JOURNAL OF THE CANADIAN SOCIETY OF EXPLORATION GEOPHYSICISTS
VOL. 20, NO. 1 (DEC. 1984), P. 55-59

SEISMIC TECHNIQUES IN CARDIUM EXPLORATION[1]

A. EASTON WREN[2]

ABSTRACT

The application of modern seismic methods in the exploration for stratigraphic traps in Alberta over the past decade has met with mixed success. There has been a growing awareness that many known and potential reservoirs are "seismically invisible" on the basis of conventional acoustic impedance modelling. Geophysicists have become frustrated in their attempts to correlate synthetics with real data in areas of stratigraphic subtleties. In the meantime, seismic acquisition and processing continues to pursue the ideology that "more is better", and statistical redundancy appears to know no bounds. This is particularly significant in the context of common depth point (CDP) shooting.

Recently released material has cast doubts on the usefulness of stacked sections for stratigraphic interpretation purposes and revealed the significance of other seismic parameters including Poisson's Ratio and offset in terms of their effect on amplitude and phase. An understanding of the contribution of these parameters reduces the problem of "seismically invisible" to "acoustically invisible".

This paper will discuss the relevance of these simple methods, address the problem of synthetic-real data calibration and the potential danger of CDP stacking, and demonstrate that there may be few targets that are "seismically invisible". The existence of a diagnostic Cardium signature in the Cyn-Pem area will be demonstrated.

INTRODUCTION

This paper has its origins in the basic assumption that reflected signals are related to geological boundaries and, more specifically, that the reflection coefficient of the boundary determines the amplitude of the reflected signal. In 1955 Koefoed drew our attention to the possibility that ". . . in a more remote future it may become possible to draw conclusions concerning the lithological nature of rock strata from the reflection coefficient behaviour as a function of offset and Poisson's Ratio." He was essentially advocating stratigraphic interpretation at a time when no one was interested. In 1956, however, Mayne captured the industry's interest by suggesting a statistical approach to acquisition using multiplicity of shot and receiver, and later (1962) demanded the industry's attention with the publication of his classic paper on common reflection point horizontal stacking techniques.

It should be emphasized that Mayne's contribution was timely and effective in terms of the exploration objectives of the day. However, with hindsight and within the context of the post - "Bright Spot" era, it is evident that the statements of Koefoed and Mayne are contradictory.

COMMON DEPTH POINT SHOOTING

Common depth point shooting has been of significant use in areas of structural complexity in terms of apparent data-quality improvement. It is important to remember that stacking improves the signal-to-noise ratio but does nothing for the signal. In addition, we must now consider what detrimental effects stacking may have. In particular, how significant is the *averaging* of subtle wavelet attributes of amplitude, frequency and phase? These are the specific attributes we use for modern stratigraphic interpretation, calibration and resolution.

In the post - "Bright Spot" era we have come to recognize that many factors combine to influence the propagating wavelet in terms of attributes. We have learned how to deal with these through amplitude recovery and preservation, deconvolution for frequency, and wavelet processing with dephasing for phase distortion.

Nevertheless, over the last few years the industry has had mixed success in seismic exploration for subtle stratigraphic traps. There has been a growing feeling that some subtle reservoirs may be "seismically invisible" on the basis of conventional acoustic modelling. In addition, there has been some frustration in trying to correlate synthetics (based on sonic and/or density logs) and real data. In the meantime, the evolution of seismic acquisition and processing methods continues to pursue the ideology that "more is better", and statistical redundancy appears to know no bounds. This is particularly true in the context of common depth point shooting.

CALIBRATION

Traditional problems of tying synthetics to real data have often been resolved by static shifts or, more recently

[1]Paper Presented to the Joint CSEG-CSPG Convention, Calgary, Alberta, June 1984

[2]Petrel Consultants Ltd., 565, 800 - 6th Avenue S.W., Calgary, Alberta, Canada T2P 3G3

and in a more sophisticated fashion, by equating the phase of the wavelets involved. However, miscorrelations still exist. Does this mean that the synthetic is fundamentally wrong and the data (section) fundamentally correct? Or is it vice versa? Or are they both wrong? This is not a trivial question. There is reason to suspect that, for stratigraphic purposes, neither the synthetic nor the stacked section has any usefulness!

Synthetic seismograms are typically 100% normal incidence and based on the reflectivity series generated from sonic and/or density logs. The seismic section is multifold, non-normal incidence (even though stacking with NMO attempts to simulate normal incidence) and is probably influenced by rock properties in addition to P-wave velocity and density.

Koefoed (1955) demonstrated that the reflection coefficient is a function of P-wave velocity and density (impedance) but also a function of offset and Poisson's Ratio (which is a function of P and S-wave velocities). His results (Fig. 1) demonstrate clearly the influence of offset and Poisson's ratio on the reflection amplitude. This behaviour is predictable, and is a result of mode conversion at the boundary as a function of the angle of incidence and the P and S-wave velocities above and below the boundary. It can also be seen that, at certain offsets, the reflection amplitude may change polarity. The significance of these results is that CDP stacking of variable range traces in the gather will produce an average amplitude for average range, and may have no relationship to the zero-offset (or normal incidence) synthetic. Hence the need for offset-dependent synthetics that include Poisson's ratio, or offset-limited processed seismic sections. Only in this way can we study the subtle stratigraphic signature. Figure 2 shows an example involving a strong decrease in Poisson's Ratio. In this case the polarity "flips" for the P-wave reflection.

The ramifications of this become alarming. What is the usefulness of running instantaneous amplitude or phase on a stacked section? What is the usefulness of inverting a stacked 1200% section?

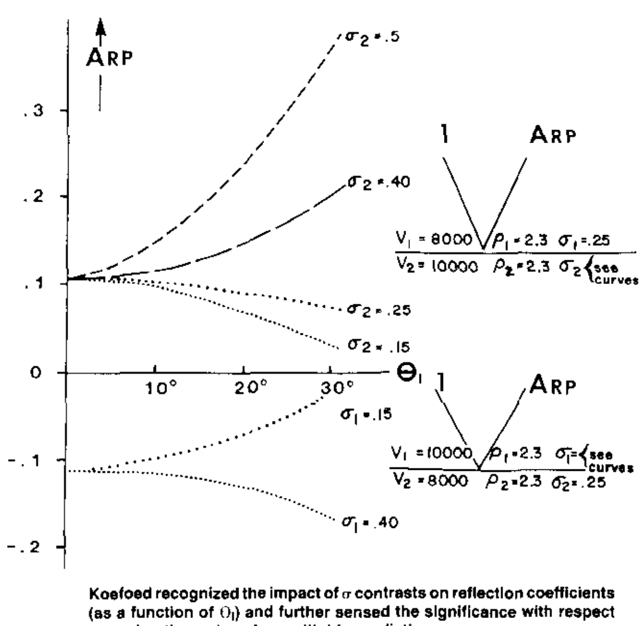

Fig. 1. The relationship between offset and Poisson's Ratio in determining the reflection coefficient (Koefoed, 1955).

SYNTHETIC CDP GATHER - FLATTENED P WAVE

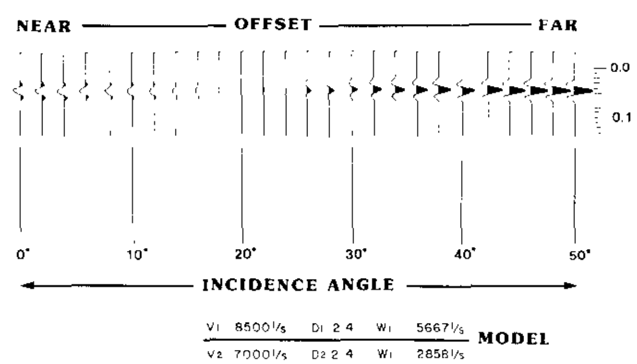

Fig. 2. Synthetic showing effect of Poisson's Ratio and offset on amplitude.

THE CARDIUM SIGNATURE

The Cardium reservoir of the Cyn-Pem Pool is a conglomerate with a predictable synthetic response (Fig. 3). There is clear evidence of an amplitude increase with reservoir on normal polarity synthetics. The synthetic strongly suggests that the amplitude anomaly would have substantial presence on real data sections. This is not usually the case.

One approach to defining the Cardium signature on real data is to process and display a series of offset-dependent sections. This should illustrate the combined effect of Poisson's ratio and offset on the signal amplitude, and can be performed on data that correlate producing wells and dry holes. The converse process, or forward modelling, involves the generation of offset synthetics, and without shear wave information and/or Poisson's Ratio this is not possible. Poisson's ratio can certainly be derived from laboratory measurements, and can be substituted into Knott Zoeppritz formulation.

The approach here is to reprocess to the stacking stage, but to output the data as a series of offset-dependent 300% stacked sections. The smallfold stack does permit some improvement in S/N ratio.

Figure 4 shows a piece of seismic data shot in 1977 and processed conventionally to a 12-fold stack. The Cardium zone is identified, but there is no consistent Cardium signature that would permit the interpreter to decide the difference between a producer and a dryhole location. In Figure 5, the data have been repro-

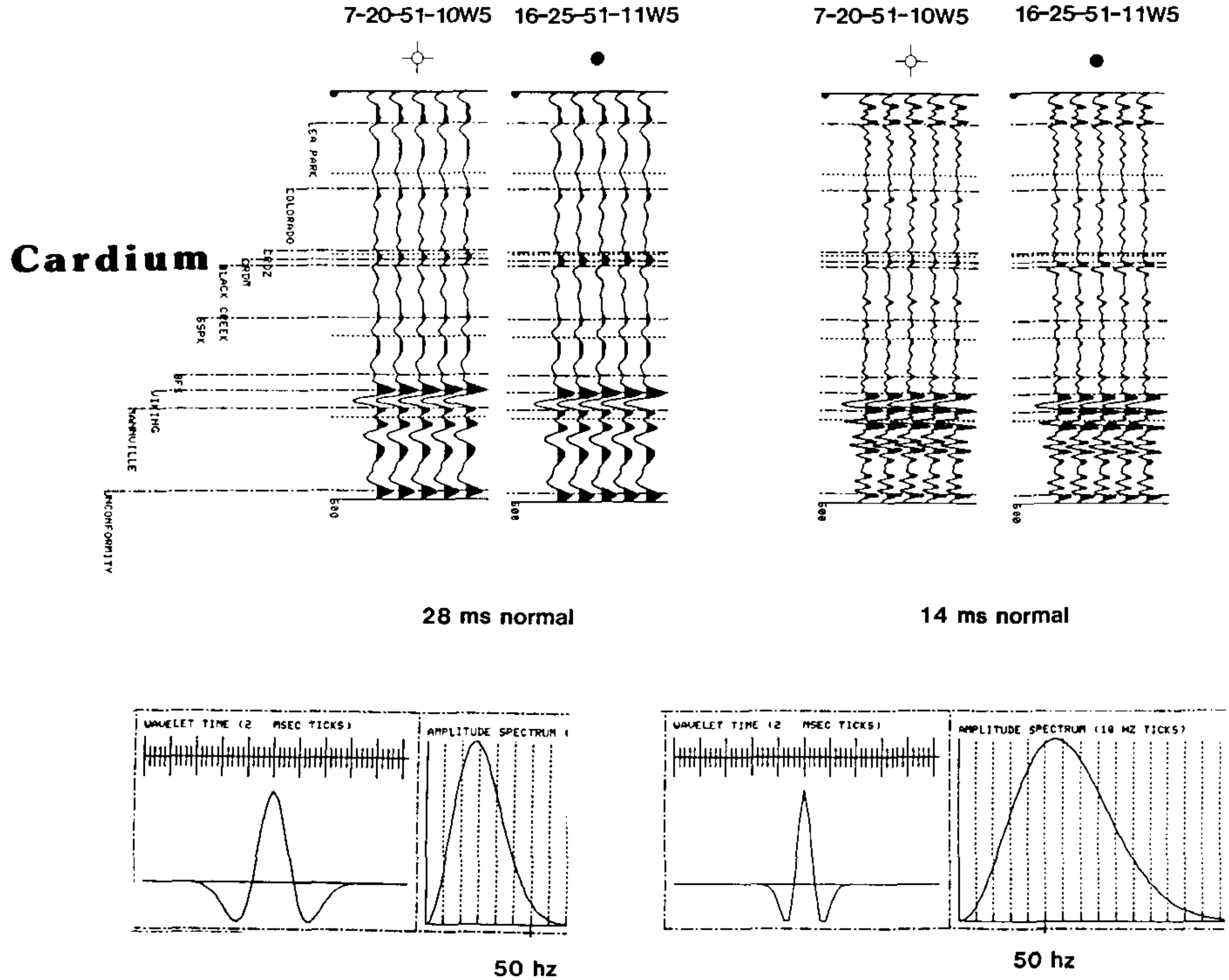

Fig. 3. Conventional synthetics showing amplitude increase with Cardium production.

cessed (essentially wavelet processed) and displayed as a series of partial offset sections ranging from 132-330 m to 660-858 m to 1452-1650 m. The change in character and signal-to-noise as a function of range is evident. It is also clear that the peak corresponding to the Cardium pay is at a maximum and most coherent at the intermediate range (660-858 m). Figure 6 is a coloured instantaneous amplitude display showing clearly the Cardium reservoir amplitude signature from the intermediate offset range.

This amplitude behaviour of the Cardium, in reaching a maximum amplitude at intermediate offset, is not fully understood although it appears to be diagnostic. The possibility of tuning and multiple interference cannot be discounted. On the other hand, Koefoed's curves can be changed with certain parameters to deviate from constant amplitude increase or decrease below critical angle.

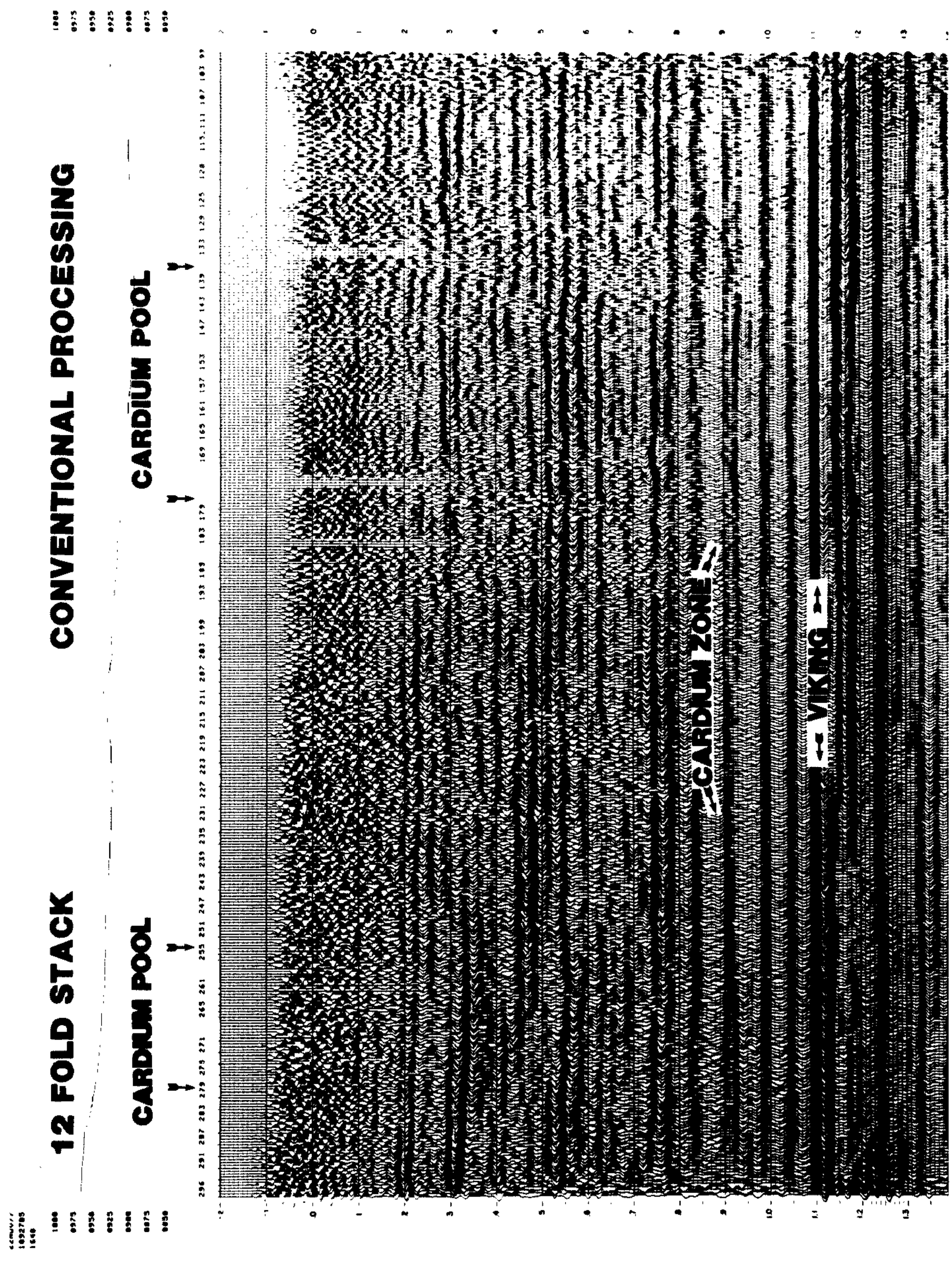

Fig. 4. Seismic section, 1200%, conventional stack.

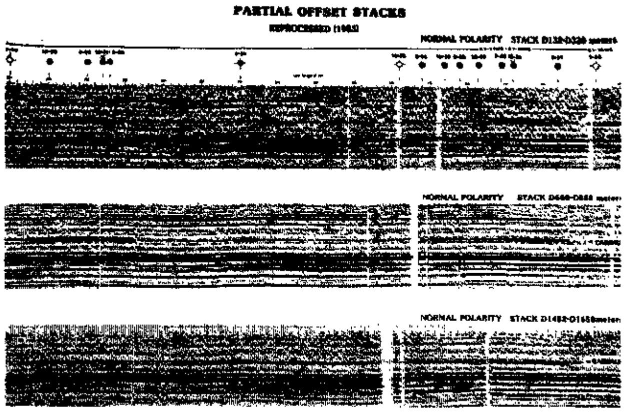

Fig. 5. Seismic sections displayed at variable offset, minimum stack.

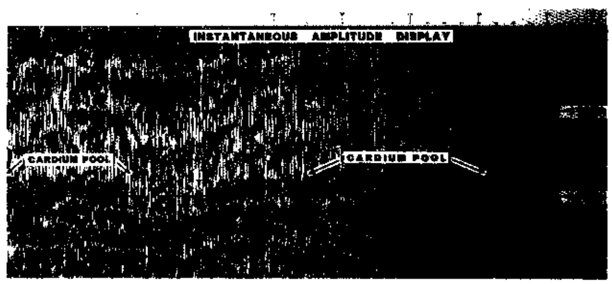

Fig. 6. Instantaneous amplitude colour display on 660-858 m stack range.

Conclusions

This may appear as a severe indictment against CDP stacking. It is not intended to be so. CDP techniques have proved enormously beneficial in the last three decades of seismic exploration. The advantages in processing cannot be overstated. The practice must be continued. However, in areas of subtle stratigraphic change, the offset-unstack approach should be considered. In addition, other basic data are necessary. These would encompass shear wave seismic and VSP information to allow forward modelling. Without forward modelling, the only pragmatic approach is to "unstack" the real data and correlate variable offset with log information.

We may begin to realize that in describing subtle reservoirs as "seismically invisible" we have really meant "acoustically invisible". Since a reservoir will involve a change in Poisson's Ratio, the reflection coefficient must change as a function of offset, even though velocity and density indicate a small impedance contrast. There should be a sense of optimism that this approach will help resolve other stratigraphic reservoirs in the Cretaceous and older sections, and may be the proverbial "tip of the iceberg".

References

Koefoed, O. 1955, On the effect of Poisson's Ratio of rock strata on the reflection coefficients of plane waves: Geophysical Prospecting, v. 3, p. 381-387.

Mayne, W.H. 1956, Seismic Surveying: U.S. Patent 2,732,906 (application 1950) (Abstract): Geophysics, v. 21, p. 856.

——— 1962, Common reflection point horizontal data stacking techniques: Geophysics, v. 27, p. 927-938.

Reference for General Reading

Ostrander, W.J. 1984, Plane wave reflection coefficients for gas sands at non-normal angles of incidence: Geophysics, v. 49, p. 1037-1648.