Tutorial

Anisotropic effects on full and partial stacks

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ABSTRACT

Nonhyperbolic moveout resulting from localized variations in anisotropy can create many misleading artifacts such as apparent faults, folds, channels, flat spots, dim spots, bright spots, and AVO anomalies on fully and partially stacked seismic sections. This tutorial shows how these interpretation pitfalls may result when isotropy is assumed in processing.

INTRODUCTION

Anisotropic effects on seismic stacked sections are often ignored during conventional processing. Using anisotropic ray-trace models, we show that many interpretation pitfalls may appear on stacked sections because of the existence of anisotropy. Simple models, which consist of a localized transversely isotropic (TI) block embedded in a layered isotropic medium, are used. The symmetry axis of the TI blocks is assumed to be vertical in all models.

METHOD

Ray tracing is used to generate the anisotropic P-wave seismic synthetic data, assuming (Fagin, 1991) (1) reflection ray-paths are in the plane of the seismic section and (2) reflection arrival times and lateral position are not subject to image ray effects.

The P-wave reflection coefficient during ray tracing is calculated by Ruger's approximation (Ruger, 1997):

\[
R_p(\theta) = \frac{1}{2} \left[ \frac{\Delta Z_0}{Z_0} + 1 \left( \frac{\Delta \alpha_0}{\alpha_0} + \frac{2 \beta}{\alpha} \right) \frac{\Delta G_0}{G_0} + \Delta \delta \right] \times \sin^2 \theta + 1 \left( \frac{\Delta \alpha_0}{\alpha_0} + \Delta \delta \right) \sin^2 \theta \tan^2 \theta, \tag{1}
\]

where \( \theta \) is the incident angle, \( \alpha_0 \) is the P-wave average vertical velocity, \( \beta_0 \) is the SV-wave average vertical velocity, \( Z_0 = \rho_0 \alpha_0 \) is the vertical P-wave impedance, \( G_0 = \rho_0 \beta_0 \) is the vertical shear modulus, and \( \delta \) and \( \epsilon \) are Thomsen's anisotropic parameter (Thomsen, 1986; Banik, 1987).

The differences in anisotropy across the boundary are written as \( \Delta \epsilon = (\epsilon_2 - \epsilon_1) \), \( \Delta \delta = (\delta_2 - \delta_1) \). This may result in incorrect reflection coefficients for large angles of incidence. However, the equation is adequate for demonstration purposes.

The models consist of three horizontal layers over a half-space (Figure 1). A TI block is embedded in either the first layer (for near-surface TI case study) or the second layer (for the deeper TI case study). Table 1 lists the model parameters. The anisotropy of the TI block is described by using anisotropy coefficients \( \epsilon \) and \( \delta \) (Thomsen, 1986, 1993). In the TI block, the vertical velocity is always set equal to the isotropic velocity of the same interval. The \( \epsilon \) value is set to be 10% for a weak anisotropy case and 30% for a strong anisotropy case. Elliptical anisotropy is assumed in all the TI blocks so that \( \Delta \delta > 0 \).

Although elliptical anisotropy is not physically realistic (Daley and Hron, 1979), some of the artifacts in processing should be similar to actual observations.

Forward modeling is performed by assembling 48-fold synthetic data across the whole line (offset range: 0–2350 m; offset interval: 50 m). The near stack is made of the 24 near traces, and the far stack is made of the 24 far traces. Random noise is added to the model data to simulate a realistic stacked section.

ANISOTROPIC EFFECTS ON CDP GATHER AND VELOCITY SPECTRUM

The effect of anisotropy upon CDP gathers is important because it distorts the moveout curve and directly affects the estimated stacking velocity spectrum (Tsvankin, 1996).

For TI media, the phase and group velocities change with angle of propagation through the medium. As a result, the near-trace stack, the far-trace stack, and the full stack can only be fit by the hyperbolic moveout curve over a limited range

Manuscript received by the Editor August 16, 1999; revised manuscript received December 28, 1999.
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of offsets. The problem is one of attempting to fit the true nonhyperbolic moveout with an assumed hyperbolic formula. This means noise is introduced to the full or partial stack as a result of ignoring the anisotropy. This section describes how this nonhyperbolic noise affects the CDP gather and ultimately the interpretation.

Figure 2 shows three CDP gathers plotted on top of each other for a 30% near-surface anisotropy case similar to model 1. CDP gather 1 shows a perfect hyperbolic curve, meaning all the raypaths are within the isotropic region. However, CDP gathers 2 and 3 show that, because of the anisotropy, the curves are nonhyperbolic. This means part or all of the raypaths of the CDPs pass through the anisotropic region.

Obviously, this near-surface anisotropy has stronger effects on shallow reflections. As a result we can see only small nonhyperbolic moveout remaining on the far end of the second event in Figure 2.

Because of the existence of nonhyperbolic effects, picking a proper stacking velocity through conventional processing software without higher order corrections is difficult or impossible. Processing tests show that an overestimate of velocity can result from the influence of anisotropy.

ANISOTROPIC EFFECTS ON FULL AND PARTIAL STACKS

Stacking events with nonhyperbolic moveout can produce apparent structures and responses, including faulting, flat spots, folds, amplitude anomalies, and AVO artifacts.

Figures 3a and 3b are near-trace and far-trace stacks for 10% weak anisotropy in the TI block in model 1. After careful velocity picking, the anisotropic effect on the near-trace stack (Figure 3a) is almost removed. However, a pseudostructure on the far-trace stack results from the improperly removed anisotropic effect. Figure 3c is a fully stacked section of the boxed portion of Figure 3b. A mild structure with a flat spot can be observed. This phenomenon is a result of localized near-surface weak anisotropy. The pseudoflat spot is caused by the near-offset traces which are correctly moved out, while the structure is caused by far-offset traces that have had too much NMO applied.

By introducing stronger anisotropy of 30%, the effect on the near-trace stack becomes more serious and cannot be removed totally (Figures 4a and 4b). On the near-trace stack, an amplitude anomaly is observed irrespective of the chosen velocity. On the far-trace stack, this stronger anisotropy creates a structure for the shallow reflections as well as two apparent faults on the deep reflections.

If the near-surface anisotropy is totally ignored and only a constant rms velocity is applied, some apparent channels may be introduced on the full-stack section, as in Figure 4c.

DEPTH DEPENDENCE OF ANISOTROPIC EFFECTS

In this section, we compare the effects of a buried TI block with those of a near-surface block.

![Model geometries](Fig. 1. Model geometries (parameters defined in Table 1).)

<table>
<thead>
<tr>
<th>Model 1</th>
<th>Model 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st layer</td>
<td>2nd layer</td>
</tr>
<tr>
<td>Vp (m/s)</td>
<td>1700</td>
</tr>
<tr>
<td>Vs (m/s)</td>
<td>850</td>
</tr>
<tr>
<td>Density (g/cm³)</td>
<td>1.6</td>
</tr>
<tr>
<td>δ</td>
<td>10%~30%</td>
</tr>
<tr>
<td>δ</td>
<td>10%~30%</td>
</tr>
<tr>
<td>Thickness (m)</td>
<td>800</td>
</tr>
</tbody>
</table>

![Fig. 2. Superimposed CDP gathers](Fig. 2. Superimposed CDP gathers in (top) isotropic region, (middle) isotropic and anisotropic regions, and (bottom) anisotropic region, showing the effects of anisotropy on reflector moveout.)
Figure 5 shows the far-trace stack when there is a buried TI block with weak 10% anisotropic effects (model 2). While there is no effect on the near stack, on the far stack the middle part of the second reflection, corresponding to the bottom TI block, is pulled slightly up and the amplitude increased. Compared with Figure 3, where the TI block was at the surface with the same degree of anisotropy, the effects of anisotropy are significantly reduced.

Figures 6a and 6b show the effects of 30% anisotropy (model 2) on the near-trace and far-trace stack. If compared with Figures 4a and 4b (the near-surface version of this model), the anisotropic effect is reduced on both near and far stacks. However, on the far stacks, twin events appear. This means the anisotropic effect is still strong enough to cause artifacts. Two apparent faults, although small, appear on the deeper event. On the full-stack section in Figure 6a, the middle portion of the second reflection, corresponding to the bottom of the TI block in model 2, appears to be a strong AVO anomaly (an anomalous AVO decrease can be observed on Figure 6a and 6b). Figure 6c shows the resulting apparent flat spot on the full stack.

![Fig. 3. (a) Near-trace, (b) far-trace, and (c) full stack (10% anisotropy, model 1).](image1)

![Fig. 4. (a) Near-trace, (b) far-trace, and (c) full stack (30% anisotropy, Model 1).](image2)
In summary, the effect of a localized TI block diminishes rapidly with depth if the anisotropy is weak (around 10%). However, for large but feasible anisotropy—30%, for example—false structures and hydrocarbon indicators may result.

**CONCLUSIONS AND DISCUSSION**

Conventional processing software that assumes hyperbolic moveout may produce false structures and false responses below anisotropic regions because of improper removal of NMO. Thus, anisotropy effects can create pitfalls for interpreters on stacked and partially stacked sections. These pitfalls include pseudofaults, anticlines, channels, amplitude anomalies, and flat spots. The interpreter should be particularly suspicious of structures evident on full or far-offset stacks that do not appear on near-offset stacks.

Quality control methods (e.g., inspecting NMO corrected gathers) exist to mute the improperly flattened events. However, when far-offset information is important, muting is not a viable solution. Even higher order moveout corrections may not entirely correct these problems, and complete anisotropic processing may be necessary. Short of this, automatic detection of nonhyperbolic moveout may provide a useful diagnostic for identifying such pitfalls.

**REFERENCES**


——— 1993, Weak anisotropic reflections: Offset-dependent reflectivity—Theory and practice of AVO analysis, IG-8, 103–111, SEG.