The importance of accounting for seismic anisotropy in seismic exploration and reservoir exploitation has become an accepted fact somewhat two decades ago. Nowadays, modern processing work flow would include seismic anisotropy and very often seismic acquisition is planned in such a way that seismic anisotropy can be estimated.

Anisotropy is the dependence of a physical property (in seismic case, we are talking about seismic wave propagation velocity $v$) upon the direction of measurement. Mathematically it can be formulated in the following way:

$$v = v(\hat{n} \cdot \hat{i})$$

velocity $v$ is measured at the point $\mathbf{n}$ in space along the direction $\mathbf{i}$. As a result, anisotropy affects both kinematic and dynamic properties of the wavefield, and if we are to obtain a reliable subsurface image, it cannot be ignored.

Anisotropy in subsurface is very often associated with intrinsic properties of rocks, fine layering, or sets of fractures (which can occur due to e.g. special stress regime). Understanding of the seismic anisotropy can be useful in exploration and reservoir characterization since it can provide additional important information. For example, shale reservoirs are very often discovered based on the effect of seismic anisotropy. There is number of different mathematical models to describe seismic anisotropy. The simplest and the most commonly used one is vertical transverse isotropy or VTI model. Finely (compared to the wavelength) layered medium will exhibit VTI properties, affecting seismic wave propagation through it.

Amplitude variation with offset techniques are widely used nowadays, because reflection amplitudes are highly resolved in depth/time, unlike traveltime methods, providing a detailed measure of local properties of the subsurface. It has been also noticed that effect of seismic anisotropy on reflected and transmitted amplitudes is strong even when the magnitude of anisotropy is small (Ruger, 1998) and, hence, can be estimated using AVO analysis. Understanding the behavior of $P$-wave reflection coefficient in presence of anisotropy affects seismic wave propagation through it.

Figure 1: Wavefront distortion due to presence of TTI anisotropy

(a) VTI layer
(b) TTI layer

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Fig. 3: Palynofacies, redox conditions and palaeoenvironmental interpretation throughout the succession. The images are representatives of each palynofacies (Panou, 2015)

Fig. 4: The main palynofacies categories compared to HI, TOC and $\delta^{13}$C (Panou, 2015)
In present study, I demonstrate the effect of tilt angle on wavefield and in particular, on the reflected amplitudes. Proposed 3D approximation for the 3D pseudowave P-wave reflection coefficient at the boundary between TTI half-spaces is not shown here due to complexity of the expression (Ivanov and Stovas, 2015). Figure 1 shows how tilt affects the wavefront of the P-wave traveling in TTI layer as it has encountered a boundary. Model consists of two layers with a horizontal boundary at the depth of 200 m, top layer is isotropic, bottom - TTI. Layers have identical properties ($v_p = 2.3$ km/s, $v_S = 1.8$ km/s (velocities along the axis of symmetry for anisotropic layer)), $\rho = 2.3$ g/cm$^3$ anisotropy is introduced into layer 2 ($\phi = 0.2$). P-source is located at the surface at $x=1000$ m. Receivers are located at the surface $x=0$. In Figure 1a tilt angle introduced into layer two is $0 ^\circ$, we observe symmetrical wavefront, whereas tilt of $45 ^\circ$ (counterclockwise) is introduced into layer two in Figure 1b. Wavefront distortion is clearly visible. Effect of the tilt angle upon amplitudes can be seen in Figure 2, where color represents the receiver where signal was measured (according to Figure 1), solid line corresponds to VTI case, and dashed line - to TTI. Reflected P-wave AVO curves extracted from recorded seismograms are shown in Figure 3. It can be seen that amplitude along the profile is higher for the model with TTI layer. Another important observation is that minimum of the TTI amplitude curve is shifted from the normal incidence location (offset=0) towards the “dip of layers” constituting TTI medium. Present study shows that dependence of the P-wave reflection coefficient on the direction of symmetry axis even for a weakly anisotropic medium is strong and complex and cannot be neglected. Using of anisotropic (TTI/VTI) AVO in combination with other methods of fracture characterization can be used to increase the amount and accuracy of information about fractured reservoirs derived from conventional seismic data.

References