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A SEISMIC PERSPECTIVE ON THE PANNY AND TROUT FIELDS OF NORTH-CENTRAL ALBERTA

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ABSTRACT

We present three example seismic sections from the general Senex area of Alberta, two from the Panny field and one from the Trout field. The seismic expressions of various stratigraphic units that are of significance in the interpretation are discussed. The Keg River Formation is the principal reservoir facies in the Senex area and typically is productive where draped across or wedged out against Precambrian structural highs. The Keg River Formation is overlain by the Muskeg Formation (the basal Muskeg anhydrite and interlayered succession of Muskeg salts, anhydrites and carbonates), the Watt Mountain Formation and the Slave Point Formation. The contact between the Keg River Formation and the basal Muskeg anhydrite does not generate a discernible seismic event. Therefore, structure at this level must be inferred on the basis of time-structural relief along three other more prominent reflections: the Precambrian, the base of the Muskeg salt and the Slave Point events. In those areas where the Precambrian is overlain by middle Muskeg units, reflection-continuity problems are encountered. In these places, the overlying Muskeg salts have commonly been leached and, as a result of collapse, the Slave Point Formation is often anomalously low, although the Muskeg does not have to be in contact with the Precambrian for salt removal to have occurred. On the basis of the amplitude of the Precambrian event and the presence or absence of diffractions, areas of extensive dissolution and basement structural lows can usually be differentiated.

INTRODUCTION

During late Eifelian to early Givetian time (Figure 1), the Senex area of north-central Alberta, to the northeast of the Peace River arch, was part of the fringing Keg River Formation carbonate shelf (Figures 2 and 3). These shelfal carbonate sediments of the present-day Keg River Formation have a variable argillaceous content. Typically, they overlie a thin veneer of basal Paleozoic clastics (Granite Wash) and the Precambrian. They, in turn, are overlain by the interlayered anhydrite salts and carbonates of the Muskeg Formation. In places, Precambrian basement highs may be overlain by middle Muskeg units in the absence of the Keg River Formation and the basal portion of the Muskeg Formation. In such areas, the salts of the Muskeg Formation may have been extensively dissolved (Anderson et al., 1989a, b).

The Keg River Formation is the principal reservoir facies at the Panny and Trout fields of the Senex area, the basal Paleozoic clastics being a secondary target (Figure 1). Generally, reservoirs occur where the Keg River Formation is structurally closed across, or against the flanks of, underlying Precambrian highs. Such structures are usually characterized on seismic data by time-structural closure at the Slave Point, base of the Muskeg salt, and Precambrian horizons; also by lateral variations in the amplitudes of these events. Exceptions occur where Precambrian structural highs have triggered extensive post-depositional dissolution of the Muskeg Formation salts. In such areas, the Slave Point Formation can be anomalously low as a result of the leaching and subsequent collapse.

Very little has been publicly presented on the Senex area, either of a geophysical or a geological nature. Campbell (1987) discusses the stratigraphy and facies of the area; Cant (1988) discusses the regional structure and tectonic development of the Peace River arch and adjacent areas, while Mitchell (1988) summarizes (from an oral presentation) many of the seismological aspects.

Throughout this paper, such expressions as *the Keg River horizon* or *event* or *reflection* refer to the top of the named unit unless explicitly otherwise stated. Similarly,

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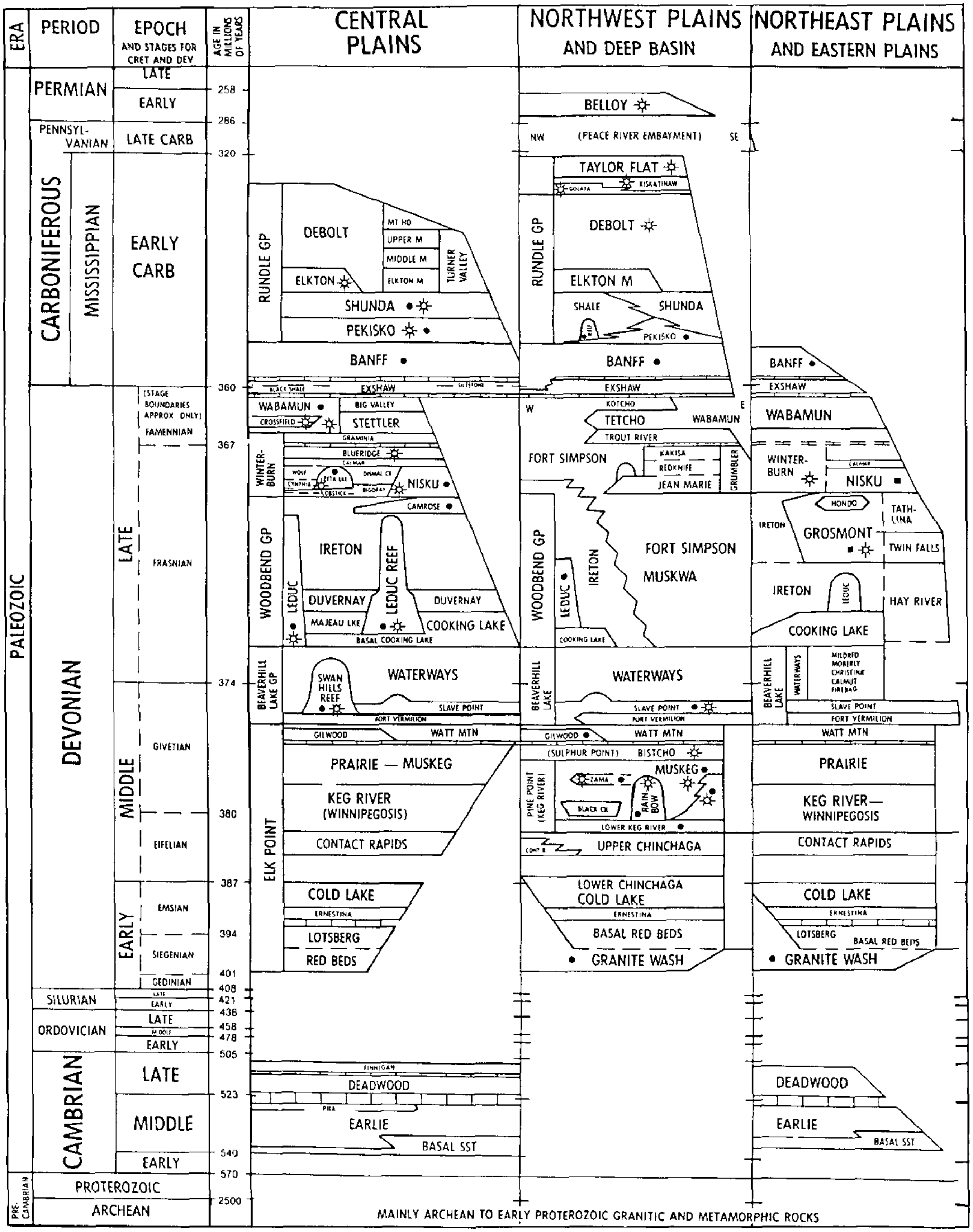

Fig. 1. Stratigraphic chart for the Paleozoic of central and northern Alberta (modified after AGAT Laboratories, 1988).

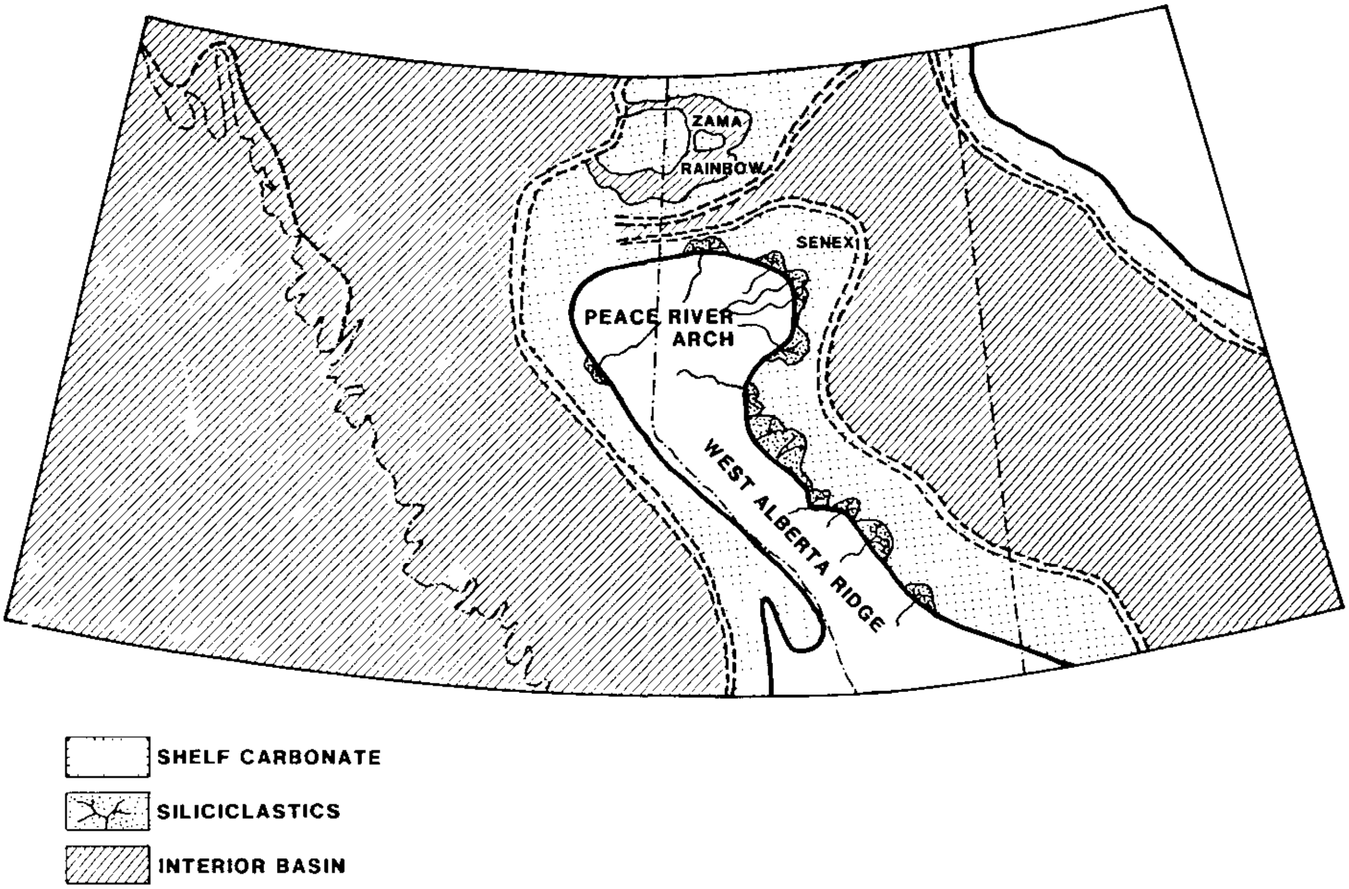

Fig. 2. Paleogeography of the Elk Point basin, Keg River time (after Nelson, 1970; Campbell, 1987).

such expressions as *the Slave Point/Keg River interval* refer to the interval between the two named tops, unless the word *inclusive* is added, in which case the lower unit is also to be included in the interval. The maps of the Panny and Trout areas (Figures 4 and 5) show the locations of the wells incorporated in the geologic cross-sections and the approximate locations of the example seismic lines used as templates in this paper. In the following discussions, emphasis is placed on those geologic features which are pertinent to the interpretation of the example seismic data.

Panny Field

Interpretation of the geologic cross-section

Two of the four wells incorporated into the structural geologic cross-sections, 1-3-96-6W5 and 3-11-96-6W5 (Figure 6, line 1), drilled in 1983 and 1984, respectively, currently produce oil from the Keg River Formation. The other wells, 3-5-96-6W5 and 4-5-96-6W5 (Figure 7, line 2), were drilled in 1984 and abandoned. Log suites for each of these wells are shown in Figures 6 and 7. Structural relief between the wells has been inferred from the seismic data.

The deepest horizon identified on the cross-section is the Precambrian. As illustrated (Figure 8), this is a surface of considerable relief, typically up to 100 m, as a result of pre-Devonian tectonism and erosion. Structural highs, such as those beneath the 3-11 and 3-5 wells (Figures 6 and 7) are prevalent throughout the Panny area. Generally, such structures are mapped by seismic data as being areally closed rather than as lineaments, a pattern which is consistent both with the notion of an erosional surface and with that of later (post-Devonian) faulting on conjugate sets of planes. As shown for our examples (Figures 6 and 7), the basal Paleozoic clastics and Keg River sediments thin significantly from off-structure to on-structure. This is consistent with the idea that the Precambrian relief is essentially unchanged since the Early Devonian and that drape of overlying formations is a result of differential compaction. However, there is evidence, both geological (Cant, 1988) and geophysical (P.C. Starnino, pers. comm.) of renewed faulting since Keg River time (Middle Devonian), either on new surfaces or as reactivation of former faults. Many cases have been observed on seismic data where Devonian sediments thicken over Precambrian structural highs, presumably as a result of reactivation of faults which then could have served as conduits for waters which, in places, have leached out quantities of salt (P.C. Starnino, pers. comm.). It may well be that different tectonic and sedimentary effects have dominated in different parts of this extensive area (Figure 3). This is a fertile area for future research.

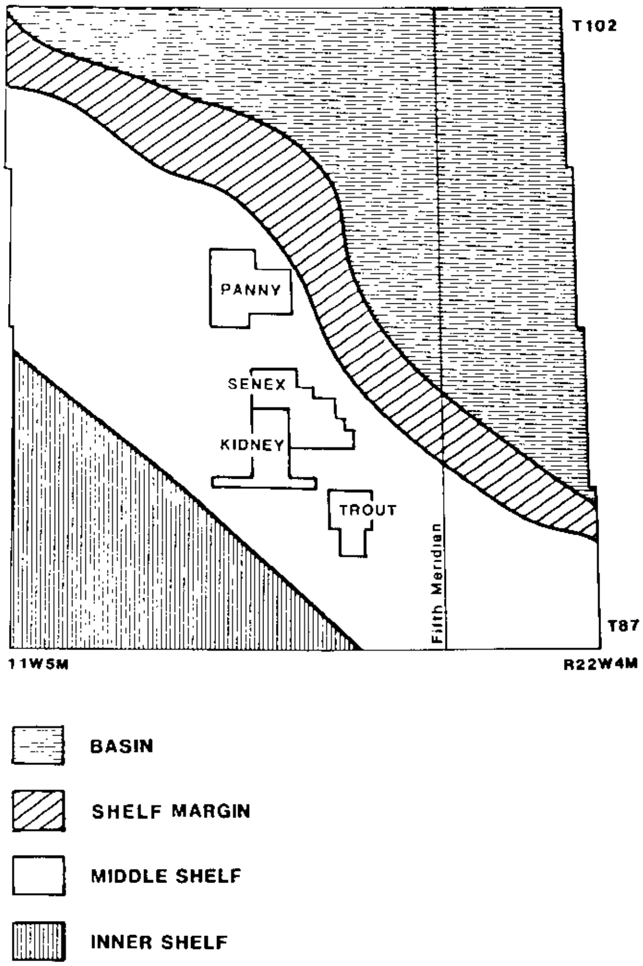

Fig. 3. Facies map of the general Senex area showing locations of the Panny and Trout fields (after Campbell, 1987).

Within the study area, the Precambrian is overlain by basal Paleozoic clastics and the Keg River Formation. Generally, the Keg River is thinner above Precambrian highs and thicker elsewhere. For example, the Keg River

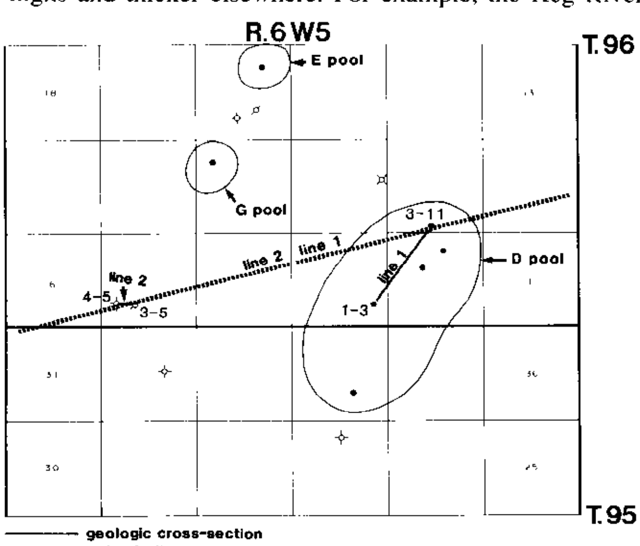

Fig. 4. Map of the Panny study area in Alberta showing the wells used in the cross-sections (Figures 6 and 7).

Formation in the 3-5 and 4-5 wells is 4 and 45 m thick, respectively (Figure 7), while the Precambrian in the 3-5 well is 81 m structurally higher than in the 4-5 well. In addition, the top of the Keg River Formation in the 3-5 well is 41 m higher than in the 4-5 well and structurally closed.

Argillaceous carbonates tend to predominate in the lower Keg River Formation while cleaner carbonates are predominant in the upper part (Figures 6 and 7). Typically, these upper carbonates are productive where they are structurally closed over the underlying Precambrian, such as in the 1-3 and 3-11 wells (Figure 6). As evidenced by these two wells, argillaceous carbonates are generally absent where the Precambrian is anomalously high.

The Keg River Formation in the Panny area is overlain by the Muskeg Formation, an interlayered sequence of salts and anhydrites. As shown in Figures 6 and 7, the basal anhydrite of this formation seals the Keg River reservoir. Although this basal anhydrite has a slightly higher velocity and density than the underlying Keg River Formation, the contact between these two units is not well imaged on the seismic data. However, the contact between this basal anhydrite and the overlying salt can be delineated seismically and is frequently referred to as the near-Keg River event. As is evident on the cross-sections (Figures 6 and 7), the near-Keg River (salt/anhydrite) contact is more or less parallel to the anhydrite/Keg River contact. In Figures 6 and 7, one may also see that the Muskeg, Slave Point and Beaverhill Lake horizons drape across anomalous Precambrian structures.

Interpretation of the seismic line

The two example seismic lines (Figures 9 and 10) are 96-trace 24-fold data and were recorded in 1982 using a Vibroseis source. They were shot using a 1530-m split spread, 120-m shot spacing and a 24-m group interval. In Figure 11, a one-dimensional (1-D) synthetic seismogram for the 3-11-96-6W5 well is presented. The synthetic and field data correlate at the Precambrian, near-Keg River, Slave Point, and Ireton events. The Wabamun event, although not shown on the synthetic, is also confidently identified on the seismic data (Figures 9 and 10) on the basis of regional correlations. The Wabamun event is usually not displayed on synthetics in the Senex area as casing is usually set below this horizon prior to logging. In Figure 12, a velocity model and a corresponding two-dimensional (2-D) synthetic seismic section for the geologic cross-section (line 2) is presented.

Each of Figures 13 and 14 also show sonic-log models with corresponding 2-D synthetic seismic sections. These models demonstrate how the amplitudes of the Precambrian and near-Keg River events vary as a function of relief along the Precambrian. As the Keg River Formation is typically, though not always, productive where draped across closed Precambrian highs, the capability of recognizing the signatures of such features is critical. On the synthetic seismic sections, the amplitudes of

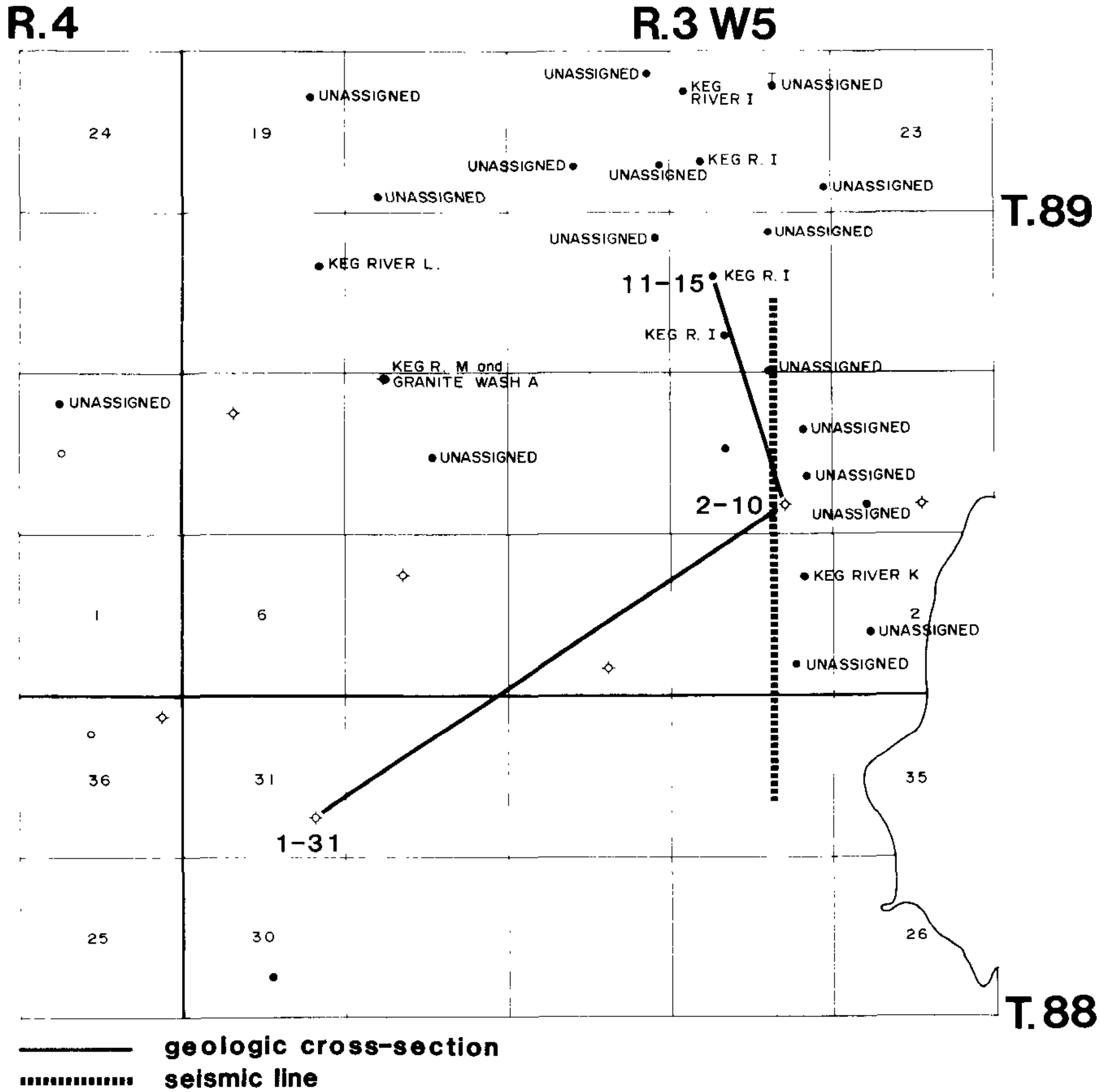

Fig. 5. Map of the Trout study area in Alberta showing the wells used in the cross-section (Figure 15).

both the Precambrian and the near-Keg River events are greater off-structure than they are on-structure. As discussed below, these lateral amplitude changes are attributed principally to interference effects related to the on-structure thinning of both the basal Paleozoic clastic section and the basal Muskeg anhydrite/Precambrian interval.

The effect of thinning of the basal Paleozoic clastic section is illustrated in Figure 13. In this model, the thickness of the basal Muskeg anhydrite/Keg River (inclusive) interval is kept constant while that of the basal Paleozoic clastics is varied from 65 m (approximately a half-wavelength) to zero. Maximum tuning of the reflections from the top and base of the clastics occurs at thicknesses near 32 m (approximately a quarter-wavelength). At thicknesses of less than an eighth of a wavelength (16 m) the basal Paleozoic clastics cannot be confidently resolved. At zero thickness, the Precambrian is unconformably overlain by the Keg River Formation.

The effect of thinning of the basal Muskeg anhydrite/Precambrian interval is modelled in Figure 14. Here, for illustrative purposes, the thickness of this interval is decreased proportionately from 80 m (approximately a half-wavelength). Maximum tuning of the near-Keg River and Precambrian events occurs at thicknesses of a half-wavelength (about 80 m) and maximum destructive interference at thicknesses of a quarter-wavelength (about 40 m). As the modelled thickness is decreased, the Precambrian and near-Keg River events become

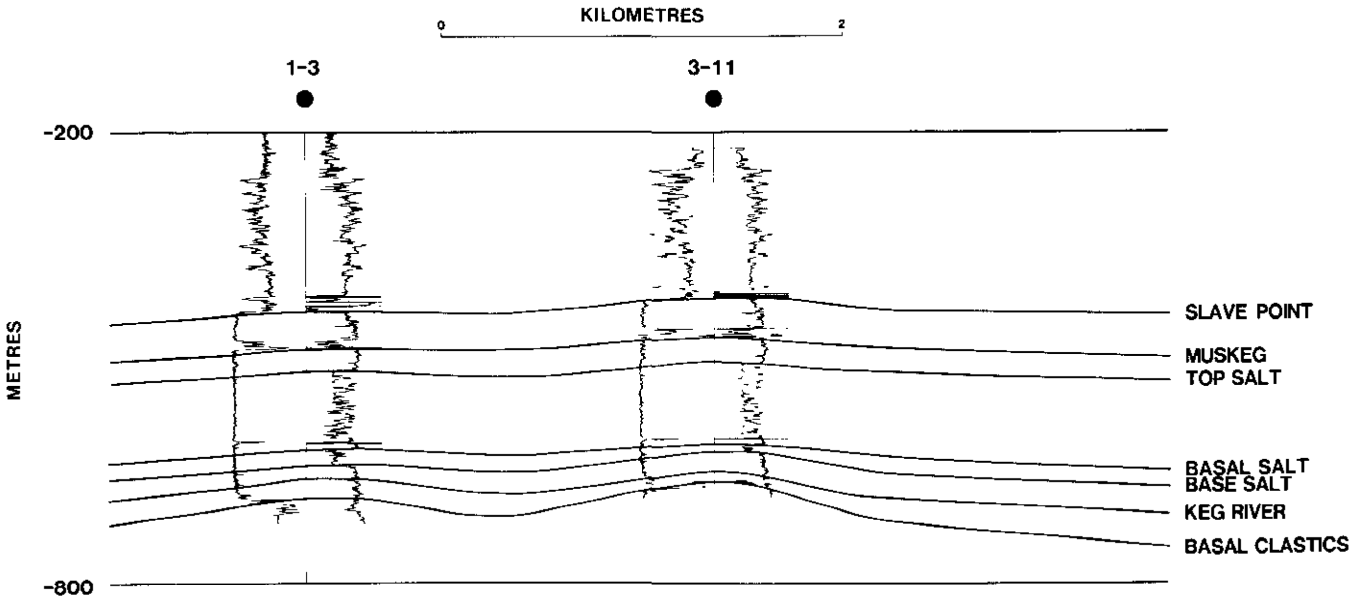

Fig. 6. Geologic cross-section for line 1 (Figure 4), Panny study area. Well logs shown are gamma-ray (left) and sonic (right).

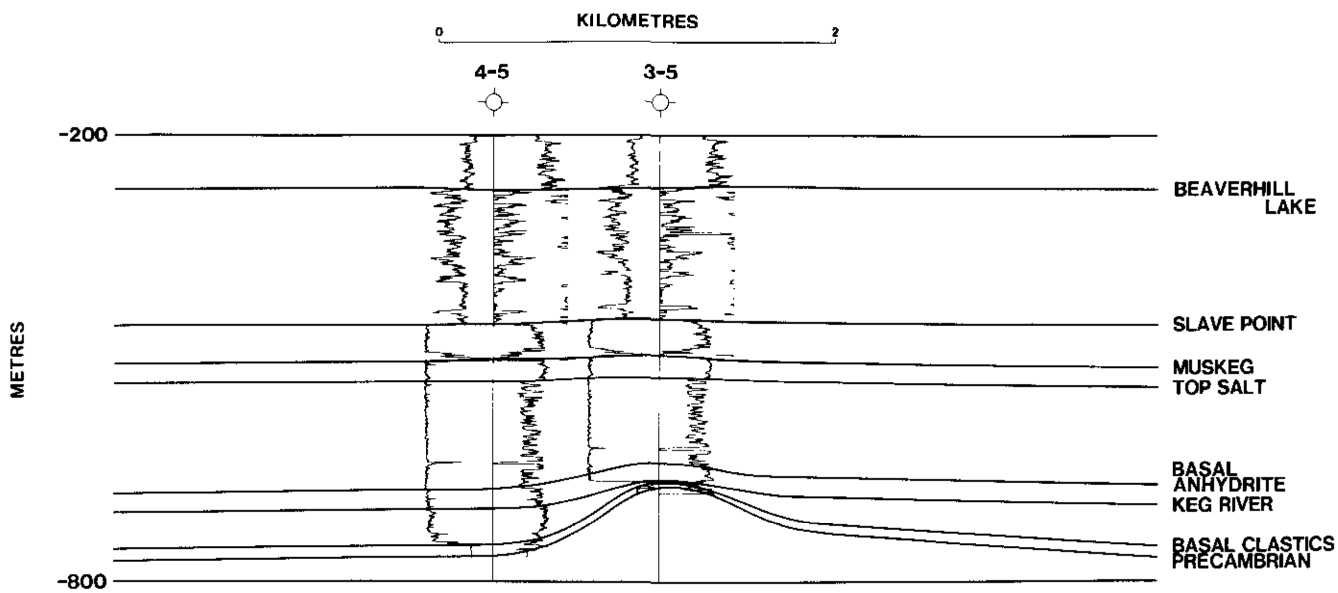

Fig. 7. Geologic cross-section for line 2 (Figure 4), Panny study area. Well logs shown are gamma-ray (left) and sonic (right).

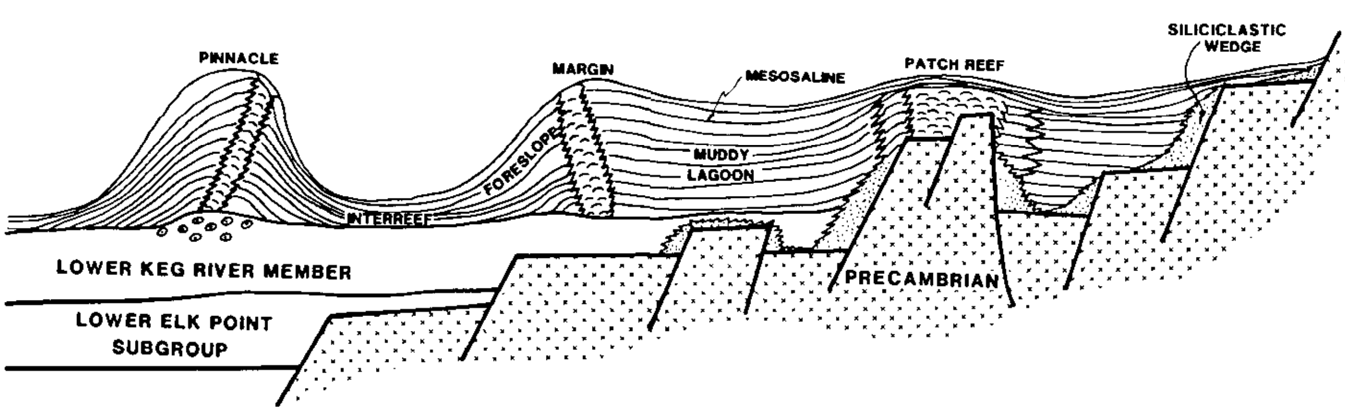

Fig. 8. Generalized cross-section of the Keg River to Precambrian interval in the Peace River arch area (after Campbell, 1987) as viewed from the northwest.

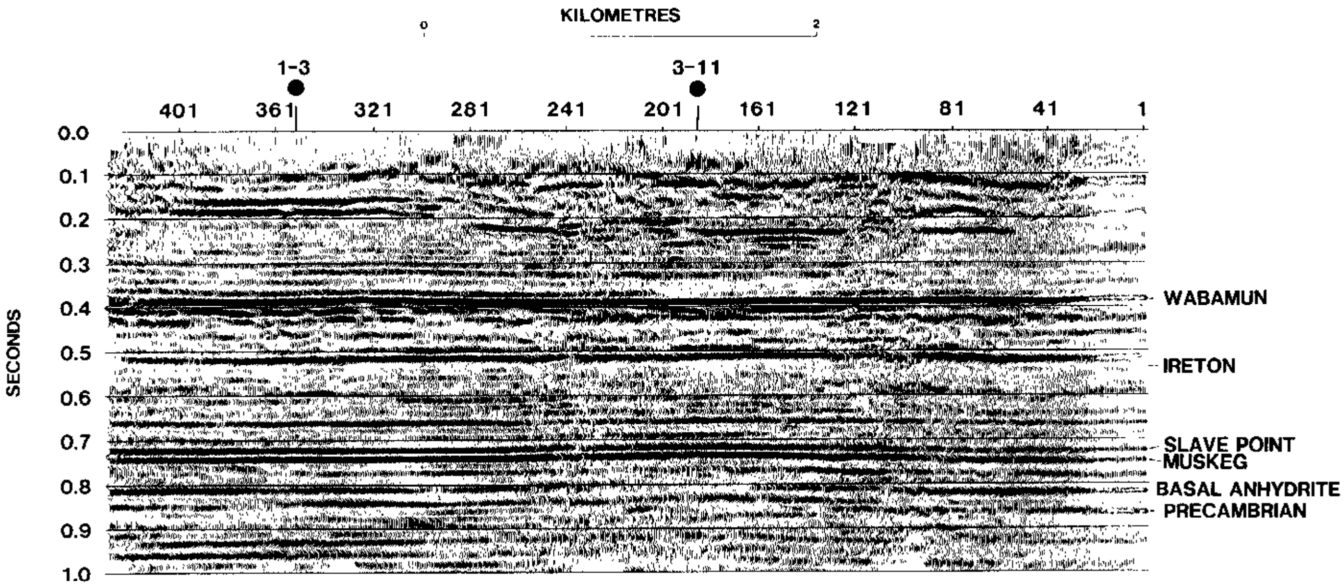

Fig. 9. Normal-polarity seismic section for line 1, Panny study area; see Figure 4 for well locations relative to the seismic line. The TD (total-depth) point for the 1-3 well is in the Precambrian; for the 3-11 well it is in the Chinchaga Formation.

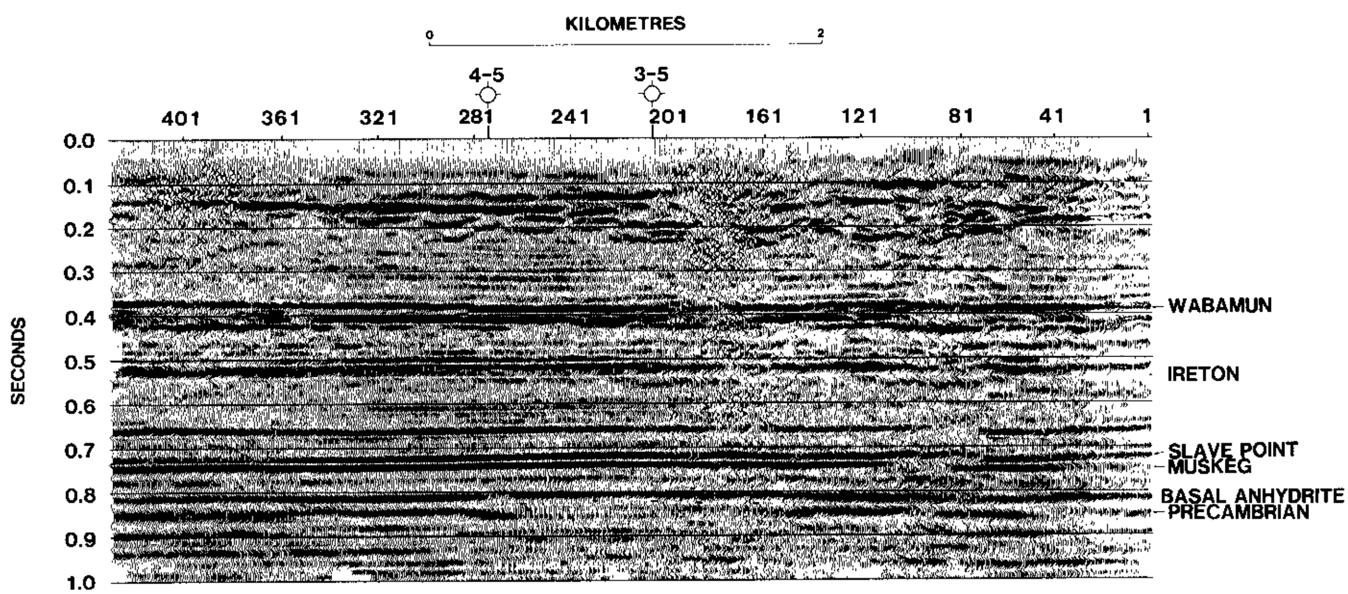

Fig. 10. Normal-polarity seismic section for line 2, Panny study area; see Figure 4 for well locations relative to the seismic line. The TD point for each of these wells is in the Precambrian.

increasingly tuned to each other. At the extreme of zero thickness, the Precambrian would be unconformably overlain by Muskeg salt, though this relationship is not known to occur in practice.

In the interpreted seismic sections of line 1 (Figure 9) and line 2 (Figure 10) the lowest event identified, the Precambrian, is time-structurally highest in the vicinity of traces 185 and 207, respectively, which coincide with the locations of the 3-11 and 3-5 wells, respectively. In particular, one may note on line 1 (Figure 9) that the Precambrian event at traces 41 and 301 is about 18 ms and 8 ms lower than at trace 185, respectively. On line 2 (Figure 10) the Precambrian at traces 61 and 281 is about 40 ms and 20 ms lower than at trace 207, respectively. As shown on the geologic cross-sections (Figures 6 and 7), these time-structural highs correlate with anomalous relief along the Precambrian surface. As anticipated, both the near-Keg River and Slave Point events drape across these Precambrian highs. The Slave Point/Precambrian time-thickness decreases significantly (on the order of 20 to 30 ms) from off-structure to on-structure, indicating that the Slave Point/basal Paleozoic section, inclusive, is depositionally thinner on-structure. The overlying Wabamun event does not drape significantly across the Precambrian highs.

As the analysis of the suite of models would predict,

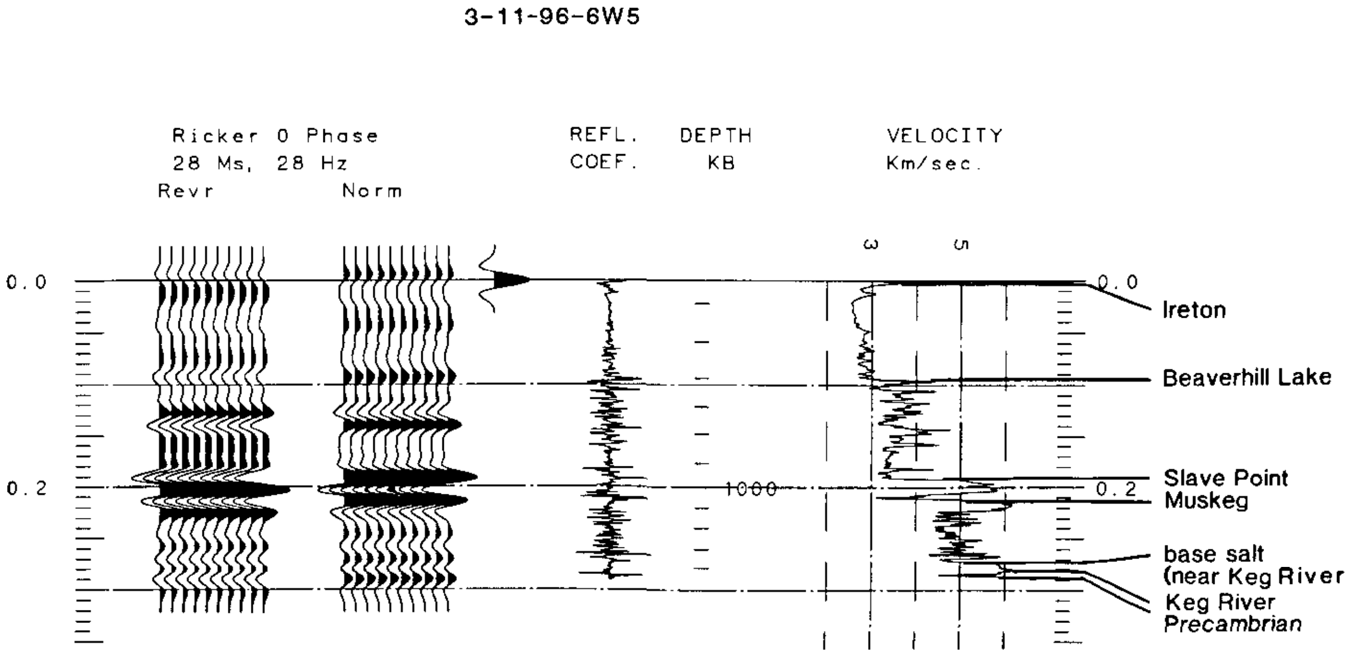

Fig. 11. 1-D synthetic seismogram for the 3-11-96-6W5 well.

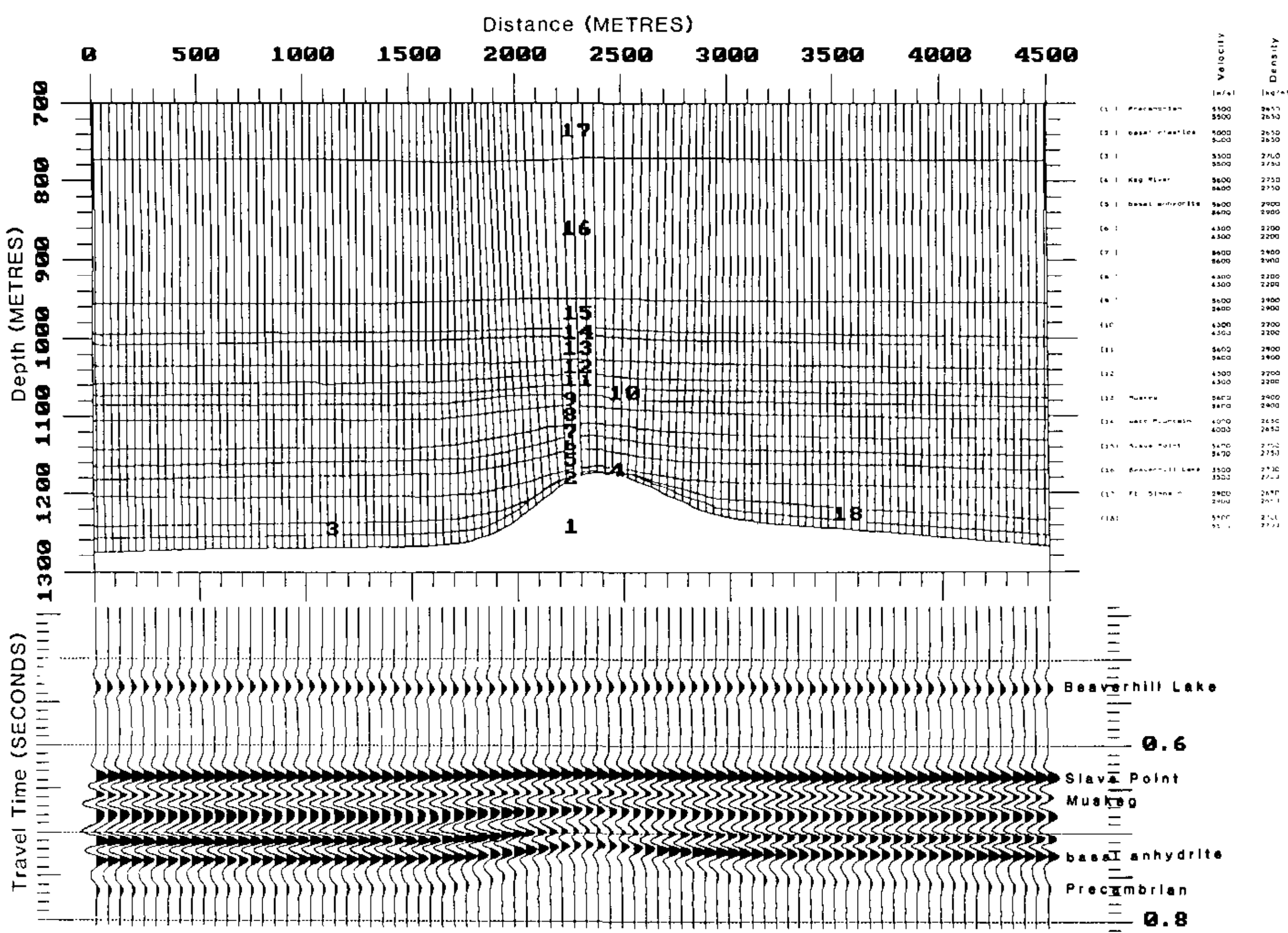

Fig. 12. Velocity model and corresponding 2-D synthetic seismic section for the geologic cross-section of line 2, Panny study area (shown, with the relevant well locations, in Figure 7).

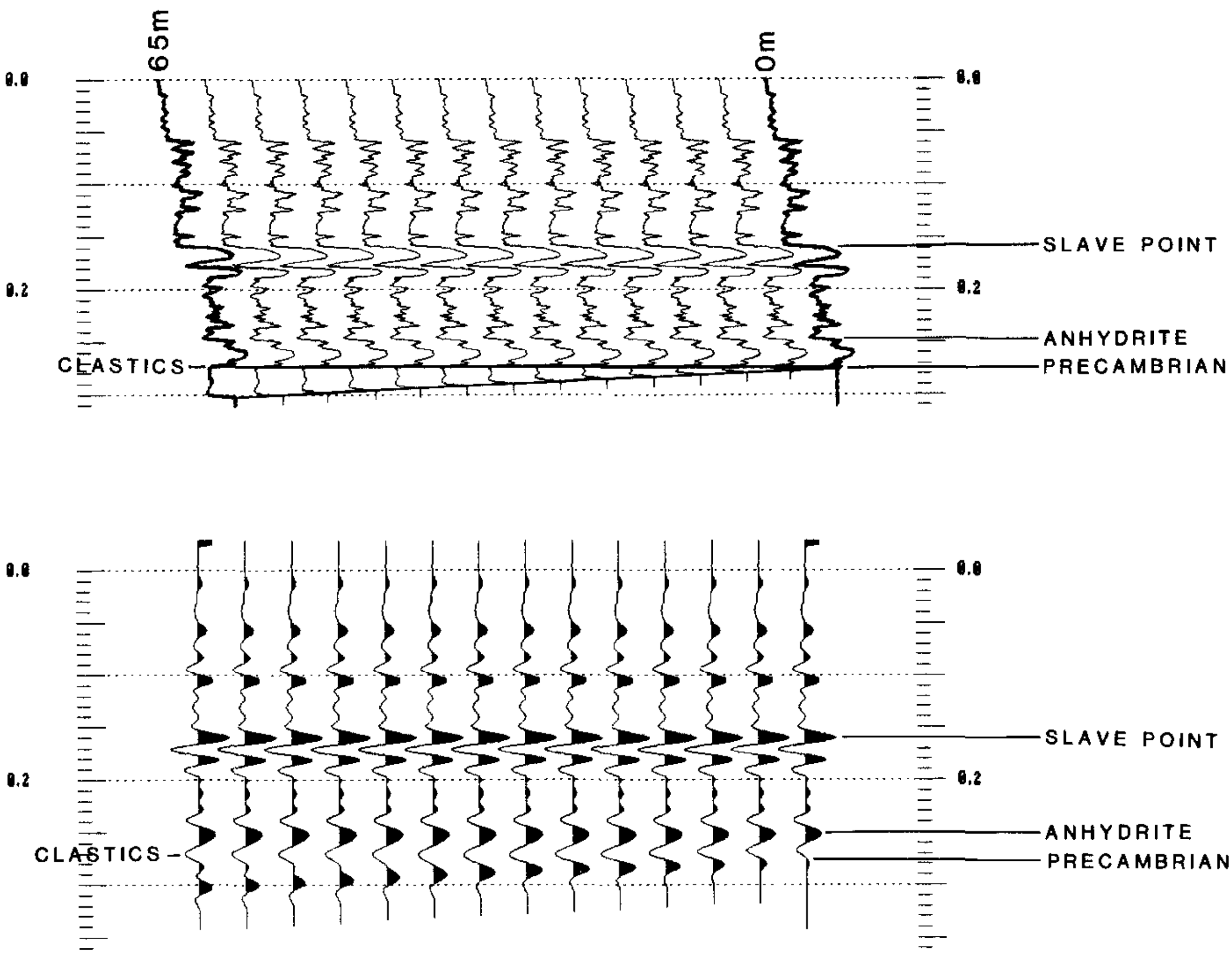

Fig. 13. Sonic-log model and corresponding 2-D synthetic seismic section illustrating the seismic response to the thinning of the basal Paleozoic clastic section. The vertical scales are two-way traveltime in seconds.

anomalous structures along the Precambrian are manifested as lateral amplitude changes and associated time-structural relief along the Precambrian and near-Keg River events. More specifically, the amplitudes of both the Precambrian and near-Keg River reflections are significantly lower on-structure [in the vicinities of shotpoints 185 (line 1) and 207 (line 2)] than elsewhere. As demonstrated by modelling (Figures 11 through 14), these lower amplitudes are interference effects caused by both the thinning of the basal Paleozoic clastics and of the Muskeg anhydrite/basal clastic section on-structure. One may observe (Figure 10) that in the vicinity of the 3-5 well where the Muskeg anhydrite/Precambrian interval is thin (approximately 35 m or slightly less than a quarter-wavelength), the amplitude of the intervening peak is extremely low, supporting the idea of destructive interference. In the vicinity of the 3-11 well (Figure 9) the section is about 45 m thick (or slightly greater than a quarter-wavelenth) and the amplitude of the intervening peak is marginally higher. Presumably, with ever increasing relief at the Precambrian, the amplitude of the peak would decrease to the point where the near-Keg River and Precambrian events would visually merge. Where the basal Muskeg anhydrite and the Keg River sediments are absent (presumably due to nondeposition across Precambrian structure as in the 2-10-89-3W5 well at the Trout field), the overlying Muskeg salts have typically been dissolved. The resulting collapse features are readily identified on seismic sections (e.g., Figure 16).

Trout Field

Interpretation of the geologic cross-section

Figure 5 shows the approximate orientation of the seismic line and the locations of the three wells incorporated into the corresponding geologic cross-section (Figure 15). Only one of the three, the 11-15-89-3W5 well (completed in 1987), currently produces from the Keg River Formation; the other two stand abandoned. As illustrated in Figure 15, the 1-31-88-3W5 well (1972) is off-structure and the Keg River Formation here is wet. In contrast, while the 2-10-89-3W5 well (1978) is on-structure, the Keg

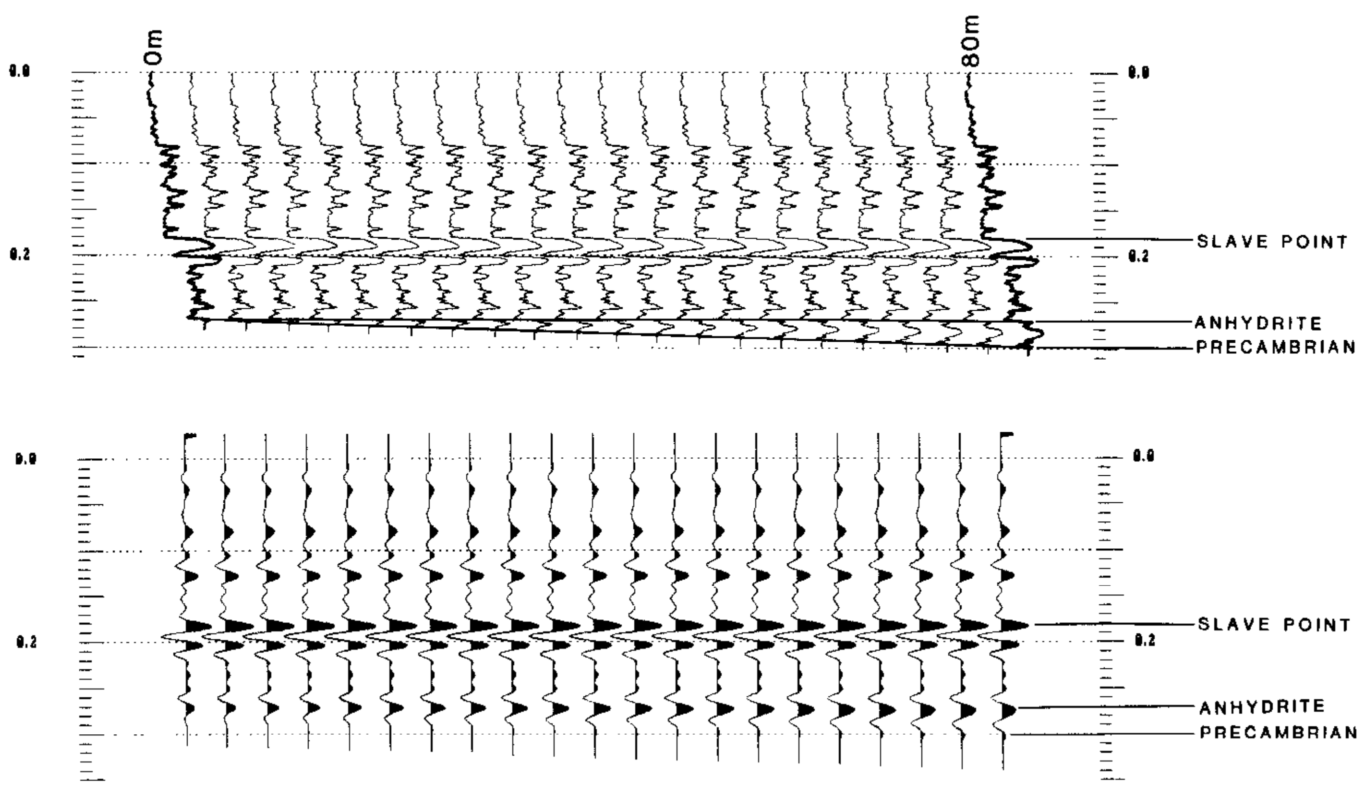

Fig. 14. Sonic-log model and corresponding 2-D synthetic seismic section illustrating the seismic response to the thinning of the basal anhydrite/Precambrian interval. The vertical scales are two-way traveltime in seconds.

River Formation here is absent, presumably due to nondeposition on this Precambrian high.

The lowest horizon identified on the cross-section (Figure 15) is again the Precambrian. In the Trout area, like the Panny area, this is a surface of considerable relief and the basement structures mapped seismically are generally areally closed. As depicted in Figure 15, the basal Paleozoic clastic and Keg River sediments thin on-structure, being depositionally absent in the 2-10 well, indicating that relief at the Precambrian is at least partially erosional in origin. This observed thinning on-structure generates a corresponding lateral variation in the amplitude of the reflection from the Precambrian horizon (Figure 16).

Within the study area, the Precambrian is generally overlain by basal Paleozoic clastics and the Keg River Formation. As discussed above, these strata thin on-structure and in extreme cases can be depositionally absent. Both horizons are typically areally closed across, or against

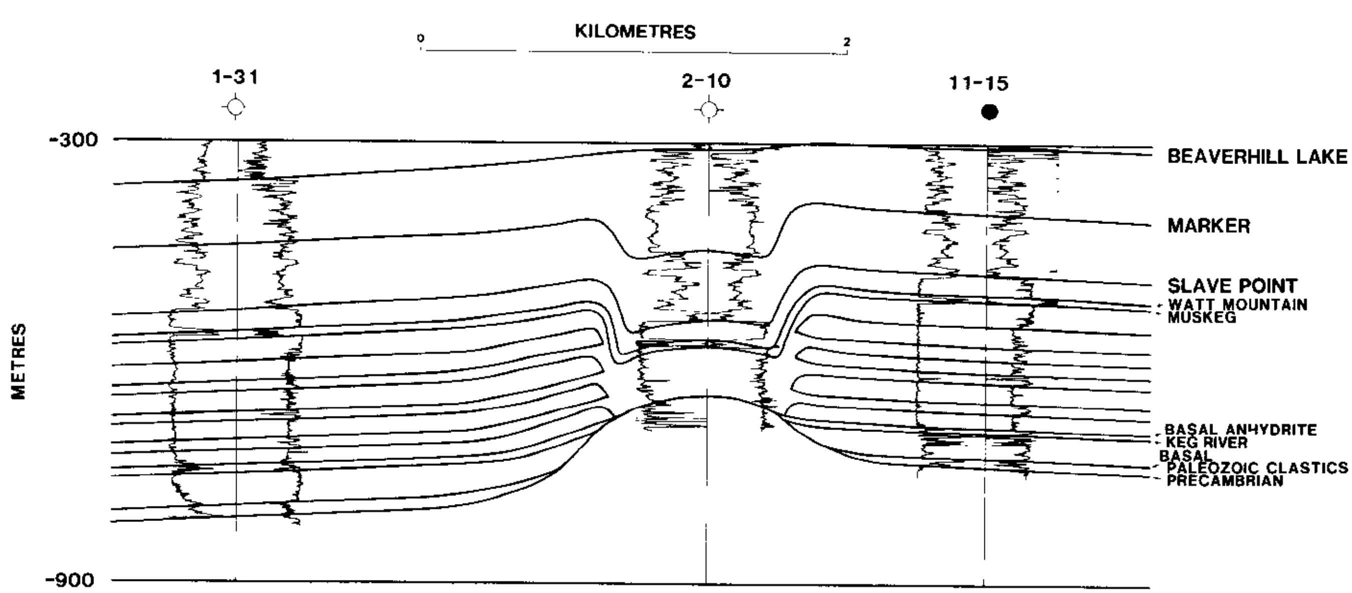

Fig. 15. Geologic cross-section, Trout study area (Figure 5). The well logs shown are gamma-ray (left) and sonic (right).

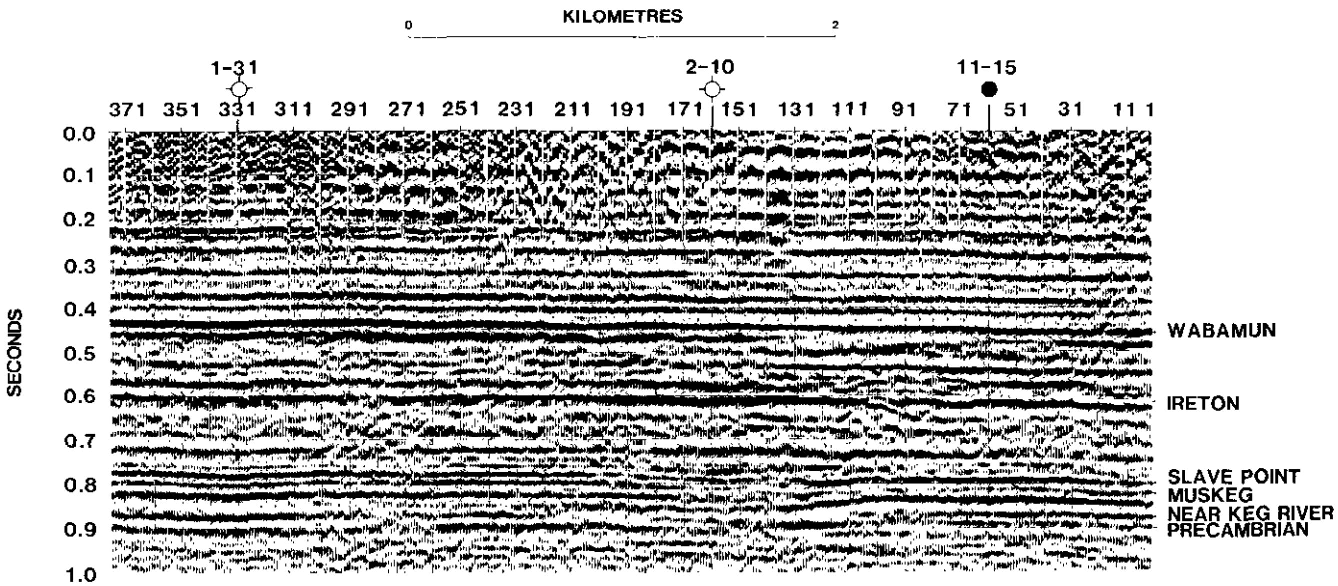

Fig. 16. Normal-polarity seismic section, Trout study area; see Figure 5 for well locations relative to the seismic line. The TD point for each one of these wells is in the Precambrian.

the flanks of, Precambrian basement highs. Such closure, in general attributed both to differential compaction and to fault reactivation, is illustrated in the 11-15-89-3W5 well.

Once again, the near-Keg River event is seismically more prominent than the Keg River event and as shown in Figure 15, this salt/anhydrite contact more or less parallels the anhydrite/Keg River contact.

In places, as evidenced by the 2-10 well (Figure 15), the basal Paleozoic clastics, Keg River Formation and basal part of the Muskeg Formation are absent. In these areas, interlayered salts and anhydrites were deposited directly on the Precambrian. Typically, such salts have been postdepositionally leached. Dissolution in the 2-10 well is interpreted as having occurred principally during Beaverhill Lake time due to waters percolating through the weathered Precambrian (Anderson et al., 1989b) or through conduits arising from fault reactivation (P.C. Starnino, pers. comm.; Cant, 1988). As depicted in Figure 15, pronounced collapse features can be associated with salt dissolution.

The Muskeg, Watt Mountain and Slave Point Formations typically drape across underlying Precambrian structure as a result of compaction. As illustrated in Figure 15, exceptions occur in areas of extensive salt dissolution. As evidenced by the 2-10 well, overlying horizons can be anomalously low where the Precambrian is anomalously high. The seismic interpreter should bear this potential relationship in mind and not simply assume that time-structure above the Precambrian is always a subdued replica of the Precambrian structure itself.

Interpretation of the seismic line

The 12-fold seismic data (Figure 16) were recorded on 120 traces using single 2.25-kg charges at depths of 15 m, with a 1560-m split spread, 130-m shot spacing and a 26-m group interval. Just as for the Panny examples, the labelled events are confidently identified along the seismic line (Figure 16) on the basis of ties to synthetic seismograms and regional correlations.

In Figures 13 and 14, sonic-log models and their corresponding 2-D synthetic seismic sections are shown. These models demonstrate how the amplitudes of the Precambrian and near-Keg River events vary as a function of relief along the Precambrian. As mentioned earlier, the Precambrian event is of relatively high amplitude off-structure where it is overlain by a thick veneer of low-velocity basal Paleozoic clastics and of lower amplitude on-structure where it is progressively overlain by thinner basal Paleozoic clastic Keg River and basal Muskeg anhydrite sections. The modelled lateral amplitude variations are due both to interference effects (due to thinning of low-velocity material) and to lateral variations in acoustic-impedance contrasts. The near-Keg River event is also seen to decrease in amplitude on-structure and to terminate where the salts have been leached. This amplitude decrease on-structure represents interference phenomena caused by the progressive thinning of the interval from the base of the salt to the Precambrian. The event terminates where the salts are dissolved, that is, where the near-Keg River horizon as defined herein does not exist.

These modelled relationships are observed on the seismic line of Figure 16. For instance, the amplitude of the Precambrian event decreases as structural relief increases. In the vicinity of traces 141 to 191, where the Muskeg anhydrite directly overlies the Precambrian, this contact can be confidently mapped only by using sonic-log control from the 2-10 well. The amplitude of the near-Keg River event is similarly higher off-structure. In the vicinity of trace 191, where the Muskeg salts have been leached, this reflection disappears completely.

In contrast, the overlying Slave Point event can be correlated confidently along the entire seismic line. As a consequence of compaction, this event drapes across the underlying Precambrian, except where the Muskeg salts have been dissolved in post-Slave Point time (Figure 16, traces 141 to 191). In such places, as a result of leaching and collapse, the Slave Point event is anomalously low, even though it overlies a Precambrian high.

The overlying Beaverhill Lake, Ireton and Wabamun horizons drape only slightly across the Precambrian, suggesting that the dissolution of the Muskeg salts occurred, for the most part, prior to the end of Beaverhill Lake time.

Concluding Discussion

The Keg River Formation is the principal reservoir facies in the general Senex area. The basic structural relationships with which the explorationist active in this area should be familiar are, namely, that:

(1) Keg River reservoirs are present where this formation either drapes across or wedges out against Precambrian structural highs;

(2) generally, the Slave Point Formation drapes across Precambrian basement structures, but where Muskeg salts have been leached during post-Slave Point time, this drape can be subdued or overturned; and

(3) dissolution of Muskeg salts is common throughout the study area and has occurred both where the Precambrian is unconformably overlain by the Muskeg Formation (typical of Trout) and also where thick Keg River and Granite Wash sections are present (typical of Panny).

In the general Senex area (Figure 2), it is essential to be able to identify Precambrian structures on seismic data. Where salt dissolution has not occurred, this exercise consists merely in distinguishing structural-relief effects from statics problems, assuming one has good data to work with (e.g., free of multiple interference). Where leaching of the salt has occurred, the exercise is more complex as the Slave Point event is then often anomalously low, in particular at Trout, where the Precambrian is high; this depends on the timing of the salt dissolution. Furthermore, the Precambrian and near-Keg River events in these areas are usually difficult to correlate. This lack of lateral continuity is often the key to distinguishing zones of salt dissolution from structural lows at the Precambrian level. Where the Precambrian is low, both this event and the near-Keg River reflection should be of relatively high amplitude. Other features characteristic of salt dissolution include diffraction patterns and extreme time-structural relief at the Slave Point level. Structure at the Slave Point level due to compaction should be less abrupt.

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