Wave Polarizations in Anisotropic Media

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Particle motion

Seismic exploration consists in acquiring, then analyzing "particle motion" triggered by a seismic source. Except in a 1D space, a motion is defined by its amplitude and orientation.
For a number of decades, being able to detect spatially consistent particle motions was seen as, and indeed was, an effective exploration tool. AVA analysis gradually widened the field of seismic exploration, and this is probably a reason why motion orientation is most often ignored.
Of course, neglecting orientation, assuming the vertical emergence of seismic waves, can be seen as a reasonable approximation as long as only P-mode propagation is considered and as long as approximate high degree AVA terms are accepted.
Nevertheless, even if a P source is used, non compressional wave modes also propagate in the subsurface since a portion of the incident compressional energy is converted to shear by transmission or by reflection at each interface.
Moreover, it is becoming increasingly clear that anisotropy has to be taken into account in seismic processing, while anisotropy causes deviations in wave polarization.
This mean that taking care of wave polarization becomes essential, a reason for a reminder of the theory of elasticity in anisotropic media.

Wave polarization

Theoreticians see the heart of the theory in the 6x6 Christoffel matrix leading to the conclusion that the description of an elastic material involves up to 21 elastic constants. These constants generally designed by a Cij symbol ($1 \le i,j \le 6$) deliver a number of combinations including density.

Among them geophysicists retain velocities, Vp, Vs then $\varepsilon, \delta, \gamma$ (Thomsen's parameters) λ, μ (Lamé's constants) while mechanical engineers prefer Young's modulus and Poisson's ratio.
Important conclusions can be drawn from the properties of the matrix:

- Three wave modes propagate within any elastic material. They are characterized by their velocity of propagation, classified in decreasing order: the faster mode is said to be compressional (P). The other two modes, S1 then S2, are said to be shear modes
- The particle motion of each mode is parallel to an axis of a rectangular trihedral
- in the isotropic case, P-mode polarization is along the orientation of the wave propagation, S1 and S2 are mixed, orthogonally to the orientation of propagation (fig 1)
- in the case of weak anisotropy, generally accepted in seismic, the qP polarization (quasi-P) remains closer to the orientation of propagation while qS1 and qS2 are within planes that are orthogonal to it (fig 2)

Polarizations and symmetries

When the material has rotation axes of symmetry or planes of symmetry the number of elastic constants decreases. This can be imaged by using colors to figure the non-zero values of the Christoffel matrix.
Figures 3 to 7 correspond to the particular cases practically considered in geophysics.
Note that these figures are valid only when the reference coordinate system used to describe the material coincides with the symmetry axes of the material. If not, any material (excepted isotropic) would appear as triclinic. In practice, for example in the case of azimuthal anisotropy, the reference system has to be oriented along the natural coordinates.

Multi-component seismic and wave polarizations

Obviously, multi-component seismic only can approach problems remaining out of the range of a single component seismic:

- even when P mode only is considered, MC analyses are necessary to better evaluate the axial or azimuthal anisotropy parameters. These parameters are essential to reach optimum accuracy in depth imaging as well as definition of AVA parameters,
- polarization filters can substantially improve data denoising,
- access is given to non compressional modes that contain potential information as reach as the P mode one.

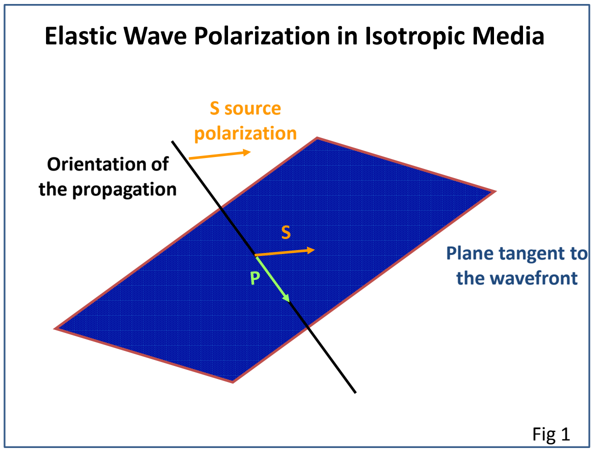

Fig 1

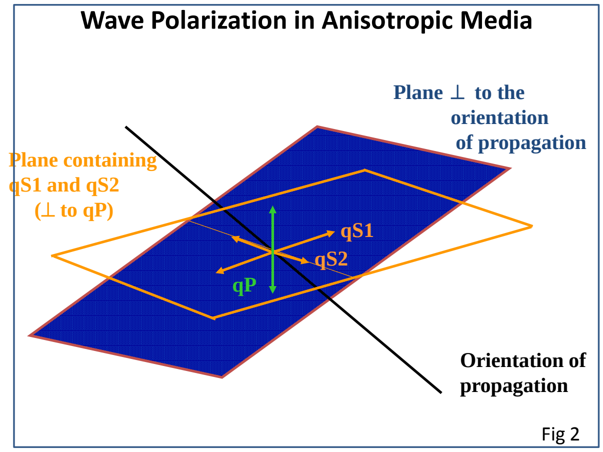

Fig 2

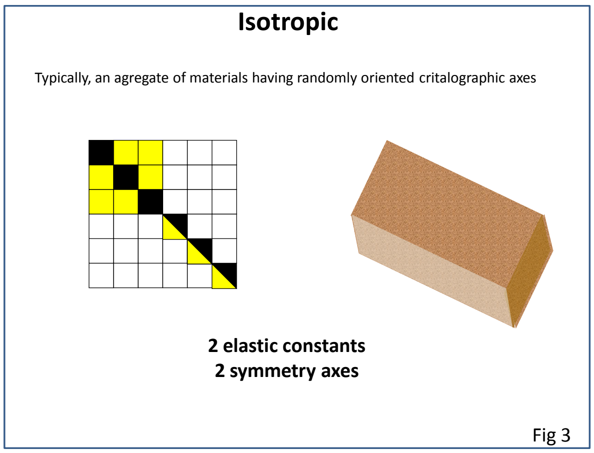

Fig 3

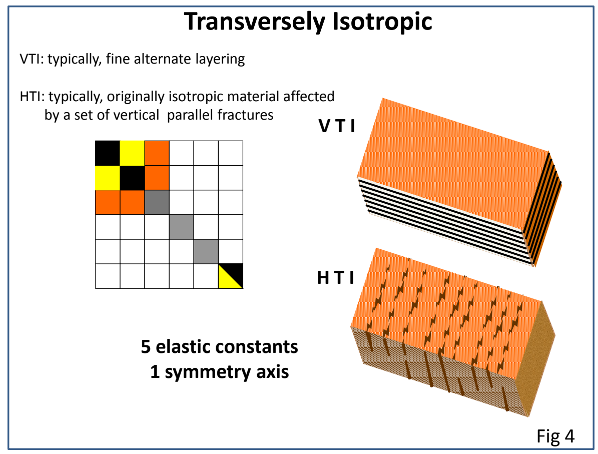

Fig 4

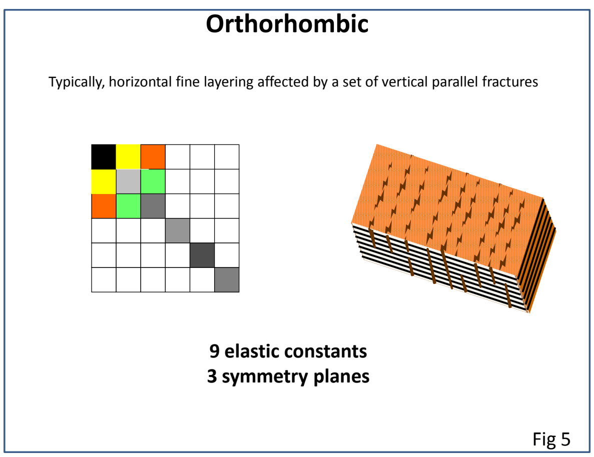

Fig 5

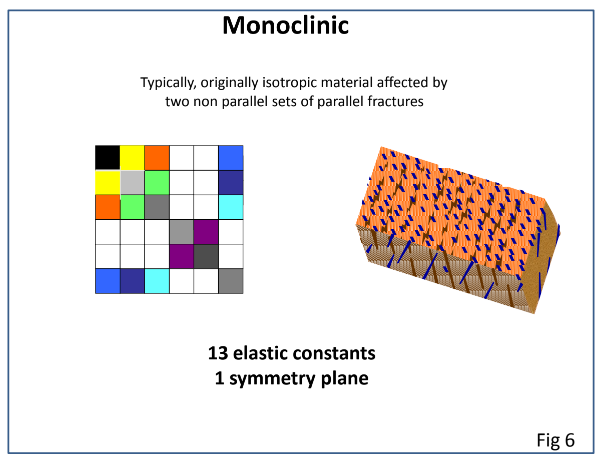

Fig 6

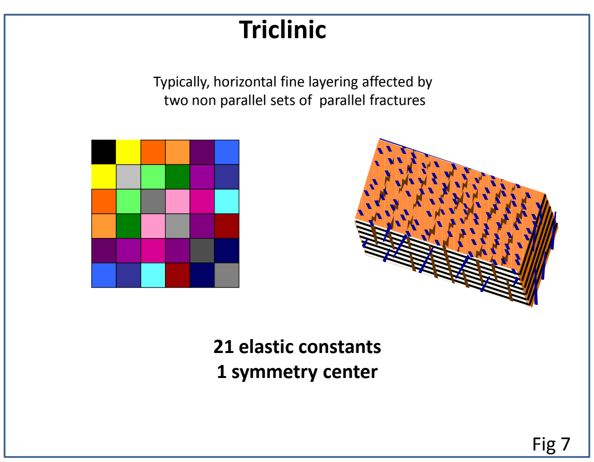

Fig 7