CHAPTER 1 – PALEOZOIC CLASTIC RESERVOIRS

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INTRODUCTION

Oil and gas are produced from several clastic reservoirs which occur in Paleozoic strata of the Western Canada Sedimentary Basin. These include the Granite Wash zone, Gilwood Member, Watt Mountain Fm, Belloy Fm (a mixed sandstone, limestone and dolomite unit) and Bakken Fm. This chapter is concerned only with the informally named Granite Wash zone and the Gilwood Member (Watt Mountain Fm) in Northern Alberta, both of which are prolific oil reservoirs. Several pools which illustrate the various types of traps are discussed and their locations are shown on Figure 1.1. The stratigraphic column is illustrated in a table of formations in the Introduction.

The Peace River Arch was a principal influence on sedimentation of Devonian clastic rocks in northern Alberta. This structure was a large northeast-trending positive feature cored by Precambrian crystalline rocks and created by pre-Middle Devonian uplift (Burrows and Krause, 1987; Cant, 1988). Extensive normal faulting probably was involved in both the uplift and the Mississippian collapse of the Peace River Arch (de Mille, 1958; Sikabonyi and Rodgers, 1959). During the Devonian, material eroded from the emergent Arch was deposited as the Granite Wash zone and the Gilwood Member (de Mille, 1958).

The Granite Wash zone is a diachronous basal clastic unit which is probably the non-marine to shallow marine equivalent of Devonian carbonates, evaporites and shales deposited further from the Peace River Arch (Grayston et al, 1964; Pugh, 1973). Williams (1984), however, cautions that such correlations are "singularly unconvincing" in light of the lack of paleontological control. No attempt is made here to clarify the complex stratigraphic relationships of the basal Paleozoic clastic units discussed in this chapter.

The Granite Wash zone is composed of interbedded sandstones, siltstones and shales with minor amounts of dolostone and anhydrite. The sandstones range from fine-grained to conglomeratic and are composed primarily of quartz and feldspar derived from the Peace River Arch (Goodman, 1956; Greenwalt, 1956; de Mille, 1958).

The distribution of the Granite Wash was strongly influenced by the paleotopography on the Precambrian surface (Greenwalt, 1956) and in many areas, trapping of hydrocarbons in the Granite Wash is related to the paleotopography on the Precambrian surface. In some pools the reservoir sandstone laps out against the flank of a Precambrian high and dips away from it due to differential compaction. In other areas the sandstone is continuous over positive features on the basement and the traps are closures formed by differential compaction.

Some of the paleotopography on the basement may be due to faulting (Sikabonyi and Rodgers, 1957; de Mille, 1958). Possible pre-Granite Wash faulting, inferred from abrupt slope changes on the Precambrian surface recognized on seismic, does contribute to the basement relief but it may be viewed as a subsidiary influence on trapping. This appears to be true at the Otter Granite Wash F and I oil pools in Township 88 Range 11 and 12W5M. In a few areas, however, such as at the Evi Granite Wash P oil pool in Township 87 R11W5M, post-depositional faulting is largely responsible for the formation of the trap. All three trap types are schematically illustrated in Figure 1.2.

The Gilwood Member is a sandstone unit within the laterally equivalent, predominantly shaly Watt Mountain Fm (Alcock and Benteau, 1976). The Gilwood is lithologically similar to the Granite Wash zone and many authors also considered it to be derived directly from the Precambrian rocks of the Peace River Arch (eg. Jansa and Fischbuch, 1974; Kramers and Lerbekmo, 1967). Shawa (1969), however concluded that the sandstones of the Gilwood Member at Nipisi are at least a second cycle deposit. In some areas the Gilwood Member is trapped where it drapes over paleo-highs on the Precambrian surface, for example at the Evi Field in Township 87 Range 12 and 13W5M (west of the Evi Granite Wash P pool discussed in this chapter), but most of the oil in the Gilwood is trapped stratigraphically by updip facies changes of the reservoir sandstone to shale as at the Mitsue and Nipisi fields (Kramers and Lerbekmo, 1967; Shawa, 1969; Christie, 1971; Alcock and Benteau, 1976).

The sandstones of the Granite Wash and Gilwood Member are generally radioactive and therefore gamma ray logs do not clearly define the reservoir interval. The geological cross-sections included with each example are illustrated with gamma ray and sonic logs to show the lithologic boundaries and do not clearly define the quality of the individual reservoirs. A log analysis using all available logs must be completed in order to determine reservoir quality.

The Granite Wash zone and the Gilwood Member have been the targets of active exploration and development drilling since the discovery of oil in the Granite Wash zone at Great Plains Triad Muskeg Gilwood 1-9-73-18W5M, drilled in 1954 (Sproule, 1956). Alberta's Energy Resources Conservation Board (ERCB, 1988) assigns recoverable oil reserves of 28.8 x 10^6m^3 to the 12 recognized Granite Wash fields. Total production to the end of 1987 was 14.3 x 10^6m^3. Only one Granite Wash gas field is recognized, the single-well Worsley Granite Wash A pool which is now shut-in after having produced 461 x 10^6m^3 of natural gas.

Only 9 Gilwood oil fields are listed by the ERCB, but total reserves are 121.2 x 10^6m^3. The Nipisi Gilwood A and Mitsue Gilwood A pools account for the vast majority of this oil, with estimated reserves of 119.3 x 10^6m^3, or 98.5% of the total Gilwood reserves. These two fields have produced 83.5 x 10^6m^3 of oil to the end of 1987, 98% of the 84.9 x 10^6m^3 Gilwood total.

Total gas reserves assigned to the Gilwood are 8.239 x 10^6m^3 in four fields, but again the largest share is at Nipisi and Mitsue (7.540 x 10^6m^3), 91.5% of the total, most of which is solution gas.

ACKNOWLEDGEMENTS

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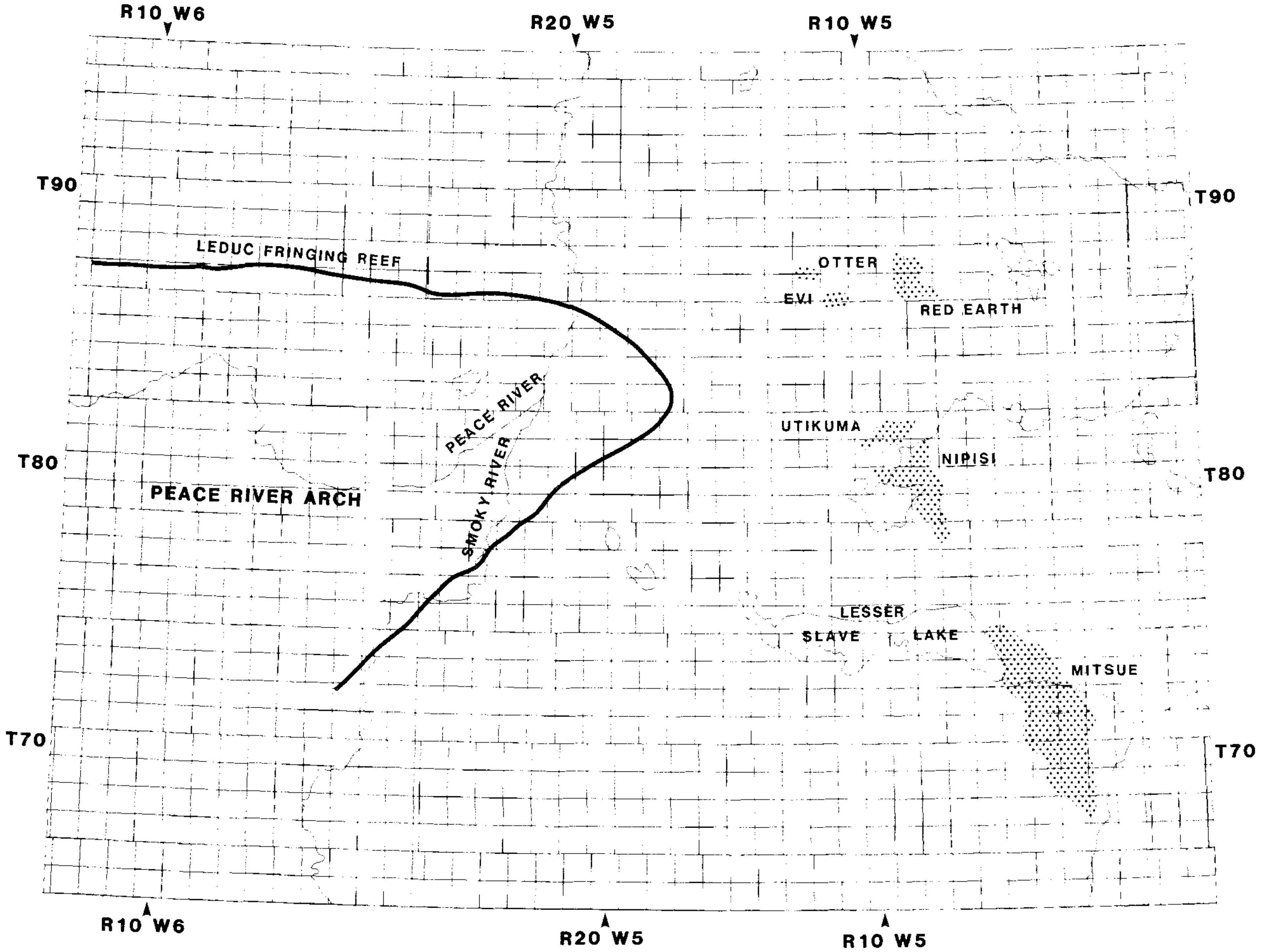

Figure. 1.1. Distribution of Granite Wash zone/Gilwood Member oil fields in northern Alberta.

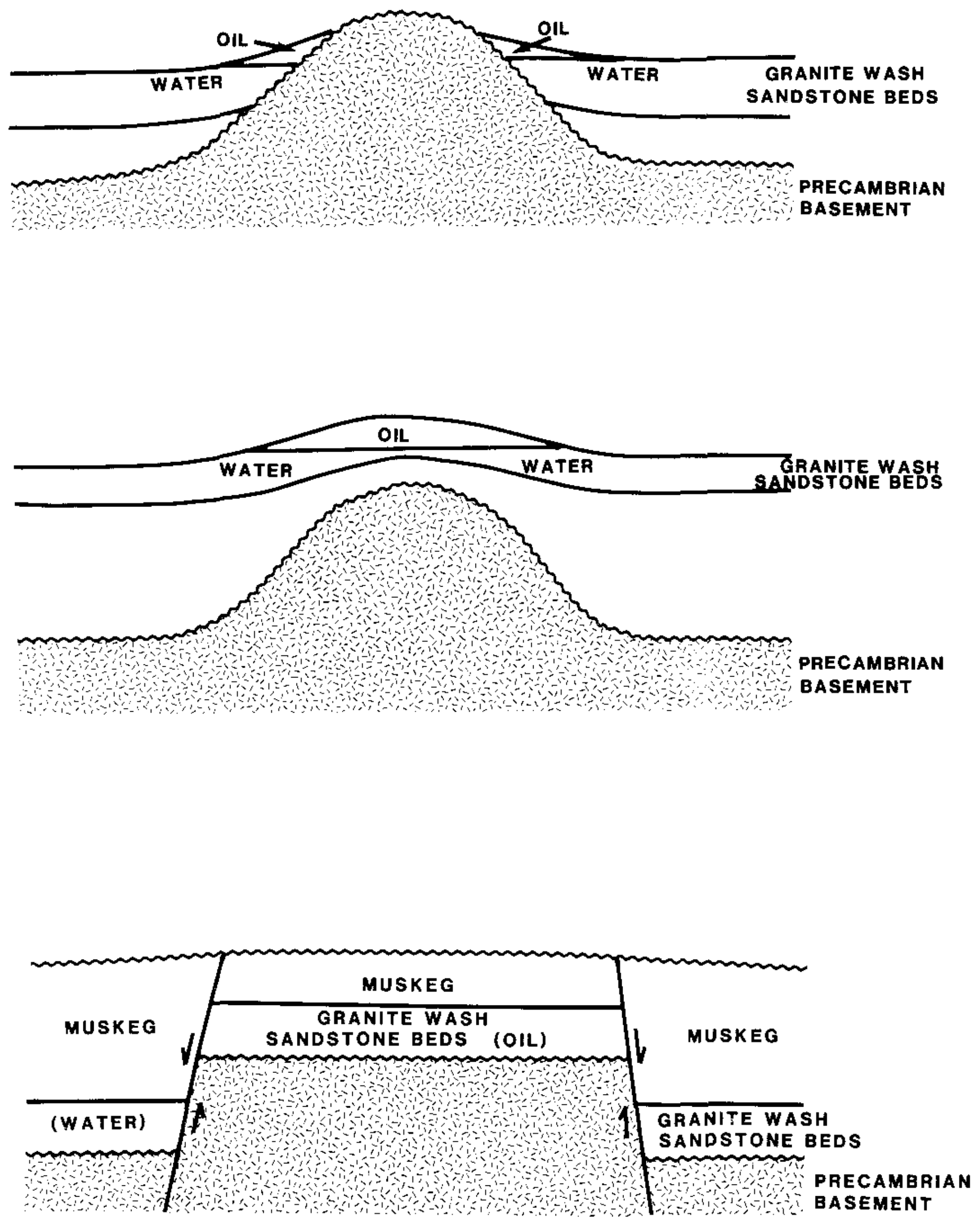

Figure. 1.2. Schematic models of Granite Wash zone traps - Schematic illustration of the various relationships between the Granite Wash sandstones and the underlying structure on the Precambrian basement.

The paleotopography on the Precambrian erosional surface is extremely irregular throughout Northern Alberta. Exploration for hydrocarbon pools associated with these basement highs is therefore seismically intensive. There is significant risk in this play, particularly in situations where:

1) the Granite Wash section may be missing due to non deposition or erosion over highs on the Precambrian surface; and

2) wells are drilled on the flanks of highs in structurally low positions such that they encounter water bearing sandstone.

Traps associated with faulting are likewise adequately defined only by detailed seismic coverage. Seismic has been comparatively less important in the discovery of stratigraphic traps of the Gilwood Member (Christie, 1971).

UTIKUMA LAKE KEG RIVER SANDSTONE A AND RED EARTH GRANITE WASH A OIL POOLS

The geology of the Utikuma Lake Keg River Sandstone A and the Red Earth Granite Wash A oil pools (the largest pools in their respective fields) are quite similar and thus they are discussed together in this section. Both pools produce from Granite Wash sandstone reservoirs which unconformably overlie the Precambrian basement, although Alberta's Energy Resources Conservation Board (1988) considers the producing sandstone at Utikuma Lake to be within the Keg River Fm.

The discovery well for the Utikuma Lake field, and the Keg River Sandstone A pool, is Atlantic IOE Utikuma 10-27-81-9W5M, drilled in 1963. A total of 71 oil wells have been drilled into the pool of which 53 were on production as of January 1, 1988. Cumulative production is 5.46 x $10^6 m^3$ of oil.

The Red Earth Granite Wash A pool was discovered with the drilling of Union Red Earth 10-1-88-9W5M in 1958, about two years after the discovery of the Red Earth field. Thirty nine of the 57 oil wells drilled into the pool are still producing. Cumulative production is 2.88 x $10^6 m^3$. Reservoir parameters for the pools are shown in Table 1.1

At both pools oil is trapped in Granite Wash sandstone reservoirs which pinch out against or drape over numerous positive paleotopographic features on the Precambrian surface. The top of the Granite Wash zone is sealed by the overlying Muskeg Fm anhydrite, however individual sandstone beds within the Granite Wash may be sealed by enclosing shale beds. Where the reservoir laps out against the flank of a paleotopographic high on the Precambrian surface, lateral seal may be provided by tight basement rocks. Most of the traps are probably due to drape over paleotopographic highs on the basement although some may be related to faulting. Pugh (1973) considers the Granite Wash zone at Red Earth and Utikuma to be a facies equivalent of the Keg River Fm and shows that the field lies just downdip of the updip facies change of the Keg River Fm from sandstone to dolostone which implies a potential stratigraphic component to the trapping mechanism.

TABLE 1.1: Reservoir parameters, Utikuma Lake Keg River Sandstone A and Red Earth Granite Wash A Oil Pools (ERCB, 1988)

	UTIKUMA LK. KEG R. SS A	RED EARTH GRANITE WASH A
AREA (ha)	4207	3776
NET PAY (m)	3.60	3.72
POROSITY (m)	18.6	14.9
WATER SATURATION	29	20
SHRINKAGE	0.85	0.86
RECOVERY FACTOR (%)	45	30
RECOVERABLE RESERVES ($x\ 10^3 m^3$)	7650	4320

RED EARTH GEOLOGICAL CROSS-SECTION

Figure 1.3 shows the location of a geological cross-section (Fig. 1.4) oriented north-south through the southwest portion of the Red Earth Granite Wash A oil pool. All the wells are represented by gamma-ray/sonic-logs except for 16-2-87-9W5M, for which a gamma-ray/bulk-density-log is shown.

The Precambrian basement is unconformably overlain by the Granite Wash zone, which is the reservoir interval. The Muskeg Fm overlies the Granite Wash zone (the nature of the contact is uncertain) and is in turn overlain unconformably by the Watt Mountain Fm. All the contacts are conformable between the overlying Fort Vermilion, Slave Point and Beaverhill Lake formations.

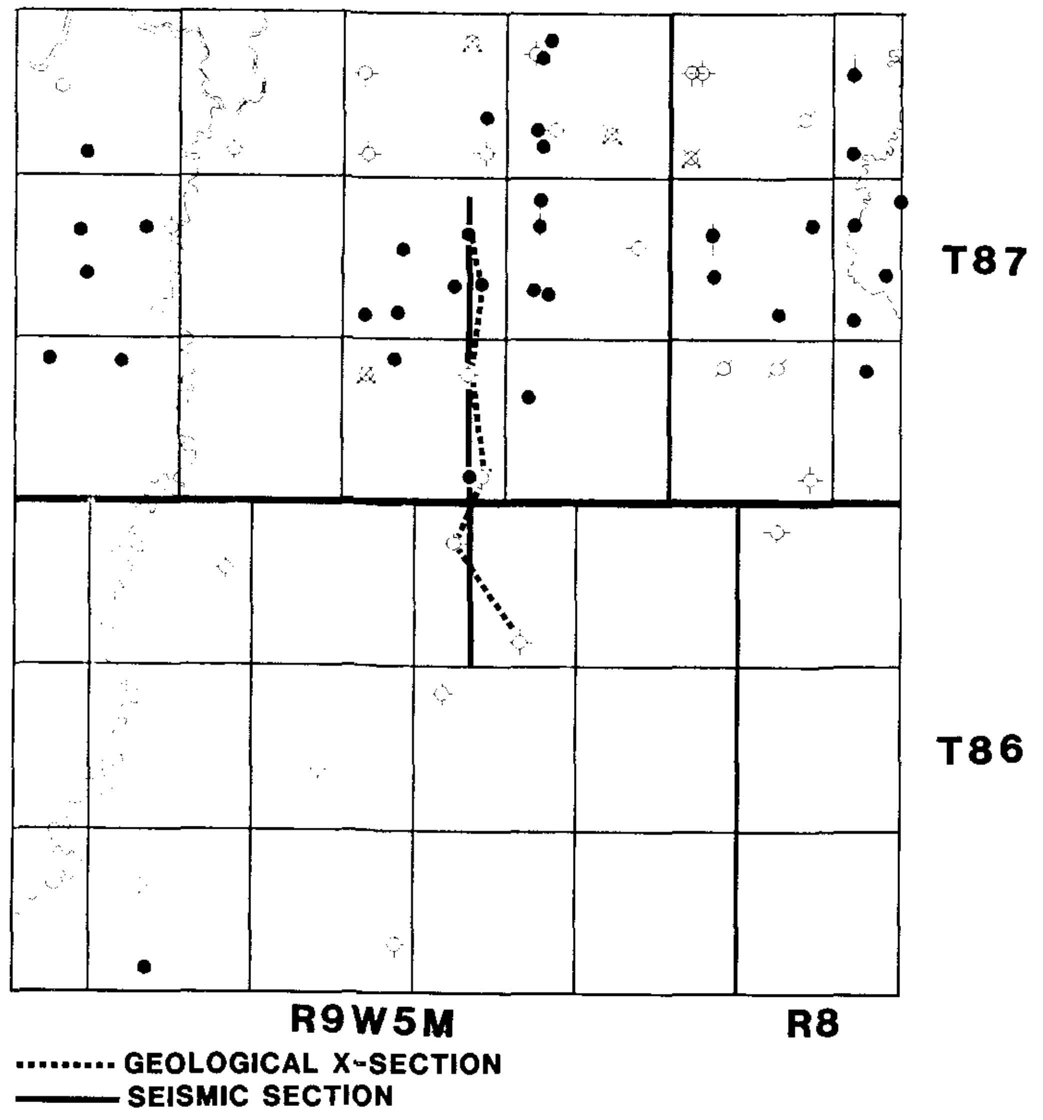

Figure 1.3. Base Map - Red Earth example.

The two northernmost wells, BP et al Red Earth 9-11-87-9W5M and BP et al Red Earth 8-11-87-9W5M, are Granite Wash oil wells. To the west, Apache Uno-Tex Red Earth 16-2-87-9W5M encountered only a thin, shaly Granite Wash zone containing no reservoir sandstone. At BP Ethyl Red Earth 1-2-87-9W5M and BP Ethyl Red Earth 13-35-86-9W5M the Muskeg Fm lies directly on the Precambrian, no Granite Wash zone having been deposited. SXDC et al Red Earth 2-35-86-9W5M penetrated a thick Granite Wash zone but the section is water bearing. A drillstem test was run over the Granite Wash zone and the recovery was 710 m of oil-flecked salt water.

Faulting is present in the Red Earth area as can be observed on the example seismic section. The Granite Wash zone is quite thin at 16-2-87-9W5M, showing that the basement was a paleotopographic high during Granite Wash deposition. However it can be seen on seismic (Fig. 1.5) that the 16-2 well is now in a small graben. Well data indicates that the Watt Mountain Fm thickens into the graben. The Muskeg is also slightly thicker at 16-2 than at 8-11 whereas the strata above the Watt Mountain are unaffected by the faults. This implies that the faulting was initiated slightly before the start of Watt Mountain deposition. A slight additional thickness of Muskeg Fm is preserved in the graben and, due to increased movement on the faults, a relatively thick Watt Mountain section was also deposited. The fault movement ceased by the end of Watt Mountain deposition. In contrast, at the Evi Granite Wash P pool, discussed in the next section of this paper, there are faults of similar age but the thickness of the Watt Mountain Fm is relatively constant and unrelated to the faulting. Rather, significant thickness variations occur in the underlying Muskeg Fm. The faults at Evi must have formed slightly earlier than at Red Earth, allowing additional time for erosion to bevel the Muskeg Fm surface.

There are two normal faults across which the basement steps down from 13-35-86-9W5M to 2-35-86-9W5M. The presence of an anomalously thick Granite Wash section at 2-35 indicates that the faulting pre-dates or occurred during deposition of the Granite Wash. The Fort Vermilion and Slave Point formations at 2-35 are slightly thicker than at 13-35 and there may have been a small amount of later movement on the faults and consequent thickening of these beds on the downthrown sides.

The geological cross-section illustrates an interesting example of a Granite Wash pool since several potential trapping elements are represented. Prior to the episode of faulting during Watt Mountain Fm deposition, there was a trap east of 16-2 associated with the lapout of the Granite Wash sandstone against the Precambrian hill to the west. The fault between 8-11 and 16-2 produced another trapping configuration. If the uppermost Granite Wash zone on the downthrown side of the fault is shale, then any sandstone on the upthrown side would be in trap position, sealed by that shale and the anhydrite of the Muskeg Fm across the fault.

The mechanism that actually caused the trap depends on the lithology of the Granite Wash near the fault and on the timing of oil migration, both of which are uncertain.

SEISMIC SECTION

Figure 1.5 is a seismic section oriented north/south through the south end of the Red Earth Granite Wash A pool (Fig. 1.3). This line was shot for Husky Oil Operations Ltd. in February of 1982. A two hole dynamite source (2 x 1 kg) was used at a shot depth of 14 m. The acquisition system consisted of a 96 channel DFS V recorder operating at a 2 ms sample rate. Twelve fold coverage was obtained with a near and far offset distance of 25 and 1200-m respectively, and a group and shot interval of 25 and 100-m. Nine 40-Hz geophones, laid out over 25-m, straddled each station and were summed unweighted.

This line was processed by CGG Geophysics Canada Ltd. using the sequence tabulated in Table 1.2. Data quality is good.

Several wells are tied to this seismic line. From north to south they are: 9-11-87-9W5M, 8-11-87-9W5M, 16-2-87-9W5M, 1-2-87-9W5M, 13-35-86-9W5 Mand 2-35-86-9W5M. Wells 9-11 and 8-11 are Granite Wash oil wells, 16-2, 1-2 and 13-35 have a thin to non-existent Granite Wash zone, and 2-35 has a thick and wet Granite Wash sandstone section. Sonic-logs are available for all wells except 16-2.

A typical Granite Wash geological section is observed in the Granite Wash oil well 9-11-87-9W5M which ties the seismic line at trace 25. A synthetic seismogram generated from the 9-11 sonic-log was used to identify horizons of interest (Fig. 1.6). The stratigraphically lowest reflection identified on the seismic section is the Precambrian event (red). This high amplitude, positive reflection coefficient (peak) event represents the interface between the low velocity Granite Wash zone and the high velocity Precambrian basement. Above this event is a high amplitude negative reflection coefficient (trough) event (yellow) representing the interface between the Granite Wash zone and the overlying, high velocity Muskeg Fm evaporites. The combination of these two events, a high-amplitude trough over a high amplitude Precambrian peak, is an important criterion for the prediction of the presence of Granite Wash section.

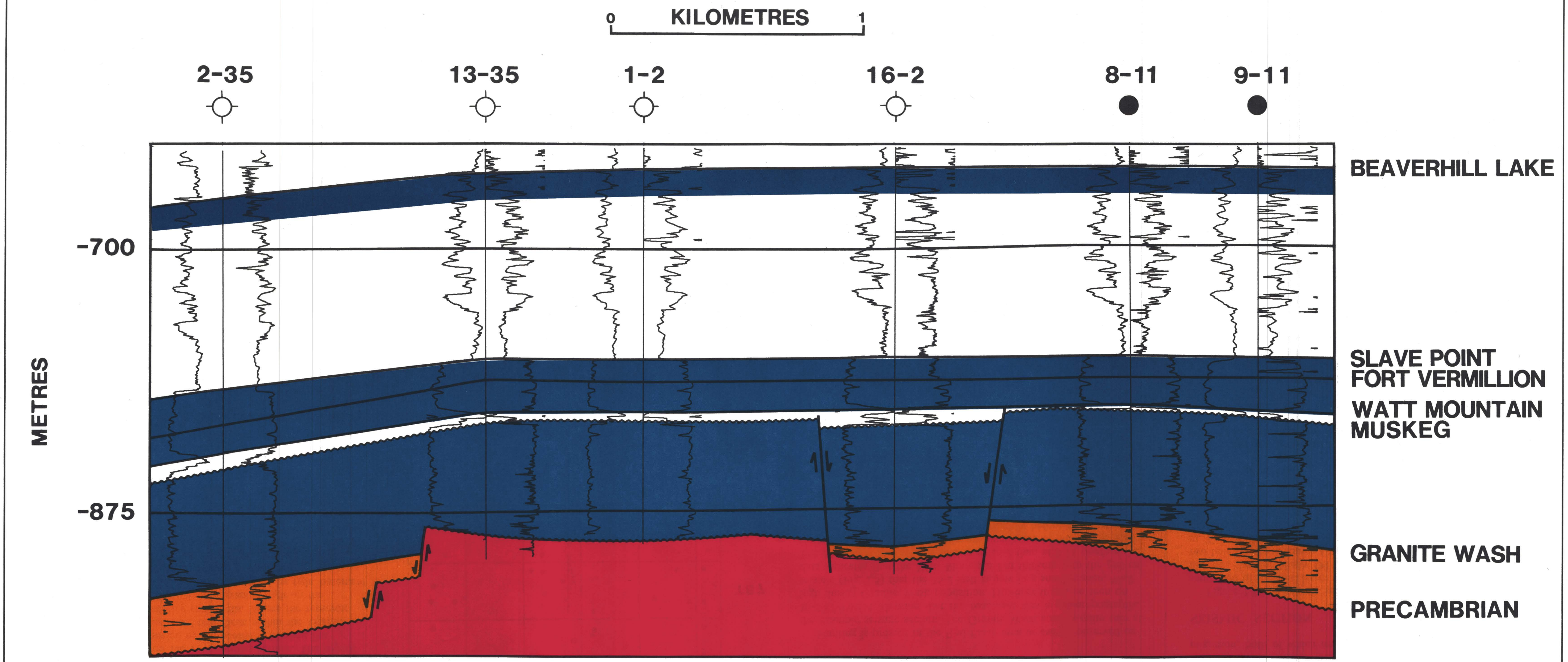

Figure 1.4. Geological cross-section - Red Earth example.

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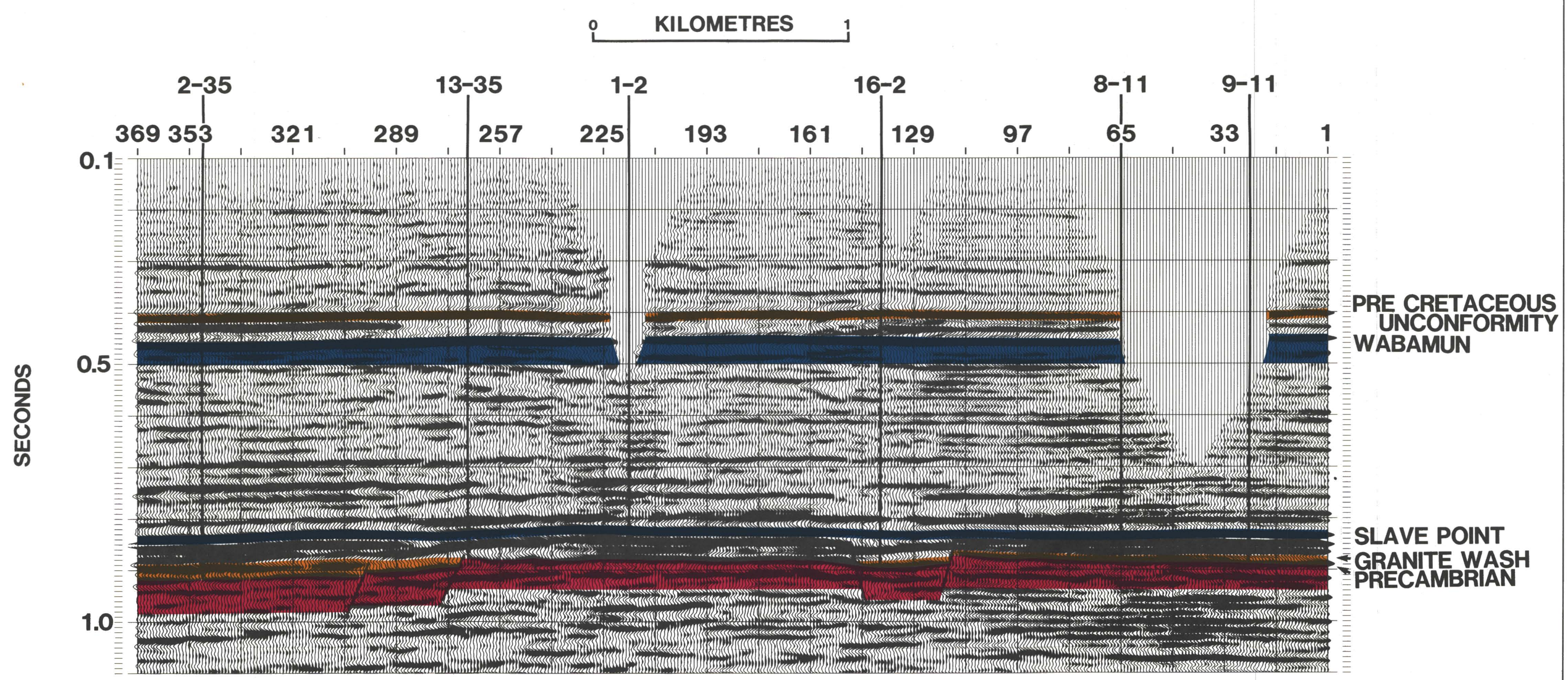

Figure 1.5. Seismic section - Red Earth example.

DONOR: HUSKY OIL OPERATIONS LTD | PROCESSOR: CGG GEOPHYSICS CANADA LTD | AUTHOR: J. WYLIE

TABLE 1.2: Processing sequence Red Earth seismic line

1) Demultiplex at 2 ms;
2) True amplitude gain recovery;
3) Relative preserved amplitude recovery;

4) Crooked line CMP positioning and binning;
5) Instrument and geophone dephasing;
6) Spiking deconvolution;
7) Statics (Elevation (floating datum), weathering, surface consistent automatic);
8) Velocity analysis and application;
9) Mutes;
10) Statics (Elevation (fixed datum), surface consistent automatic #2);
11) F/K multiple removal;
12) CDP trim auto statics;
13) Stack 1200%;
14) Wave equation migration;
15) Random noise attenuation (F-X deconvolution);
16) Filter 10/14 - 90/110; and
17) Equalization

These events are often obscured by multiple energy. Horizons of interest above the Muskeg Fm are, in ascending order, the top of Slave Point Fm carbonate (peak in blue), the top of the Wabamun Group carbonate (peak in blue) and the pre-Cretaceous unconformity (peak in yellow).

Typical time intervals utilized for Red Earth Granite Wash exploration include Wabamun to Slave Point, Wabamun to Precambrian and Slave Point to Precambrian. The significance of these intervals in delineating the structural and stratigraphic configuration of Red Earth type oil traps (see interpretation of the geological cross-section) is discussed in the following section.

The interpretation of the seismic section delineates a buried Precambrian paleotopographic high which has been modified by several periods of pre-Slave Point Fm faulting. These features are delineated by the time interval Wabamun to Slave Point which is observed to decrease over the paleo-high. The wells located at 9-11, 8-11 and 2-35 flank this paleo-high and the wells located at 16-2, 1-2 and 13-35 are located in crestal positions on it. Low velocity sandstones and shales of the Granite Wash zone onlap this high and are recognized seismically as a high amplitude trough event overlying a high amplitude Precambrian peak event. This character is observed

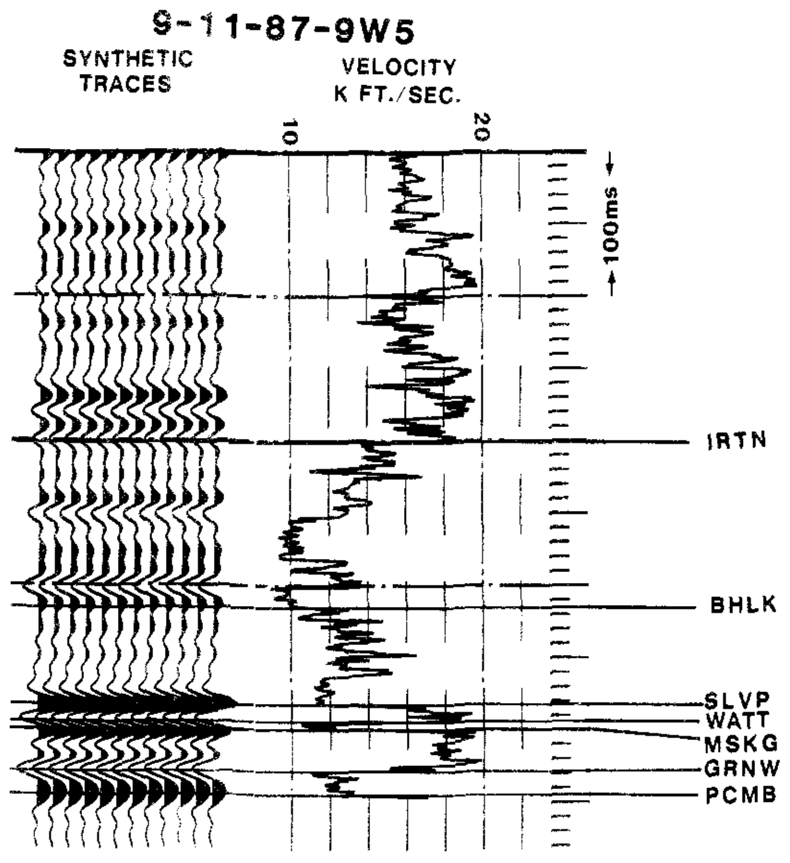

Figure 1.6. 9-11-87-9W5M - Velocity log and synthetic seismogram. Synthetic traces generated by convolving the reflection coefficient series with an Ormsby 10/15 - 60/65-Hz wavelet.

at the 9-11, 8-11 and 2-35 locations where thick Granite Wash sections are present. As the Granite Wash section thins on the flanks of the hill both the trough and underlying peak weaken in amplitude. This loss in amplitude is observed at the 13-35 location where the Granite Wash section is missing and the high velocity Muskeg Fm evaporates directly overlie the high velocity Precambrian basement.

The time interval Slave Point to Precambrian decreases as the Granite Wash section thins. This is observed moving up the high from the flanking 8-11 location to the crestal 13-35 location.

The criteria discussed to this point are insufficient to explain the time intervals and seismic character observed at the nearly bald of Granite Wash 16-2 and 1-2 locations. Both locations share a basal seismic character (strong trough over strong peak) indicative of a thick Granite Wash section. It has been determined that this character arises from a zone of low velocity, weathered Precambrian section located between the Muskeg Fm and the unweathered Precambrian basement. At the 16-2 location a faulted graben was formed during the deposition of the Watt Mountain Fm resulting in an increased time interval Slave Point to Precambrian, incorrectly suggesting a thick Granite Wash section. (See interpretation of geological cross-section). It is uncommon to encounter faulting of this age in the Red Earth area.

Seismic exploration for Granite Wash targets in the Red Earth area requires careful attention to seismic amplitude and character in the zone immediately above the basement. Delineation of fault trends and fault timing is crucial to trap delineation as well as to prediction of the presence of a Granite Wash reservoir.

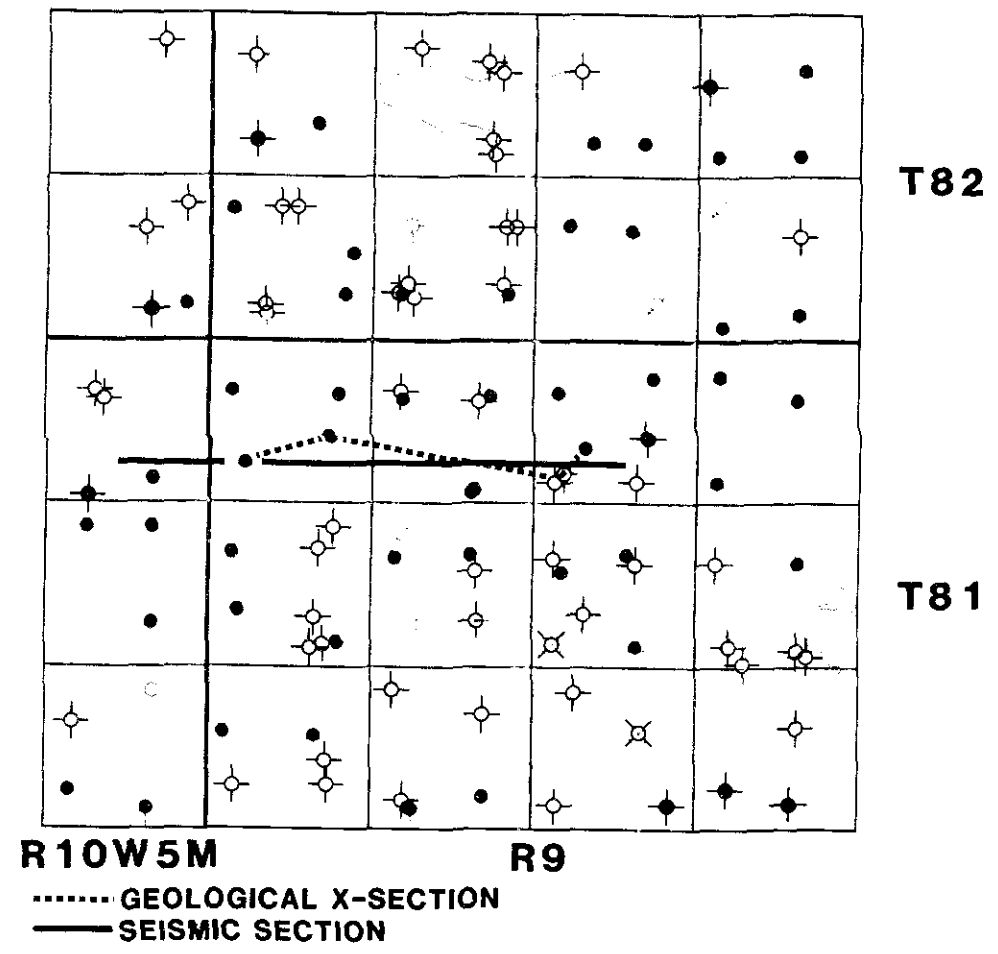

Figure 1.7. Base Map - Utikuma example.

UTIKUMA

GEOLOGICAL CROSS-SECTION

Figure 1.7 shows the location of a geological cross-section (Fig. 1.8) oriented east-west through the western edge of the Utikuma oil field. All the wells are represented by gamma-ray/sonic-logs.

The Precambrian basement is unconformably overlain by the Granite Wash zone, which is the reservoir interval. The Muskeg Fm overlies the Granite Wash zone (the nature of the contact is uncertain) and is in turn overlain unconformably by the Watt Mountain Fm. All the contacts are conformable between the overlying Fort Vermilion, Slave Point and Beaverhill Lake formations.

The Muskeg Fm evaporites provide top seal for the reservoir within the Granite Wash zone and are observed to thicken from west to east. This thickening is largely depositional, possibly related to relative movement of the Peace River Arch during Muskeg time.

The most easterly well, Husky Numac Utikuma 6-33-81-9W5M, is a producing Granite Wash oil well. To the west Uno-Tex Numac Utikuma 4-33-81-9W5M dry hole encountered less than two metres of shaly Granite Wash. Husky Numac Utikuma 7-31-81-9W5M and PCI Esso Utikuma 4-31-81-9W5M encountered thick Granite Wash sections. Both are currently producing oil from the Granite Wash.

The original 4-33 well encountered a thin Granite Wash section on top of a paleo-high. The seismic line (Fig. 1.9) delineates this positive basement feature showing sharp, possibly fault controlled, sides. This interpretation was confirmed when the 4-33 well was whipstocked 79.6 m north and 91.4 m east of the original location and encountered a thick Granite Wash section.

An increase in Granite Wash section thickness is observed between 7-31 and 4-31. The seismic line indicates that between these wells there is a fault that moved before or during deposition of the Granite Wash section.

If the reservoir interval at Utikuma Lake is a facies of the Keg River Fm then the field lies very close to the updip facies change from dominantly clastic to dominantly carbonate deposition in the Keg River Fm as described by Pugh (1973). This implies a possible stratigraphic component to the trap provided that the dolostone is sufficiently impermeable to provide a seal. The main trapping mechanism however is related to possibly fault controlled paleotopography on the basement. In the area crossed by the example seismic line it appears that the oil is trapped in small Granite Wash zone filled grabens on a broad positive basement feature otherwise devoid of Granite Wash section.

SEISMIC SECTION

Figure 1.9 is a seismic line oriented east/west through the western edge of the Utikuma Granite Wash oil field (Fig 1.7). This line was shot for Husky Oil Operations Ltd. in January of 1984. The source consisted of three 75 cu.in. air guns spaced in-line over 30-m straddling the shot point. This 24-fold line was acquired using a 96 channel split spread cable configuration with a near and far offset of 60 and 1470-m respectively. The shot point interval is 60-m and the station interval 30-m. Nine 30-Hz geophones, laid out over 30-m, straddled each station and were summed unweighted.

This line was processed by CGG Geophysics Canada Ltd. using the sequence outlined in Table 1.3. Data quality is fair.

Four wells directly tie or can be reasonably projected onto the seismic section. They are from east to west: 6-33-81-9W5M, 4-33-81-9W5M, 7-31-81-9W5M and 4-31-81-9W5M. Synthetic seismograms generated from sonic-logs acquired at the four locations are used to identify horizons of interest on the seismic section. It is observed that the ties from the synthetic traces to the seismic line are generally poor. This may be a result of multiple contamination or phase distortion caused by incorrect deconvolution assumptions related to poor surface conditions.

A representative geological section is observed in the Granite Wash zone oil well 6-33-81-9W5M (Fig 1.10). The synthetic seismogram generated from the sonic log from 6-33 ties the seismic section at trace 58. The stratigraphically lowest reflection identified on the seismic section is the peak representing the Precambrian event (red). This event is generated at the interface between the low velocity sandstones of the Granite Wash zone and the underlying crystalline Precambrian basement. Above this event is a high amplitude trough (yellow) representing the interface between the Granite Wash section and the overlying, high velocity Muskeg Fm evaporites. The combination of these two events, a high amplitude trough over a high amplitude Precambrian peak is an important criterion for the prediction of the presence of Granite Wash section.

TABLE 1.3: Processing sequence Utikuma seismic line

1) Demultiplex at 2 ms;
2) True amplitude gain recovery;
3) Relative preserved gain recovery;
4) Crooked line CMP positioning and binning;
5) Instrument and geophone dephasing;
6) Spiking deconvolution;

7) Statics (Elevation (floating datum), weathering, surface consistent automatic);
8) Velocity analysis and application;
9) Mutes;
10) Statics (Elevation (fixed datum), surface consistent automatic #2);
11) F/K Multiple removal;
12) CDP trim statics;
13) Stack 2400%;
14) Wave equation migration;
15) Random noise attenuation (F/X deconvolution);
16) Filter 12/18-70/80; and
17) Equalization.

Horizons of interest above this are the top of the Calmut Mbr of the Beaverhill Lake Group (peak in blue), top of Wabamun Group carbonates (peak in blue) and pre-Cretaceous unconformity (peak in yellow). Note that although the top of the Slave Point Fm is resolvable at the 6-33 location it is not at the other locations.

Typical time intervals used for mapping in this area include Wabamun to Calmut, Wabamun to Precambrian and Calmut to Precambrian. The significance of these intervals in delineating the structural and stratigraphic configuration of Utikuma type oil traps (see Interpretation of geological cross-section) is discussed in the following sections.

The seismic line is interpreted to show a buried, steep sided Precambrian high flanked to the east and west by lows infilled with Granite Wash section. This interpretation is supported by the Wabamun to Calmut time interval which shows thinning over the crest of the high. The presence of the Granite Wash zone in the areas flanking the central high is inferred from the observation of a "high amplitude trough over Precambrian peak" relationship and a thick Calmut to Precambrian time interval. These criteria are observed on the seismic at the 6-33, 7-31 and 4-31 locations. The 4-33 well (projected 250 m from the southeast) was drilled on the central basement feature where little or no Granite Wash is present and the high velocity Muskeg Fm section overlies the Precambrian basement. This low velocity contrast interface does not generate a good basement reflection.

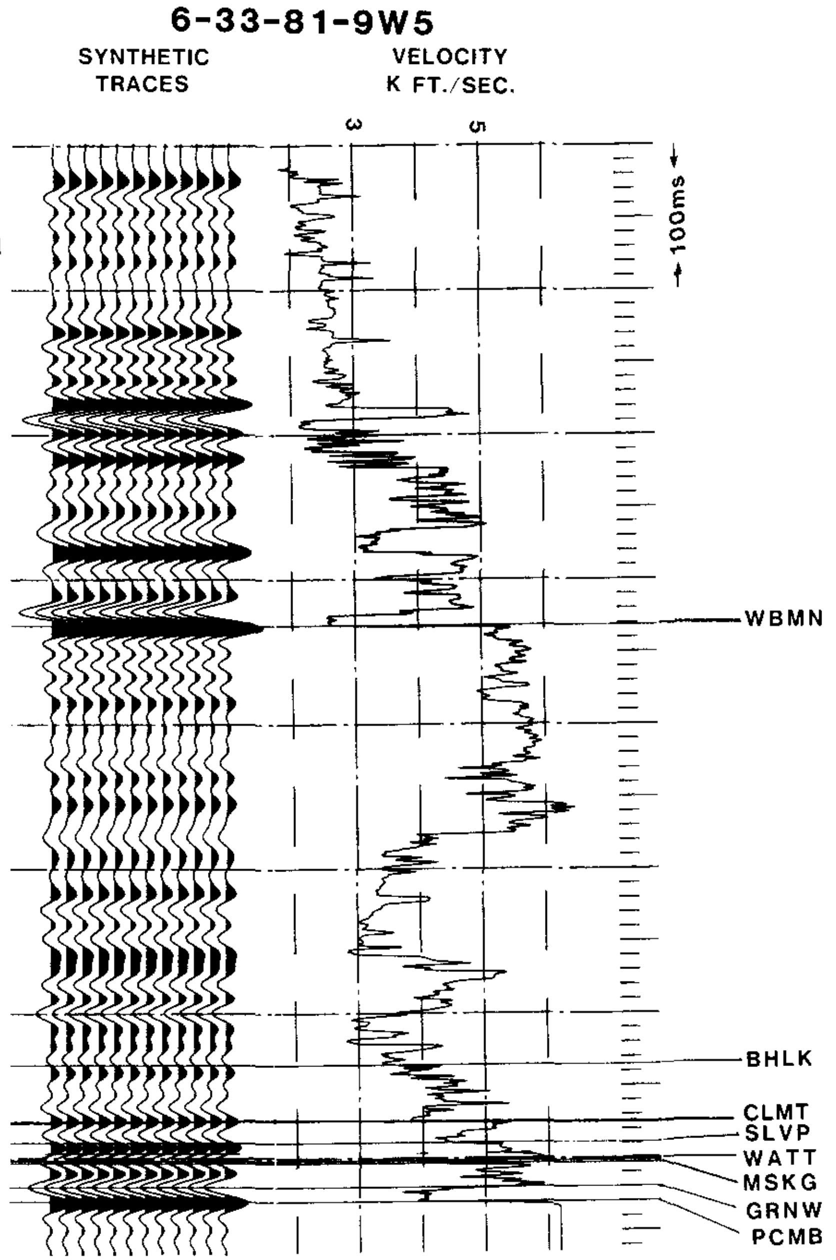

Figure 1.10. 6-33-81-9W5M - Velocity log and synthetic seismogram. Synthetic traces generated by convolving the reflection coefficient series with an Ormsby 10/15 - 60/65-Hz wavelet.

Exploration for Utikuma Granite Wash sandstone oil traps requires careful analysis of the time interval data and attention to the seismic amplitudes of events overlying the basement event.

Complex fault patterns in the Utikuma area make 2-D seismic exploration difficult. A 3-D survey might clarify the structural and stratigraphic configuration.

EVI GRANITE WASH P OIL POOL

The Evi Granite Wash oil pool in Townships 86-87, Ranges 10-11W5M well was discovered in December, 1985, by the drilling of Husky et al Lubicon 9-1-87-11W5M. As of January 1, 1988, there were seven oil wells in the pool. Cumulative production to the end of January 1, 1988 is 0.15 x $10^6 m^3$. Reservoir parameters are shown in Table 1.4.

The ERCB figures for the Granite Wash P pool also include data from the Keg River B pool. The reservoir is a thin dolostone overlying the Granite Wash. It may be correlative with the Keg River Fm but the relationship is not clear and for that reason it is considered in this chapter as the basal portion of the Muskeg Fm.

TABLE 1.4: Reservoir parameters, Evi Granite Wash P Oil Pool (ERCB, 1988)

AREA (ha)	448
AVERAGE NET PAY (m)	9.84
AVERAGE POROSITY (%)	19.4
AVERAGE WATER SATURATION (%)	27
SHRINKAGE	0.85
RECOVERABLE RESERVES (x $10^6 m^3$)	1.33

The trap at Evi is structural, formed by faulting which occurred approximately contemporaneously with the development of the pre-Watt Mountain Fm unconformity. The Muskeg Fm is anomalously thin, or missing, on the upthrown block due to the effects of pre-Watt Mountain Fm erosion. The Muskeg Fm is much thicker on the downthrown sides of the faults and the juxtaposition of the Granite Wash sandstone against the Muskeg Fm anhydrite across the faults produces the seal. Top seal is provided by the Muskeg Fm, or by the Watt Mountain Fm where the Muskeg Fm is absent.

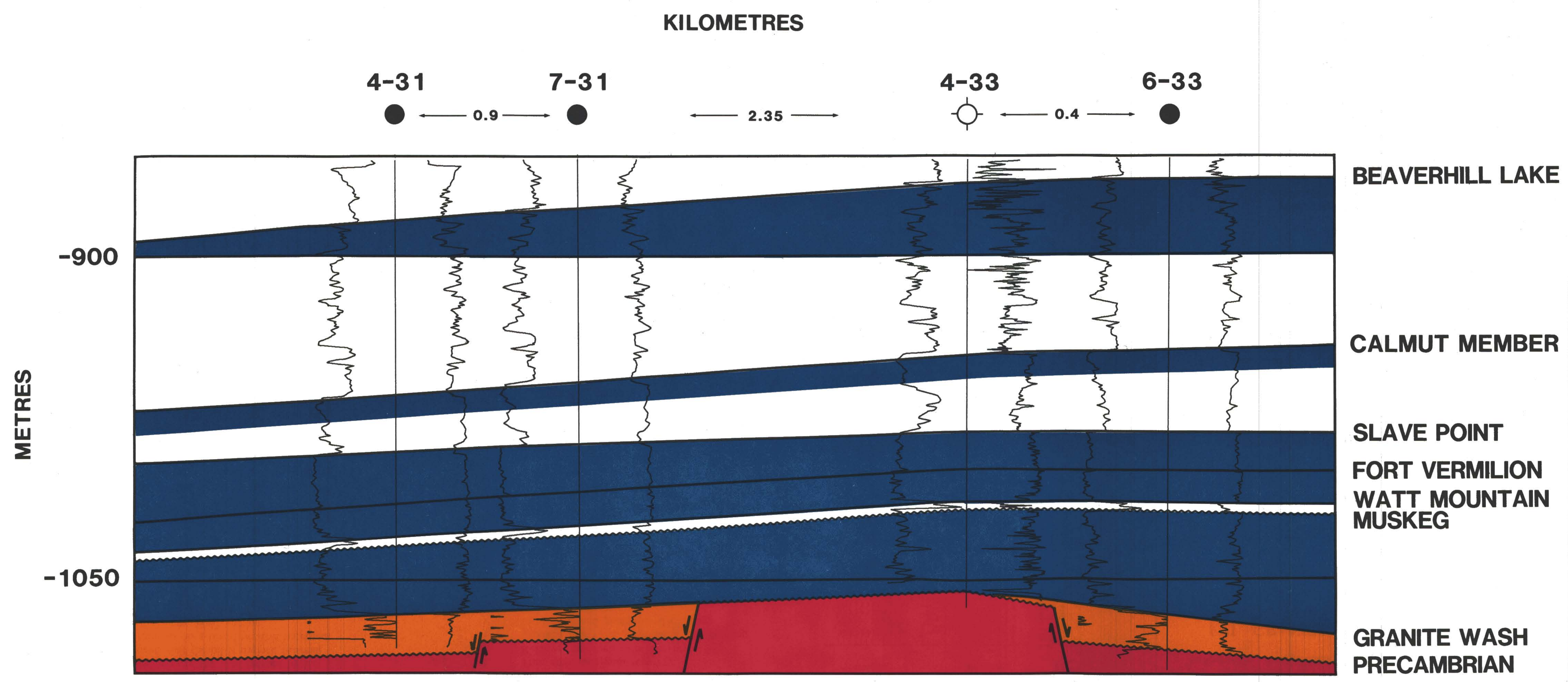

Figure 1.8. Geological cross-section - Utikuma example.

DRAFTING: | LOG PLOTS: RILEY'S DATASHARE INTERNATIONAL LTD. | AUTHOR: W. McCLOSKEY

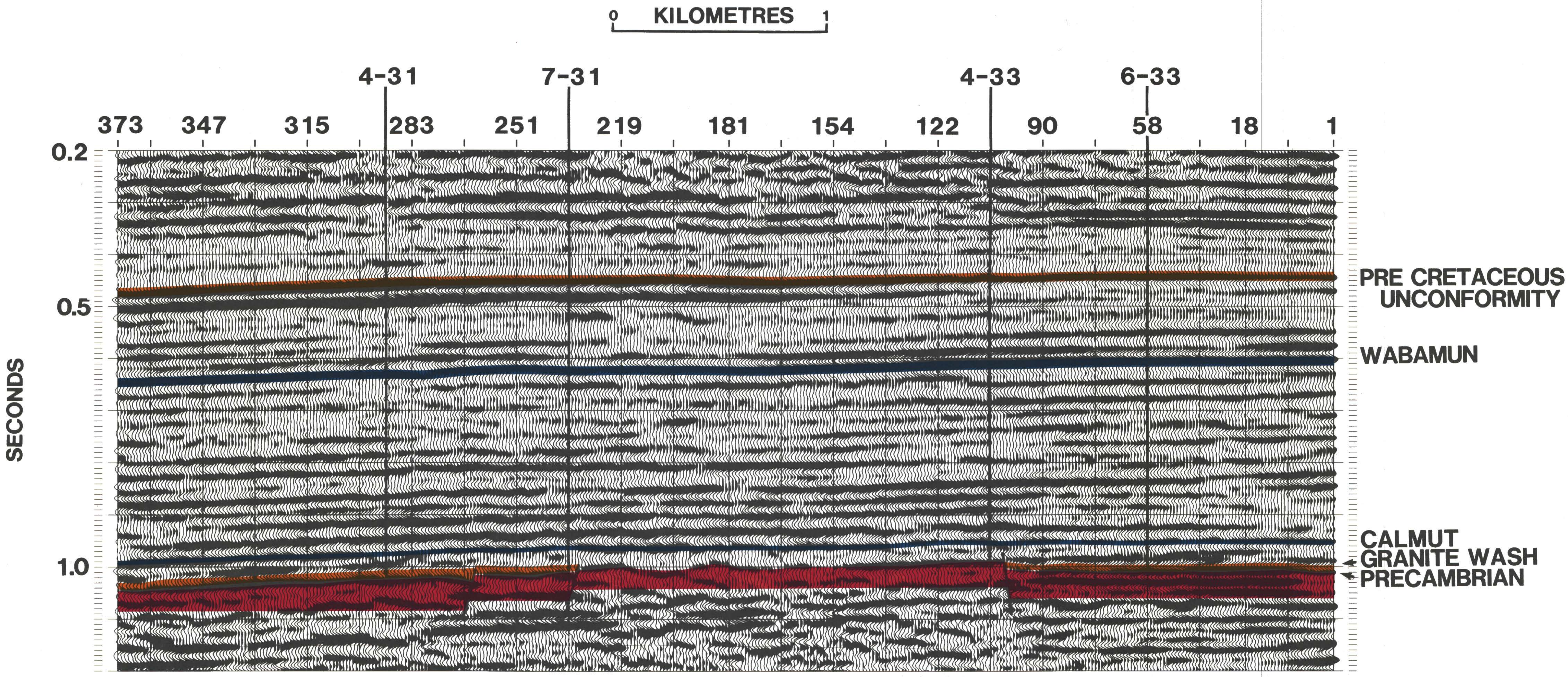

Figure 1.9. Seismic section - Utikuma example.

DONOR: HUSKY OIL OPERATIONS LTD | PROCESSOR: CGG GEOPHYSICS CANADA LTD | AUTHOR: J. WYLIE

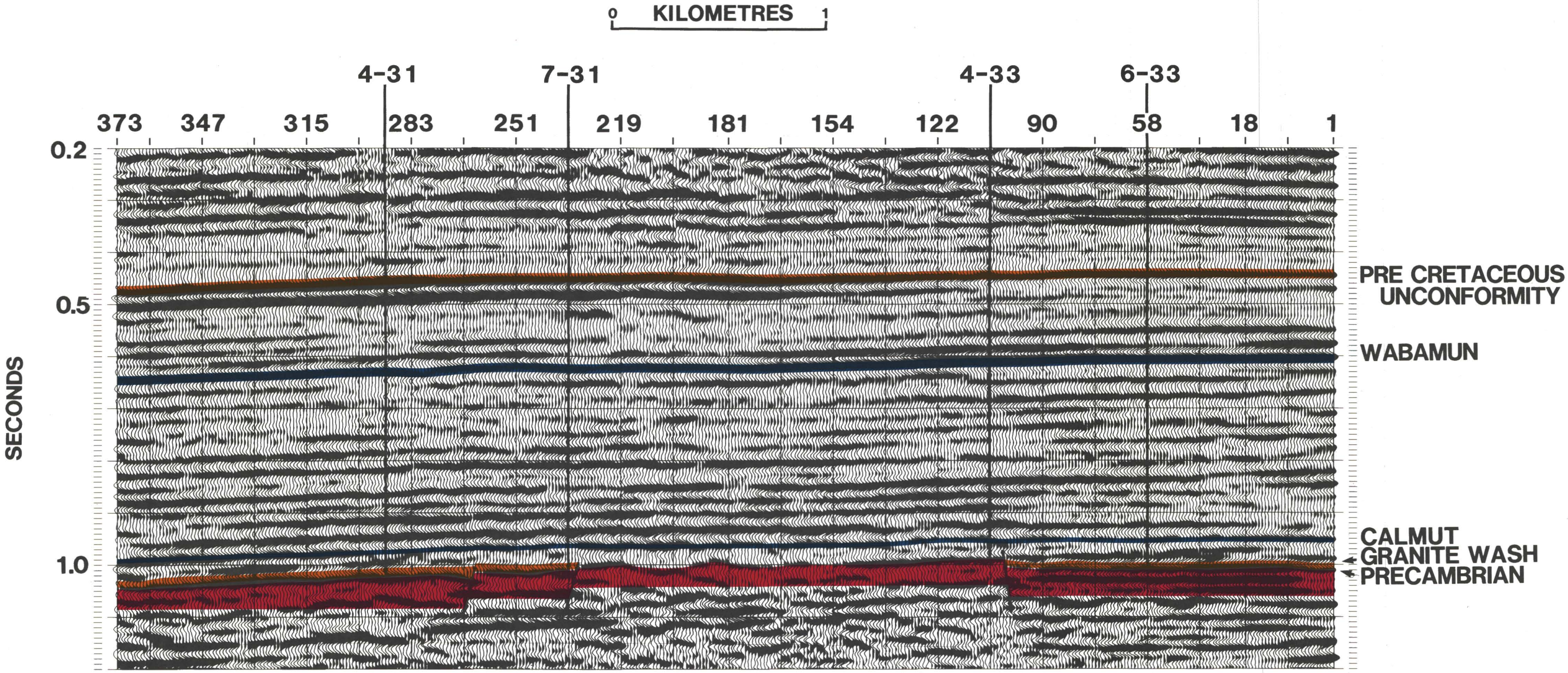

Figure 1.9. Seismic section - Utikuma example.

DONOR: HUSKY OIL OPERATIONS LTD | PROCESSOR: CGG GEOPHYSICS CANADA LTD | AUTHOR: J. WYLIE

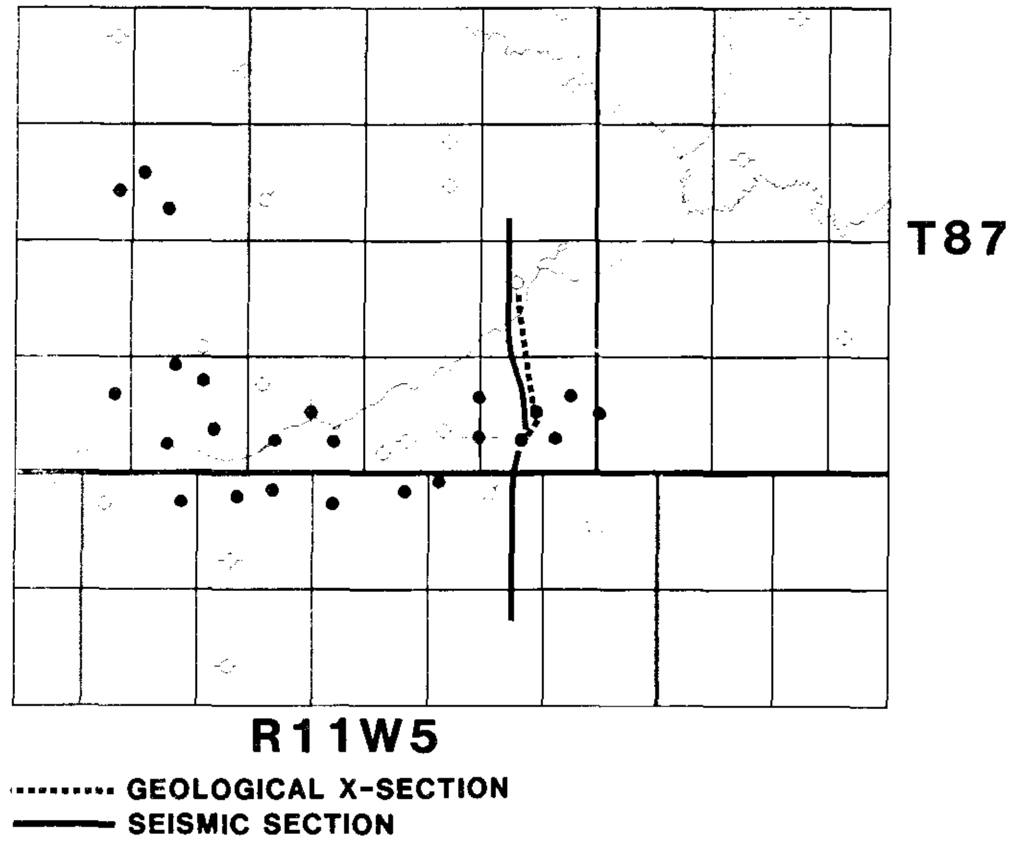

Figure 1.11. Base Map - Evi example.

GEOLOGICAL CROSS-SECTION

Figure 1.11 shows the locations of the geological cross-section (Fig. 1.12) and seismic section (Fig. 1.13) through the Evi field. All the curves on the cross-section are from gamma-ray/sonic-logs. Husky et al Lubicon 6-1-87-11W5M was directionally drilled, but the log shown is the true vertical depth version. Due to the presence of intermediate casing set in the Beaverhill Lake Group in Husky et al Evi 11-1-87-11W5M, only the lower part of the section was logged. The log shown from Husky et al Lubicon 11-12-87-11W5M is from the original well drilled at that location, not from the directional well drilled from the same surface location to a bottom hole location in 14-12. The 6-1 and 11-1 wells are producing oil from the Granite Wash whereas 11-12 is a dry hole drilled prior to the discovery of the pool.

The Granite Wash zone lies unconformably on the Precambrian basement. At 6-1-87-11W5M the top of a zone between the Granite Wash and the unweathered basement which is marked by a sharp decrease in interval transit time, may represent a weathered layer of Precambrian rock. The Granite Wash zone is overlain by the Muskeg Fm which is quite thin in the 6-1 and 11-1 oil wells but much thicker in the 11-12 dry hole on the downthrown side of the fault. These variations in the thickness of the Muskeg Fm are key to the recognition of traps associated with pre-Watt Mountain faulting. The Muskeg Fm is unconformably overlain by the Watt Mountain Fm. The lack of any significant variations in the thickness of the Watt Mountain Fm indicates that the faulting occurred prior to the deposition of this unit. The Watt Mountain Fm is conformably overlain by the Fort Vermilion, Slave Point formations and Beaverhill Lake Group.

The most significant feature in the pool is the major fault between the 11-1 and 11-12 wells across which there is 50 to 55 m of displacement of the basement. The position of the fault was determined from the seismic but its existence is confirmed and the timing of the faulting revealed by the variations in the thickness of the Muskeg Fm. The Granite Wash reservoir is laterally sealed against the Muskeg Fm across the fault.

This type of trap is a very attractive exploration target because it may contain a thick oil-bearing section. In contrast, traps associated with drape over paleotopographic highs on the basement typically contain much thinner pay intervals. It appears however, that the pattern of faulting is largely unrelated to the Precambrian paleotopography since in addition to the depressions filled with thick reservoir sands shown on Figure 1.12, paleotopographically high areas where no Granite Wash was deposited are also faulted up. An example of this is found west of the wells on the cross-section at Husky et al Evi 6-2-87-11W5M, which did not encounter any Granite Wash sandstone but where the Muskeg is anomalously thin. It is apparent that drilling locations must be selected to maximize the chance of finding both a faulted structure and the Granite Wash reservoir.

SEISMIC SECTION

Figure 1.13 is a seismic section oriented north-south through the Evi Granite Wash P pool. This line was shot for Husky Oil Operations Ltd. in December, 1986. A single-hole dynamite source of 1 kg was used at a shot depth of 15 m. The acquisition system consisted of a 120 channel DFS V recorder operating at a 2 ms sample rate. Thirty-fold coverage was obtained with a near and far offset distance of 30 and 1210-m respectively and a group and shot interval of 20 and 40-m. Nine 14-Hz geophones, laid out over 25-m straddled each station and were summed unweighted.

This line was processed by Geophysical Service Incorporated using the sequence shown in Table 1.5. Data quality is good.

TABLE 1.5: Processing sequence Evi seismic line

1)	Demultiplex at 2 ms;
2)	Weathering statics;
3)	Trace editing;
4)	True amplitude gain recovery;
5)	Pre-deconvolution mute;
6)	Deconvolution;
7)	Designature (shot domain);
8)	Trace equalization;
9)	F/K Multiple attenuation;
10)	Regional velocity analysis;
11)	Residual statics (surface consistent automatic statics);
12)	Detailed velocity analysis;
13)	Relative statics and residual statics application;
14)	NMO correction;
15)	Mean datum statics application;
16)	Stack mute;
17)	Trim statics;
18)	Stack;
19)	Predictive F-X filter;
20)	Migration (Finite difference);
21)	Filter 12/18-80/90 Hz; and
22)	Time variant scaling.

The stratigraphically lowest reflection identified on the seismic section is the peak representing the Precambrian basement event (red). The high-velocity Precambrian is overlain by the low-velocity Granite Wash zone resulting in a large positive reflection coefficient. Throughout this area the quality of the Precambrian reflection is affected by multiple interference. Above this event is a high amplitude trough (yellow) representing the interface between the Granite Wash zone and the overlying, high-velocity, Muskeg Fm evaporites. The next two reflections identified are the Muskeg and Slave Point events (both peaks shown in blue). These exhibit drape over paleotopographic features on the basement. A small amount of drape may also be observed on the overlying Beaverhill Lake reflection (blue). The top of the low-velocity Ireton Fm shale section is represented by a trough (yellow). Above the Ireton reflection is the high-amplitude peak associated with the top of the Wabamun Group (blue). The strength of this reflection is due to a large acoustic impedence contrast between the high-velocity Wabamun Group limestone and the overlying low-velocity Exshaw Fm shale. A common practice is the production of time interval maps between the Wabamun Group and one of the seismic events in the zone of interest. The stratigraphically youngest reflector identified on the section is the pre-Cretaceous unconformity surface (yellow). Cretaceous shale and sandstone lie unconformably on the limestone and calcareous shale of the Banff Fm.

On the central portion of the line the seismic expression of the faulted structure tested by the 6-1 and 11-1 oil wells may be observed. The presence of a thick Granite Wash zone is indicated by a strong trough (yellow) overlying the Precambrian peak. The Muskeg Fm is only 12 m thick at the 6-1 location and is, therefore, not seismically resolvable.

To the north, at 11-12-87-11W5M, the high-amplitude trough associated with the presence of the Granite Wash zone is also observed. Due to the increased thickness of the Muskeg Fm on the

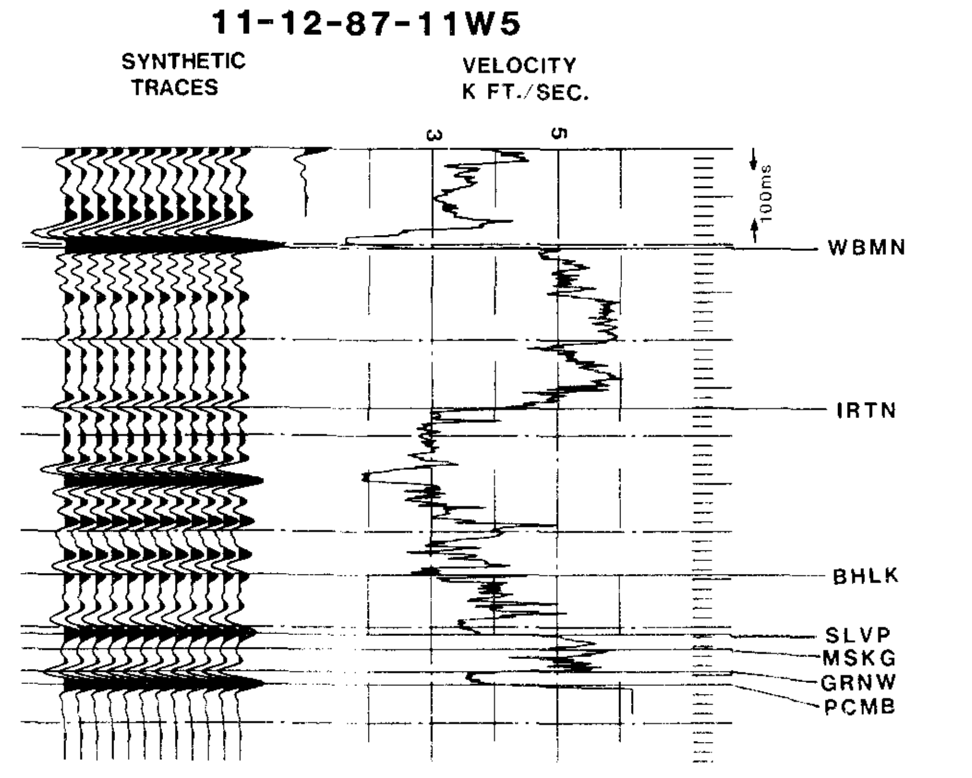

Figure 1.14. 11-12-87-11W5 - Velocity log and synthetic seismogram. Synthetic traces generated by convolving the reflection coefficient series with an Ormsby 10/15 - 60/65-Hz wavelet.

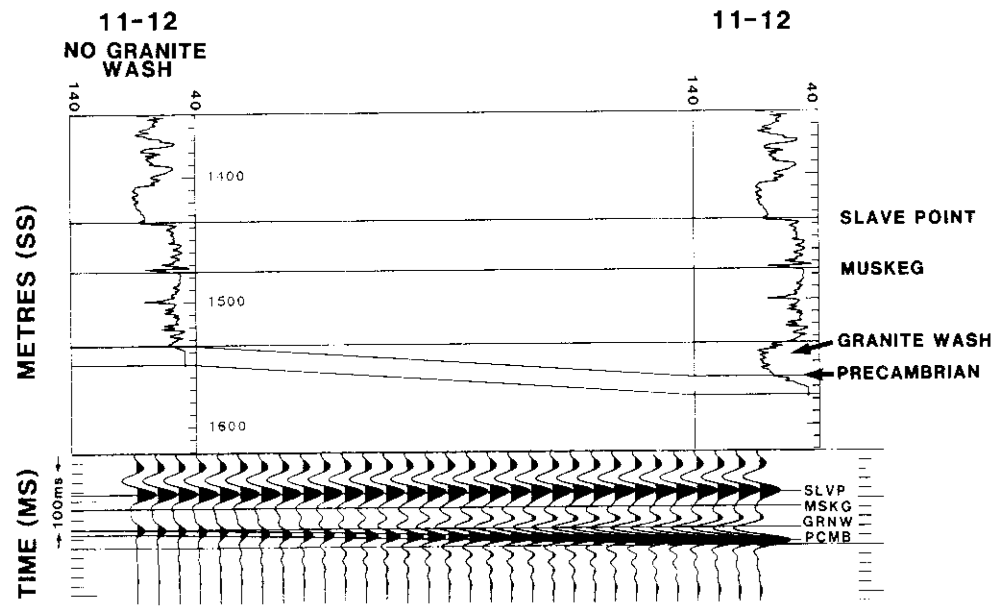

Figure 1.15. Evi Granite Wash Seismic Model - This model illustrates seismic response associated with progressive thinning of the Granite Wash zone over a Precambrian high. The synthetic seismic traces were generated by convolving the model reflection coefficient series with an Ormsby 10/15-60/65-Hz wavelet.

downthrown side of the fault the top of the Muskeg Fm can be resolved seismically. A synthetic seismogram has been included from this well as an example of a representative well tie (Fig 1.14).

The relationship between a strong trough overlying the Precambrian peak and the presence of a thick Granite Wash zone is substantiated by a seismic model (Fig 1.15). On the right side of the figure is the sonic-log from 11-12-87-11W5M and on the left side is the same log which has been modified by removal of the Granite Wash zone. Figure 1.15 also shows the synthetic seismic section resulting from this hypothetical cross-section. This model demonstrates the loss of amplitude of the Granite Wash trough and the Precambrian peak in response to progressive thinning of the Granite Wash zone.

Figure 1.16 shows a model which illustrates the change in seismic character in response to a progressive thinning of the Muskeg Fm. On the right side of the figure is the sonic-log from 11-12-87-11W5M and on the left side is the same log which has been modified by removal of the Muskeg Fm. On this model seismic section the amplitudes of the Precambrian peak and the Granite Wash trough have been maintained but the character of the Muskeg reflection changes in a manner very similar to that seen on the seismic section (Fig 1.13).

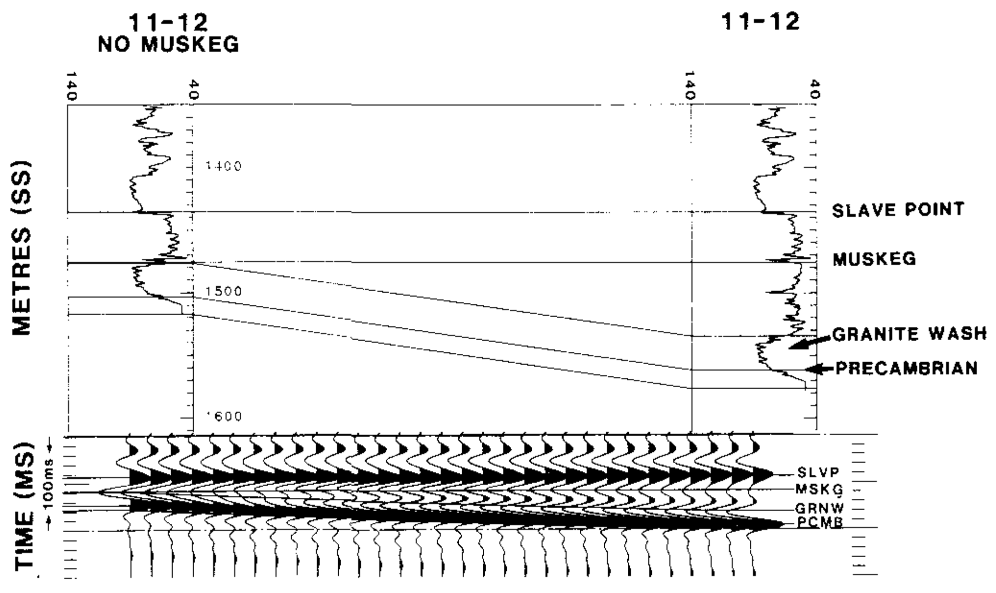

Figure 1.16. Evi Muskeg Seismic Model - This model illustrates the seismic response associated with progressive thinning of the Muskeg Fm over a Precambrian high. The synthetic seismic traces were generated by convolving the model reflection coefficient series with an Ormsby 10/15 - 60/65-Hz wavelet.

The recognition of the seismic character associated with a thick Granite Wash section on a faulted Precambrian structure (defined by a thin Muskeg Fm) is critical to exploration for this type of trap.

OTTER GRANITE WASH F AND I OIL POOLS

The Otter Granite Wash F and I pools are adjacent to each other and are similar geologically and so will be treated together as one example. The discovery well is TP et al Otter 2-6-88-11W5M (rig release date: March 29, 1984) and the pools now produce from a total of 15 wells. Cumulative oil production to September, 1988 for Otter Granite Wash F and I pools are 0.77 x $10^6 m^3$ oil and 175 mmcf gas and 0.45 x $10^6 m^3$ oil and 92.2 mmcf gas respectively. The reservoir parameters are tabulated in Table 1.6.

Oil is trapped in Granite Wash sandstone which pinches out against a paleotopographic high on the Precambrian unconformity surface. Top seal is provided by the anhydrite of the Muskeg Fm. The two pools are separated by a depression on the unconformity surface and are differentiated on the basis of the elevations of the oil/water contacts.

TABLE 1.6: Reservoir parameters, Otter Granite Wash F and I Oil Pools (ERCB, 1988)

	F POOL	I POOL
AREA (ha)	640	192
AVERAGE NET PAY (m)	3.57	4.25
AVERAGE POROSITY (%)	19.0	22.0
AVERAGE WATER SATURATION (%)	33	35
RECOVERY FACTOR (%)	30	30
SHRINKAGE	0.89	0.89
RECOVERABLE RESERVES (x $10^3 m^3$)	776	311

GEOLOGICAL CROSS-SECTION

Figure 1.17 shows the locations of Figure 1.18, a geological cross-section which is approximately parallel to the seismic line included as Figure 1.19. All the logs on the geological cross-section are gamma-ray/sonic-logs.

Reservoir rocks of the Granite Wash zone lie unconformably on the Precambrian basement and are overlain by the anhydrite of the Muskeg Fm which acts as top seal. Because the Granite Wash zone is diachronous the nature of its contact with the Muskeg Fm is unclear and it may be unconformable. The Muskeg Fm is unconformably overlain by the shaly Watt Mountain Fm which is in turn overlain conformably by the evaporites of the Fort Vermilion Fm, the Slave Point Fm (limestone) and the Beaverhill Lake Group (interbedded shale and limestone).

The distribution of the reservoir rocks and the geometry of the trap are closely related to the paleotopography on the Precambrian basement. The structured configuration of the Precambrian surface as interpreted from seismic (Fig. 1.19) is reflected in the overlying strata although the relief is attenuated up the section. In some places the basement paleotopography appears very abrupt on the seismic line and may be fault-controlled.

The easternmost well on the geological cross-section, TP et al Otter 9-6-88-11W5M, produces from the F pool. To the east of this well drape over a possibly fault-controlled paleotopographic scarp on the basement produces significant relief on the overlying beds.

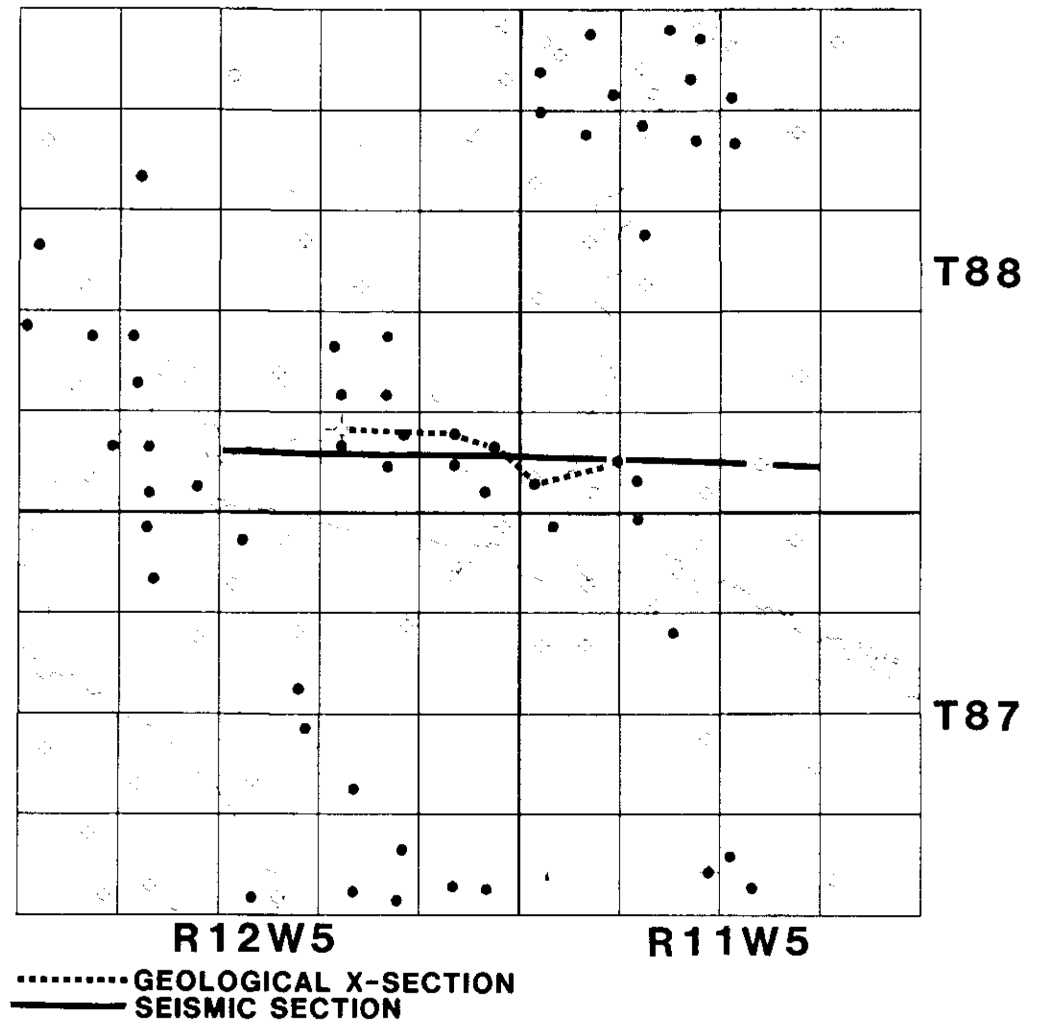

Figure 1.17. Base Map - Otter example.

The F and I pools are separated by a paleotopographic low on the Precambrian surface west of the 9-6-88-11W5M oil well. Because of compaction the Granite Wash zone has sagged into the depression and the top of the sandstone is now below the elevation of the oil-water contact in the F pool (-973 m). To the west of this low area there is a small sharp-sided depression, possibly a graben, penetrated by TP et al Otter 5-6-88-11W5M and containing water-bearing Granite Wash. A drillstem test was run over the Granite Wash in 5-6 and the recovery was 169 m of salt water cut mud, 255 m of slightly oil stained salt water and 705 m of salt water. On the seismic line, Figure 1.19, which was shot 500 m north of the well, this graben appears considerably deeper than at 5-6 and it is probably partly responsible for the separation of the pools.

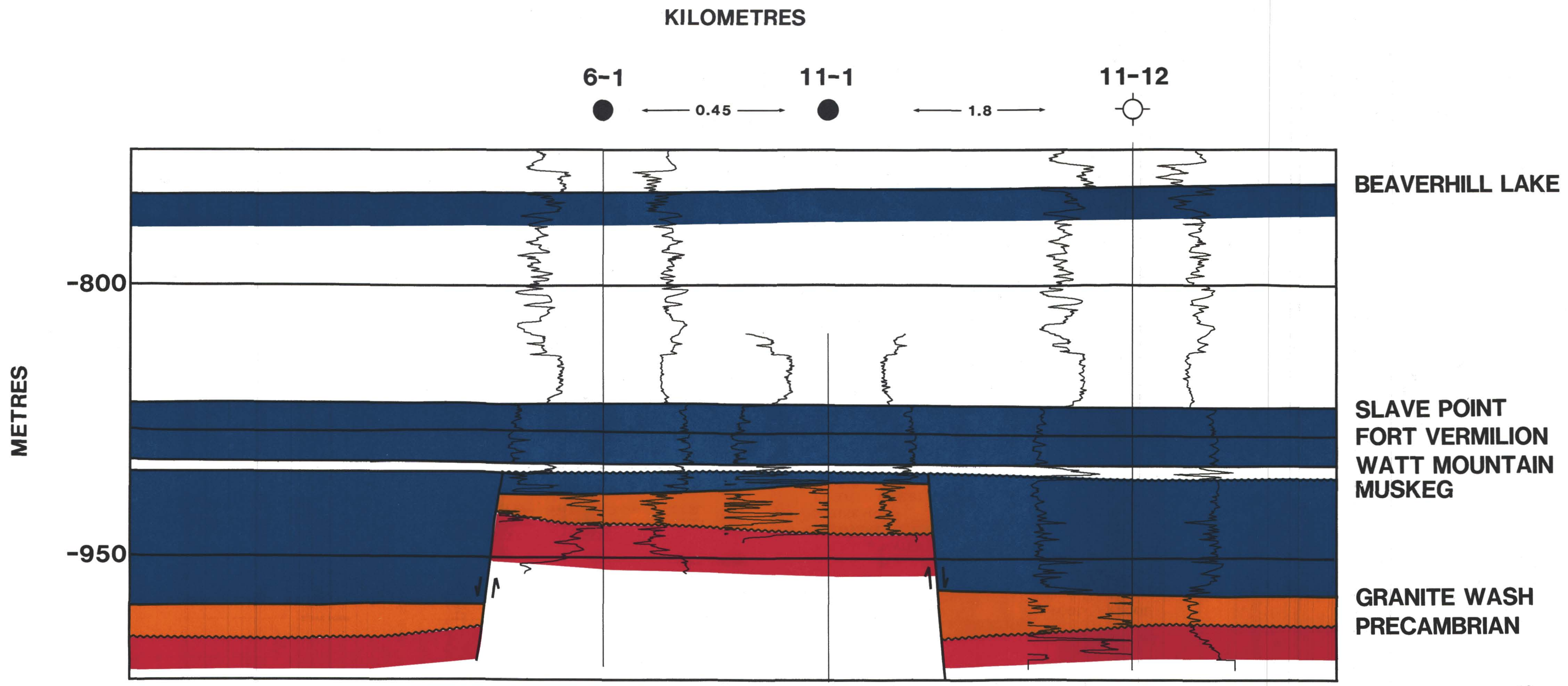

Figure 1.12. Geological cross-section - Evi example.

DRAFTING: | LOG PLOTS: RILEY'S DATASHARE INTERNATIONAL LTD. | AUTHOR: W. McCLOSKEY

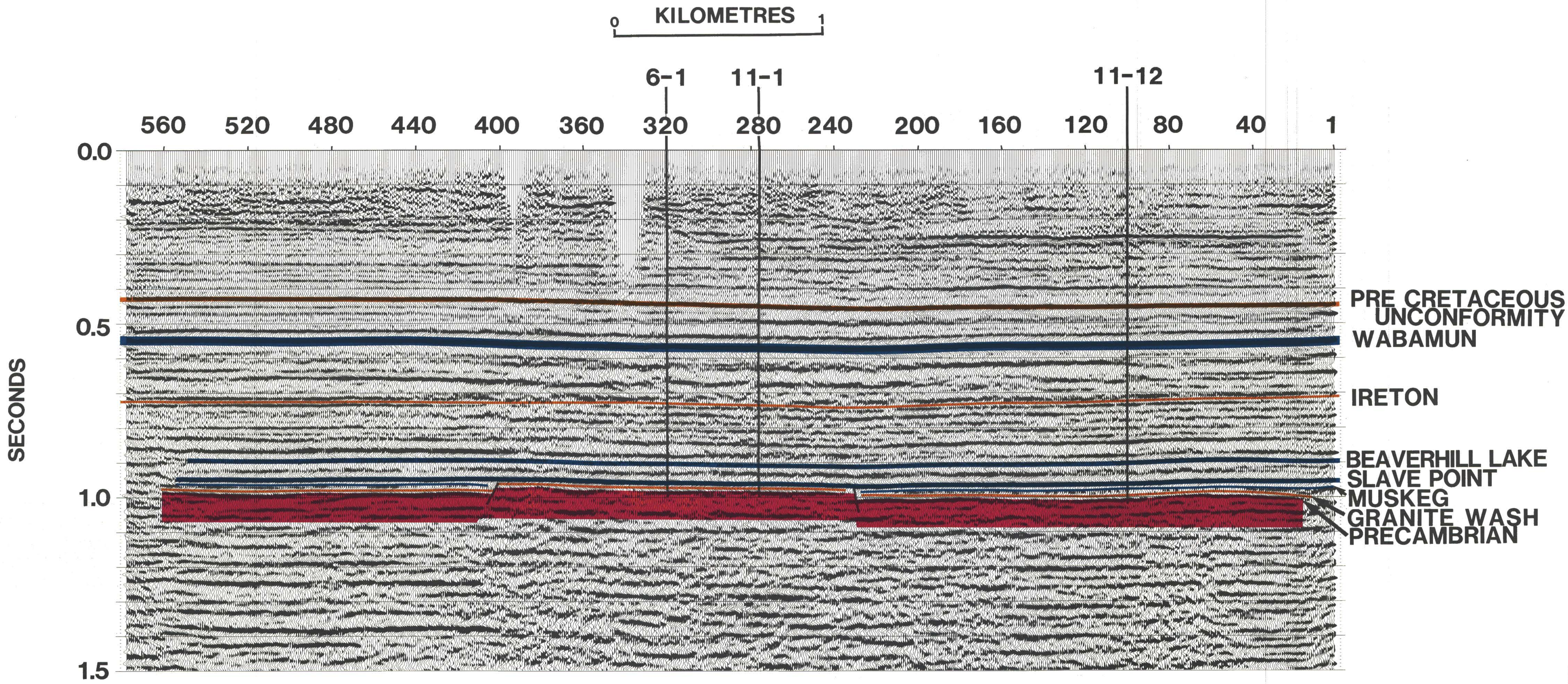

Figure 1.13. Seismic Section - Evi example.

DONOR: HUSKY OIL OPERATIONS LTD. | PROCESSOR: GEOPHYSICAL SERVICES INC. | AUTHOR: D. NOBLE

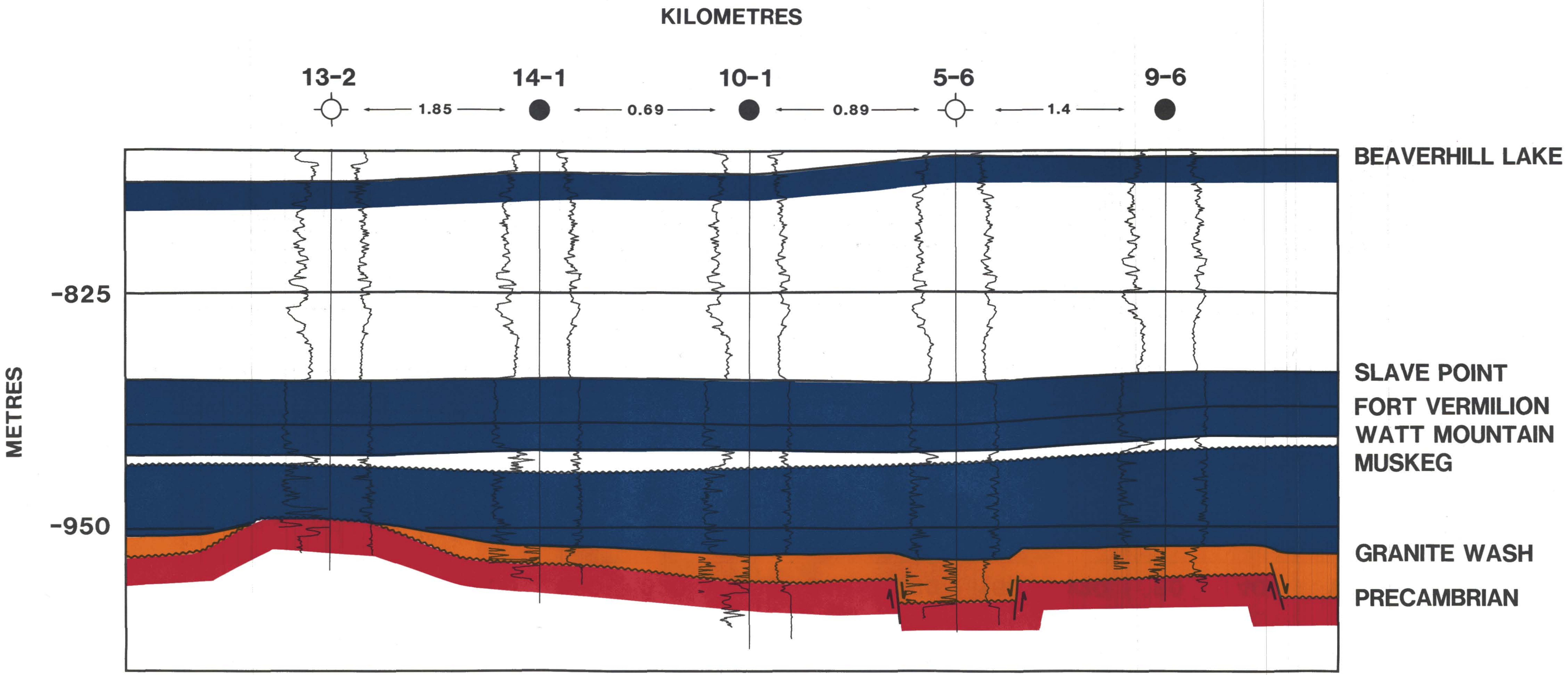

Figure 1.18. Geological cross-section - Otter example.

DRAFTING: | LOG PLOTS: RILEY'S DATASHARE INTERNATIONAL LTD. | AUTHOR: W. McCLOSKEY

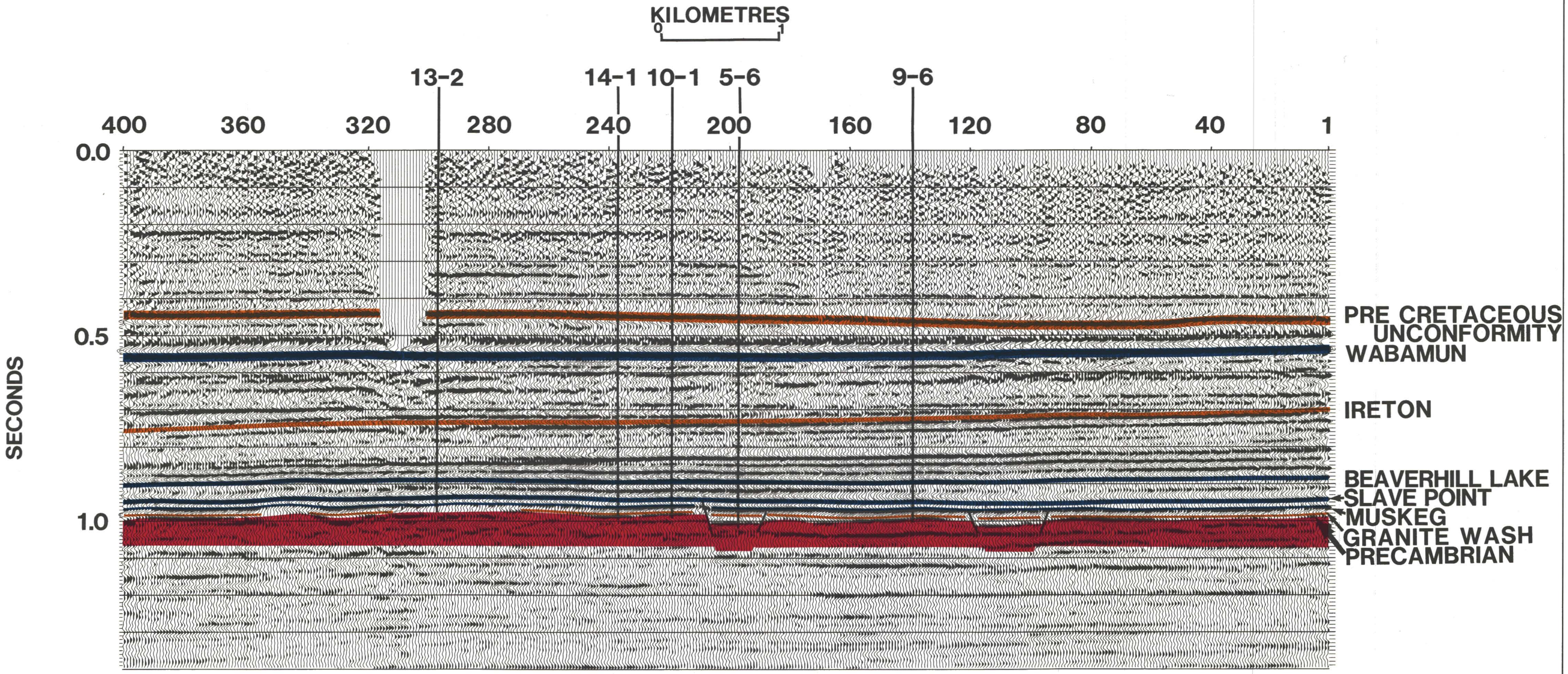

Figure 1.19. Seismic section - Otter example.

DONOR : NORCEN ENERGY RESOURCES LTD. | PROCESSOR : GEO-X SYSTEMS LTD. | AUTHOR : D. NOBLE

The other wells shown on the geological cross-section produce from the Otter Granite Wash I pool except for TP et al Otter 13-2-88-12W5M at the extreme western end. The Granite Wash laps out onto and dips away from the Precambrian high penetrated by the 13-2 dry hole. This is the key feature of the trap. It should be emphasized however, that the paleotopography on the Precambrian surface in this area is extremely irregular and that the relationships shown on the geological cross-section, based on only one seismic line, are rather simplified.

SEISMIC SECTION

Figure 1.19 is a seismic section oriented east-west through the Otter Granite Wash F and I pools. Figure 1.17 shows its location. This line was shot for Norcen Energy Resources Ltd. in January, 1982. A two-hole pattern dynamite source (2 x 1 kg) was used with a shot depth of 13.7-m. The acquistion system consisted of a 48 channel DFS IV recorder operating at a 2 ms sample rate. Twelve fold coverage was obtained with a near and far offset distance of 100.6 and 1559-m respectively and a group and shot interval of 50.3 and 100.6-m. Ten 8-Hz geophones, laid out over 50.3-m straddled each station and were summed unweighted. This line was processed by Geo-X Systems Ltd. using the sequence shown in Table 1.7.

TABLE 1.7 Processing sequence Otter seismic line

1) Demultiplex at 2 ms:
2) Amplitude recovery;
3) Instrument and Geophone Phase Compensation;
4) Deconvolution;
5) Statics - Elevation, Weathering and Drift;
6) Preliminary Velocity Analysis and Preliminary Surface Consistent Automatic Statics;
7) Final Velocity Analysis;
8) Scaling;
9) Mute;
10) Final Surface Consistent Automatic Statics;
11) Stack 1200%;
12) TP Multiple Attenuation;
13) CDP Trim Statics;
14) K-K Migration 90% RMS Velocities;
15) Phase Rotation 60;
16) Filter 10/14-65/75; and
17) Equalization.

The stratigraphically lowest reflection identified on Figure 1.19 is the peak representing the Precambrian basement event (red). The top of the Precambrian is represented by a large positive reflection coefficient as it is overlain by the low velocity Granite Wash zone. Throughout this area the quality of the Precambrian reflection is variably affected by multiple interference. Above this event is a high amplitude trough (yellow) representing the interface between the Granite Wash zone and the overlying, high velocity, Muskeg Fm evaporites. Overlying the Precambrian event are reflections from the Muskeg and Slave Point formations (both peaks shown in blue). These events drape over underlying paleotopographic features on the basement. Less drape is exhibited by the overlying Beaverhill Lake reflection (blue). The top of the low-velocity Ireton Fm shale section is represented by a trough (yellow). Above this is the high-amplitude Wabamun peak, caused by the large acoustic impedence contrast between the low-velocity Exshaw Fm shale and the underlying high-velocity Wabamun Group carbonates (blue). Time interval mapping of the seismic data from this area commonly involves using the Wabamun event, as a datum, and one of the seismic events in the zone of interest. The next significant reflector above the Wabamun event is the pre-Cretaceous unconformity surface (yellow). In this area Cretaceous sandstones and shales unconformably overlie the limestone and calcareous shale of the Banff Fm.

A synthetic seismogram for the 10-1-88-12W5M well has been included as an example of a representative well tie and is shown in Figure 1.20. The easternmost well that is tied into the seismic line is Westcoast et al Otter 9-6-88-11W5M, which produces from the F pool. The presence of a low-velocity Granite Wash section is indicated by a high-amplitude trough overlying the Precambrian peak. The scarp on the Precambrian to the east of this well may be fault-controlled.

A paleotopographic and structural low, possibly a graben, west of the 9-6 well separates the F and I pools. West of this, the Granite Wash section laps out against the Precambrian high penetrated by Westcoast et al Otter 13-2-88-12W5M, which has been projected onto the line. The amplitudes of the Granite Wash section trough and the Precambrian peak decrease considerably toward and over the area of non-deposition of the Granite Wash zone. This change in seismic character has been reproduced in a seismic model. Figure 1.21 shows the model, with the sonic-log from the 10-1-88-12W5M well (Granite Wash present) reproduced on both sides of 13-2-88-12W5M (Granite Wash absent; a "bald high"). The key feature is the weakening of both Granite Wash zone and Precambrian reflections in response to the thinning of the Granite

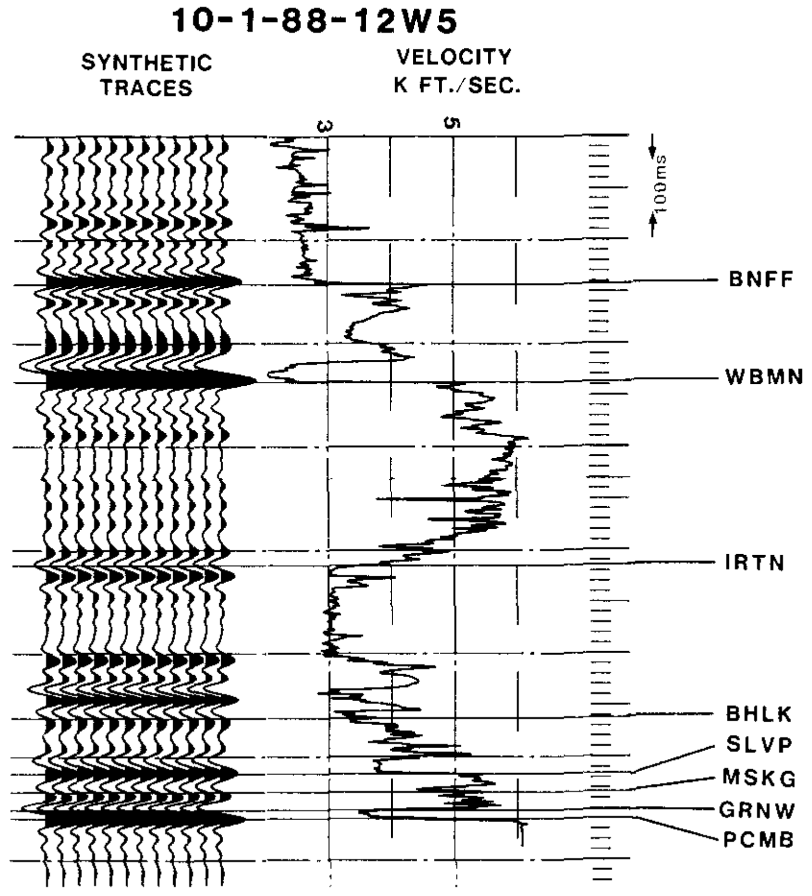

Figure 1.20. 10-1-88-12W5M - Velocity log and synthetic seismogram. Synthetic traces generated by convolving the reflection coefficient series with an Ormsby 10/15 - 60/65-Hz wavelet.

Wash section. The recognition of the seismic character associated with a thinning of the Granite Wash zone over a Precambrian paleotopographic high is critical to exploration for this type of trap.

MITSUE GILWOOD A AND NIPISI GILWOOD A OIL POOLS

The geology of the Mitsue and Nipisi Gilwood oil fields is very similar so these two examples will be reviewed together. It is unfortunate that these two pools, the largest discussed in this chapter, result from geological situations which do not produce a diagnostic seismic response. It is possible however, that with advancing geophysical technology it may one day be possible to seismically prospect for this type of trap.

The Mitsue Gilwood A pool, the only pool in the field, has produced 43.1 x $10^6 m^3$ of oil since it was discovered by the drilling of SOBC CalStan Hondo 2-1-71-4W5M in 1964. Of the 472 oil wells drilled into the pool, 267 are still on production. The discovery well at Nipisi is Mobil Nipisi 7-6-79-7W5M, drilled in 1965. Since that time the Nipisi Gilwood A pool, by far the largest of the seven pools in the Nipisi Field, has produced 40.4 x $10^6 m^3$ of oil. There are now 203 producing oil wells from the total of 350 that were drilled. Figure 1.22 shows the areal extent of both the Mitsue and Nipisi

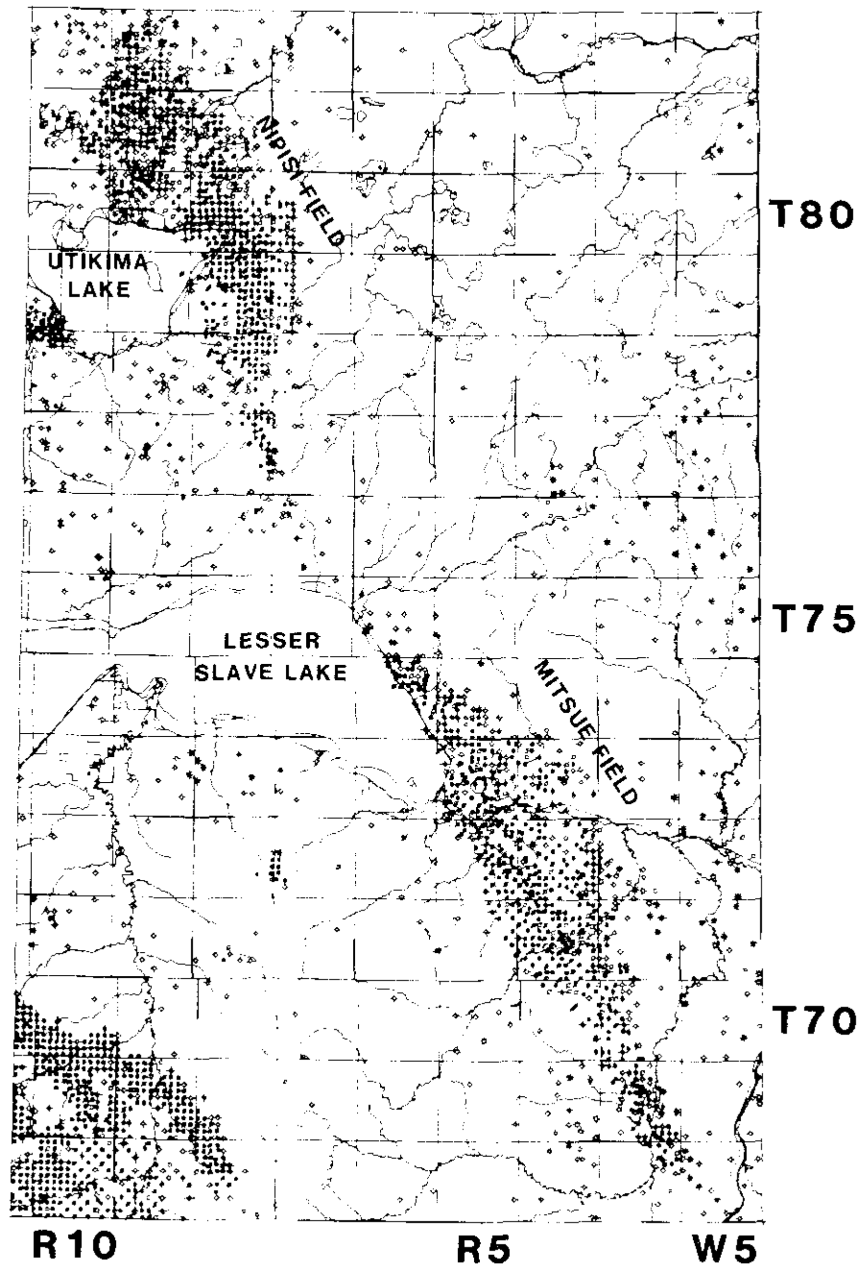

Figure 1.22. Mitsue and Nipisi Field Location.

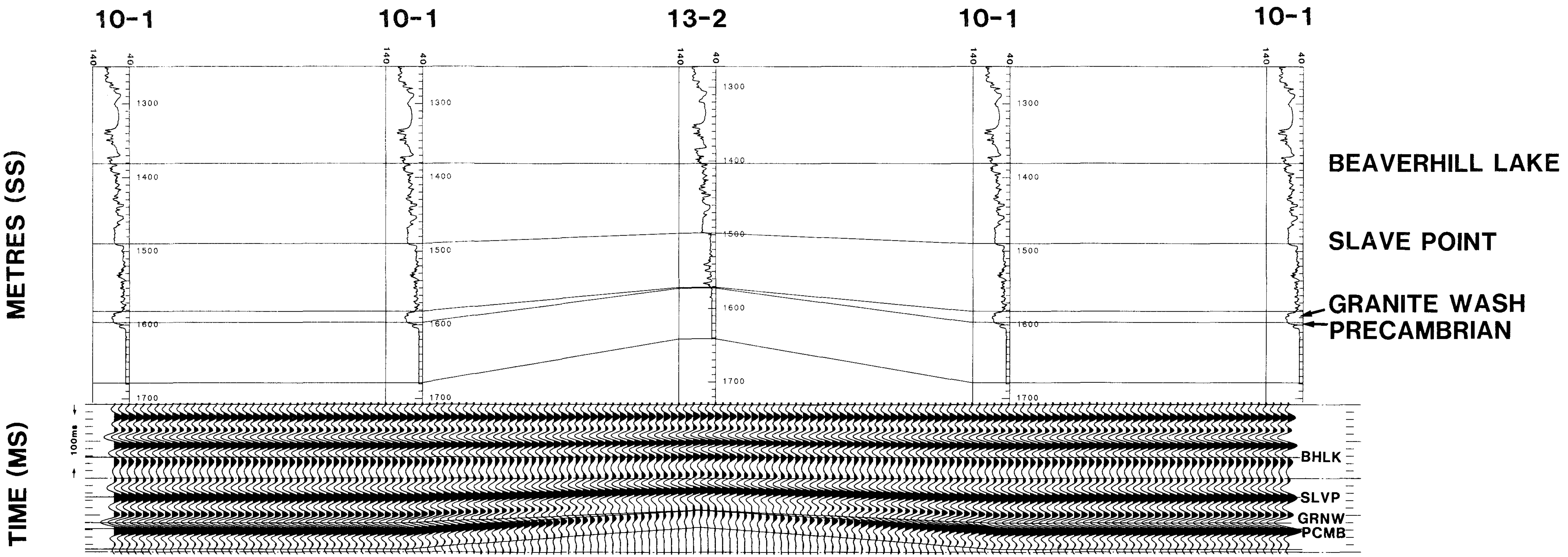

Figure 1.21. Otter Granite Wash seismic model - This model illustrates the seismic response associated with the on-lap of the Granite Wash zone against a "bald" Precambrian high. The synthetic seismic traces were generated by convolving the model reflection coefficient series with an Ormsby 10/15 - 60/65-Hz wavelet.

fields. Reservoir parameters for the pools are listed in Tables 1.8 and 1.9.

The trap at both fields results from the updip (northeasterly) facies change of the Gilwood Member sandstone into the shale of the Watt Mountain Fm. Top seal is provided by the anhydrite of the Fort Vermilion Fm (Alcock and Benteau, 1976). At Nipisi, a possibly facies-related eastward increase in the amount of anhydrite and silica cements coincident with a decrease in grain size may be partly responsible for trapping (Shawa, 1969; Alcock and Benteau, 1976). A similar situation may occur at Mitsue.

TABLE 1.8: Reservoir parameters, Mitsue Gilwood A Pool (ERCB, 1988)

	PRIMARY AREA	SOLVENT FLOOD AREA	WATER FLOOD AREA	TOTAL
AREA (ha)	1495	13259	32642	47396
AVERAGE NET PAY (m)	6.07	5.45	3.20	
AVERAGE POROSITY (%)	12.0	14.4	12.4	
AVERAGE WATER SATURATION (%)	36	36	36	
SHRINKAGE	0.78	0.78	0.78	
RECOVERY FACTOR (%)	<20	25 (primary) 38 (enhanced)	25 (primary) 17 (enhanced)	
RECOVERABLE RESERVES ($x\ 10^3m^3$)	30080	32760	43410	60850

TABLE 1.9: Reservoir parameters, Nipisi Gilwood A Pool (ERCB, 1988)

	PRIMARY AREA	SOLVENT FLOOD AREA	WATER FLOOD AREA	TOTAL
AREA (ha)	2944	8512	20736	32192
AVERAGE NET PAY (m)	2.28	7.20	3.83	
AVERAGE POROSITY (%)	10.4	15.6	13.7	
AVERAGE WATER SATURATION (%)	34	35	33	
SHRINKAGE		0.83	0.83	
RECOVERY FACTOR (%)	20	26 (primary) 35 (enhanced)	26 (primary) 16 (enhanced)	
RECOVERABLE RESERVES ($x\ 10^3m^3$)	765	31300	25300	57370

Deposition of the Gilwood Member took place within a number of sub-environments of a deltaic system (Kramers and Lerbekmo, 1967; Shawa, 1969; Christie, 1971; Jansa and Fischbuch, 1974; Alcock and Benteau, 1976). Detailed descriptions of the petrology of the Gilwood have been published by Kramers and Lerbekmo (1967) and by Jansa and Fischbuch (1974). Sandstone deposition at Nipisi, and therefore the ultimate position of the field and thickness of the reservoir, was influenced by a north-northwest trending depression on the surface of the underlying Muskeg Fm possibly caused by solution of salt from within the Muskeg Fm (Thachuk, 1968; Alcock and Benteau, 1976).

GEOLOGICAL CROSS-SECTIONS

MITSUE

Figure 1.23, shows the location of a geological cross-section (Fig. 1.24) through the east-central portion of the Mitsue Gilwood A pool. The line of section is approximately co-incident with the seismic line included as Figure 1.25. All the logs on the geological cross-section are gamma ray/sonic logs.

The easternmost two wells are the only wells on the geological cross-section that were drilled deeper than the Muskeg Fm. Both reached total depth in the shale of the Contact Rapids Fm, which is conformably overlain by the dolostone of the Keg River Fm. The Muskeg Fm evaporites, which are shaly in this area, lie conformably on the Keg River Fm and are unconformably overlain by the Watt Mountain Fm and the sandstone of the Gilwood Member. The upper part of the section consists of the Fort Vermilion, Slave Point formations and Beaverhill Lake Group with all of the contacts conformable.

The trap results from a combination of westerly dip and eastward reduction in the reservoir quality of the Gilwood Member as it changes facies to shale. The easterly deterioration of the reservoir is not obvious from the sonic-logs on the geological cross-section but is substantiated by core data. The two westernmost wells, Mobil SOBC Mitsue 10-15-72-4W5M and Chevron MGSU 1 Mitsue 3-14-72-4W5M, are Gilwood oil wells, whereas Decalta et al Mitsue 2-13-72-4W5M is a suspended Gilwood oil well and Pan Am Pacific A-1 Mitsue 4-8-72-3W5M and 2-4-72-3W5M are dry holes. The Gilwood Member was cored in all these wells, although the core from 2-4 was not analyzed. The core data are tabulated in Table 1.10.

TABLE 1.10: Reservoir data from core analyses, Gilwood Member sandstone, for wells shown on Figure 1.24

WELL	GIL WD. SS.(m)	AVG POROS-ITY (%)	AVG PERM-EABILITY (md)	INTERVAL
10-15-72-4W5M	3.7	8.4	27.2	all but basal 3 m of Watt Mtn., missed about 1.5 m of Gilwood
3-14-72-4W5M	5.2	9.2	67.3	all of Gilwood
2-13-72-4W5M	3.1	10.4	44.1	all but lowest 3 m of Watt Mtn. Includes all of Gil-wood
4-8-72-3W5M	0.9	4.1	1.5	lower 6.8 m of Watt Mtn. Includes all of Gilwood
2-4-72-3W5M	**CORE NOT ANALYSED**			

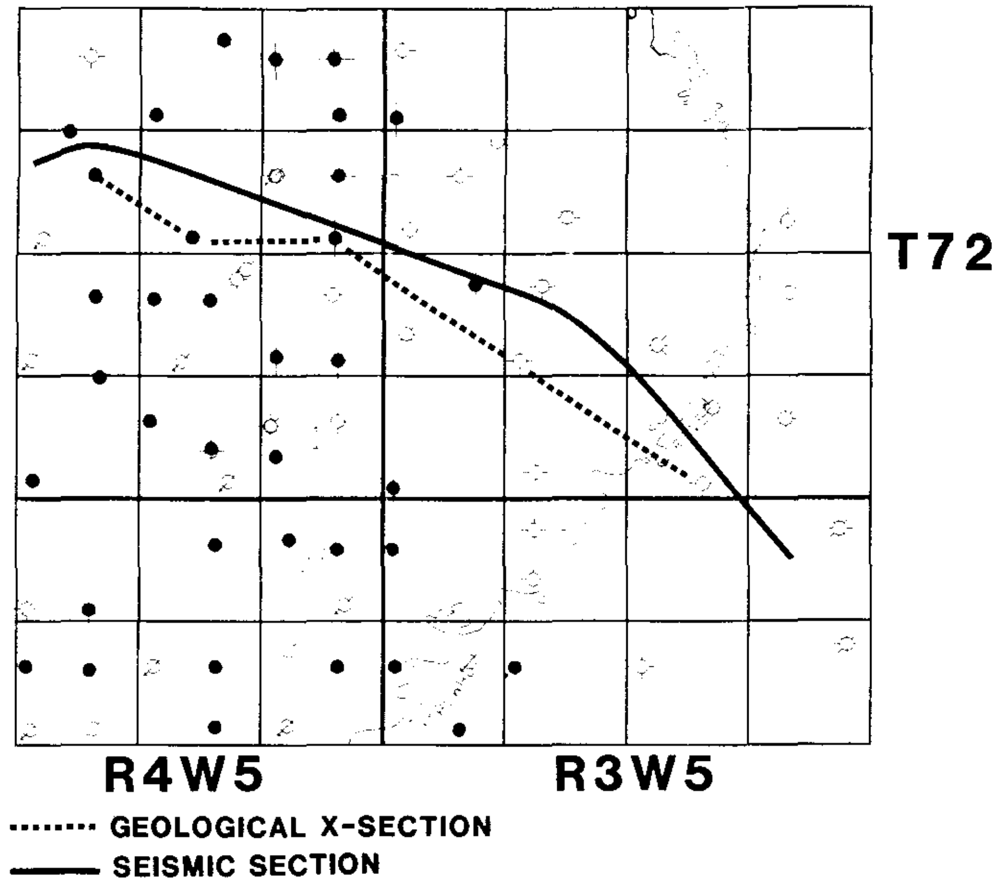

Figure 1.23. Base Map - Mitsue example.

Due to the heterogeneous nature of deltaic reservoirs and to the effects of diagenesis, reservoir thickness and quality do not vary in a regular fashion from west to east. It is clear however, that there is better Gilwood Member sandstone reservoir in the western wells than in 4-8-72-3W5M.NIPISI

Figure 1.26 illustrates the location of the geological cross-section (Fig. 1.27) and seismic section (Fig. 1.28) through the extreme eastern portion of the Nipisi Gilwood A oil pool. All the wells are represented by gamma-ray/sonic-logs except for 12-20-80-7W5M for which a gamma-ray/bulk-density-log is shown. The only well drilled deeper than the Muskeg Fm is Pacific et al Nipisi 4-26-80-8W5M which reached the Precambrian. There is no Contact Rapids Fm present in this well and the Keg River Fm lies directly and unconformably on the basement. The stratigraphy from the Keg River Fm to the Beaverhill Lake Group is the same as at Mitsue.

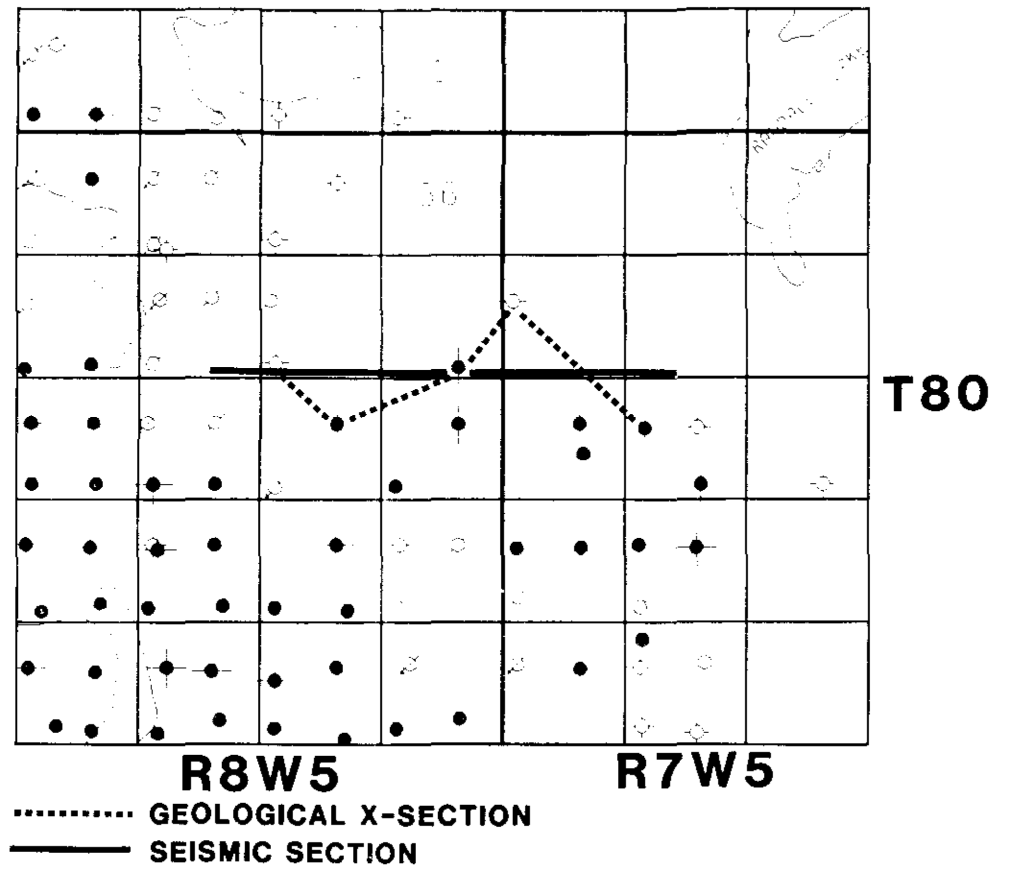

Figure 1.26. Base Map - Nipisi example.

The trapping mechanism at Nipisi, as at Mitsue, results from an updip loss of reservoir quality due to an easterly shale out of the Gilwood Member sandstone. The reservoir distribution is more complex than that shown on the cross-section through Mitsue (Fig. 1.24). The reservoir heterogeneity resulting from both depositional and diagenetic factors is particularly evident near the updip edge of the pool. The cross-section runs essentially east-west, oblique to the strike of the sandstone. The most westerly well on the cross-section, Pacific et al Nipisi 4-26-80-8W5M, is a dry hole but east of this there are two oil wells, Pacific et al Nipisi 10-23-80-8W5M and Denison Nipisi 2-25-80-8W5M, a second dry hole at Hamilton Uno-Tex Nipisi 12-30-80-7W5M and another oil well at Cairn et al Nipisi 12-20-89-7W5M. It is apparent that the limit of effective reservoir is irregular, perhaps as shown in Figure 1.29. The core derived reservoir parameters are shown in Table 1.11.

TABLE 1.11: Reservoir data from core analyses, Gilwood Member sandstone, for wells shown on Figure 1.29

WELL	GIL WD. SS.(m)	AVG POROSITY (%)	AVG PERMEABILITY (md)	INTERVAL
4-26-80-8W5M	1.8	8.6	0.6	all of Watt Mtn./Gilwood
10-23-80-8W5M	3.8	10.6	4.1	all but top 1.3 m of Watt Mtn. Includes all Gilwood
2-25-80-8W5M	2.5	11.6	13.1	all of Watt Mtn./Gilwood
12-30-80-7W5M	2.5	7.5	0.9	all but basal 3.2 m of Watt Mtn. Missed possibly 1.3 m of Gilwood
12-20-80-7W5M	2.8	7.5	12.5	all but top 3 m of Watt Mtn. Includes all Gilwood

Because these wells are located near the eastern limit of the pool they did not encounter particularly high quality reservoir. It is obvious however, that the permeability of the Gilwood Member in the dry holes (less than 1 md) is significantly less than in the oil wells. The depositional limit of the Gilwood Member lies to the east of the field boundary (Alcock and Benteau, 1976).

SEISMIC SECTIONS

Example seismic sections for Mitsue and Nipisi fields are shown in Figures 1.25 and 1.28 respectively. Both sections are located near the eastern updip edge of the fields (Figs. 1.22, 1.23 and 1.26).

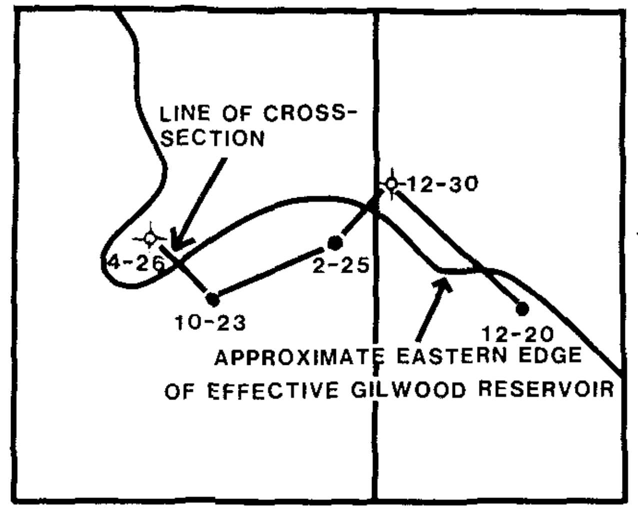

Figure 1.29. Schematic Map - eastern edge Nipisi Field - This diagram schematically illustrates the approximate eastern edge of the effective Gilwood Member reservoir.

MITSUE

The seismic example from Mitsue (Fig. 1.25) is oriented approximately northwest-southeast over the eastern edge of the Mitsue field (Fig. 1.23). These data were shot for Chevron in October of 1979. A single-hole dynamite source of 4 kg was used at a shot depth of 18-m. A 96 channel DFS V recorder was used operating at a 2 ms sample rate. Twelve fold coverage was obtained by using a split-spread configuration of 40-m at the near traces and 1920-m at the far traces. The shot point interval was 160-m and the group interval 40-m. Nine 10-Hz geophones, laid out over 40-m, straddled each station and were summed unweighted. The seismic line is of fair quality.

This line was processed by Geo-X Systems Ltd. using the sequence shown in Table 1.12.

Five wells tie or have been projected on to the seismic line. They are from west to east: 10-15-72-4W5M, 3-14-72-4W5M, 2-13-72-4W5M, 4-8-72-3W5M and 2-4-72-3W5M. The 10-15, 3-14 and 2-13 locations are oil wells and the 4-8 and 2-4 locations are dry holes and all have sonic-logs.

TABLE 1.12: Processing sequence Mitsue seismic line

1) Demultiplex at 2ms;
2) Amplitude Recovery;
3) Instrument and Geophone Phase Compensation;
4) Deconvolution Spiking 80 ms .1% PW;
5) Statics Elevation, Weathering and Drift;
6) Preliminary Velocity Analysis and Preliminary Surface Consistent Automatic Statics;
7) Display for Q.C.;
8) Final Velocity analysis every 24 CDPS;
9) Scaling;
10) Mute;
11) Final Surface Consistent Automatic Statics;
12) Stack 1200%;
13) CDP Trim Statics;
14) K-K Migration 90% RMS Velocities;
15) Noise Reduction Medium F-K;
16) Filter 10/14 - 70/80 Hz; and
17) Equalization.

A representative synthetic seismogram is included from the 4-8-72-3W5M well (Fig. 1.30) as it is the only well that has a sonic log run from the Cretaceous down to below the Keg River Fm. Most of the wells in the field have sonic-logs run over just the Slave Point Fm to Muskeg Fm interval. The stratigraphically lowest reflection tentatively identified on the seismic section is the Precambrian event (red). The 4-8 sonic-log did not penetrate the Precambrian basement but there should be a large positive reflection event below the Keg River Fm defining the Precambrian surface. Multiple contamination of this zone makes correlation difficult. Above this event the first horizon that ties the synthetic is the Muskeg event (peak in blue). It represents a large positive reflection coefficient generated at the interface between the low-velocity Watt Mountain/Gilwood section overlying the high-velocity Muskeg Fm. The trough above this peak represents the top of the Watt Mountain/Gilwood section (yellow) and the peak above it, the top of Slave Point Fm carbonate (blue). The horizons of interest above the Slave Point Fm are the top of the Wabamun Group carbonate (peak in blue) and the pre-Cretaceous unconformity (peak in yellow).

The Gilwood reservoir is not seismically resolvable because of the thinness of the Watt Mountain/Gilwood zone combined with the interference effects of the strong peaks of the Slave Point and Watt Mountain events. Christie (1971) concurs that the Mitsue field lacks

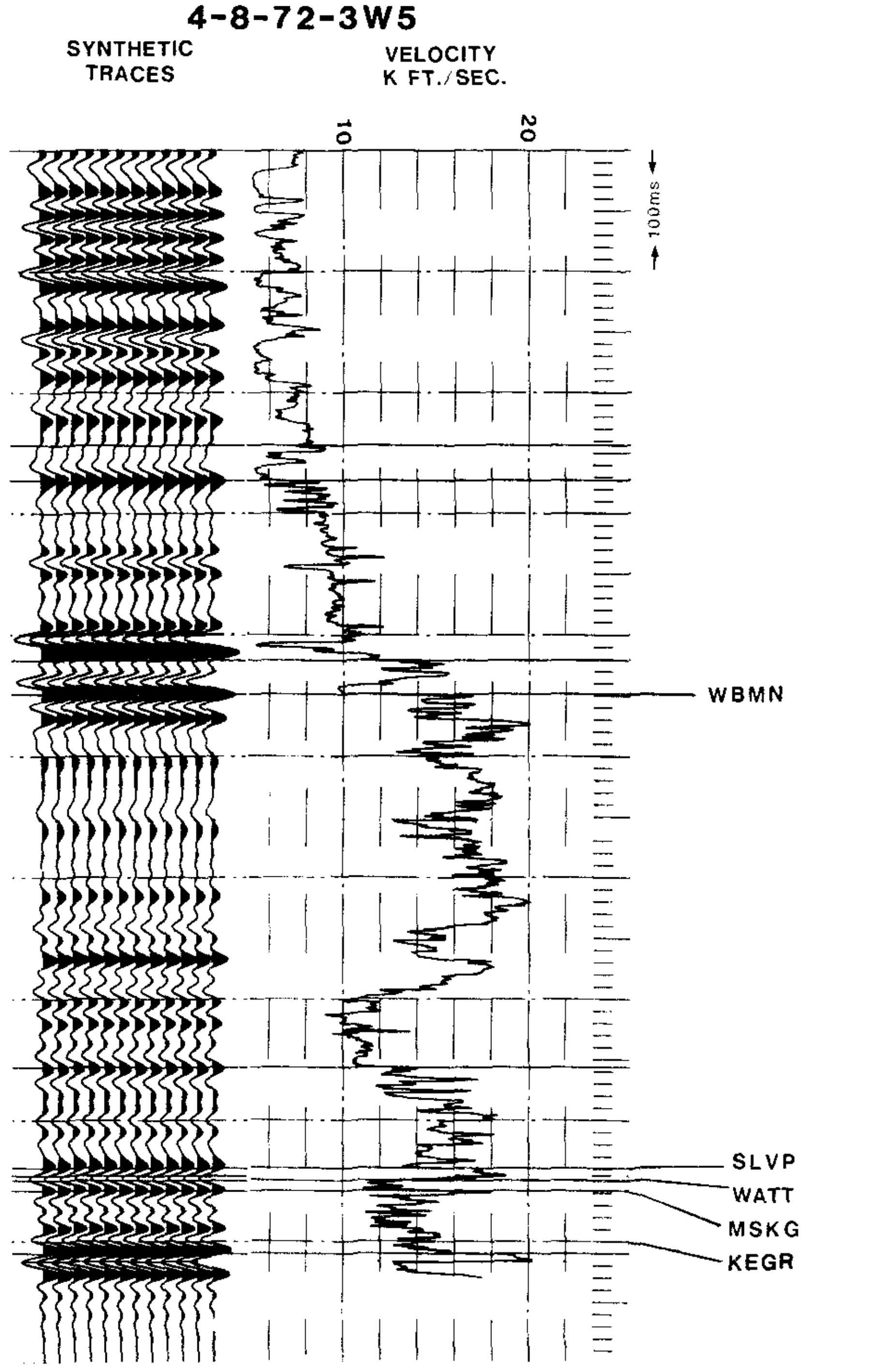

Figure 1.30. 4-8-72-3W5M - Velocity log and synthetic seismogram. Synthetic traces generated by convolving the reflection coefficient series with an Ormsby 10/15 - 60/65-Hz wavelet.

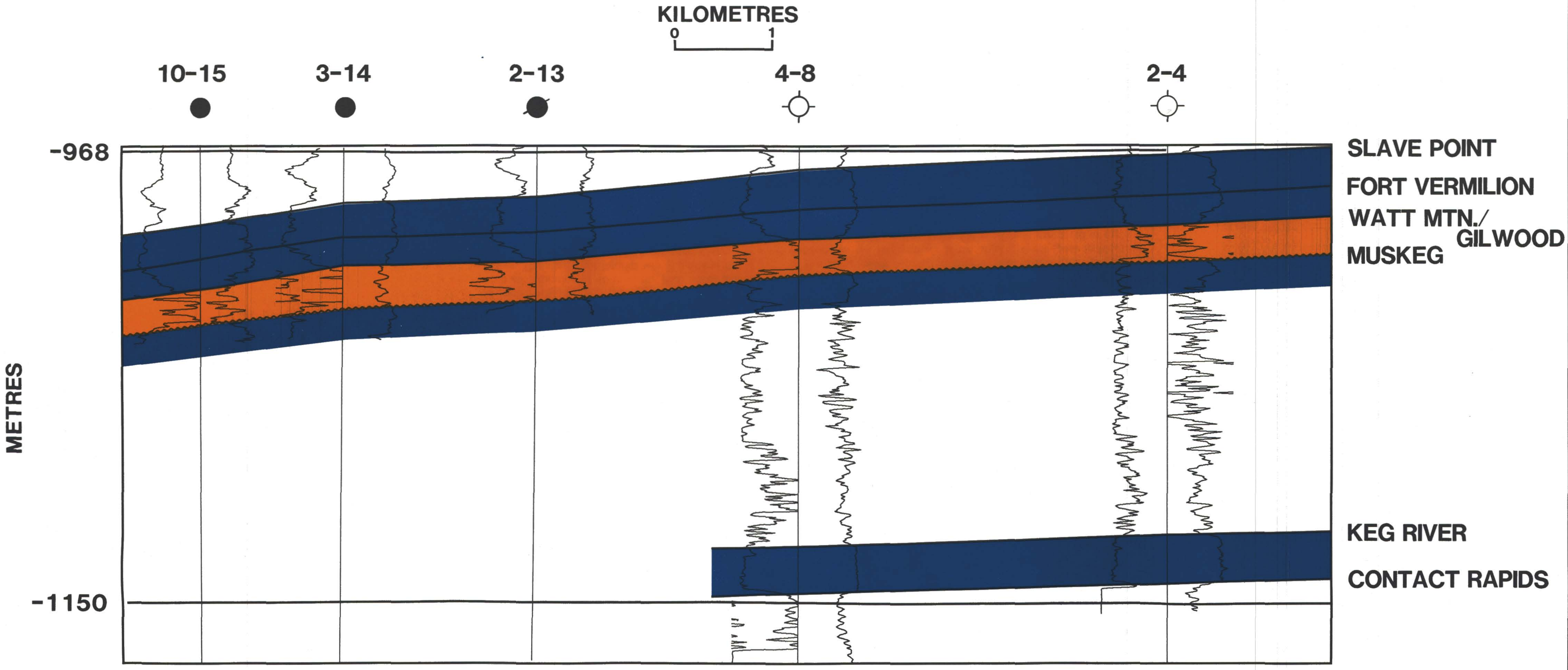

Figure 1.24. Geological cross-section - Mitsue example.

DRAFTING: | LOG PLOTS: RILEY'S DATASHARE INTERNATIONAL LTD. | AUTHOR: W. McCLOSKEY

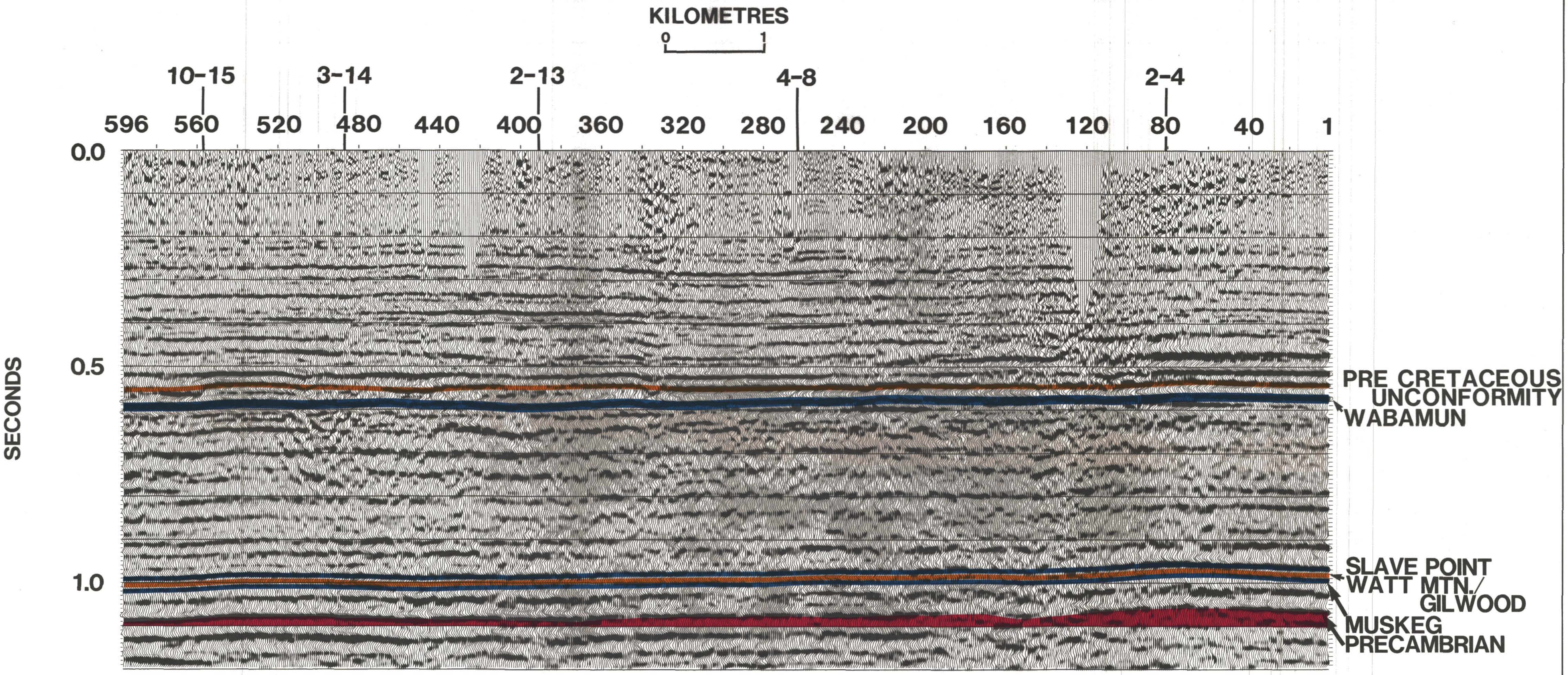

Figure 1.25. Seismic section - Mitsue example.

DONOR: CHEVRON CANADA RESOURCES LTD. | PROCESSOR: GEO-X SYSTEMS LTD | AUTHOR: K. ANGUS

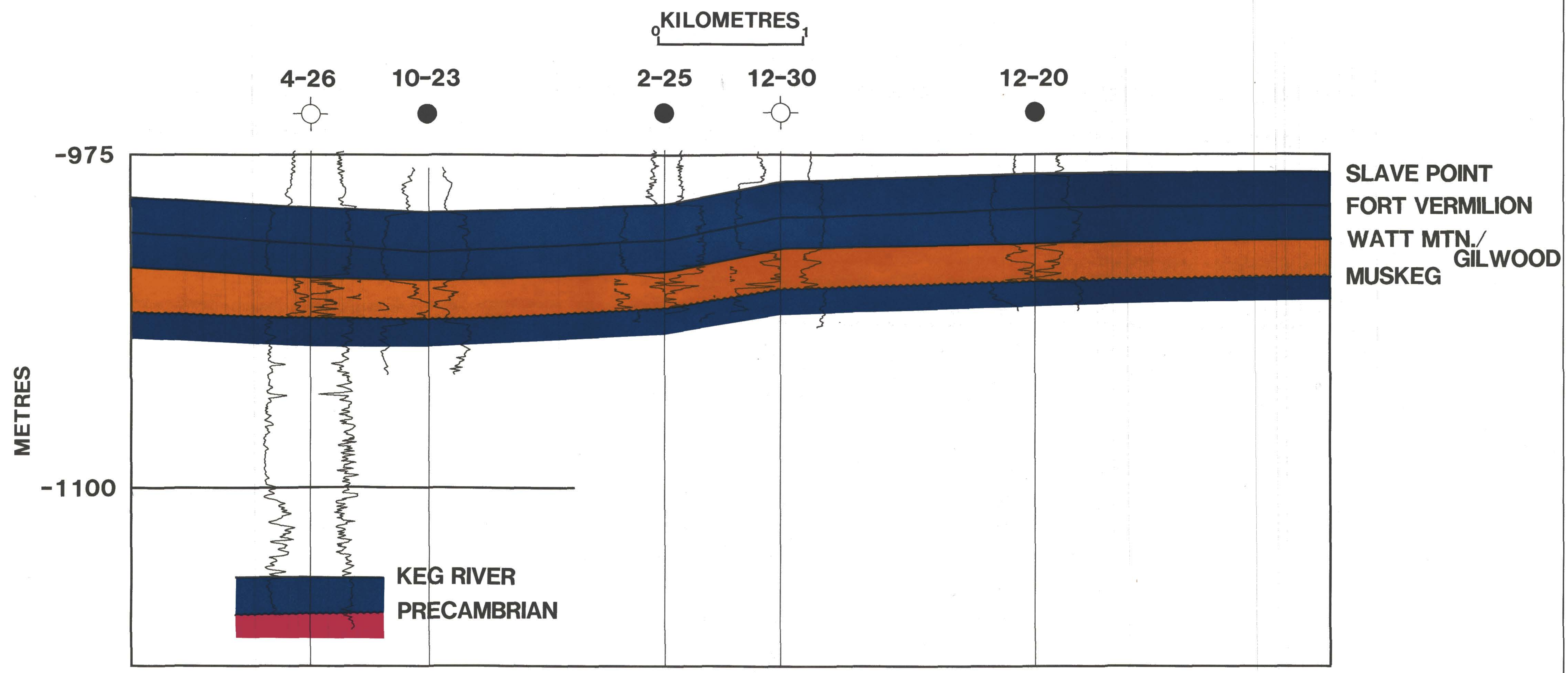

Figure 1.27. Geological cross-section - Nipisi example.

DRAFTING: | LOG PLOTS: RILEY'S DATASHARE INTERNATIONAL LTD. | AUTHOR: W .McCLOSKEY

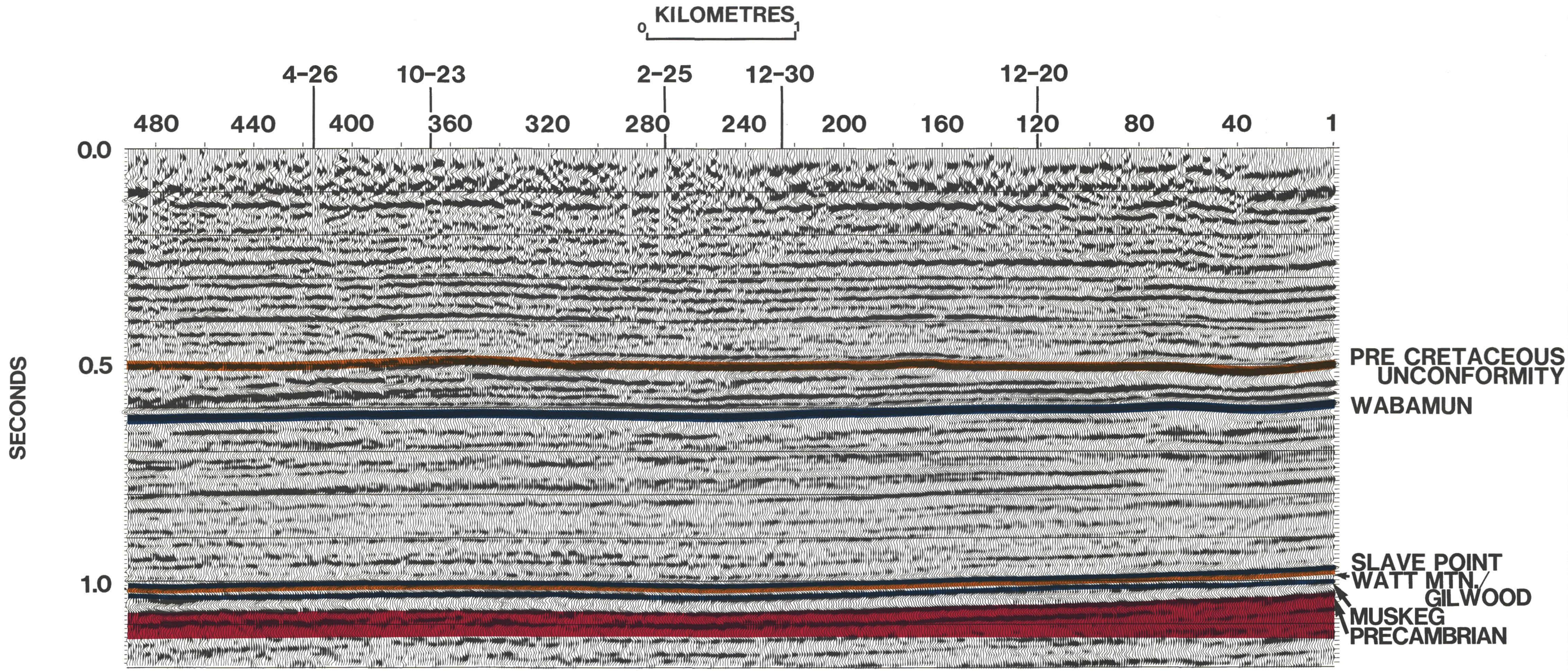

Figure 1.28. Seismic section - Nipisi example.

DONOR: GEO TRADES LTD | PROCESSOR: GEO-X SYSTEMS LTD | AUTHOR: K. ANGUS diagnostic seismic character and is a stratigraphic trap that is not seismically definable.

NIPISI

The seismic example from Nipisi (Fig. 1.28) is oriented east/west near the updip edge of the Nipisi field (Figs. 1.22 and 1.26). These data were shot for Geo-Trades in March of 1983. Four inline vibrators were used spaced 11-m apart. Eight 12 sec. long, 70 - 10-Hz sweeps were summed at each shot point. A 96 channel DFSV recorder was used operating at a 2 ms sample rate. Twelve fold coverage was obtained by using a split spread configuration of 100.5-m at the near traces and 1675-m at the far traces. The source interval was 134-m and the group interval 33.5-m. Nine 10-Hz geophones laid out 4.2-m apart straddled each station and were summed unweighted. The seismic line is of good quality.

This line was processed by Geo-X Systems Ltd. using the sequence shown in Table 1.13.

TABLE 1.13: Processing sequence Nipisi seismic line

1) Demultiplex at 2ms;
2) Amplitude Recovery;
3) Instrument and Geophone Phase Compensation;
4) Deconvolution;
5) Statics-Elevation, Weathering and Drift;
6) Preliminary Velocity Analysis and Preliminary Surface Consistent Automatic Statics;
7) Display for Q.C.;
8) Final Velocity analysis every 24 CDPS;
9) Scaling;
10) Mute;
11) Final Surface Consistent Automatic Statics;
12) Stack 1200%;
13) CDP Trim Statics;
14) K-K Migration 90% RMS Velocities;
15) Noise Reduction Medium F-K;
16) Filter 10/14 - 70/80 Hz; and
17) Equalization.

Five wells tie or have been projected into the seismic line. They are from west to east: 4-26-80-8W5M, 10-23-80-8W5M, 2-25-80-8W5M, 12-30-80-7W5M and 12-20-80-7W5M. The 10-23, 2-25 and 12-20 locations are oil wells and the 4-26 and 12-30 locations are dry holes. All wells except the 12-20 have sonic-logs.

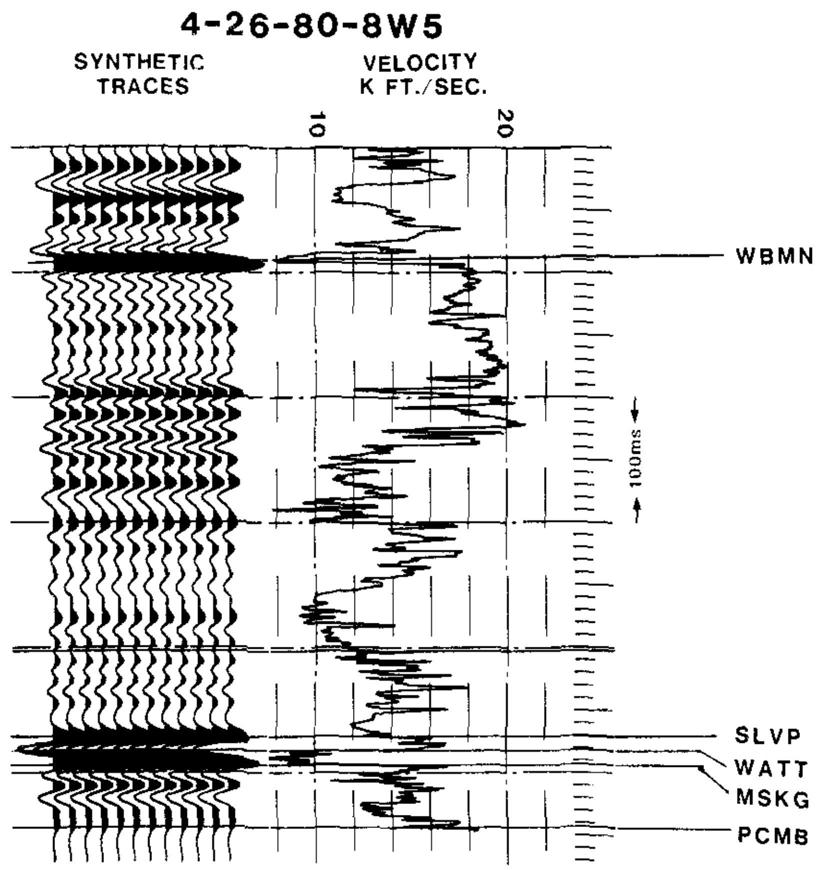

Figure 1.31. 4-26-80-8W5M - Velocity log and synthetic seismogram. *Synthetic traces generated by convolving the reflection coefficient* series with an Ormsby 10/15 - 60/65-Hz wavelet.

A representative synthetic seismogram has been included from the 4-26-80-8W5M well (Fig 1.31) as it is the only well that penetrated the Precambrian basement. The stratigraphically lowest reflection identified on the seismic section is the peak generated from the Keg River Fm/Precambrian (red). Thin Keg River Fm carbonates lie directly on the Precambrian basement and, therefore, do not produce separate and distinct seismic events. As can be observed on both the synthetic seismogram and on the seismic section the combination of these two produce a broad peak. Above this event is the peak-trough-peak of the Slave Point (blue), Watt Mountain/Gilwood (yellow) and Muskeg (blue) events which are very similar to that observed in the Mitsue example. The horizons of interest above the Slave Point event are the top of the Wabamun Gp carbonate (peak in blue) and the pre-Cretaceous unconformity (peak in yellow).

It is unfortunate that both the Mitsue and Nipisi fields do not appear to be seismically definable using present day seismic techniques. The problem lies in trying to resolve a discontinuous 3-5 m sandstone interval that lies between two large positive reflection coefficients at a depth of approximately 1700 m. Conventional seismic cannot resolve the sandstones into distinct events and as a result the updip deterioration of the reservoir cannot be seismically defined. In the future, very high resolution techniques may resolve this problem but for now the Mitsue and Nipisi fields remain as seismically undefinable stratigraphic traps.

CONCLUSIONS

Successfull exploration for hydrocarbon accumulations within the Paleozoic clastic strata of the Western Canada Sedimentary Basin requires careful integration of geological and geophysical information. Attention to seismic amplitude and character in the zone immediately above the Precambrian basement is crucial to delineation of the Granite Wash reservoirs at the Red Earth, Utikuma, Evi and Otter fields. Seismic modelling, which integrates geological and geophysical concepts, aids in understanding the changes in seismic amplitudes and character observed on the seismic data.

The structural configurations of the Precambrian basement that influence trapping of hydrocarbons, exhibit distinct seismic expressions. The three most common trap types are illustrated in Figure 1.2. Time interval mapping aids in the recognition of these structural configurations.

The first type of trap, illustrated in Figure 1.2, shows onlap of Granite Wash zone sandstones onto a bald Precambrian high. A reduction in amplitude of the trough/peak associated with the Granite Wash/Precambrian events, as the Granite Wash thins onto the flanks of the Precambrian highs, is the main seismic characteristic of this feature. Decreases in the time intervals, Wabamun to Slave Point and Wabamun to Precambrian are observed over these highs. This type of trap is illustrated in the model shown in Figure 1.21.

The second type of trap involves the presence of Granite Wash sandstones draped over Precambrian paleotopographic highs. The trough/peak associated with the Granite Wash/Precambrian events does not lose amplitude and is continuous over the crest of the Precambrian high. A decrease in the time intervals, Wabamun to Slave Point and Wabamun to Precambrian is observed over these highs but may not be as obvious as over the bald type of structure.

The third type of trap involves post Muskeg Fm faulting which preserves a thick Granite Wash zone on top of faulted Precambrian highs. The diagnostic seismic characteristic of this type of trap is the presence of a high amplitude trough/peak associated with the Granite Wash/Precambrian events on top of the faulted high. The peak associated with the Muskeg Fm is not seismically resolvable over these faulted Precambrian highs due to the erosional thinning of this interval associated with post-Muskeg Fm faulting. Time interval mapping of the Wabamun to Slave Point and Wabamun to Precambrian may show a decrease over this type of trap but is not as diagnostic as over the first two types of traps discussed.

The two largest oil accumulations in the Paleozoic clastic strata of the Western Canada Sedimentary Basin are the Mitsue and Nipisi fields. Analysis indicates they are not seismically definable. The examples discussed from the Red Earth, Utikuma, Evi and Otter fields clearly show that careful analysis of seismic data are required in order to resolve the complex structural and stratigraphic nature of these traps.

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