Improving vertical resolution in the Panny field using 2D seismic inversion

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ABSTRACT

Several authors (Neidell et al., 1985; Lindseth and Beraldo, 1985; Aves and Tappmeyer, 1985, and Russell, 1992, among others) have shown that the seismic inversion plays an important role in identifying seismic sequences and in delineating seismic facies by transforming seismic amplitude in velocity profile.

The actual seismic data was acquired in the Panny field, northern Alberta and represents a set of seven 2D seismic lines containing carbonates and interlayered salt-anhydrite formations at different depths. The most important formation in this field is the Keg River Fm which is productive from the carbonates located at the Upper Keg River.

From the seismic data is very difficult to determine the top of the Keg River Fm. as result of interference effects related to the on-structure thinning of both the basal Paleozoic clastic section and the basal Muskeg anhydrite/Precambrian interval (Anderson et al., 1989).

The objective of this study is to illustrate the usefulness of the seismic inversion method in mapping the top of the Keg River Fm from 2D bandlimited seismic data by characterizing the amplitudes by pseudo velocities in carbonates.

GENERAL GEOLOGIC/STRATIGRAPHIC FRAMEWORK

The study area is located at the Panny field of the Senex area in northern Alberta (Fig. 1). The Panny field was part of the fringing shelf surrounding the Elk Point Basin.

A synthesized geological history of the Upper Elk Point Subgroup was done by Brown et al. (1990) which is transcript here. A more detailed description can be found in the studies of Anderson et al. (1989), Campbell (1987) and Williams (1984) among others.

The reef platforms, i.e. the Lower Keg River Member in N. Alberta, were deposited around the end of the Eifelian when the Elk Point seas returned after a lengthy hiatus. This resulted first in a moderately shallow open-marine environment in early Keg River time and was followed by a fairly rapid transgression of the seas, which led to reef growth in late Keg River time. Uplift about the end of Keg River time caused a shallowing of the basin, cut off connections to the open sea, and led to decreased water circulation. This, coupled with increased evaporation and the associated paucity of the fresh water, resulted in greatly increased salinity. Reef growth stopped in this hypersaline environment and deposition of the basal salt units of the Black Creek Member of the Muskeg Fm occurred (Fig. 2). Renewed subsidence led to deposition of anhydrites, shales and carbonates of the upper units of these formations.

The principal producing hydrocarbon reservoir in the Panny area is the Keg River Fm deposited in the evaporitic environment of the Elk Point Basin. This reservoir facies is typically productive where structurally closed across underlying Precambric highs. Some authors believe that these highs are the result of pre-Devonian tectonism and subsequent erosion with, possibly, later stages of conjugate faulting in some areas (Anderson et al., 1988b).

The Keg River Fm in this area consists of carbonates with a variable degree of argillaceous content. The more argillaceous carbonates predominate in the lower Keg River Fm section and cleaner biostromal carbonates occur in the upper portion. Typically, these upper carbonates are productive where they are absent due to anomalously high relief of Precambrian. The Keg River Fm is overlain by the Muskeg Fm, principally an interlayered sequence of salts and anhydrites; the basal anhydrite of this formation seals the Keg River Fm reservoir facies.

LOCATION MAP

Figure 3 shows the location of the seismic sections. The 96-trace 24-fold seismic data were recorded in 1982, using a Vibroseis source, a 1500-m split spread, 120-m shot spacing and a 24-m group interval. The maximum recorded time was 1.5 sec. A total of seven seismic sections were included in this study (PA-6, 7, 8, 9, 10, 11 and 12) oriented SW-NE.

METHODOLOGY

For obtaining the best results from seismic inversion it was previously necessary to process the stacked seismic data in the Panny field. The line PA-6 was selected as a pilot line in this study due to the three control wells are closer to this line than the others lines. This pre-processing includes the following steps

Wavelet extraction

The match between synthetic and real seismic data is very important for identifying the major events on the stacked sections. Figure 4 shows the extracted seismic wavelet for the section PA-6 calculated between the cdp values 5561-5761 (time window 0.45-0.90 s) which contain the wells 3-11 and 1-3. The extracted wavelet has a phase near to 0 degrees with a peak frequency of 40 Hz. The wavelet estimation was done deterministically using the log information available from both wells. This method to remove the wavelet phase and convert it to a true zero-phase equivalent is very robust providing a good tie well-seismic data. It involves computing the varimax norm (or the cross-correlation function) over a number of constant phase rotations. Theoretically, the phase value associated with the peak value of this function is the best estimation of the seismic wavelet phase.

Figures 5a, b show the tie between the synthetic seismogram obtained from each well and seismic data for the PA-6 stacked section using the extracted wavelet. The correlation is very good permitting a clear identification of the Muskeg Fm, Belly River Fm, basal anhydrite and Precambrian. In each case the reflection associated with the contact basal anhydrite-Keg River Fm is not obvious from the seismic and synthetic data. Although the basal anhydrite of the Muskeg Fm has a slightly higher velocity and density than the underlying Keg River Fm, the contact between the two units cannot be mapped 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. This event is more or less parallel to the anhydrite/Keg River Fm contact. The same result can be observed in the other wells (1-3 and 3-5) along PA-6 line.

Deconvolution

The seismic deconvolution tries to "remove" the wavelet shape to reveal the reflection coefficients present in the subsurface. In this study, it was used a deconvolution based on the extracted wavelet due to this method showed to be consistently good. Figure 6 shows a comparison of the PA-6 section between the wells 3-11 and 1-3 after and before deconvolution at level of the formations of interest. It is evident that the deconvolved section represents better the impedance changes observed on the log. A bandpass filter 0-5-75-90 Hz was applied on the deconvolved sections before to inversion for reducing the noise introduced by the deconvolution operator.

Model-based inversion

A model-based deconvolution was used for invert the stacked sections to pseudo-velocity sections. The model-based inversion derives the impedance profile which best fits the modeled trace and the seismic trace in a least squares sense using an initial guess impedance. Basically, this inversion resolves the reflectivity from an objective function and compares its RMS amplitude with the assumed reflectivity size. The wavelet is then scaled to compensate for the difference. This iterative process for updating the estimated reflectivity requires an initial impedance value.

The initial impedance logs for the PA-6 line were obtained from the sonic and density logs of the wells 1-3, 3-11 and 3-5. The match well-seismic using the wells showed be consistent for the principal reflectors associated with the Muskeg Fm, basal anhydrite and Precambrian. A mean impedance log, obtained from the three wells (1-3, 3-11 and 3-5), was used for the PA-1, PA-7, PA-8, PA-9, PA-10 and PA-11 stacked sections. Each value of this mean impedance log corresponded to the arithmetic sum of the individual impedance values for each well divided by the factor 3. During this process each well was stretched for matching the principal impedance contrasts with the formation tops associated with the Muskeg Fm, basal anhydrite and Precambrian at the tie location. The validity of this procedure is based on the regional continuity of the principal reflectors and the absent geological complexity observed from the stacked sections in the Panny field.

A flowchart of the model-based inversion approach is shown in Figure 7.

INTERPRETATION

Figure 8 shows a detailed view of the PA-6 section around the wells 1-3, 3-5 and 3-11. It is evident the seismic response of the anhydrite/basal salt contact and Precambrian clastics. Any evidence related to the Anhydrite/Keg River Fm contact is not observed on it. The corresponding inverted section between the wells 3-11 and 1-3 is also indicated in the Figure 8. The Anhydrite/Salt contact is characterized by pseudo-velocity values between 6096 - 6550 m/s (0.87 - 0.90 sec). This velocity pattern is very consistent along the seismic line. By other hand, the Precambrian appears with velocities up to 6500 m/s. The differential compactation effect due to the Precambrian highs is evident in the upper formations (Muskeg Fm and Slave Point Fm).

Figure 9 shows a cross-section indicating the match between the real velocity log and the pseudo-velocity logs obtained around the control wells. The top of the Keg River Fm appears characterized by a sharp velocity contrast from 6096 m/s to 5187 m/s which is clearly evident for the three wells.

Using the above relationship between pseudo-velocity contrast and location of the top of the Keg River Fm was possible to delineate the time relief associated with this formation along the line PA-6 by picking this velocity contrast along its inverted section (Fig. 8). Between the cdp numbers 5581 - 5671 is observed a truncation of the Keg River Fm against the Precambrian high. A similar interpretation procedure of the inverted velocities was applied on the other inverted sections.

DISCUSSION

Figure 10 shows the difference time map for the Keg River Fm. It represents the difference in the interpreted time for the top of the Keg River Fm between using the anhydrite/salt contact and the inverted velocity contrast. From this map is evident that there is a time difference less than 50 ms in using both methods for estimating the time position of the Keg River Fm. contact. It difference zone occurs to the western edge of the Panny field. This fact indicates that the anhydrite/salt contact is a good estimator of the areal distribution of the top of the Keg River Fm. to the western section of this field.

A very different picture is obtained to the northeastern of the Panny field. Here the discrepancy is between 100 - 150 ms indicating that the above approximation diverges from the time-location estimated for the top of the Keg River Fm using the pseudo-velocity pattern observed for this formation on the inverted sections.

CONCLUSIONS

1) Under good well-seismic tie the method of seismic inversion provides a way to improve the vertical resolution.

2) It had been possible to identify the top of the Keg River Fm characterized by a sharp velocity contrast between the upper carbonates and pre-Keg River formations (6096 - 5187 m/s).

3) The use of the contact basal anhydrite/salt units of the Muskeg Fm, for estimating the top of the Keg River Fm, gives a very good estimation of the time position of the Keg River Fm contact to the western area of the Panny field. The time error is lesser than 50 ms.

4) The above estimation fails to the northeastern section of the Panny field giving time errors up to 100 ms as compared with the method of using the inverted velocity contrast.

5) A more dense seismic data, as a 3D volume, could give a better estimation of the areal distribution of the Keg River Fm in the Panny field.

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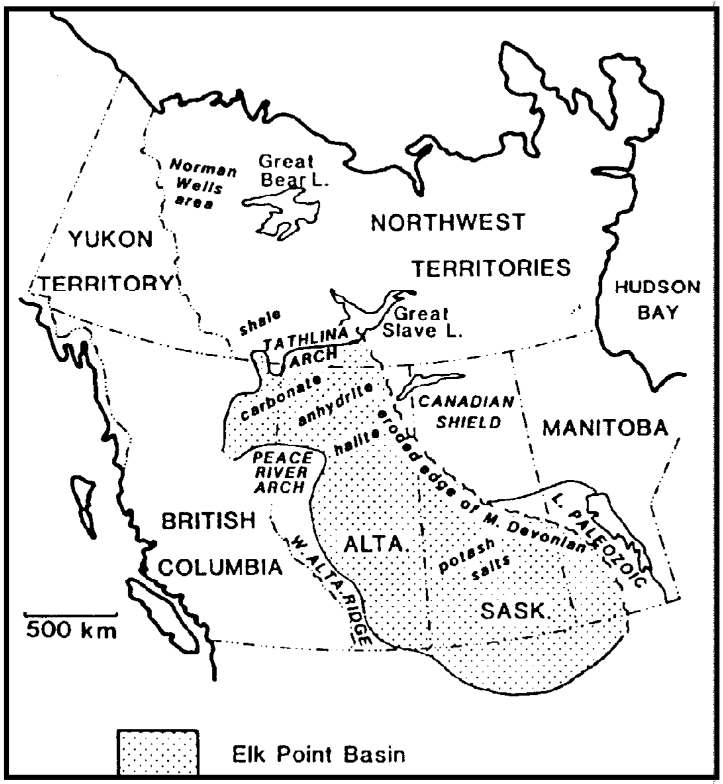

Fig. 1. Dominant lithologies of the Muskeg and Prairie Evaporite Formations (After Krause and Burrowes, 1987).

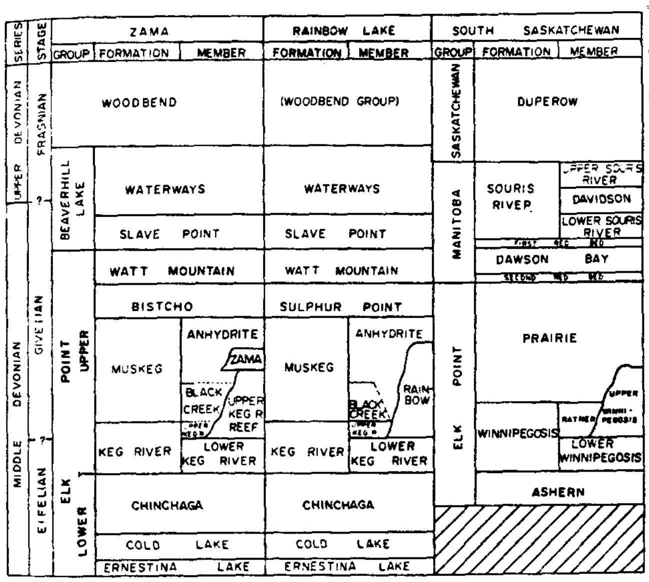

Fig. 2.Stratigraphy correlation chart showing the formations of the Group Elk Point (After Hargreaves et al., 1960).

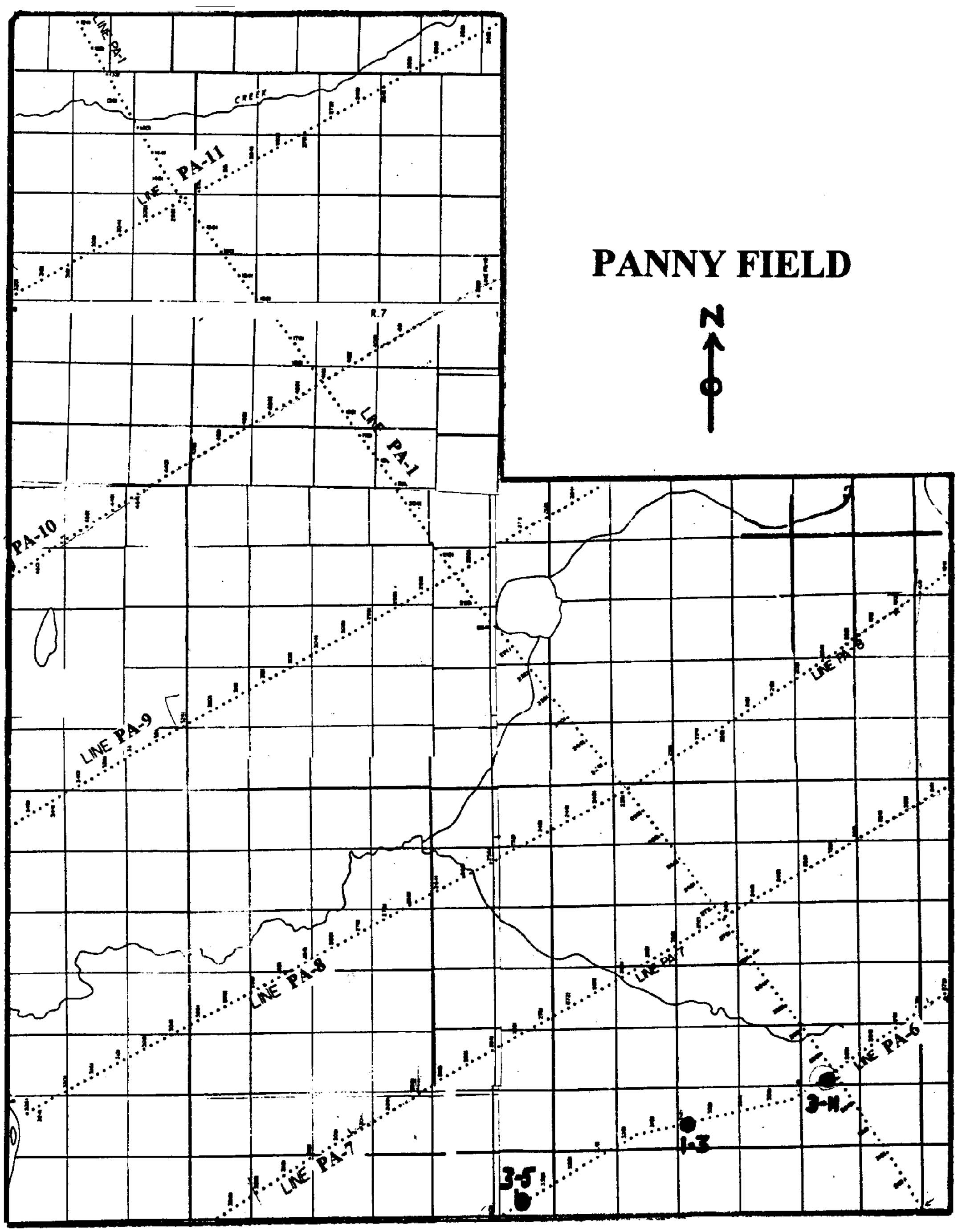

Fig. 3.Seismic and well location map in the Panny field.

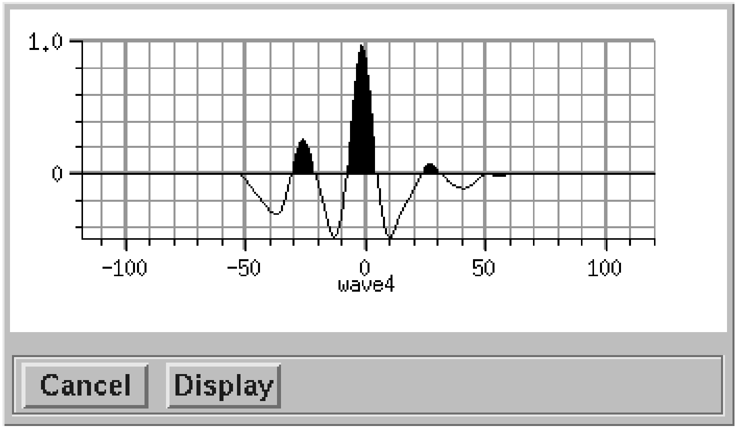

Fig. 4. Extracted wavelet for the stacked section PA-6.

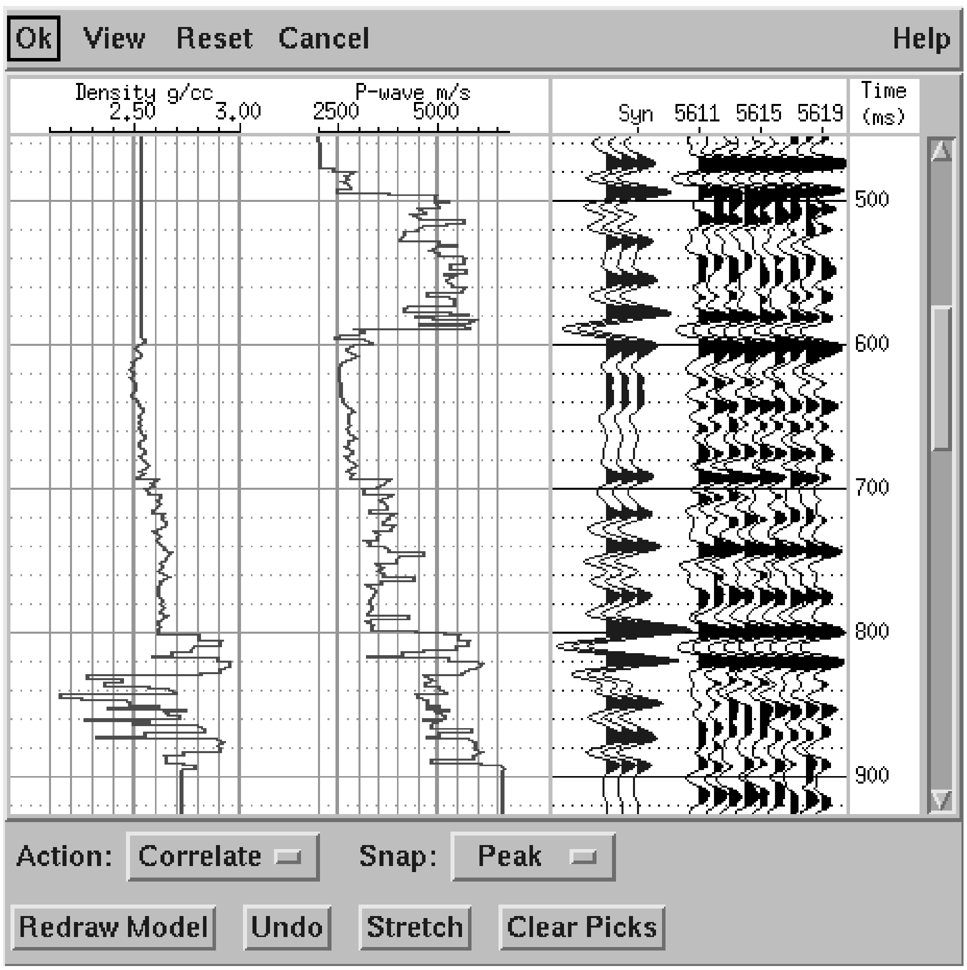

Fig. 5a. Seismic-well match for the well 3-11 at line PA-6 using the extracted wavelet in Figure 4. The anhydrite/salt contact is at 882 ms and the Precambrian at 894 ms

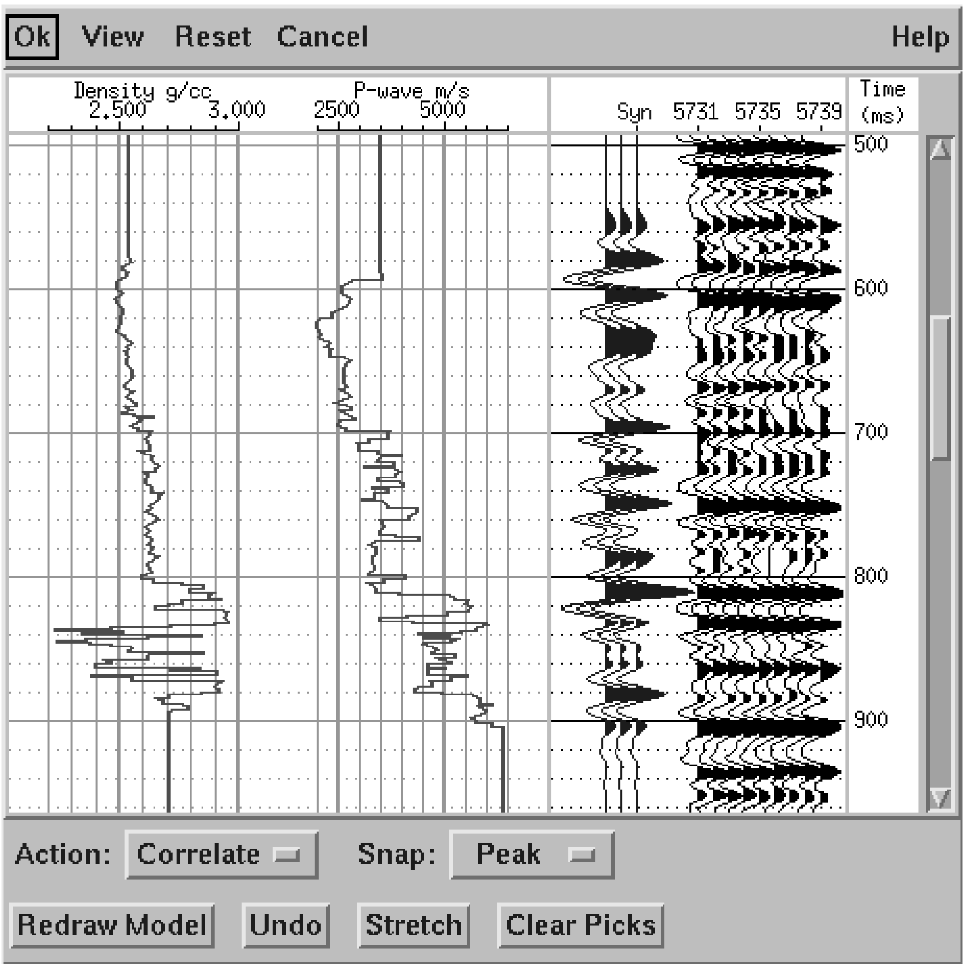

Fig. 5b. Seismic-well match for the well 1-3 at line PA-6 using the extracted wavelet in Figure 4. The anhydrite/salt contact is at 885 ms and the Precambrian at 902 ms

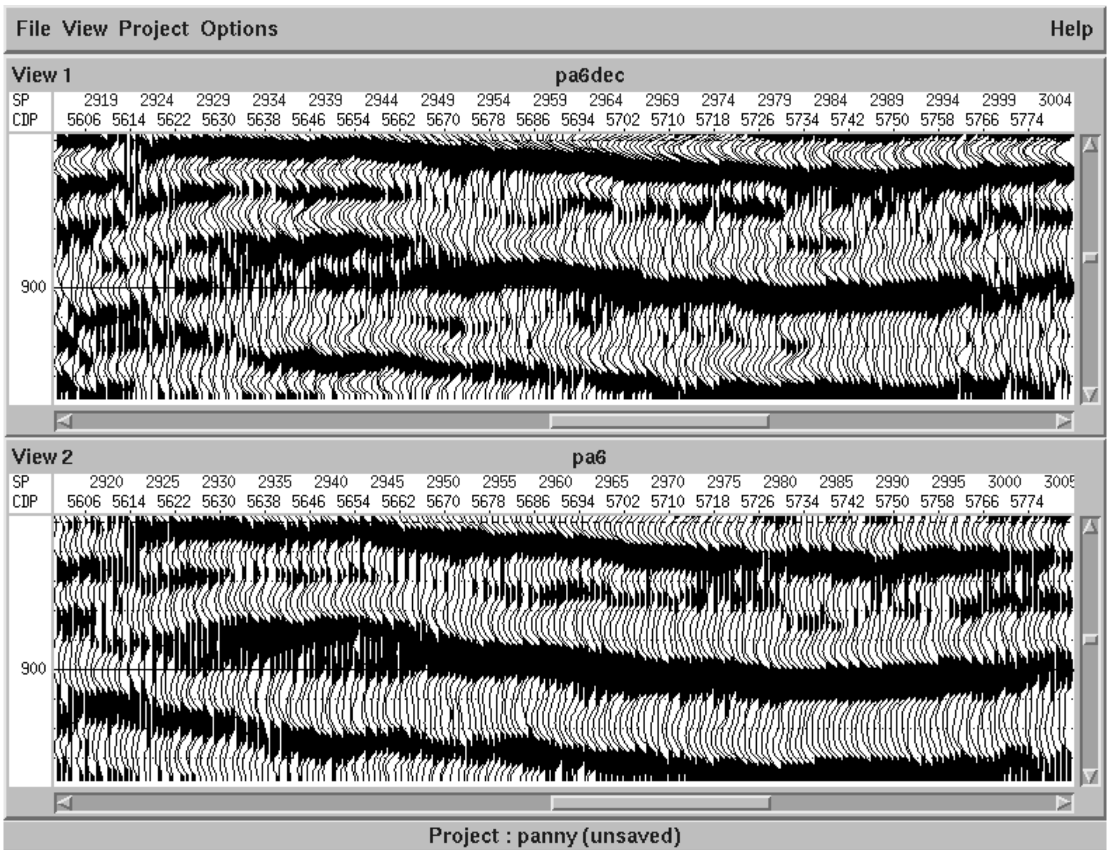

Fig. 6. Effect of the deconvolution applied on the section PA-6 between the wells 3-11 and 1-3. In the top the deconvolved section and in the bottom the stacked section.

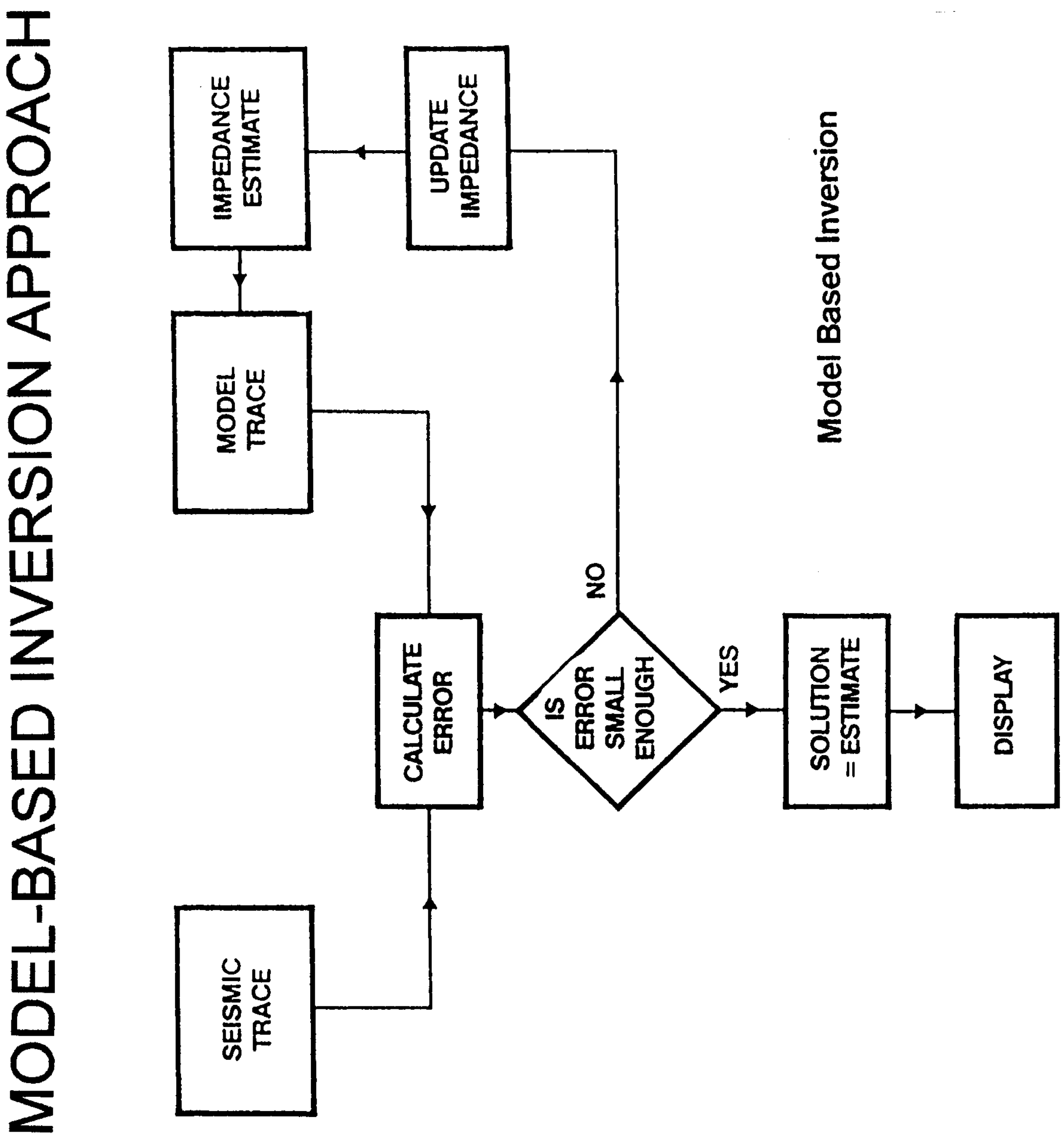

Fig. 7. Flowchart of the model-based inversion approach (After Russell, 1988).

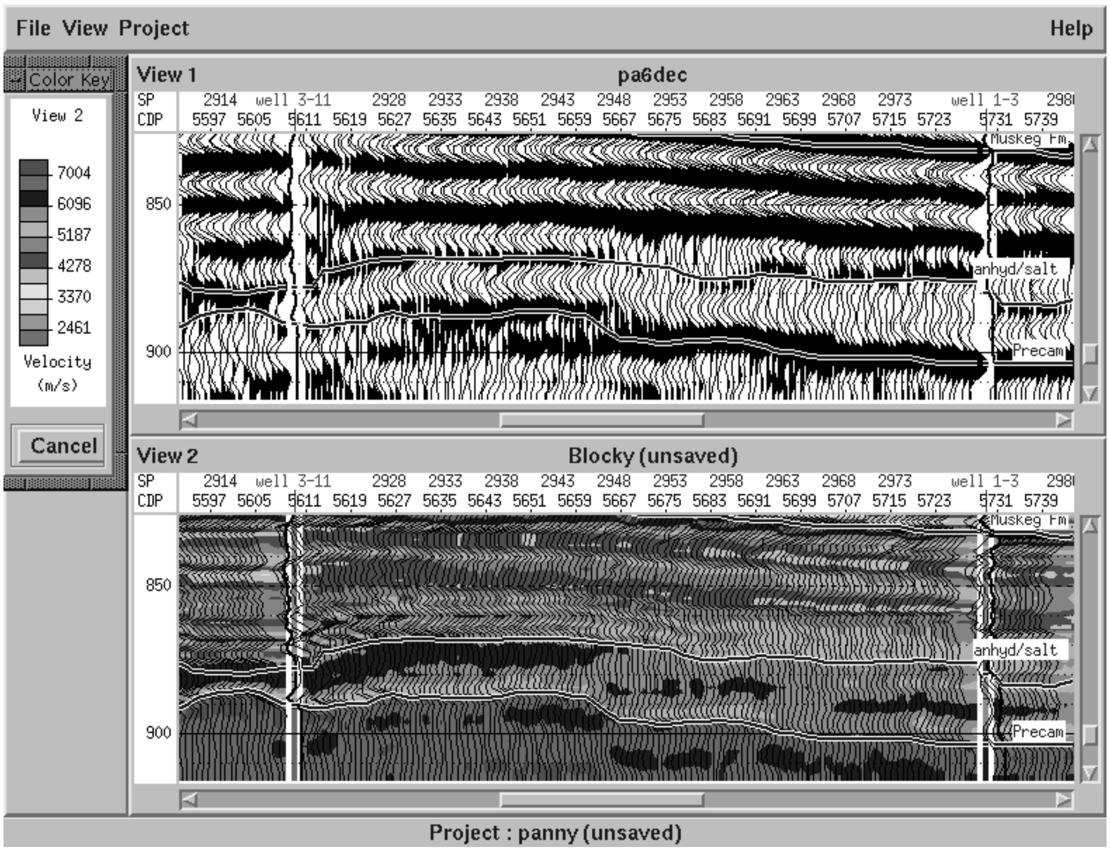

Fig. 8. PA-6 deconvolved and inverted sections between the wells 3-11 and 1-3 showing the anhydrite/salt contact and Precambrian. The Keg River Fm appears with a pseudo velocity between 5197 - 6096 m/s.

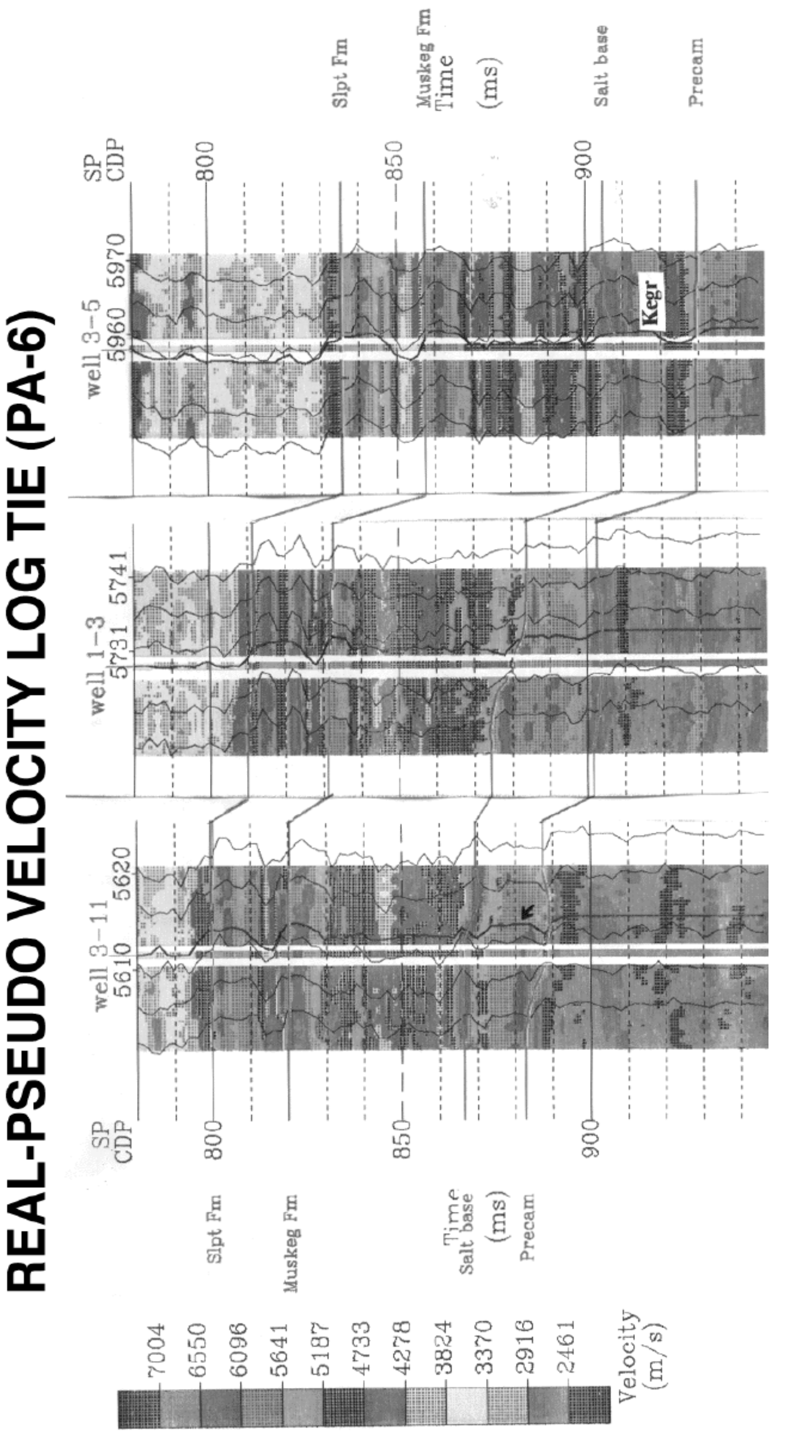

Fig. 9. Detailed cross-section at line PA-6 showing the match between the real velocity logs (center of each section) and the pseudo-velocity logs after inversion for the three control wells.

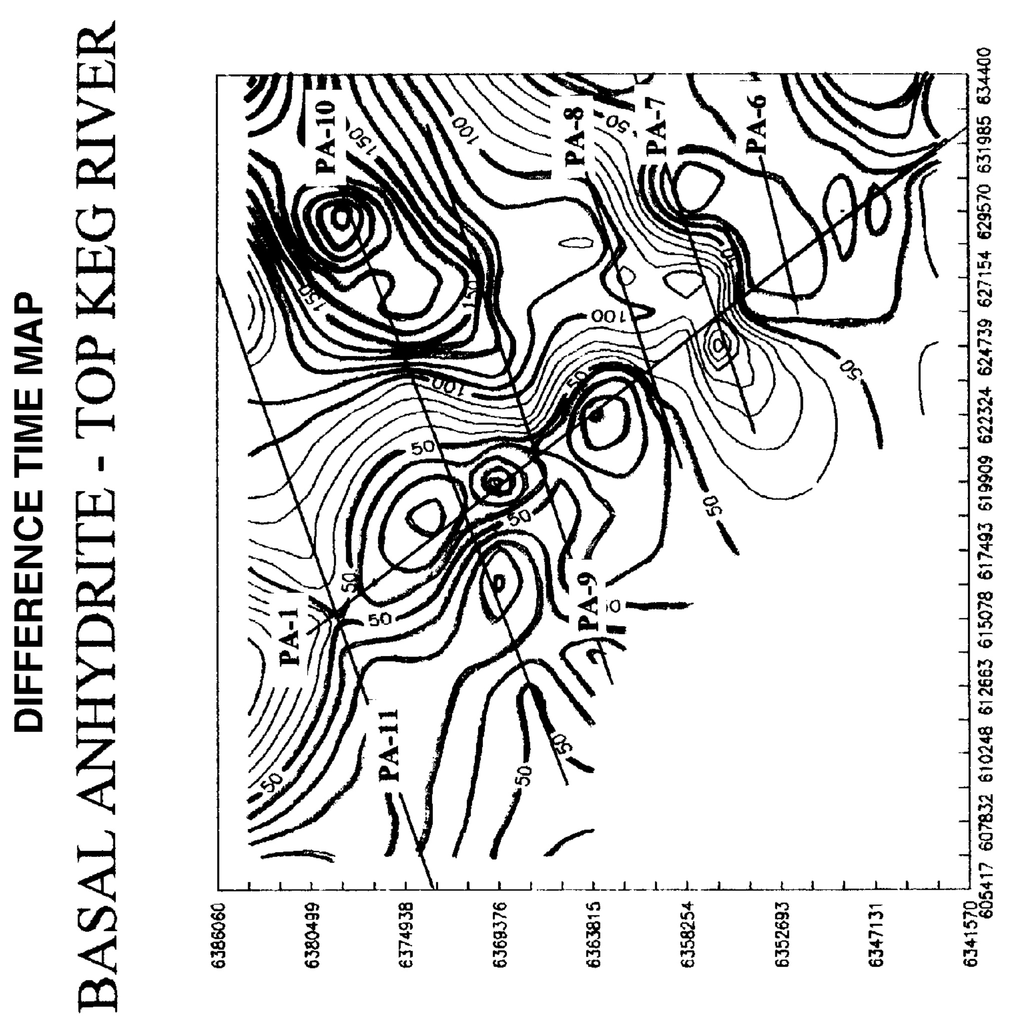

Fig. 10. Map indicating the discrepancy between the estimated time for the top of the Keg River Fm using the anhydrite/salt contact and the pseudo-velocity contrast criteria on the inverted sections.