Estimation of anisotropy parameters in application to Blackfoot seismic data

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ABSTRACT

Anisotropy parameters are obtained by anisotropic velocity analysis performed on Blackfoot P-wave reflection-seismic data, in combination with sonic-log data. First, the line was processed with ProMAX seismic data-processing software using a sequence of conventional algorithms without taking anisotropy into account, in order to choose proper analysis points and horizons with confidence. Then, at selected analysis points, we correlated well logs, synthetic data, Blackfoot seismic data, and interpreted formation tops, to obtain the vertical interval velocities. Four seismic intervals were chosen for estimation of Thomsen's anisotropy parameters. The results show that estimated values of ε and δ seem reasonable only if the time intervals are larger than about 200 ms. When the lower three layers are combined as one target layer, it exhibits relatively high values of ε and δ of about 0.37 and 0.20, respectively.

INTRODUCTION

We have demonstrated the viability of the joint inversion of P-wave reflection traveltimes and well data to give Thomsen's anisotropy parameters, ε and δ, by applying it to synthetic data (Xiao et al., 2004). However, the practical application of this approach to real data is a more challenging task. Firstly, application of the algorithm requires the recovery of nonhyperbolic moveouts from long-spread CMP gathers. Secondly, the semblance search at high incidence angles is also hindered by phase shifts in postcritical reflections. Thirdly, we have to consider the influence of noise on semblance. This paper describes an application of this inversion procedure to some real data from Blackfoot.

BLACKFOOT SEISMIC DATA PROCESSING

Processing of seismic data for anisotropy parameter estimation is a challenge since there is a precarious balance between improvements to the signal-to-noise ratio and distortion of the curvature of the reflection traveltime curves. Ideally, processing should improve the continuity and resolution of events to facilitate horizon identification and allow traveltime picks to the largest offset range possible (nonhyperbolic moveout is only evident in the far offset). We are only interested in traveltime moveout information; conservation of frequency content and amplitudes is less important.

Hence, the employed processing sequence starts with a mute, AGC, and bandpass filter. Two *f-k* filters are then applied in cascade to reduce the linear noise on the far offsets such that the picks can be extended to greater offsets. Then a predictive deconvolution filter is designed to further reduce the linear noise and improve the lateral continuity of reflectors. A second bandpass filter is applied to remove high-frequency noise introduced by the predictive deconvolution filter. Finally, adjacent CMPs are combined and similar offsets stacked.

These steps improve the continuity of reflections significantly. An extensive series of tests has been carried out to guarantee that the signal-to-noise ratio was improved and that events could be picked to large offsets without affecting the curvature of the reflections. Optimum input data for the application of this method is raw data with static corrections applied, but before top mutes are applied to remove any linear noise. Figure 1 is the CDP gather for estimating effective coefficients.

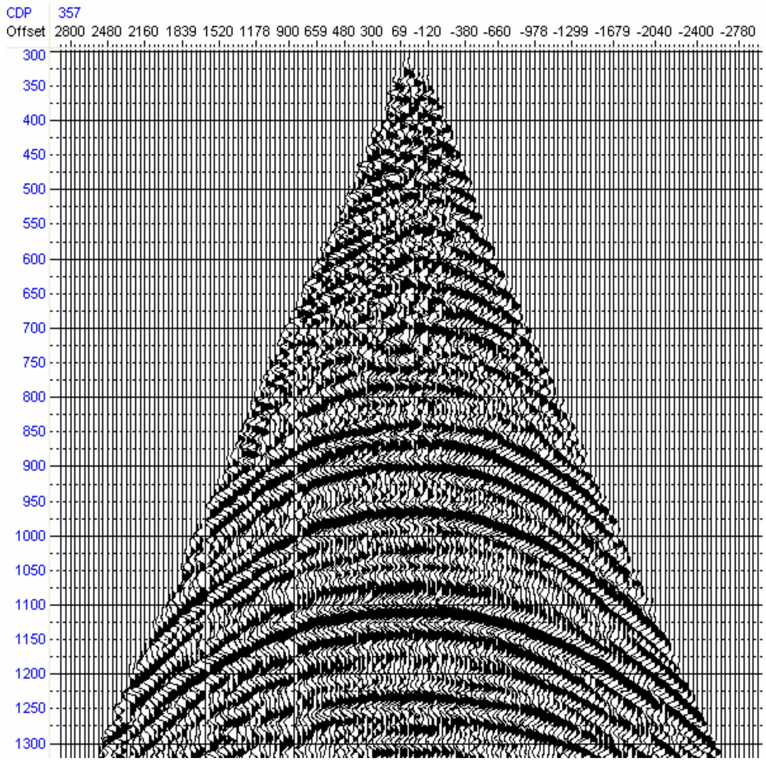


FIG. 1. The CDP gather for estimating effective coefficients.

Picking

Figure 2 shows a seismic line from south-central Alberta acquired by the CREWES Project in 1997. The line was processed with ProMAX seismic data-processing software using a sequence of conventional algorithms without taking anisotropy into account. The processing sequence is outlined in the following list:

(1) SEG-Y seismic data input
(2) Preprocessing:
    Setup of field geometry
    Automatic gain control, bandpass filter
    Editing (kill bad traces or reversed traces)
    Picking first breaks for weathering statics calculation
    Elevation correction
    Weathering statics calculation (with GLI3D)
(3) Surface-consistent deconvolution and weathering statics correction
(4) CMP sorting and velocity analysis
(5) First residual statics correction and velocity analysis

(6) Second residual statics correction and velocity analysis
(7) NMO correction, muting, and stacking
(8) Deconvolution
(9) Time-variant spectral whitening and filtering
(10) CDP trim statics
(11) Finite-difference migration
(12) SEG-Y output

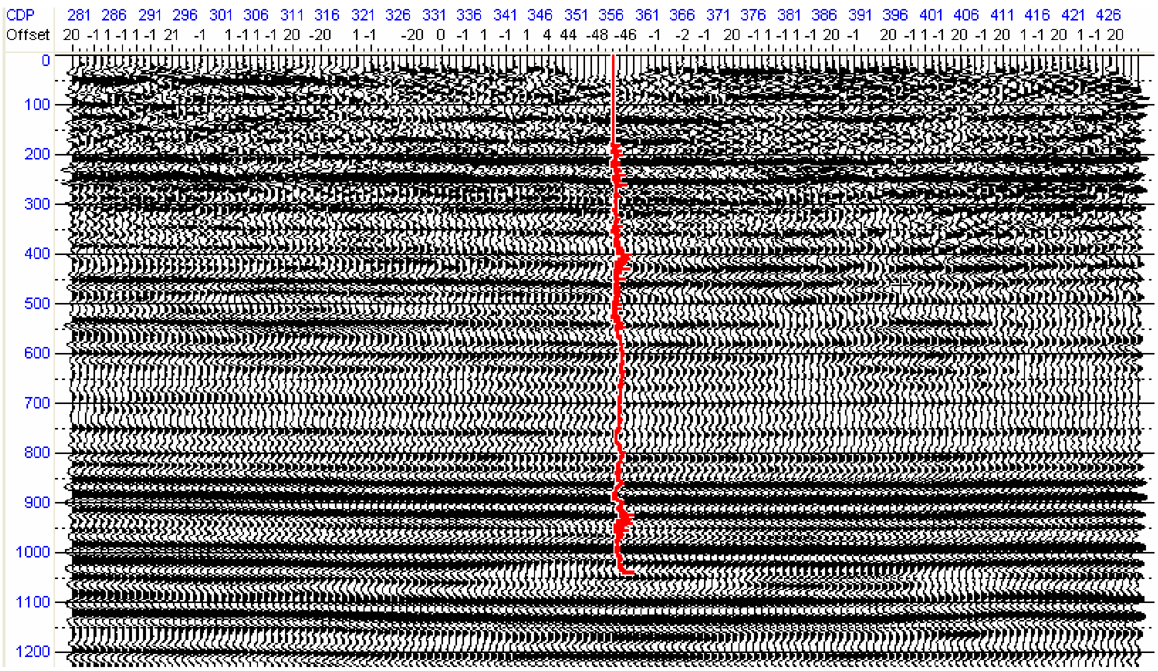


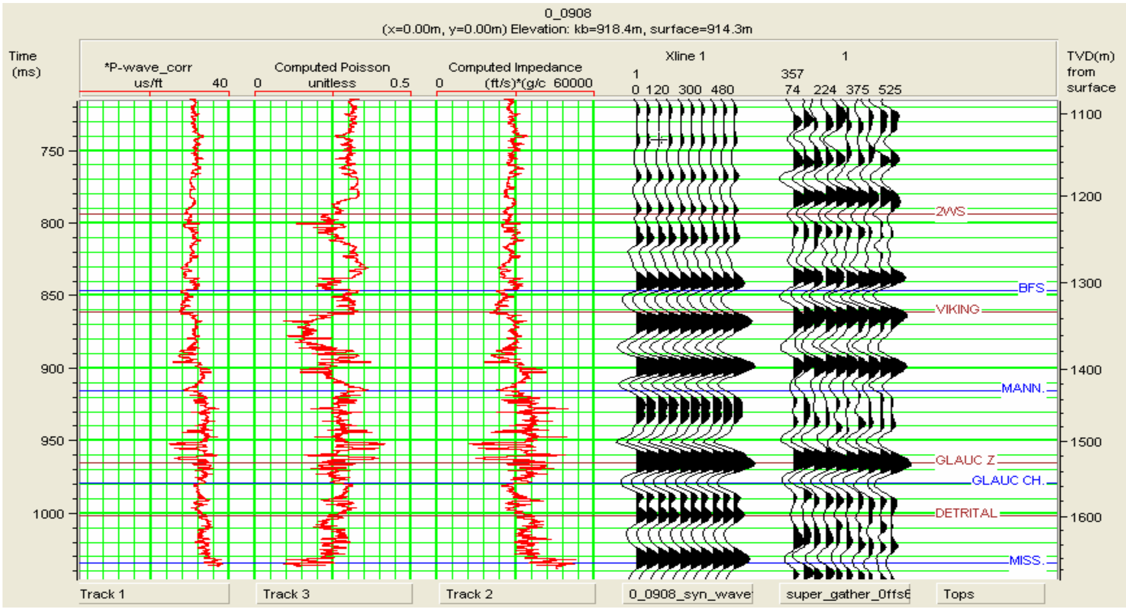
FIG. 2. Post-stack migration using a sequence of conventional algorithms.

We selected five different horizons (Figure 3) for analysis (free surface t = 0 as a horizon), choosing those where t-x picks could be made with confidence. Conventional velocity analysis was carried out along the line before the horizons were selected in order to avoid picking multiples, and as a quality control on inversion results. The picking was done on the CMP with 4 km offset to each side. The picking was difficult in the target zone due to deterioration in the data quality (Figure 1).

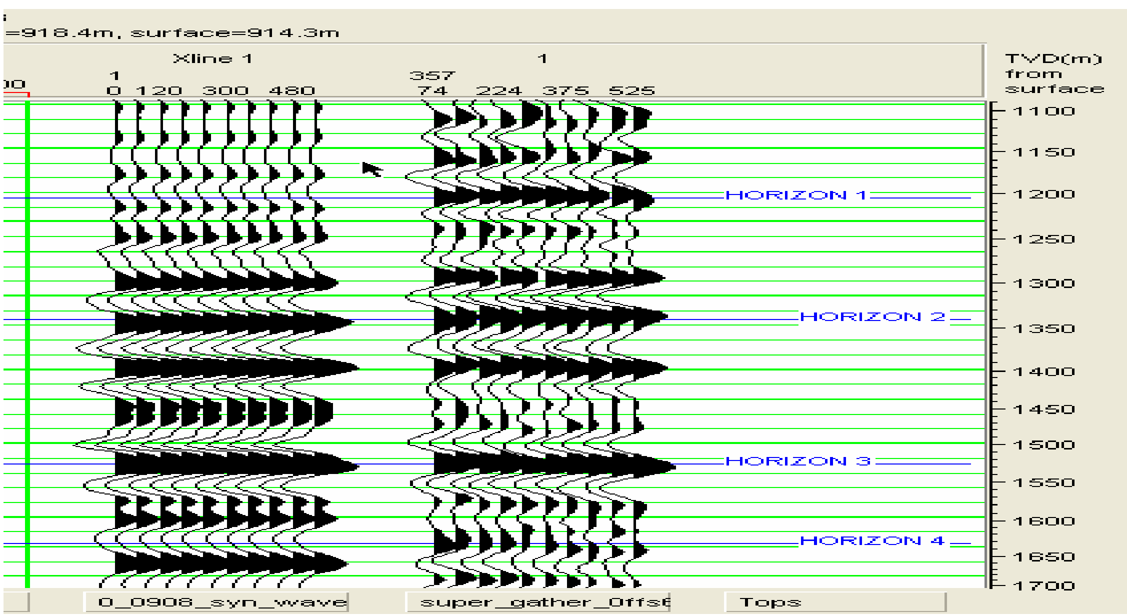
INTERVAL VERTICAL VELOCITY FROM SONIC LOG

Although anisotropic moveout (AMO) analysis can provide information about horizontal velocity, conventional moveout analysis using either NMO or AMO equations cannot provide information about vertical velocity (Yang et al., 2002). How to obtain vertical and horizontal velocities is an important task in many applications such as AVO inversion, anisotropic imaging, and pore-pressure prediction. Vertical velocity is important information for the success of AVO inversion, anisotropic imaging, and pore-pressure prediction (Wright, 1987; Banik et al., 2003).

Figure 3(a) shows the correlation of well logs, synthetic data and Blackfoot seismic data as well as interpreted formation tops. The four seismic interfaces shown in Figure 3(b) are chosen for purposes of estimating Thomsen's anisotropy parameters.



(a)



(b)

FIG. 3. Correlation of synthetic data and real seismic data (a) with the tops of formations and (b) with the seismic horizons.

Figure 4 shows the vertical interval velocities from a sonic log after the correlation to synthetic data and real seismic data.

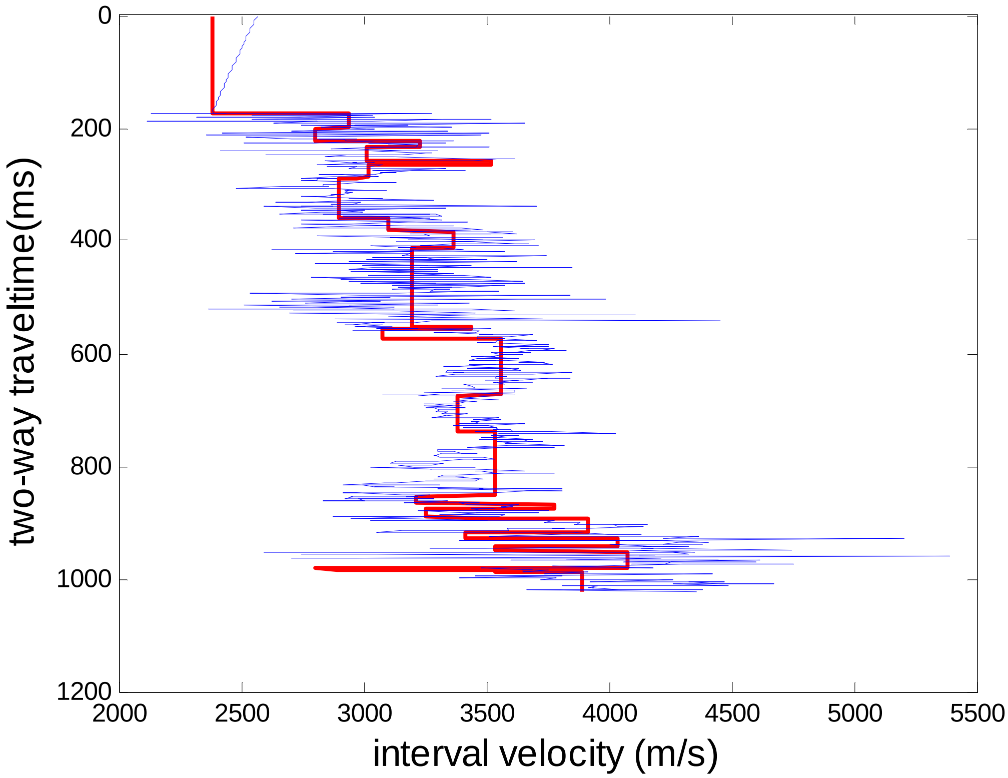


FIG. 4. Vertical interval velocities from sonic data. Blue line before block and red line after block.

ESTIMATION OF THOMSEN'S ANISOTROPY PARAMETERS

To obtain the best stack, we can make as many picks as necessary to honour changes in vertical velocity gradients. However, picks at short time intervals can yield anomalous interval coefficients from Dix-type differentiation (Yilmaz, 2001). For this reason, we should use picks at larger time intervals to estimate anisotropy parameters. From our experiments, the time interval (two-way time) should be greater than 200 ms.

Estimated values of moveout velocities and effective values of the anisotropy parameters, as well as the vertical interval velocities from sonic data, are shown in Tables 1 and 2. In Table 1, several of the estimated anisotropy parameters ε and δ in layers 2, 3 and 4 are unreasonable (larger than 0.5) due to too small time intervals (less than 100 ms). A sensitivity analysis would be a valuable aid in determining the validity of estimates.

Estimated values of ε and δ in Table 2 seem more reasonable. The new layer 2 (from horizon 1 to horizon 4, our target zone) exhibits relatively high, but not unreasonably high, values of anisotropy. Layer 1 (above horizon 1) displays lower values of anisotropy.

Table 1. Estimated effective coefficients and anisotropy parameters (time interval < 200 ms).

Layer	Time interval	α_0 (m/s)	V_{NMO} (m/s)	V_h (m/s)	ε, δ
1	786	3099	2919	3185	0.0281, -0.0564
2	82	3299	3266	3257	0.5587, 0.9353
3	98	3823	3279	3637	0.6902, -0.1063
4	56	3882	3315	3782	0.3880, -0.0286

Table 1. Estimated effective coefficients and anisotropy parameters (time interval > 200 ms).

Layer	Time interval	α_0 (m/s)	V_{NMO} (m/s)	V_h (m/s)	ε, δ
1	786	3099	2919	3185	0.0281, -0.0564
2	236	3882	3315	3782	0.3737, 0.2029

INTERPRETATION AND CONCLUSIONS

The presence of anisotropy causes two principal distortions of reflection moveouts. First, the short-spread moveout velocity in the presence of anisotropy is not, in general, equal to the rms vertical velocity, even for horizontal layers (Thomsen, 1986). Thus, application of the Dix formula in anisotropic formations results in erroneous interval velocities and inaccurate estimations of reflector depths.

Secondly, anisotropy leads to nonhyperbolic moveout, even in a homogeneous layer. If not properly corrected for, nonhyperbolic moveout causes distortions in velocity estimation and deteriorates the quality of stacked sections.

Ever since Dix's classic paper (1955), velocity analysis based on a hyperbolic moveout model has been in wide use. Velocities estimated in this way are routinely used to improve signal quality by stacking multifold seismic data. Also, the stacking velocity spectrum is used to obtain some lithologic information about the subsurface (Cook and Taner, 1969). However, as exploration interests turn to subtle stratigraphic traps associated with thin layers, the hyperbolic traveltime model is no longer adequate to preserve the signal resolution through stacking. Furthermore, stacking-velocity estimates alone are not sufficient to distinguish among different lithologies. For example, isotropic sandstone and transversely isotropic shale buried in a similar depositional environment can show a widely overlapping range of stacking velocities.

In conclusion, if the objective is to obtain an optimum CMP stack with the highest stack power possible, moveout-velocity anaysis at selected CMP locations along the line or over the 3-D survey area yields a robust velocity section. If, on the other hand, the objective is to derive interval coefficients from Dix-type differentiation, then horizon-consistent velocity analysis is recommended, and the time interval should be larger than 200 ms to yield results that are geologically plausible.

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