THE APPLICATION OF INVERSION TO SEISMIC INTERPRETATION PROBLEMS IN THE FOOTHILLS†

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ABSTRACT

Complex subsurface structures in the Alberta Foothills provide prolific hydrocarbon reservoirs in Mississippian formations. However, the identification and correlation of these formations is often unreliable due to extreme variations in the near-surface,, on-and off-line diffractions and frequently poor signal transmission throught various fault zones. These problems are common to both conventional dynamite and surface sources.

While structural complexities may be partially resolved with migration, the identification of individual reflectors is not always simplified by the same process. Fortunately, *zones bounded by major reflectors have* distinct interval velocity characteristics in sonic logs, particularly in the normal range of seismic frequencies.

In seismic inversion the nearsurface influence on deeper data is minimized by replacing the porpagating wavelet with a spike, providing relectivity index sections as well as interval velocities. By matching the pseudo-acoustic logs to actual sonic logs, reflectors are more readily identified and thrust fault interpretation is improved.

The advantage of this approach can be readily illustrated in a series of real data cases from the Alberta Foothills.

INTRODUCTION

Geological Review

The Candadian Rockies may be split into four separate and distinct geological provinces. From east to west these are the Foothills, the Front Ranges, the Main Ranges and the Western Ranges. In this paper we shall confine ourselves to the Foothills. These begin a few miles west of Calgary and are characterized by topographically distinct ridges of moderate relief with outcropping rocks of Cretaceous age. The ridges are due to thrust-faults which involve west-dipping plates of both Mesozoic and Paleozoic rocks.

The deformation of the Rocky Mountains is the result of the Laramide orogeny. The underlying Pre-Cambrian basement is undisturbed and dips gently to the west, serving as a major seismic reflecting horizon as well as a base datum in geological construction (Figure 1). Structural movement in the Foothills probably culminated about Oligocene time and resulted in an overall one hundred miles of foreshortening in the Paleozoic section which now forms a diverse array of interleaved and overlapping slip surfaces of these rocks stacked up as imbricate thrust slices and associated folds. The overlying Mesozoic clastic rocks are themselves structurally complex with numerous imbrications, and folds drape the Paleozoic skeletons of these same thrust sheets. The leading edges of the sheets are usually a mile or less in width and are the primary reservoirs where they involve Paleozoic carbonates.

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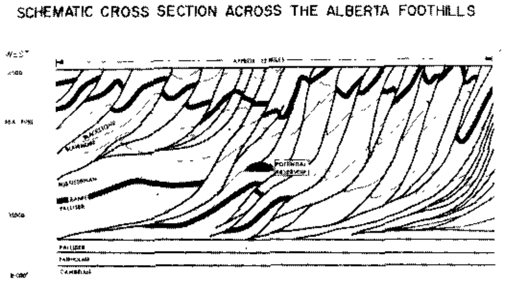

Fig. 1. Representative geological cross section through the Alberta Foothills.

All the fields found to date in the Foothills belt are primarily in the Mississippian Turner Valley and Mount Head formations. Diagenetic changes, such as dolomitization and late fracturing due to structural deformation in these carbonates has led to increased reservoir quality.

Geophysics in the Foothills:

Over the last few years there has been a surge of activity employing new seismic techniques such as the heliportable operation, surface sources and 3-D recording and processing. While these techniques have had some measure of success, we are still far from being able to obtain definitive data in all areas. Getting energy into the ground and the energy return in a complex geological environment still constitute major problems.

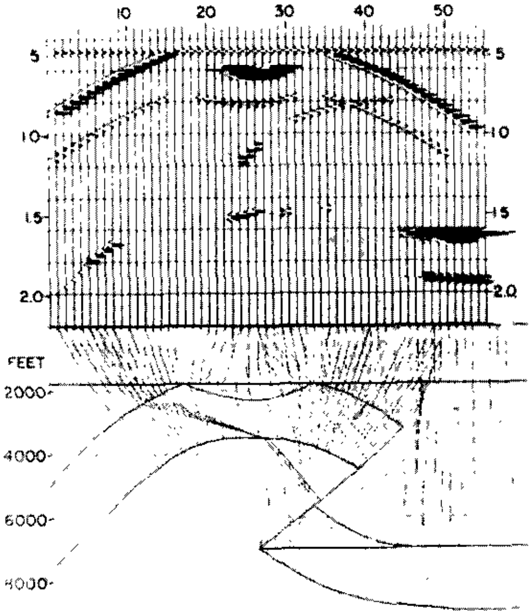

Fig. 2. Overthrust fault model — normal incidence version. (Courtesy GeoQuest, Houston)

The problem of geometry can be illustrated with a model study from GeoQuest. The model (Figure 2) is a simplified overthrust fault, probably the most difficult subsurface structure to interpret. In this model there is a gas reservoir in the underthrust block. The lower right diagram shows the set of normal incidence rays coming from the thrust fault face. It is apparent that seismic energy cannot illuminate the entire fault face because of incidence angles exceeding the critical angle at overlying interfaces causing "blind spots". On the synthetic seismic section there is very little suggestion of the thrust itself other than fragmentary diffractions.

In addition to the complexity illustratd by the simple two-dimensional noise-free model described above, the interpretation has to contend with out-of-the-plane events, signal transmission in anisotropic media and the energy absorption in the fault zones. Thus the likelihood of obtaining reliable seismic sections is reduced within the context of the mechanics of CDP acquisition and stacking. Reflection identification and correlation across fault zones is often difficult. Migration resolves some of the apparent complexity of the seismic section but does not always simplify the identification or correlation of individual reflectors. In the following sections we describe a method of increasing the reliability of this identification and correlation of important events.

The Sonic Log and its Principal Reflectors:

The sonic log is one of the most familiar pieces of information to geophysicists and certainly one of the most useful. Figure 3 shows, at the top, an unfiltered sonic log from a Foothills well. Note the position of two of the principal reflectors, at approximately 1.4 and 1.6 seconds. The second trace represents seismic reflection data at the well after inversion. The third trace is a smoothed, or filtered, version of the second trace using a 5-sample (or 10 millisecond) moving average. The bottom trace is that obtained by passing the top trace, the sonic log, through a 10-55

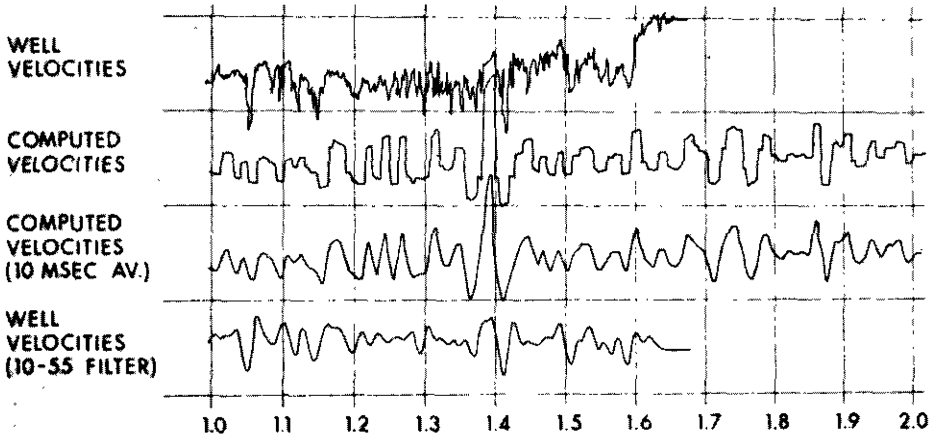

Fig. 3. Correlation between sonic derived and inversion derived velocities.

filter. This filter is the same as that applied in the original processing of the seismic trace used to determine the computed velocities of trace 2.

The significance of this diagram is that the sharp velocity cantrast at 1.6 second is severely reduced on trace 4 because of the effect of the low-cut filter. i.e. Severe bandlimiting in recording and processing has eliminated the main characteristic of the principal reflector. However, the principal reflectors on trace 4 can be identified on traces 2 and 3 and, most significantly, the signatures of these reflectors at 1.4 and 1.6 seconds are distinct from each other.

In isolating signatures of principal reflectors a signature template analysis is being performed, the significance of which will become obvious in examples to follow.

Seismic Inversion

The inversion of a seismic trace, or equivalently the conversion of the seismic trace to a sampled log of interval velocities in the transmitting medium, was first introduces by Delas et al. (1970). This technique has received considerable attention over the last two years. Jain and Wren (1977) described a method of estimating the propagating wavelet from the seismic trace alone and then replacing it by a spike of appropriate amplitude and polarity. The seismic trace is thus reduced to a set of spikes, each of them representing a reflectivity index encountered by the seismic waveform. The reflectivity index section thus obtained has much greater resolution than the normal seismic section. Since the wavelet is computed for each trace, the effect of

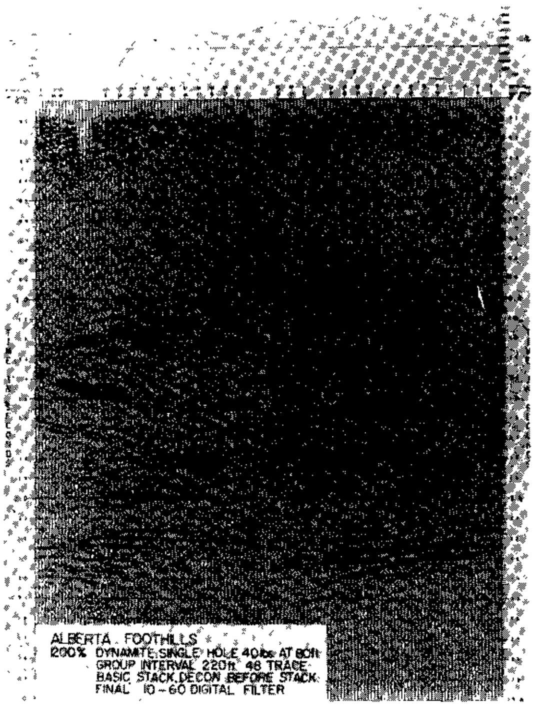

Fig. 4. A section from the Alberta Foothills. *(Example 1)*

distortion in the reflection character introduced by the variations in the near-surface layer(s) is also reduced. Consequently, the zones of interest can be correlated with more confidence in the reflectivity index section than in the normal section. The velocities computed by integrating the reflectivity index section show closer resemblance to sonic logs than would be possible from normal processed sections.

Example 1:

This section (Figure 4) might be considered as a typical "spaghetti" or "bird's nest" example from the Foothills. Notice the lack of reflection continuity, the amount of deffraction energy and, most important, the similarity in character of the various reflection fragments. It should be emphasized that the picking on the section is not intended as an interpretation, but only to highlight the problems.

Figure 5 shows the sonic logs from two wells in the general vicinity of the seismic section. Alongside each of the sonics we have a hi-cut (0-60) filtered version. The segment of the filtered sonic of location A between 1.2 and 1.7 seconds is used as a signature template (X) and the zone between 0.7 to 1.3 seconds on the filtered sonic of location B is used as signature template (Y). The next diagram, Figure 6, shows these "tadpole" signature templates superimposed on the inverted seismic section to provide the optimum cross correlation. It is apparent from this section that a well drilled at Shot Point 46, west of the crest, and with the deviation illustrated would not encounter the principal reflector at Shot Point 43, which is probably the Mississippian. i.e., what was identified as

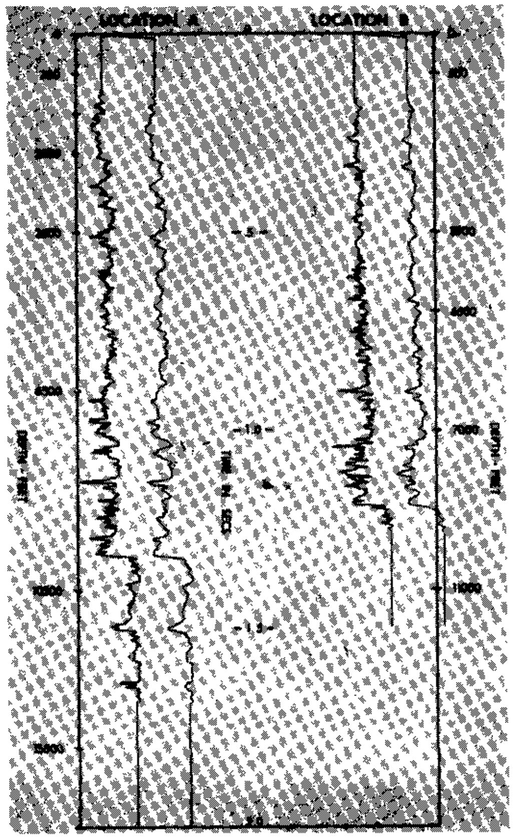

Fig. 5. Filtered and unfiltered sonic logs from two Foothills wells.

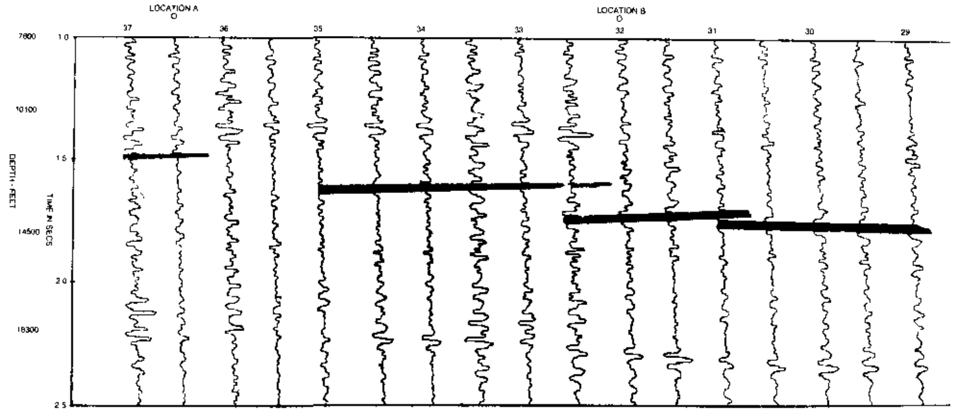

Fig. 6. Relationship between inverted velocities and the template signatures from sonic logs.

Mississippian on the seismic section is probably Blairmore.

Example 2:

This seismic section (Figure 7) is from a different area of the Foothills and while the *fold in only 600%, the apparent data quality* is substantially better than the previous example. Given that the major reflection at 1.4 seconds is Mississippian and the well at location A had already been drilled with some encouraging signs, a second location at B could be considered desirable. This second location would encounter the Mississippian approximately 30 milliseconds higher. The well was drilled and at 1.6 seconds had not encountered Mississippian suggesting that the seismic interpretation was totally erroneous. The question is, where is the Mississippian reflector at location B?

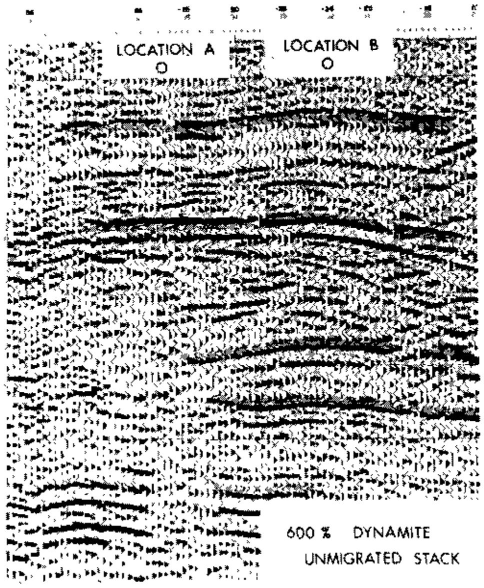

Fig. 7. A section from the Alberta Foothills. (Example 2)

Using a signature template based on the principal reflector at 1.6 seconds on the earlier diagram (Figure 3) the Mississippian event was picked on the interval velocity plot after inversion (Figure 8). It can be seen that the event in question occurs approximately 100 milliseconds lower at location B than at location A. The next diagram (Figure 9) is the reflectivity section of the previous slide and from hindsight, the probable interpretation is fairly evident.

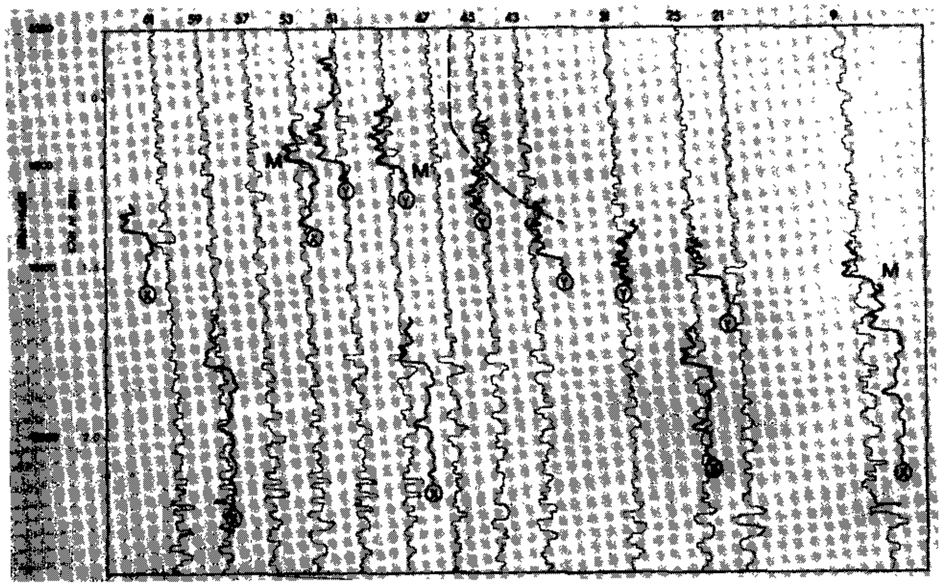

Fig. 8. Interpretation of inverted velocities computed from some traces in Figure 7.

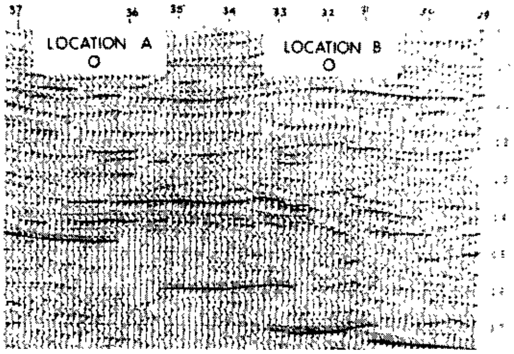

Fig. 9. Reflectivity Index section and the Mississippian reflector. Note the reliability of correlation compared to Figure 7.

CONCLUSION:

In many foothill areas, basic processing is not sufficient to properly identify and correlate the principal relectors on a seismic section. This can be achieved by special processing. If a sonic log is available in the general area, it can be used with inversion via a template approach to provide a reliable interpretation. Such a template approach is not possible with conventional seismic sections since the details have been smeared by the propogating wavelet.

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