shown in Figure 7.22. Figure 7.21 is the model from which this response was derived. It shows the impedance traces from a gas filled Halfway sandstone which thins symmetrically from a maximum of nine metres to zero by one metre increments, based on the sonic and density logs from 6-31-75-8 W6M. The units above and below the porous interval were held at constant depths as the gas-filled porous sandstone was replaced by a tight sandstone. This model attempts to mimic the geological cross-section. The synthetic seismic model was generated using a zero phase 35 Hz Ricker wavelet. The synthetic "bright spot" matches the "bright spot" on the actual seismic section very well. The tuning thickness of a gas filled Halfway Fm sandstone with a P-wave velocity of 3920 m/s and a dominant seismic frequency of 35 Hz is approximately 28 m (Widess, 1973). The top of the gas filled Halfway Fm sandstone is located below the leading trough and the base of the porosity is above the trailing peak since the maximum expected thickness, nine metres, is less than the tuning thickness of 28 m. The amplitude of the example "bright spot" has been partially attenuated due to destructive interference between the top and bottom of the porous zone. A "bright spot" of decreased amplitude is expected over the oil filled portion of the Valhalla field since the impedance of an oil filled sandstone is approximately 20% lower than that of a gas filled sandstone of equivalent porosity.

The Rock Creek Mbr is the next labelled event on the seismic section and is interpreted to be a peak resulting from the positive impedance contrast between the Rock Creek Mbr sandstone and the conformably overlying Fernie Gp shale in which it is encased.

The remaining event labelled on the seismic section is the Bluesky Fm. This event is interpreted to be a peak resulting from the positive impedance contrast between the Bluesky Fm sandstone and the conformably overlying Mannville Gp siltstone.

All of the previously described events, with the exception of the Bluesky and Halfway events, exhibit a rather abrupt change in slope in close proximity to the area of maximum Halfway sandstone deposition. These events dip gently to the west from the east end of the seismic line (trace 101), increase in dip from trace 151 to 177, and then flatten out again to a gentle westerly dip to the end of the seismic line. Investigation of the Bluesky to Rock Creek, Rock Creek to Belloy, Belloy to Debolt, and Debolt to Wabamun event isochrons, leads to the conclusion that a hinge line existed in the area of the Valhalla field with the western portion undergoing continuous subsidence or tectonic depression up to the end of the Jurassic. This hinge line is interpreted to have provided a positive bathymetric feature which resulted in a favorable environment for clean Halfway Fm sand deposition.

SUMMARY

The Valhalla field produces from a Halfway Fm barrier bar sandstone with net pay and porosity ranging from zero to nine metres and 7 to 19%, respectively. The Valhalla Halfway "C" field is a stratigraphic trap with the updip seal provided by tightly cemented shoreline facies. The seismic method is useful, both directly and indirectly, in locating this field. Direct evidence is provided by a Halfway event amplitude anomaly caused by the presence of porous Halfway Fm sandstone. Indirect evidence for Halfway Fm reservoir development is the presence of a deeper hingeline which appears to have influenced the location of the barrier bar.

WEMBLEY HALFWAY 'B' FIELD

INTRODUCTION

The Wembley Halfway 'B' field (Fig. 7.24) is located in west-central Alberta approximately 16 km northwest of Grande Prairie. Three companies operating in the area in late 1978 drilled successful wells into the Halfway Fm. The eastern portion of the oil filled reservoir was discovered with the drilling of 10-32-72-8 W6M by Total Petroleum (N.A.) Ltd. in November, 1978. This well flowed at a rate of 59.3 m^3 (373 bbls) of light gravity crude oil per day from 7 m of net pay. The central portion of the oil filled reservoir was discovered by PanCanadian Petroleum Ltd. with the drilling of 11-36-72-8 W6M in January, 1979. This well encountered 9 m of net pay and flowed light gravity crude oil (825 kg/m^3, 40° API) at the rate of 25.5 m^3 (160 bbls) per day. The gas filled portion of the Wembley field was discovered in November, 1978 by Dome Petroleum Ltd with the drilling of 6-29-73-8 W6M which encountered 8 m of net pay and has a deliverability rate of 51 x 10^3m^3 (1.8 mcf) of gas per day.

The Halfway Fm unconformably overlies the Doig Fm and is conformably overlain by the Charlie Lake Fm. The Doig Fm has been interpreted to be a regressive shale to sandstone unit. In the area, an estuarine channel, the deepest portion in excess of 40 m, cuts into pre-existing Doig Fm marine clastics and is backfilled with a crossbedded fossiliferous marine sandstone which is predominantly tight. The top of the Doig Fm is marked by an erosional surface. This erosional period was followed by a transgression and the deposition of an associated transgressive lag which has been picked to represent the base of the Halfway Fm (Campbell and Horne, 1986).

The Halfway Fm in the Wembley area has been interpreted to have been deposited in a warm arid environment at a latitude of approximately 30° north of the paleoequator (Campbell and Horne, 1986). It is a predominantly regressive nearshore to shoreline complex of prograding barrier islands and tidal channels deposited on a gently dipping surface. The Halfway Fm thins and becomes a tight back barrier sand to the northeast where it interfingers with the time equivalent evaporites of the Charlie Lake Fm. The thinning of the Halfway Fm to the northeast has been interpreted to have been caused by post Doig hinging and differential subsidence which resulted in onlapping deposition of the Halfway Fm against the resulting ramp (Cant, 1986).

The Charlie Lake Fm is a predominantly evaporitic unit, deposited in a sabkha environment, conformably overlying the Halfway Fm . It consists of dolomite, anhydrite, and minor amounts of siltstone and sandstone.

The Wembley and Hythe fields are shown in map view in Figure 7.24. Only those wells which penetrated the Halfway Fm have been plotted. Well status may reflect production from zones other than the Halfway Fm. Net pay, contoured at 8 m intervals, subsea structure on the top of the Halfway Fm, contoured at 100 m intervals, and the approximate location of the gas/oil contacts are illustrated. The location of an underlying Doig channel is also shown.

The Wembley and Hythe fields are separated on the basis of pressure data and different gas/oil contacts. The Hythe field has recoverable oil reserves which are less than 4% of the recoverable oil reserves for the Wembley field and is therefore discussed only briefly.

The Wembley Halfway 'B' pool is approximately 8 km in width and 38 km in length and trends northwest-southeast parallel to the paleoshoreline. The reservoir consists of sandstones and coquinas which were deposited in a shallow nearshore environment. The sandstones were deposited as tide and wave influenced prograding barrier bars into which tidal channels were incised. These tidal channels migrated laterally and the abandoned portions were infilled with sand and shell-hash conglomerates. The coquinas also occur as wave-built shell banks and as locally developed shell beaches (Cant, 1986). There is no structural closure of the Halfway Fm, as illustrated by Figure 7.24. The trap is stratigraphic in nature.

The reservoir is sealed updip by tightly cemented shoreline sandstones and siltstones with the overlying Charlie Lake Fm evaporites providing the top seal together with the upper few metres of the Halfway Fm itself which is tightly cemented by anhydrite.

Initial oil in place for the Halfway 'B' is estimated to be 23 x 10^6m^3 (145 x 10^6 bbls) with recoverable reserves of 4.6 x 10^6m^3 (28.9 x 10^6 bbls). Initial established reserves of marketable gas are estimated to be 6.0 x 10^9m^3 (212 Bcf). As illustrated in Figure 7.24, a free water zone is not present. Cumulative production, to the end of 1987, was 1.16 x 10^6m^3 (7.3 x 10^6 bbls) from a mean formation depth of 2128 m. The reservoir has an average porosity of 10% in the oil leg and 12% in the gas leg. The average water saturation is 27% in the oil filled portion of the reservoir and 20% in the gas-filled portion.

Oil reserves are also recognized in the Charlie Lake Fm and the Doig Fm but due to thin pay zones and poor recovery factors these reserves account for only a 7% addition in the recoverable oil reserves from the Triassic in the Wembley field.

GEOLOGICAL CROSS-SECTION

The location of the geological cross-section (Fig. 7.25) is shown on the map of the Wembley field (Fig. 7.24). It is oriented at a 45°

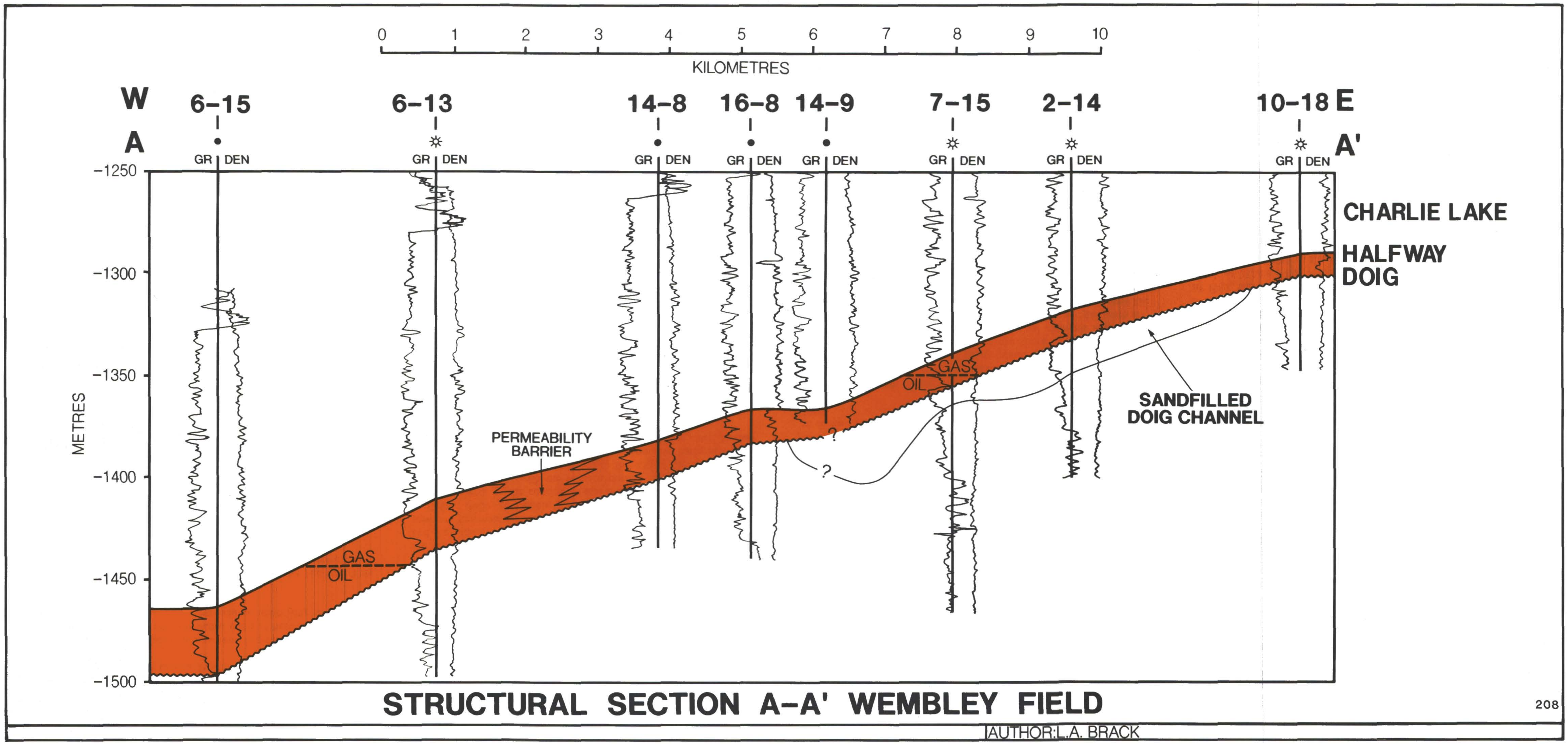

Figure 7.25. Geological cross-section, Wembley Halfway 'B' field.

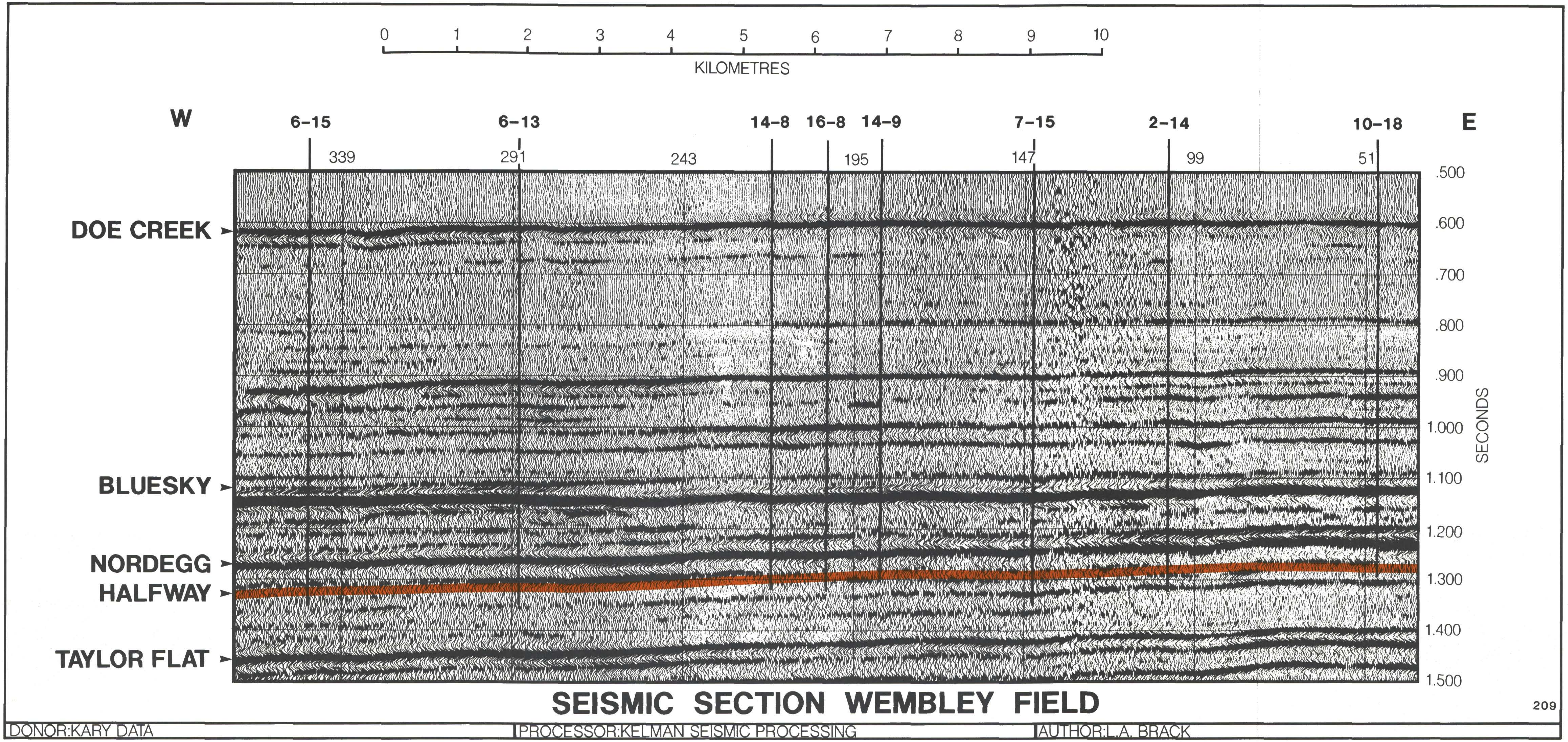

Figure 7.26. Seismic section, Wembley Halfway 'B' field.

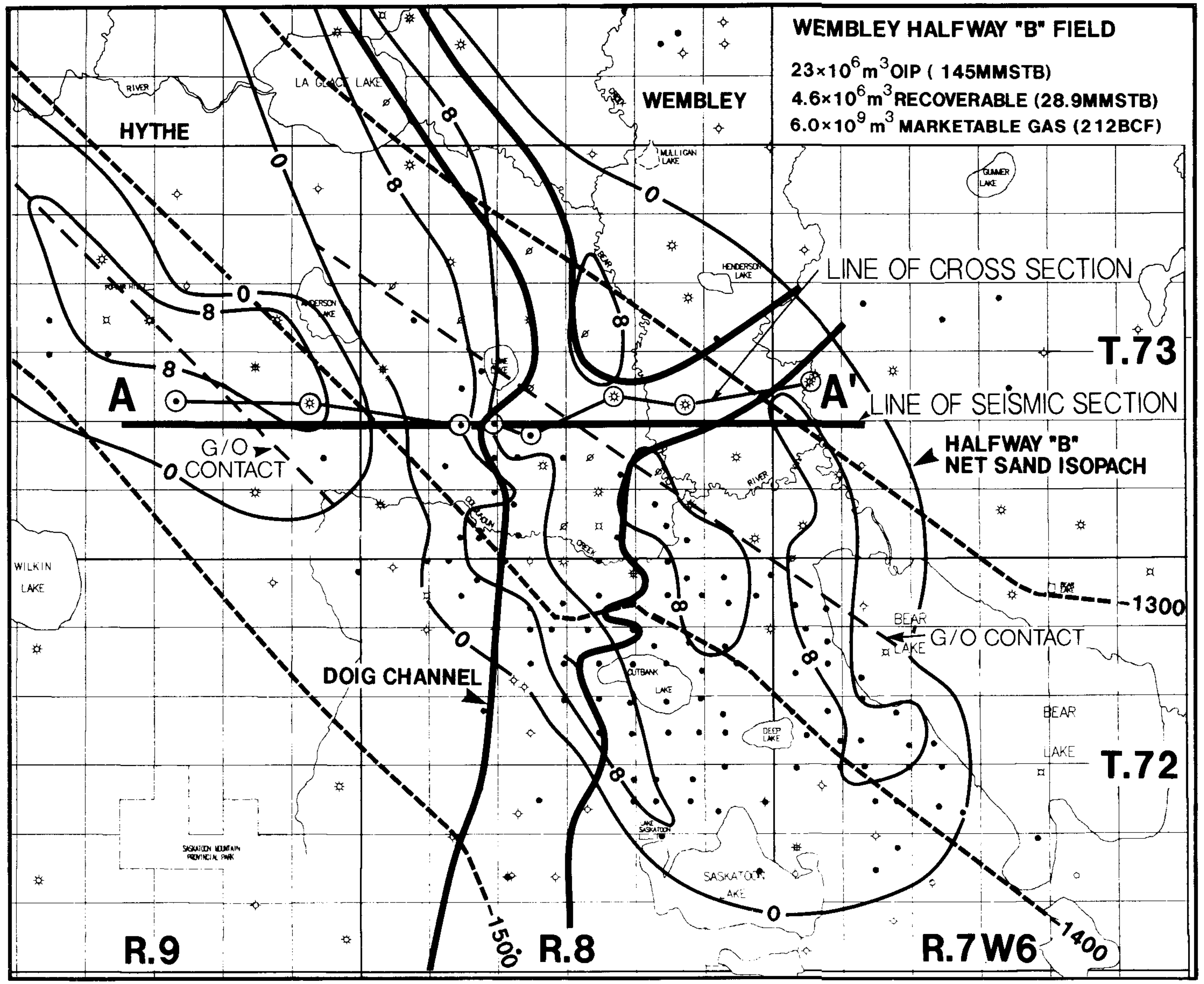

Figure 7.24. Wembley Halfway 'B' field and location of geological cross-section and seismic section.

angle to both the trend of the field and regional dip. The cross-section incorporates three oil and three gas wells which produce from the Wembley Halfway 'B' pool and one oil and one gas well which produce from the Hythe field. The log traces represented are the gamma-ray and bulk density curves.

The Doig Fm is the lowest identified horizon on the geological cross-section. The top of the Doig Fm is an erosional surface and is picked at the base of a transgressive lag which marks the start of Halfway Fm deposition. The position of a Doig erosional channel which incised into prexisting Doig Fm regressive marine clastics and was then backfilled with clean crossbedded marine sandstones is illustrated. This channel can be in excess of 40 m deep in the Wembley area. It is interpreted to be an estuarine channel (Cant, 1986) from sedimentary structures, the presence of marine fossils and linear areal expression.

The next identified horizon in Figure 7.25 is the Halfway Fm. It can be seen to thin from 30 m (6-15) to 10 m (10-18). As illustrated by the log traces, the Halfway Fm has a complex lithology in the Wembley and Hythe areas. The two wells, 6-15 and 6-13, which are located in the Hythe field, display the characteristic log response of infilled tidal channels. The lower 10 m of the Halfway Fm in the 6-15 well is a coarsening-upwards sequence truncated by the tidal channel. From the gamma-ray response the tidal channel infill is interpreted to be primarily sandstone. In the 6-13 well the lower 10 m of tidal channel infill is shell-hash conglomerate, the upper 7 m is sandfilled. A permeability barrier is present between the Hythe and Wembley fields which may be provided by a facies change or by cementation of Halfway Fm porosity. The remaining wells on the cross-section are in the Wembley field. The log traces of the 14-8 and 16-8 wells are also characteristic of tidal channel facies (Campbell and Horne, 1986). Correlation between the location of these tidal channels and the absence of underlying Doig estuarine channels may be possible. However, a detailed facies analysis of the Wembley field would be necessary to establish this. The next three wells, 14-9, 7-15 and 2-14 overlie a sandfilled Doig channel and exhibit a coarsening-upwards log signature with porosity being developed in the upper portion of the clean sandstone. The last few metres of these sandstones are tightly cemented by anhydrite, probably derived from the overlying Charlie Lake Fm evaporites. This coarsening-upwards signature is characteristic of a prograding barrier island facies (Campbell and Horne, 1986). Again, the presence of underlying Doig channel facies may have influenced the development of these barrier islands. The approximate depth of the gas/oil transition zone for both the Wembley and Hythe fields is shown on the cross-section.

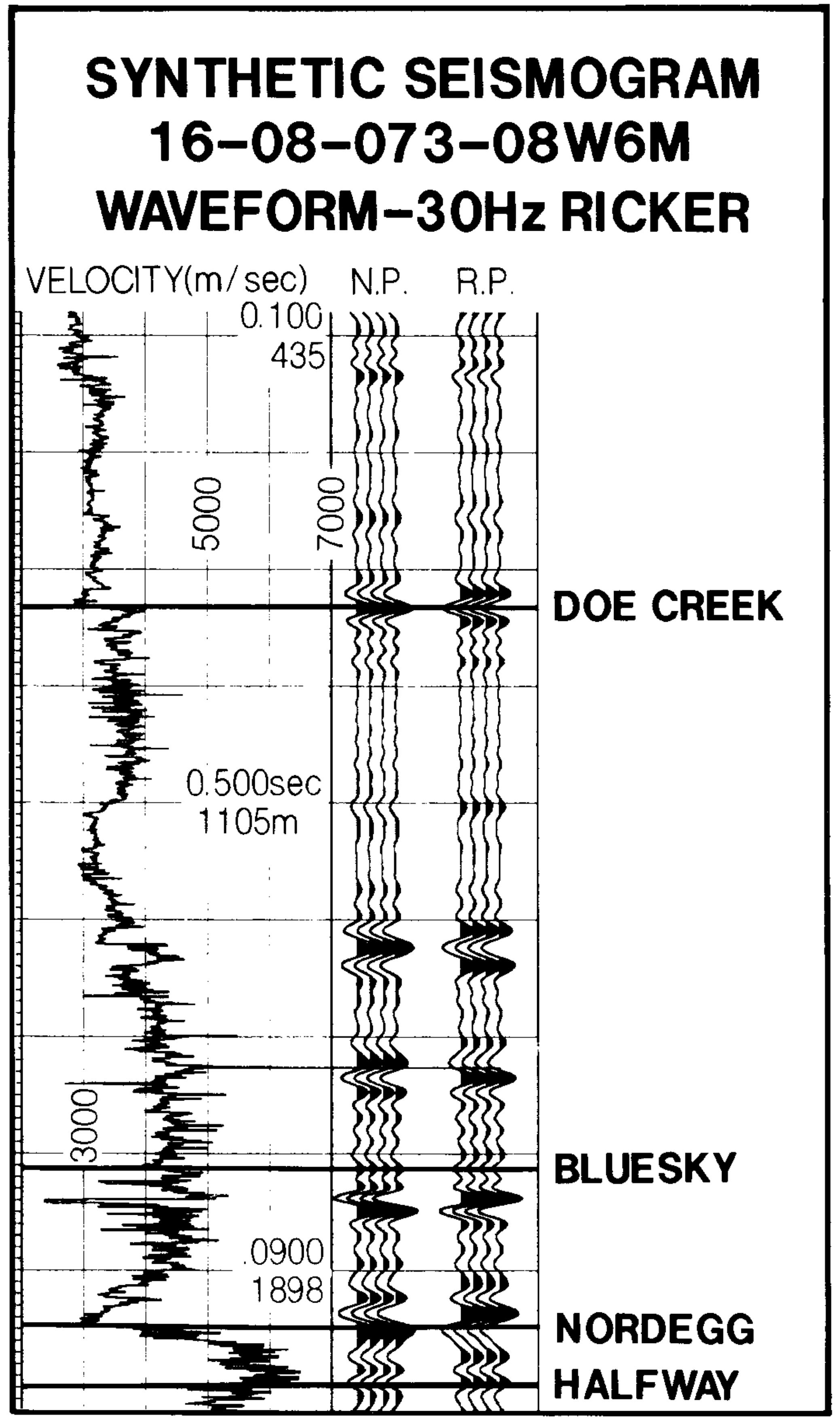

Figure 7.27. Synthetic seismogram 16-08-073-08 W6M.

The updip seal (not illustrated) for the Wembley field is provided by thin tightly cemented shoreline sandstones, similar to the Valhalla field (Fig. 7.21).

The last unit identified on the geological cross-section is the Charlie Lake Fm and is composed of alternating anhydrite and dolostone units, with minor amounts of siltstone and sandstone, deposited in a sabkha environment. As previously stated, the Charlie Lake Fm provides the top seal for the reservoir and is also the probable source for the anhydrite cement which occludes porosity in the upper few metres of the Halfway Fm.

SEISMIC SECTION

The example seismic section (Fig. 7.26) is vibroseis data acquired in January, 1978. The data were recorded utilizing a SUM-IT7 instrument, a split-spread receiver configuration (near offset 302 m, far offset 1458 m), a 50 m group interval and a 100 m source interval (1200% CMP data). A seven second sweep length was used with a 56 to 14 Hz down-sweep with 16 sweeps over 100 m. The receiver array consisted of 10 geophones over 11 m. Data were sampled at four milliseconds on a 12 second record with an out/64 Hz, notch out, field filter.

As shown in Figure 7.24 the seismic section runs east-west, approximately perpendicular to the Wembley field and at approximately 45° to regional dip, which is one degree to the southwest. The seismic section begins in the Hythe field to the west and crosses the Wembley field where it ends near the zero pay contour. It crosses the gas/oil transition zone of both fields and a Doig estuarine channel in the Wembley field. It is displayed as a normal polarity section; an increase in impedance at an interface results in a peak. Events were correlated with the aid of several synthetic seismograms, one of which is illustrated in Figure 7.27. This synthetic seismigram was generated using a zero phase Ricker wavelet having a dominant frequency of 35 Hz.

The Taylor Flat event is the lowest labelled event on the seismic section and corresponds to the peak resulting from the sharp positive impedance contrast between the Taylor Flat dolostone and the unconformably overlying Belloy Fm sandstone. This event is strong and continuous along the seismic section.

The Halfway is the next event labelled on the seismic section. This event corresponds to a weak, discontinuous trough which originates from the negative impedance contrast between the top of the porous Halfway Fm and the overlying tight Halfway Fm. The poor seismic response at this interface is the result of destructive interference between the top and bottom of the porous intervals.

The next event labelled on the seismic section is the Nordegg Fm which originates at the positive impedance contrast between the calcareous Nordegg Fm shale and the conformably overlying Fernie Gp shale. This event is strong and continuous across the seismic section but some interference from the underlying Charlie Lake Fm evaporites is evident in the development of a doublet east of trace 195.

The Bluesky event is a peak originating at the positive impedance contrast between the Bluesky Fm sandstone and the conformably overlying Mannville Gp shale.

The Doe Creek event is the last labelled event on the seismic section. This event originates at a positive impedance contrast between the top of a coarsening upwards sequence and an overlying shale within the Kaskapau Fm. This sequence is the uppermost of several coarsening upwards sequences, one of which is the Doe Creek sandstone.

Variations in the isochron values between several horizons labelled on the seismic sections were investigated. The Nordegg to Taylor Flat isochron is relatively constant from the west end of the section to the 14-8 well where it thins by approximately 5 ms and then remains constant for the remainder of the section. This thinning may be a reflection of a deep seated hingeline which influenced the location of the Halfway shoreline. The Bluesky to Nordegg isochron remains constant from the west end of the line to trace 99 at which point it thins abruptly by 10 ms. This may indicate a repositioning of the hingeline to the east. The Doe Creek to Bluesky isochron remains constant across the section indicating that no structural movement occurred during Albian to Early Turonian (Cretaceous) stages.

The Halfway event must be interpreted as a package since it is affected not only by variations in the Halfway Fm itself but also by lithological and morphological changes in the underlying Doig Fm.

The Halfway seismic package consists of a leading peak originating within the Charlie Lake Fm, the Halfway trough which originates at the top of Halfway Fm porosity, and a trailing peak which originates, when present, at the base of porous upper Doig Fm, usually channel fill. Over the Hythe field the Halfway trough is best developed in proximity to the 6-13 well where the thickest porosity is developed. This also coincides with the gas filled portion of the reservoir which has an increased impedance contrast vis a vis an oil filled sandstone of equivalent porosity. There is no obvious change in the waveform in response to the permeability barrier between the Hythe and Wembley fields. The most notable response over the Wembley field is the development of the trailing peak over the area where the underlying Doig channel is present. The Halfway trough is poorly developed at 14-8, 16-8 and 14-9, where the Halfway Fm is comprised of tidal inlet facies, and better developed east of 14-9 where it is predominantly comprised of barrier bar facies. The aforementioned waveform changes may be more apparent on higher resolution data and would require corroboration by additional seismic coverage over the area.

SUMMARY

Hydrocarbons of the Wembley Halfway "B" field are stratigraphically trapped in a reservoir which consists of sandstones and coquinas deposited in a near-shore marine environment. Reservoir parameters are quite varied due to the complex nature of the Halfway Fm in the area. The seismic method does not provide direct evidence of the Wembley field. The presence of a pre-existing hinge line, as illustrated by the seismic section, may be used indirectly to identify areas of potential shoreline development. Changes in the seismic response at the Halfway level may have limited usefulness in facies and porosity prediction.

STURGEON LAKE SOUTH TRIASSIC "A" POOL

INTRODUCTION

The Sturgeon Lake South Triassic "A" pool was discovered in 1955 by Shell Oil Company. It is located (Fig. 7.28) on the northeast edge of the Sturgeon Lake South Leduc oil pool which was discovered two years earlier. The Triassic "A" pool was discovered during development drilling of the Leduc pool . A second Triassic oil pool, Triassic "B", was discovered in 1957 on the south edge of the Leduc pool.

The Triassic "A" pool has as its reservoir one of four porous members of the Montney Fm. These four members are predominantly sandstone and dolomitic coquina which probably represent separate progradational pulses of shoreface sand. These sandstones are interbedded with siltstones and shales which make up the adjacent shelf deposits.

The Sturgeon Lake South Triassic "A" reservoir consists primarily of sandstone, and has been interpreted as a delta front facies. These sandstones represent lobes of river-dominated deltas which prograded westward from a shoreline located a few miles east of the present subcrop edge (Miall, 1976). The four porous members subcrop against the Nordegg Mbr, with a regional west-southwest dip. Drape of the Montney Fm reservoir facies over the underlying Leduc reef probably forms the trapping mechanism, whereas lateral and upper seals are provided by the Montney Fm siltstones and Nordegg Fm shales. Likely source rocks are the Nordegg Fm and Montney Fm shales, but deeper sources cannot be ruled out. Other shows from the porous Triassic member which produces at Sturgeon Lake South are the Tangent gas show from a dolomitic lens, and a gas zone at Whitelaw (Miall, 1976).

The Triassic "A70 pool had initial in-place oil reserves of 4.77 x $10^6 m^3$ (30 x 10^6 bbls). With a primary recovery factor of 11%, recoverable reserves totalled 524 x $10^3 m^3$ (3.3 x 10^6 bbls). Cumulative production to the end of 1987 was 411.8 x $10^3 m^3$ (2.6 x 10^6 bbls) of light oil (844 kg/m^3 - 36° API) from a mean depth of 1500 m. The oil pay zone has an area of 1578 ha and averages 4.08 m in thickness. Reservoir porosity averages 15%, with a 35% water saturation.

The seismic method is of limited use in defining the Triassic oil accumulations. Due to the nature of the reservoir, conventional seismic methods do not clearly indicate the presence or absence of reservoir. On the other hand, seismic clearly shows the presence of the Leduc reef and illustrates structural drape in the overlying strata. If geological mapping indicates the presence of reservoir quality rock, seismic may be used to indicate structurally favorable drilling positions.

GEOLOGICAL CROSS-SECTION

Figure 7.28 indicates the location of the cross-section shown in Figure 7.29. It also illustrates structural relief on the top of the Triassic unconformity surface. The contours indicate a reduction in the southwest trending regional dip at the edge of the Leduc pool, suggesting a "draping" of Triassic sediments over the Leduc reef. The Triassic "A" wells are annotated on the map with triangles. The remaining oil wells belong to the Leduc and Triassic "B" pools.

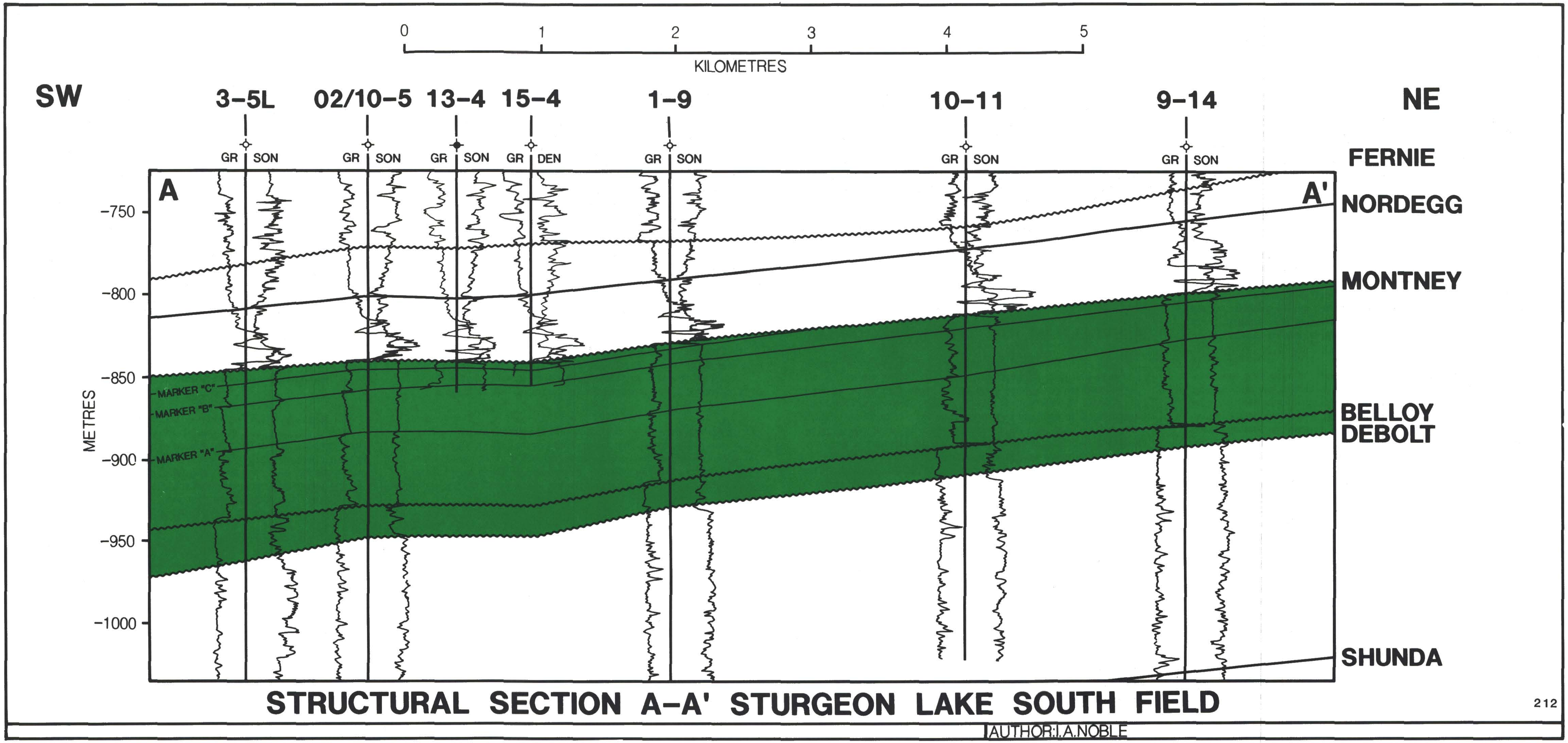

Figure 7.29. Geological cross-section, Sturgeon Lake South Triassic "A" pool.

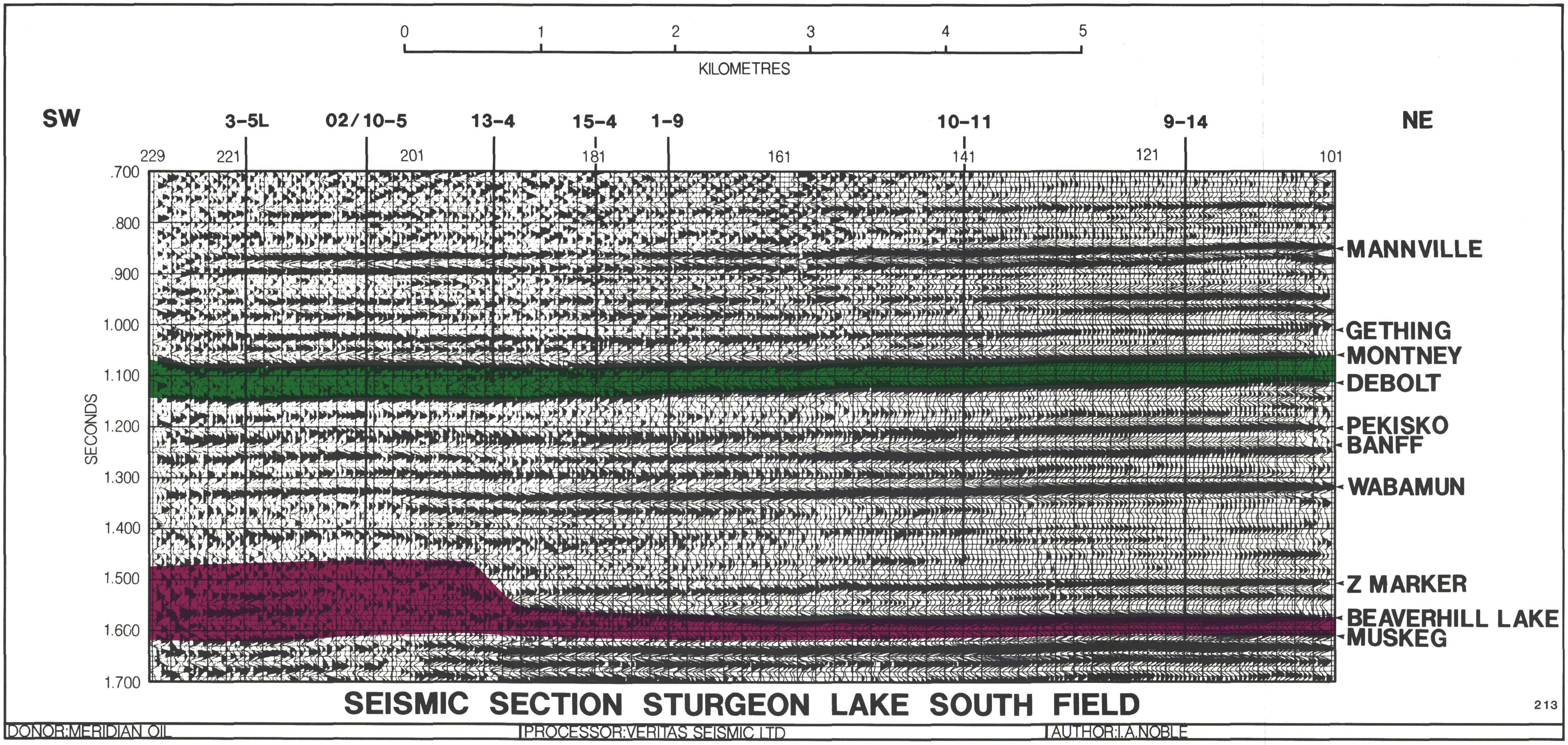

Figure 7.30. Seismic section, Sturgeon Lake South Triassic "A" pool.

Drilling density north of the Triassic "A" pool is insufficient to establish structural closure, but this is the generally accepted trapping mechanism (Podruski et al., 1987). Also, it is possible that the presence of the underlying reef influenced facies distributions within the Montney Fm, resulting in an accumulation of porous sands flanking the ancestral high (Miall, 1976).

The cross-section runs southwest-northeast through the southeast portion of the Triassic "A" pool and is comprised of three Leduc oil wells (3-5L, 02/10-5, 1-9), an abandoned Triassic oil well (13-4) and three abandoned wells (15-4, 10-11, 9-14). (Status symbols represent the Triassic level.) The log pairs illustrated on the cross-section are gamma ray and sonic transit time in each example excepting that of 15-4, where the bulk density log is depicted instead of sonic transit time.

The Mississippian unconformity exposed Debolt Fm sediments in this locale, and has been interpreted as draping over the edge of the underlying Leduc reef. Overlying the Debolt Fm are Belloy strata which are unconformably overlain by the Montney Fm. The "flattening" of the Triassic unconformity surface mentioned earlier is clearly demonstrated on the cross-section. Also, the subcrop of Montney Fm sediments is demonstrated by the correlation of three internal marker horizons ("A", "B", "C"). The producing zone at 13-4 has as its lower boundary the silty zone correlated as Marker "C", and is sealed above by the Nordegg Fm phosphatic shales. The trapping mechanism is believed to be structural drape over the Leduc reef.

SEISMIC SECTION

The location of the seismic line illustrated in Figure 7.30 is shown in Figure 7.28. The geological cross-section of Figure 7.29 was chosen to approximately parallel the location of the seismic line. The seismic data were acquired in February 1979 using a single 2.27 kg charge of dynamite at a depth of 12.2 m and a source interval of 134 m. A 48 channel DFS-V instrument was used in conjunction with a symmetric split-spread receiver configuration having a near offset of 134 m and a far offset of 1676 m. Receiver arrays were comprised of nine L-15 10 Hz geophones over 33.5 m at a group interval of 67 m. This configuration of source and receiver produced 1200% CMP coverage. Data were sampled at 2 ms on a 3 sec record with a 12-128 Hz field filter. The seismic section was produced using conventional processing and is presented as a normal polarity section. (ie. An increase in acoustic impendance at an interface produces a positive

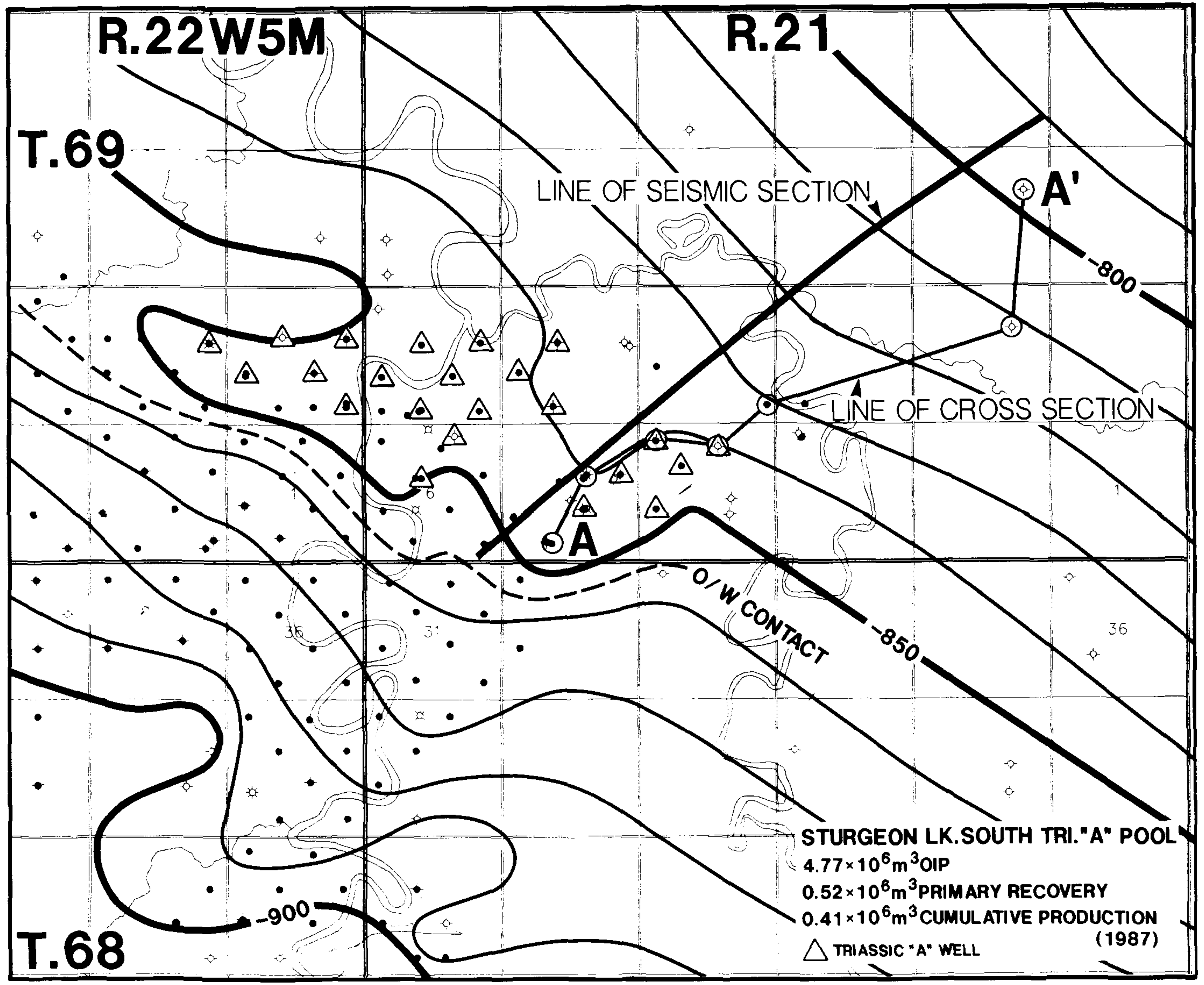

Figure 7.28. Sturgeon Lake South Triassic "A" pool showing structural relief on the Triassic surface.

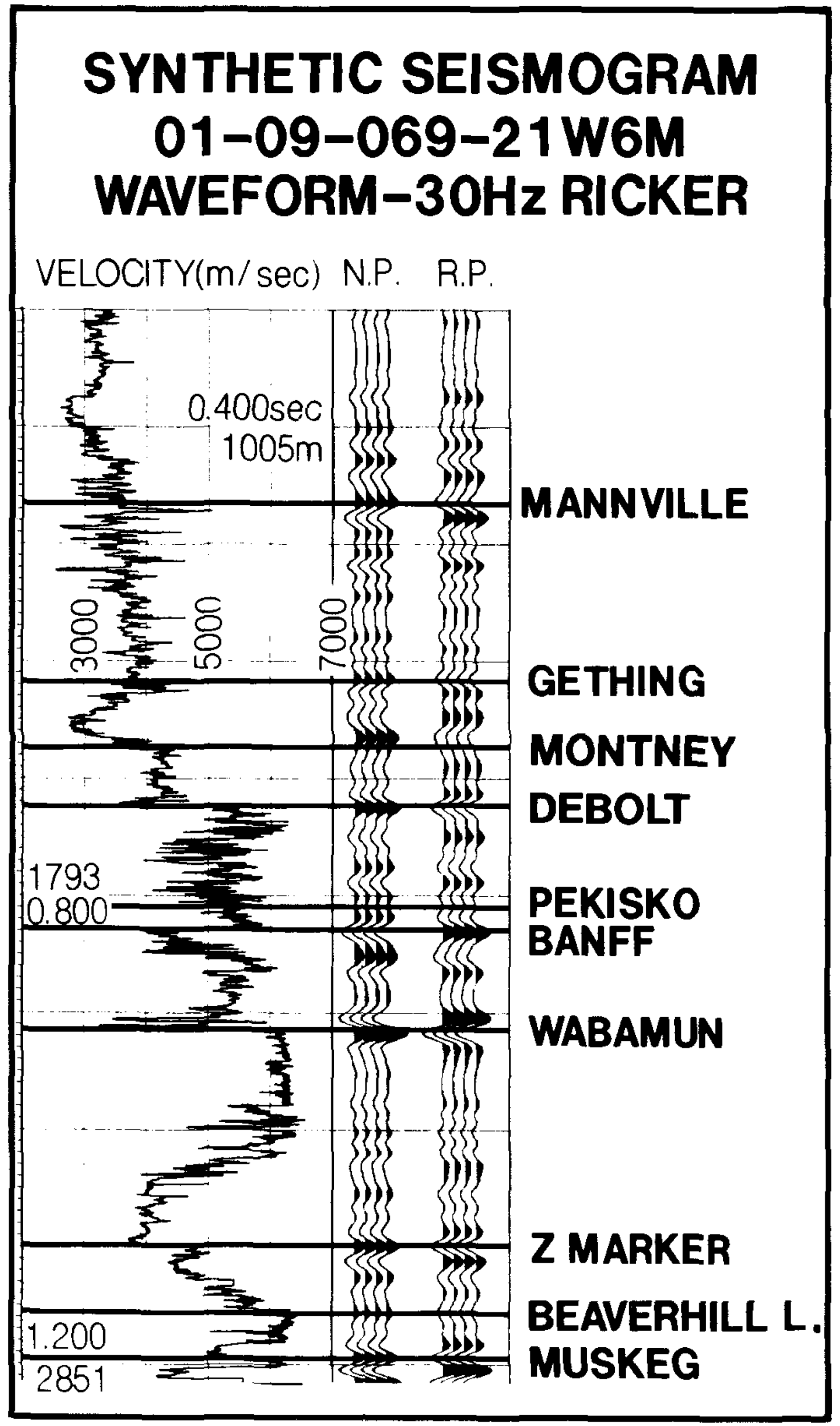

Figure 7.31. Synthetic seismogram well 01-09-069-21 W6M.

reflection coefficient resulting in a shaded deflection to the right on the seismic section.)

The seismic data were correlated with the aid of several synthetic seismograms, one of which is illustrated in Figure 7.31. This synthetic seismogram was generated with a zero phase Ricker wavelet having a central frequency of 30 Hz. The sonic log was simplified using a blocking algorithm resulting in a 0.4 m sampling. The original sonic log was sampled at 0.2 m increments.

The horizons correlated on the section are as follows:

Mannville - a continuous peak due to the transition from Harmon Fm shale to Mannville Gp sandstone.

Gething - a fairly continuous peak due to the transition from Bluesky Fm sandstone to Gething Fm interbedded silty sandstones and shales. The velocity of the shales is such that the Gething Fm has a higher average velocity than the overlying porous Bluesky Fm sandstone.

Montney - a very weak discontinuous peak associated with the transition from Nordegg Fm shale to Triassic interbedded sandstone, shale and siltstone. This weak peak is overshadowed by the large amplitude peak above it due to a sharp increase in velocity within the Fernie Fm shale.

Debolt - a fairly strong peak resulting from the sharp transition from Triassic and Belloy Fm sandstone and shale to Debolt Fm dolomite.

Pekisko - an intermittent peak due to the slight velocity increase from Shunda Fm argillaceous limestone to clean Pekisko Fm limestone.

Banff - a strong continuous trough associated with the distinct velocity decrease from the Pekisko Fm limestone to Banff Fm shale.

Wabamun - a strong continuous peak resulting from the transition from Banff Fm shale to Wabamun Gp limestone.

Z Marker - a continuous peak due to the sharp transition from shale to marlstone within the Ireton Fm.

Beaverhill Lake - a strong peak resulting from the transition from Ireton Fm marlstone to Beaverhill Lake Gp dolomite.

Muskeg - a weak peak due to the contrast between Muskeg Fm anhydrite and overlying Watt Mountain Fm shale.

The seismic data is contaminated to some degree by noise, particularly toward the southwest end of the seismic line. This noise, combined with the very small acoustic impendance contrast due to the Triassic unconformity and Montney Fm sandstone-siltstone-shale sequences, precludes detailed analysis of waveform signatures associated with the particular porous member of the Montney Fm which produces at Sturgeon Lake South. Acquiring data having a broader bandwidth, particularly in the higher frequency range, may reveal a Triassic seismic anomaly which is not apparent on the seismic section (Fig. 7.30).

The seismic section clearly shows Leduc reef development on the Beaverhill Lake platform at the southwest end of the line. The Leduc event corresponds to the peak at 1.465 seconds at the 02/10-5 location. Drape of the overlying events is also illustrated by the seismic data. A general thinning in the Montney-Debolt isochron toward the northeast end of the line is indicative of the Triassic subcropping in this area. Aside from these general observations, very little information regarding the producing zone of the Triassic "A" pool can be obtained from conventional seismic data.

SUMMARY

The reservoir of the Sturgeon Lake South Triassic "A" pool is a porous sandstone having approximately four metres of net pay. The trapping mechanism appears to be structural drape over the underlying Sturgeon Lake South Leduc reef. The play is poorly defined seismically in that there is no discernible response due to the presence or absence of reservoir. On the other hand, the draping characteristic is clearly demonstrated with seismic data. It appears that an exploration strategy for similar pools would entail geological mapping to determine the presence/absence of reservoir quality rocks, followed by seismic exploration to find a structurally favorable location.

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