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Amplitude Corrections for AVO in Anisotropic Media

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Abstract

In order to preserve the true relative amplitude in the reflection coefficient response of an interface, the AVO processing sequence must consider the anisotropic effects of the subsurface. The influence of the anisotropy on the reflected seismic amplitudes depends on three distinct factors: the source directivity, the geometrical spreading and the reflection coefficients. In general anisotropic media all these factors have angular dependence, such that they are important and must be considered when performing AVO analysis.

In this paper we investigate the influence of these three quantities on the estimated reflection coefficient response (reflection coefficient versus angle curve), which is obtained by making specific amplitude corrections on the registered seismic amplitudes. We evaluate and compare both the true anisotropic and the usual isotropic corrections for a plane interface model consisting of an anisotropic layer over an isotropic one. The vertical transversely isotropic (VTI) and orthorombic symmetries are considered in this work, by their importance in reflection seismic. The results shows that the AVO response is strongly anisotropic dependent and that the AVO interpretation can clearly be distorted if anisotropy is not considered.

INTRODUCTION

Normally the AVO analysis used in the industry makes assumption that the earth is isotropic. This is an unrealistic situation, the true earth subsurface is anisotropic. Anisotropy affects many aspects of the seismic processing, including AVO analysis. In order to make AVO interpretation properly we must to consider the effects of anisotropy on AVO response. Recent works clearly show the importance of considering anisotropy in the AVO analysis. Kim et al. (1993) and Blangy (1994) investigated the behavior of the reflection coefficients between elastic anisotropic media and their effects on the AVO analysis. Tsvankin (1995) showed the influence of the radiation pattern on the AVO response for weak VTI media. Teles et al. (1996) showed that the radiation pattern in general anisotropic media can be written as combination of two angularly dependent factors: the source directivity (spreading free amplitude of the source) and the geometrical spreading, and suggested the use of these quantities in the AVO analysis in anisotropic media. Floridia (1998) realized an extensive numerical study about the influence of these quantities on the reflected amplitude for TI and orthorombic media.

In this paper we realize a comparative study of the influence of the source directivity, geometrical spreading and reflection coefficient on the final reflected amplitude in anisotropic media. We consider a plane interface model consisting of a anisotropic layer over a isotropic one. In our analysis we investigate the VTI and orthorombic symmetries and we consider only the qP-qP wave for explosive and vertical force point sources. We show that the amplitude can reverse its relative growth when we are dealing with anisotropic models instead of isotropic ones. Then we present results that show that the usual corrections applied on the registered amplitude in order to reduce the AVO to a reflection coefficient versus angle analysis can clearly distort the true AVO anomalies. Although the results presented in this paper are only for qP-qP waves from an explosive or vertical force point source in VTI and orthorombic media, the method is general and can be applied for any kind of propagation mode, point source and anisotropic symmetry.

AMPLITUDE IN ANISOTROPIC MEDIA

It is possible to write the reflected amplitude as a combination of three different quantities (Teles, 1995): The source directivity, the geometrical spreading and the reflection coefficient. In order to evaluate the influence of these quantities on the amplitude of the reflected wave we consider a plane interface between two homogeneous anisotropic layers as showed in figure 1. In this case the magnitude of the reflected ray amplitude is given by (Floridia, 1998):

$$A(\vec{x}) = D(\vec{x}_o) R(\vec{x}_r) L(\vec{x}_o, \vec{x})$$

Where Xo is the source point, Xr is the reflection point and X is the receiver point. *D* is the directivity of the source, this quantity carries only information about the type of source and its orientation and on the surrounding anisotropic medium. It can be obtained from the eigenvalues and eigenvectors of the Christoffell equation given the propagation angle and the source type and magnitude. *R* is the reflection coefficient, it carries information about the contrast of elastic parameters at the interface. It can be obtained using the plane wave formula from the ray method for the reflection problem. *L* is related to (inverse of the square root of) the geometrical spreading along the ray propagation. It can be computed from the solution of the so called dynamic ray tracing system. All these quantities depend on the ray angle considered.

DIRECTIVITY AND SPREADING CORRECTIONS

In order to evaluate how both the directivity of the source and the geometrical spreading influence the angular behavior of the reflected amplitude, in consequence the AVO response, we transform the registered amplitude (obtained with *D, R* and *L* of the anisotropic media) into a reflection coefficient versus angle curve by applying corrections according to the following scheme:

$$A_{reg} = D_{ani} R_{ani} L_{ani} \Rightarrow R_{estimated} = A_{reg} . \frac{1}{D} . \frac{1}{L}$$

All possible corrections for *D* and *L* are analyzed: isotropic and anisotropivc ones. In the first case we use source directivity and geometrical spreading corresponding to the equivalent isotropic medium, obtained using the vertical qP and qS velocities of the anisotropic medium as P and S velocities of the desired isotropic medium, respectively. In the second case we correct the registered amplitude using the true directivity and spreading curves. The usual AVO processing sequence presuppose the subsurface is isotropic, making corrections using isotropic directivity and spreading. We`ll show how this procedure can result expressive mistakes in the AVO analysis.

NUMERICAL RESULTS AND DISCUSSION

We consider a model consisting in a plane interface between an upper anisotropic layer and a lower isotropic one, as can be seen in figure 1. The source and the receiver points are located on an unitary circle around the reflection point, reducing the AVO analysis to an amplitude variation with angle (AVA) one, so that the curves obtained with isotropic directivity and spreading corrections correspond actually to the registered (reflected) amplitude versus angle curve. In this work we investigate two situations. In the first case we consider a VTI shale extracted from Kim et al. (1993), which we vary its Thomsen`s parameters δ and ε, over an isotropic gas sand. The table below shows the vertical *P* and *S* velocities and densities for this case.

Parameter	VTI Shale	Isotropic Sand
α (km/s)	2.73	2.02
β (km/s)	1.24	1.23
ρ (g/cm**3)	2.35	2.13

In the second case the upper layer is taken to be an orthorombic medium with normalized elastic constants showed below.

$$\begin{pmatrix} 97.47 & 17.75 & 23.77 & 0 & 0 & 0 \\ 17.75 & 59.57 & 23.47 & 0 & 0 & 0 \\ 23.77 & 23.47 & 74.91 & 0 & 0 & 0 \\ 0 & 0 & 0 & 20.07 & 0 & 0 \\ 0 & 0 & 0 & 0 & 24.37 & 0 \\ 0 & 0 & 0 & 0 & 0 & 23.86 \end{pmatrix}$$

All presented quantities are normalized by their normal incidence values and taken absolute values. We also neglect wavelet effects.

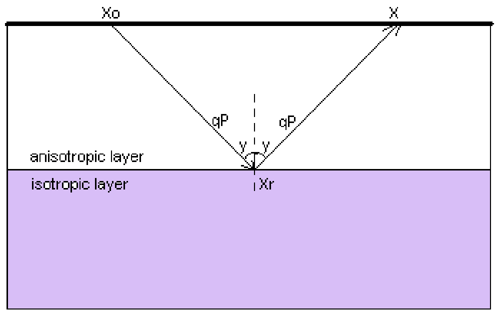

Figure 1: model used to evaluate the influence of anisotropy corrections on the AVO analysis.

Figure 2 and 3 show results for VTI media with explosive and vertical force sources, respectively. For negative values of the parameter δ the curves corrected by isotropic geometrical spreading show an unexpected decreasing AVO response. The right anisotropic spreading correction restores the positive AVO response, which is characteristic of the considered model. We can verify that the directivity correction has a secondary effect on the AVO response. Its effects are less pronounced than the geometrical effect ones. The results also show that explosive source affects the AVO response in a more relevant way than the vertical force source (it can be seen by comparing figures 2 and 3). In orthorombic media similar effects are also presented, as can be seen in figure 4. The results presented in this work demonstrate that in the presence of anisotropy the AVO analysis can not be restricted only to reflection coefficient effects, because in many situations it is not sufficient to overcome the geometrical spreading and directivity effects.

CONCLUSIONS

In a general anisotropic media tha reflected amplitude is a combination of three angularly dependent factors: source directivity, geometrical spreading and reflection coefficients. The first two factors can contribute to the AVO signature as well as the last factor. The influence of the source directivity and geometrical spreading corrections on the AVO response in the presence of anisotropy was investigated. The results obtained in this work clearly show that the named corrections can significantly change the AVO curves by masking the effects of the reflection coefficients. We also show that usual isotropic corrections can give unrealistic AVO response. Finally, we conclude that an efficient AVO analysis must consider all the three mentioned factors and must be realized with caution when we are dealing with anisotropy.

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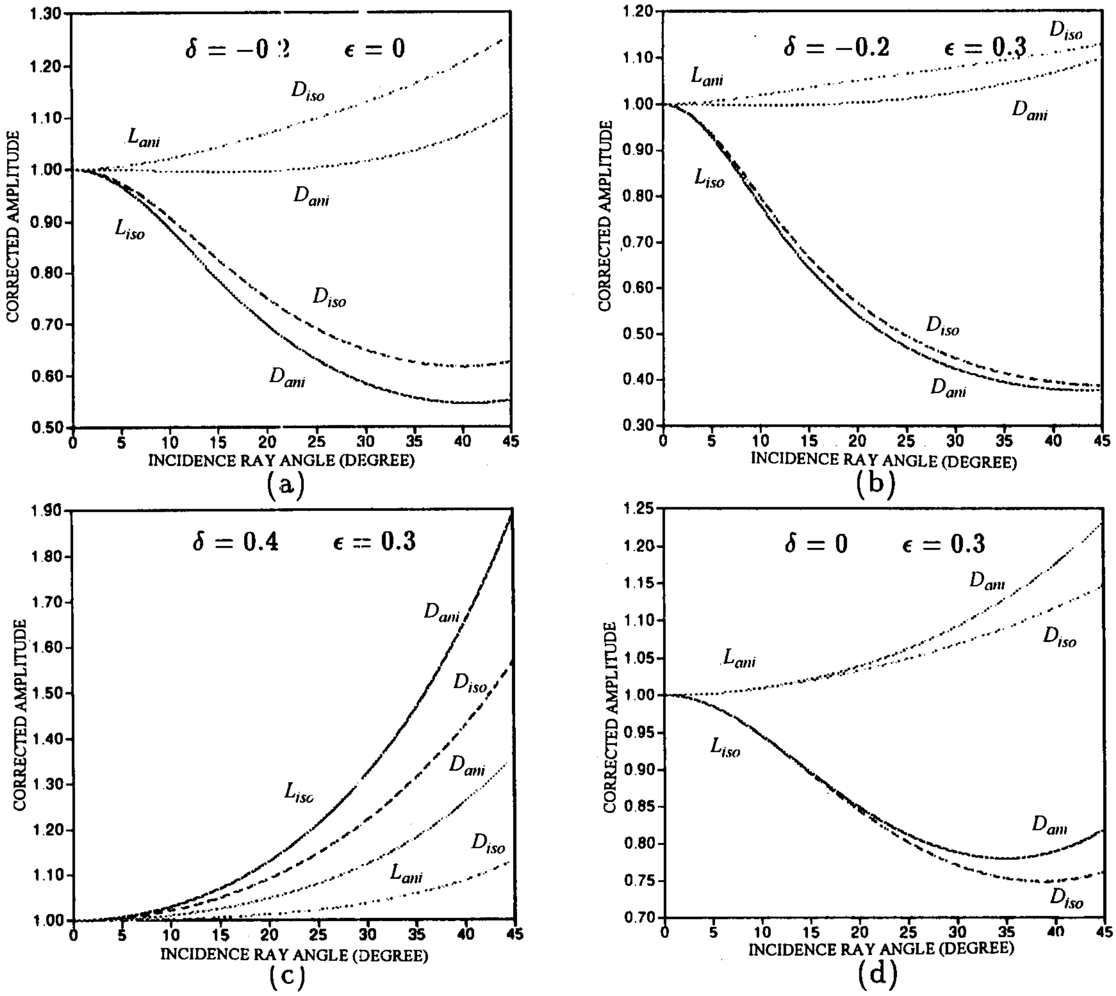

Figure 2: Amplitude versus angle curves after directivity and geometrical spreading corrections in case of VTI media and explosive source. It can be seen that AVO response reverses its behavior depending on the applied correction. The reflected amplitude depends strongly on the geometrical spreading factor. The directivity of the source is a secondary correction factor.

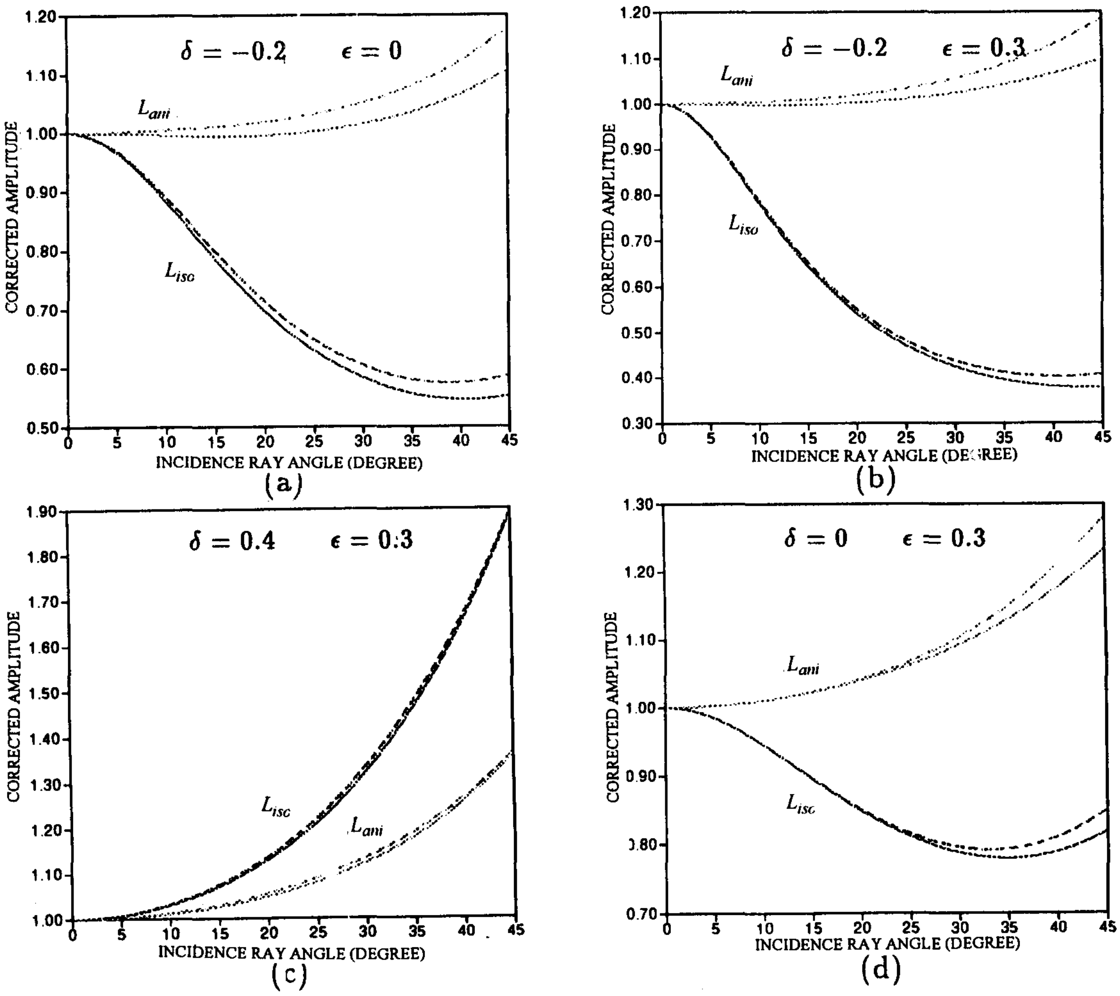

Figure 3: the same as previous figure for vertical force source.

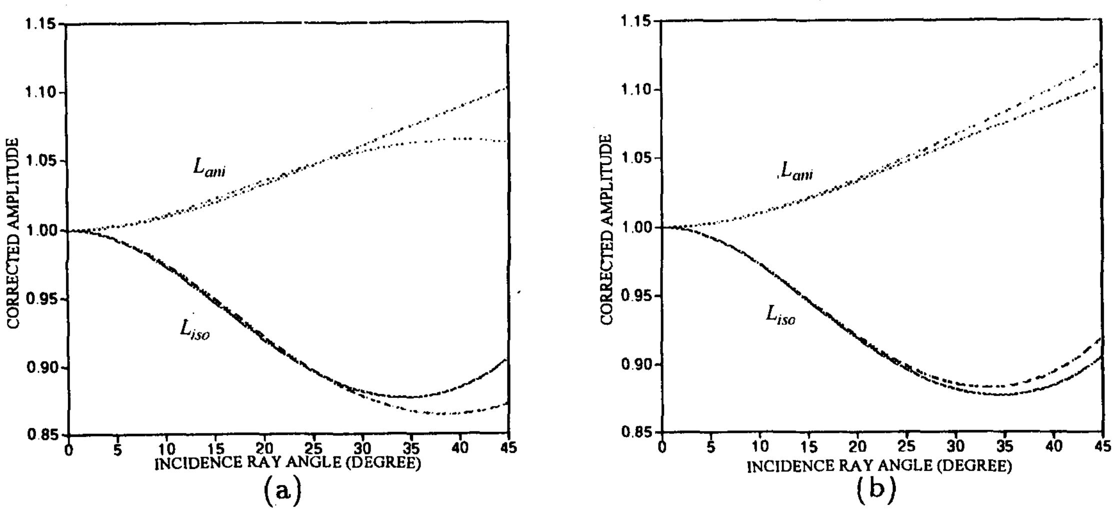

Figure 4: Amplitude curves after directivity and geometrical spreading corrections.in case of orthorrombic medium. (a) explosive source, (b) vertical force source.