GeoNeurale

October 2015

"Weak Polar Anisotropy" issues: the Volume of Investigation

GeoNeurale´s discussion with Robert Garotta

Many seismic anisotropy and rock physics studies are related to laboratory tests solving for various anisotropy models (VTI, HTI, Orthorhombic , Triclinic etc.)

Theoretical Models are upscaled at the seismic resolution scale. Rock physics models have also been developed (Sequential Effective Medium Modelling) which are appear to be most representative of the formation in place.

From these assumptions a first observation a geoscientist would probably afford is: "which is the volume of investigation for anisotropy models in the contest of 3D seismic measurements" ?

We solve also this issue considering several anisotropy models but certainly starting from weak polar anisotropy.

As far as the propagation is isotropic, two parameters only (λ, μ) are present in the non-zero Cij values of the Chirstoffel's matrix, most of them are zero.
Anisotropy means non-zero values of the $\varepsilon,\delta,\Upsilon$ Thomsen's parameters, moreover privileged orientations may exist. Since $\varepsilon,\delta,\Upsilon$ are linked to Cij constants, previously non-zero values become more complex, other ones are no longer zero.

Single component seismic has no chance to distinguish VS1 or VS2, can evaluate low resolution ε but not δ,Υ.
3D-3C (MC) seismic distinguishes VS1 or VS2, evaluates $\varepsilon,\delta,\Upsilon$: no doubt that at least some of the Cij are better defined, this is the case for polar or orthorhombic anisotropy.

Assuming the theory of elasticity and considering a possibly anisotropic solid sample the Christoffel´s matrix is the Hookes's constant expressing the proportionality between strains and stresses.
I do not see any limitation of the sample dimensions. If the medium is homogeneous the constants can characterized it. If not, they are mixtures of the different constants that are valid in some part of the sample.

Seismic can be used to estimate some of the elements of the matrix through seismic attributes (NMO, AVO) then referring to Zoeppritz' equations.

When acquisition and processing are correctly conducted (especially in MC seismic) the dimensions of the samples should be:

- Laterally the 3D bin, typically 25x25m
- Vertically the distance between two seismic samples (min. 3-6 m.). Of course this vertical resolution is finally limited by the seismic bandwidth .

A Gabor spectral filter can help in delineating details.

λ, μ parameters contain velocities Vs or Vp combined with density. From AVA, seismic correctly delivers the velocity ratio Vp/Vs but it is more delicate to obtain density then to separate Vp, Vs and density.
The results extracted from MC seismic are better than with the single component because they do not require use of wide incident angles submitted to anisotropy and differential absorption that are generally neglected. Nevertheless they are not perfect because submitted to computation singularities when Vp/Vs is 2. -This singularity can be solved in different ways requiring to use more than the three basic attributes that are zero offset reflectivity, P mode gradient, PS mode gradient defining high resolution parameter (Vp/Vs). Accepting two additional attributes, one for each PP or PS propagation mode is enough to eliminate the singularity and in addition deliver high resolution ε and δ Thomsen's parameters.

As far as Thomsen parameters is concerned they can only be referred to specific subvolumes after detailed seismic velocity analysis. First reference should be the interval velocities and correlation to specific anisotropy horizons within a layer.

Strong VTI anisotropy can be attributed to shale sequences and internal sublayering.
Velocities and seismic impedance are normally assumed constant within a layer. However they refer to reflectivity which is also referred to the upper and lower near field seismic impedance of the reflector surface. This can be a good approximation for limited thickness formations. For strong carbonate packs an interval velocity function should be carefully taken in consideration.
After Backus theory the anisotropy effect can calculated from the stiffness constants which will be averaged into a moving average function of Lame Parameters in the limited subvolume.

$$V_{Phorizontal} \approx V_{Pvertical}\left\{1+\frac{4\left\langle \Delta K \Delta \mu + \frac{1}{3}(\Delta\mu)^2 \right\rangle}{\left\langle K+\frac{4}{3}\mu \right\rangle^2}\right\} > V_{Pvertical}$$

Eq. 1 Courtesy: L. Thomsen

HTI anisotropy in subvolumes can be evidenced by azimuthal anisotropy and azimuthal AVO studies. In this context fracture subvolumes can be locally concentrated.

$$[C_{IJ}] = \begin{bmatrix} C_{11} & C_{13} & C_{13} & 0 & 0 & 0 \\ C_{13} & C_{33} & C_{33}-2C_{44} & 0 & 0 & 0 \\ C_{13} & C_{33}-2C_{44} & C_{33} & 0 & 0 & 0 \\ 0 & 0 & 0 & C_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & C_{66} & 0 \\ 0 & 0 & 0 & 0 & 0 & C_{66} \end{bmatrix}$$

$$\begin{aligned} c_{ijkl} = {} & \lambda_{\mathrm{HTI}}\delta_{ij}\delta_{kl} + \mu_{\mathrm{HTI}}(\delta_{ik}\delta_{jl} + \delta_{il}\delta_{jk}) \\ & + (C_{11} + C_{33} - 2C_{13} - 4C_{66})\delta_{i1}\delta_{j1}\delta_{k1}\delta_{l1} \\ & + (C_{13} - C_{33} + 2C_{44})(\delta_{i1}\delta_{j1}\delta_{kl} + \delta_{ij}\delta_{k1}\delta_{l1}) \\ & + (C_{66} - C_{44})\big(\delta_{il}\delta_{j1}\delta_{k1} + \delta_{i1}\delta_{l1}\delta_{jk} + \delta_{ik}\delta_{j1}\delta_{l1} \\ & + \delta_{i1}\delta_{k1}\delta_{jl}\big) \end{aligned}$$

$$\lambda_{\mathrm{HTI}} = C_{33} - 2C_{44}$$

$$\mu_{\mathrm{HTI}} = C_{44}$$

Eq. 2 HTI anisotropy stiffness tensor (L. Thomsen). Notation: L. Ikelle , L. Amundsen

So far the PP case. As far as converted waves is concerned the Christoffel equation offers the way to further generalizations as qP, qS velocity analysis, AVO-A analysis.

And Thomsen parametrization for VTI is:

$$V_{P0} = \sqrt{\frac{C_{33}}{\rho}}$$

$$V_{S0} = \sqrt{\frac{C_{44}}{\rho}}$$

$$\epsilon = \frac{C_{11} - C_{33}}{2C_{33}}$$

$$\delta = \frac{(C_{13} + C_{44})^2 - (C_{33} - C_{44})^2}{2C_{33}(C_{33} - C_{44})}$$

$$\gamma = \frac{C_{66} - C_{44}}{2C_{44}}.$$

Eq. 3 Thomsen VTI parametrization . Notation: L. Ikelle, L. Amundsen

In this context MC seismic data offers also the possibility of a more complete velocity analysis and quantitative indications on the volume of investigation of reflection phenomena especially considering subvolumes of wave polarization and velocity dispersion and AVAZ analysis.

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