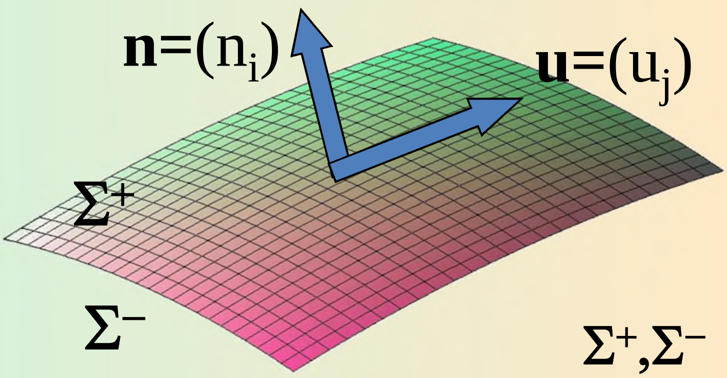
Complex Sources Modeling in Tesseral

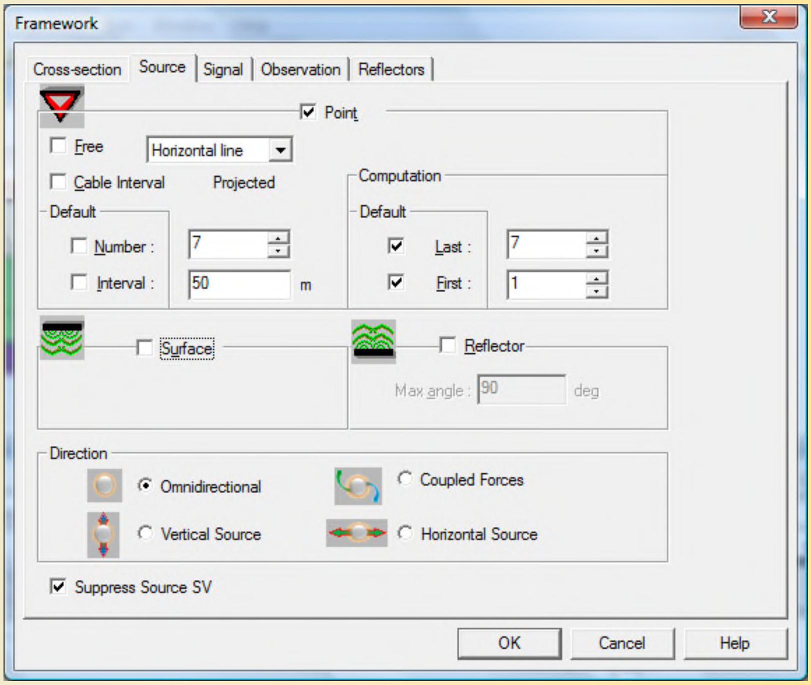


$\mathbf{n}=(n_i)$ fault normal

$\mathbf{u}=(u_j)$ slip vector

Σ^+,Σ^- inner and outer fault surfaces

Passive Seismic sources are directed by slips along a fault surface, while the tension at this surface remains continuous



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❖ Emission pattern of different vector sources

Wavefield in a homogeneous medium generated by a seismic source

$$u_n(\mathbf{x},t) = \int_{\Sigma} m_{pq} * G_{np,q} \cdot d\Sigma$$

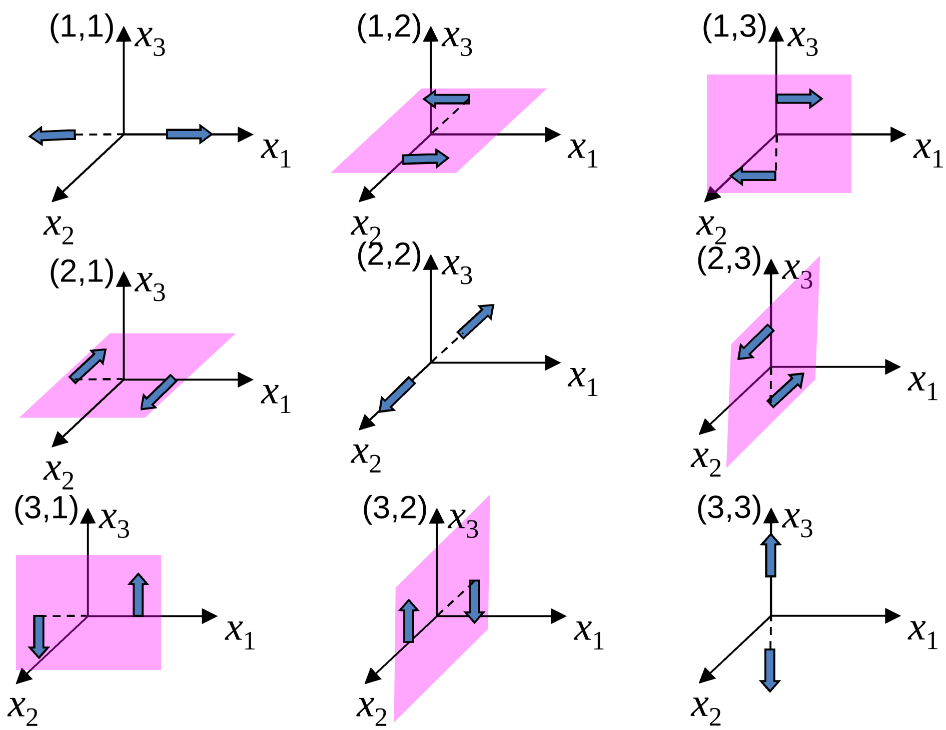
$m_{pq} = n_i u_j c_{ijpq}$ moment tensor

c_{ijpq} stiffness coefficients

$G_{np,q} = \dfrac{\partial G_{np}}{\partial x_q}$ derivative of Green function

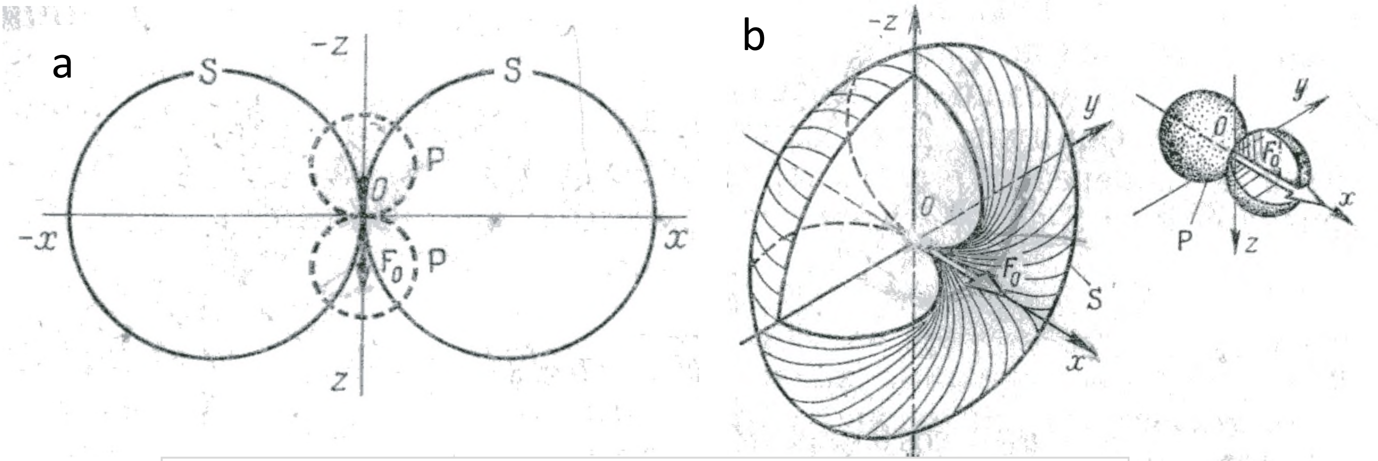
The seismic source consists of a superposition of point sources located along a fault surface. Each of the point sources is a weighted sum of different double couples (*n,p*)

Possible pairs of forces and vector dipole moments used for modeling of sources emission in passive seismic



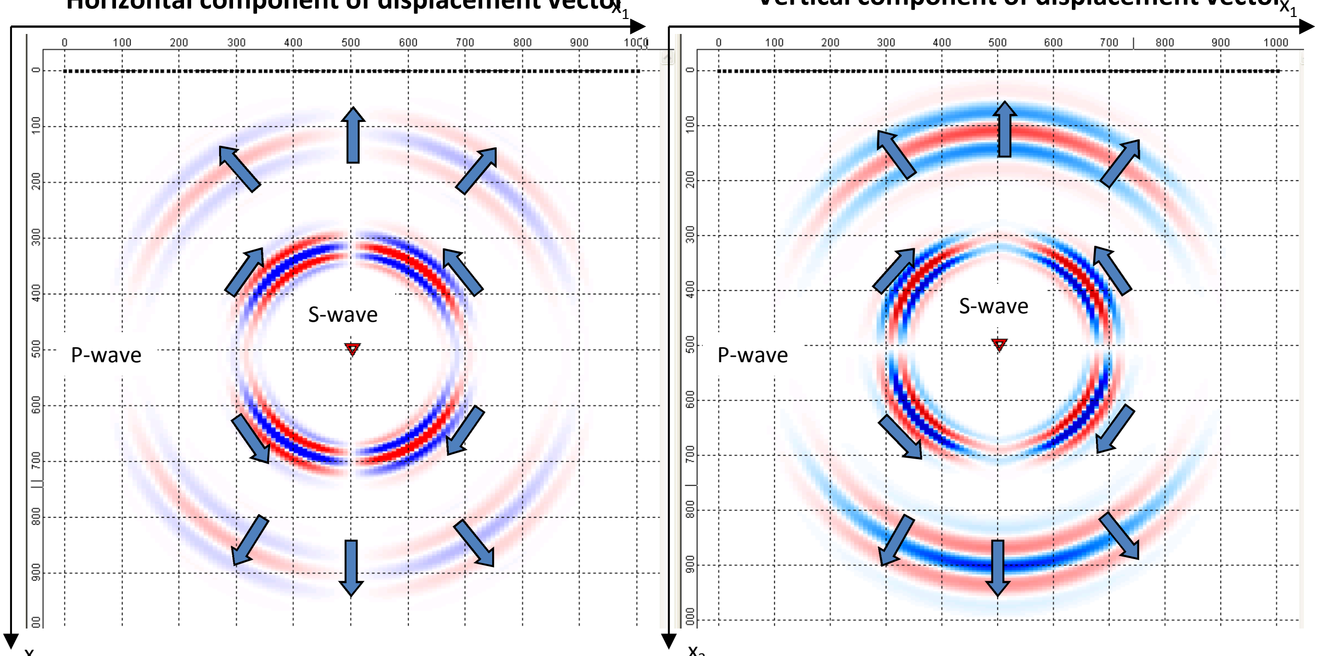
Presently the oil companies spend on *hydrofrac* as much as for seismic surveys. Hydrofrac requires monitoring based on the passive seismic. In the Tesseral package, modeling of vector sources is implemented. According ly to the theoretical concepts developed in seismology, a seismic response is formed by superposition of the dipole sources, as is shown *in this Slide* .

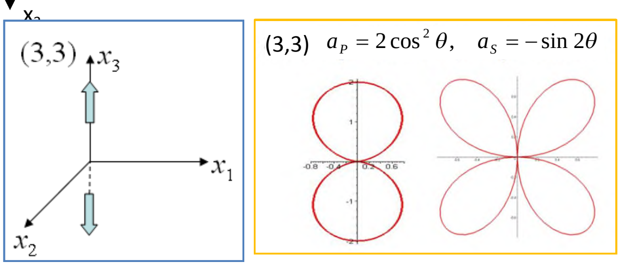
Emission pattern of different vector sources



The directional emission patterns are shown for source excitation along the X and Z axis, respectively.

Compression and shear waves from Vector Dipole (3,3) type Source





Directivity graphs of P and S waves

$$L_P = \frac{\cos^2\theta}{2\pi V_P^3} \qquad L_{SV} = -\frac{\sin 2\theta}{4\pi V_S^3}$$

The wavefields for some of these vector sources reveal their directionality as shown in *this and next Slides.*

Modeling of seismic sources

$$\boxed{m_{ij} = c_{ijpq} n_p u_q s(t)}$$

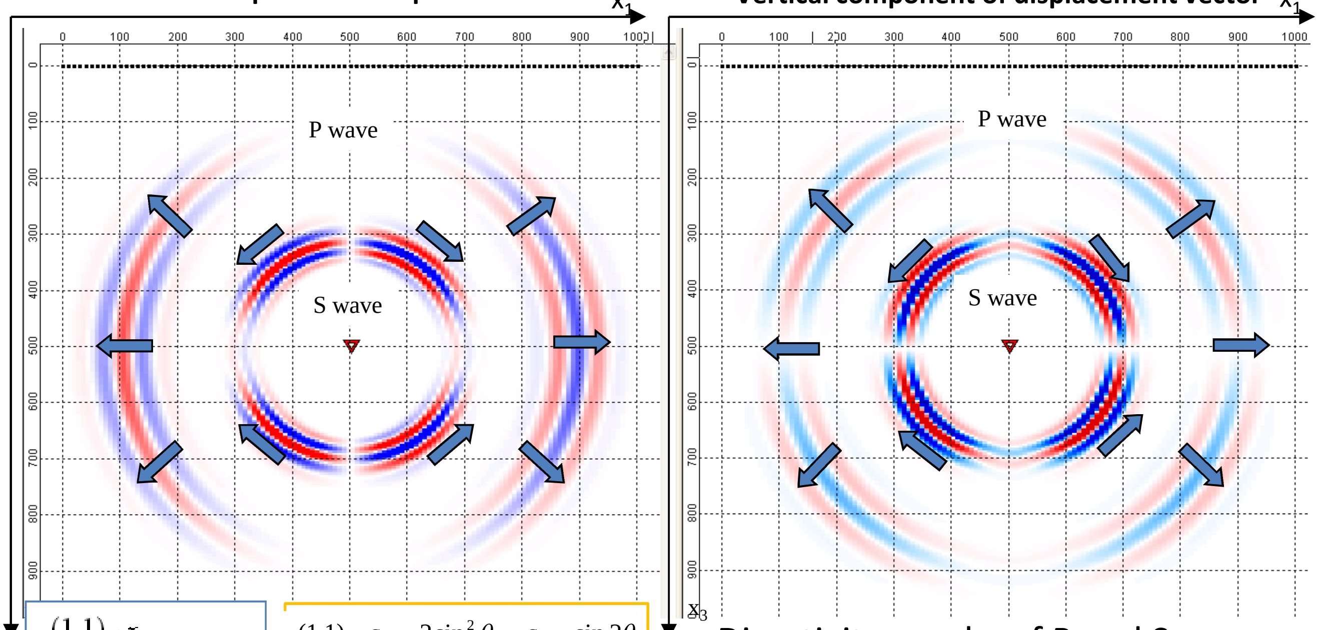
$$\boxed{\frac{\partial \tau_{ij}}{\partial t} = c_{ijpq} \frac{\partial v_p}{\partial x_q} + \frac{\partial m_{ij}}{\partial t}}$$

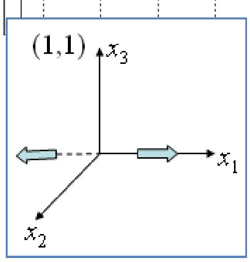
c_{ijpq} - stiffness coefficients
n_p - fault normal
u_q - slip vector
$s(t)$ - initial wavelet
m_{ij} - moment tensor
v_p - displacement velocity

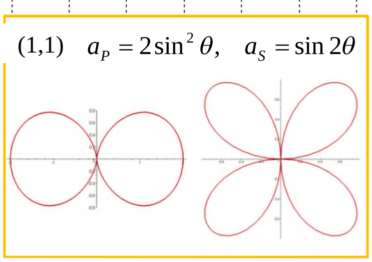
Compression and shear waves from Vector Dipole (1,1) type Source

Horizontal component of displacement vector

Vertical component of displacement vector







Directivity graphs of P and S waves

$$L_P = \frac{\sin^2\theta}{2\pi V_P^3} \qquad L_{SV} = \frac{\sin 2\theta}{4\pi V_S^3}$$

These sources have specific relations to compression and tension zones for P and S waves, and this is shown in form of the vectors of the wavefield displacement velocity.

From the wavefield directionality, it is possible to obtain the information about the main tension directions in the area of fractures or the orientation of fractures.

The interferometric migration of passive waves enables the determination of the fracture location.

Modeling of double couple and compensated linear vector dipole

$$\boxed{\begin{aligned} m_{11} &= c_{11}u_1n_1 + c_{13}u_3n_3 \\ m_{13} &= c_{55}\left(u_1n_3 + u_3n_1\right) \\ m_{33} &= c_{13}u_1n_1 + c_{33}u_3n_3 \end{aligned}}$$

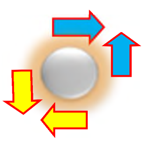
λ, μ - Lame parameters

$$u_1n_1 = \sin\theta_u \sin\theta_n \qquad u_3n_3 = \cos\theta_u \cos\theta_n$$

$$u_1n_3 + u_3n_1 = \sin\left(\theta_u + \theta_n\right)$$

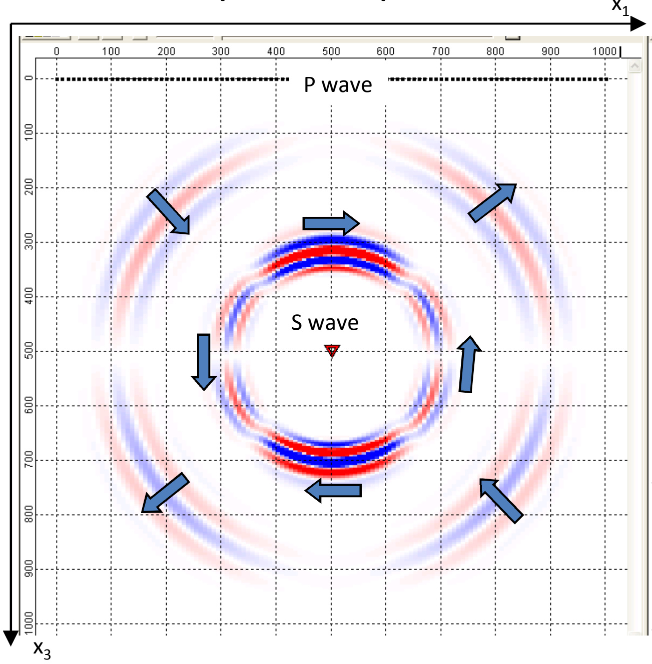
$$c_{11} = c_{33} = \lambda + 2\mu \qquad c_{13} = \lambda \qquad c_{55} = \mu$$

$\theta_u, \quad \theta_n$ - Angles between the vertical axis and vectors ***u*** and ***n***

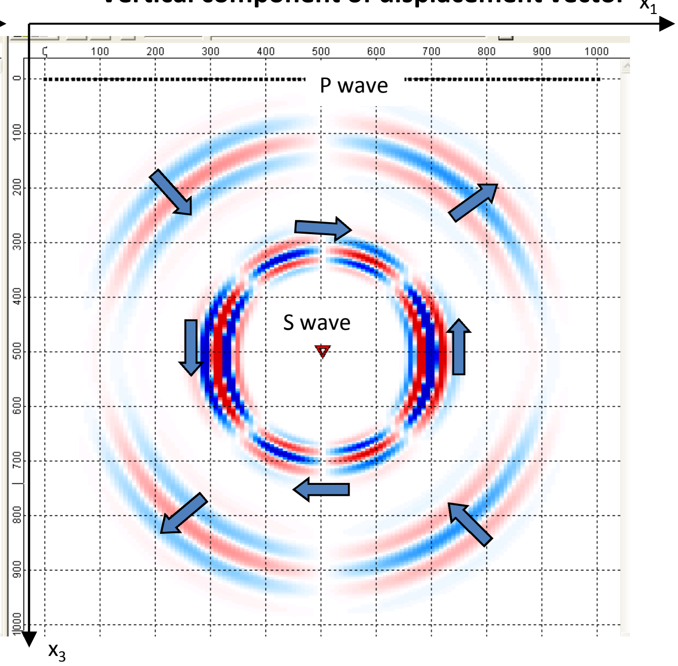


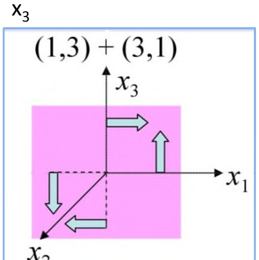
Compression and shear waves from Coupled Forces Pair(1,3) + (3,1) type Source

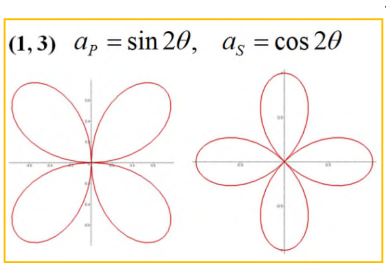
Horizontal component of displacement vector



Vertical component of displacement vector



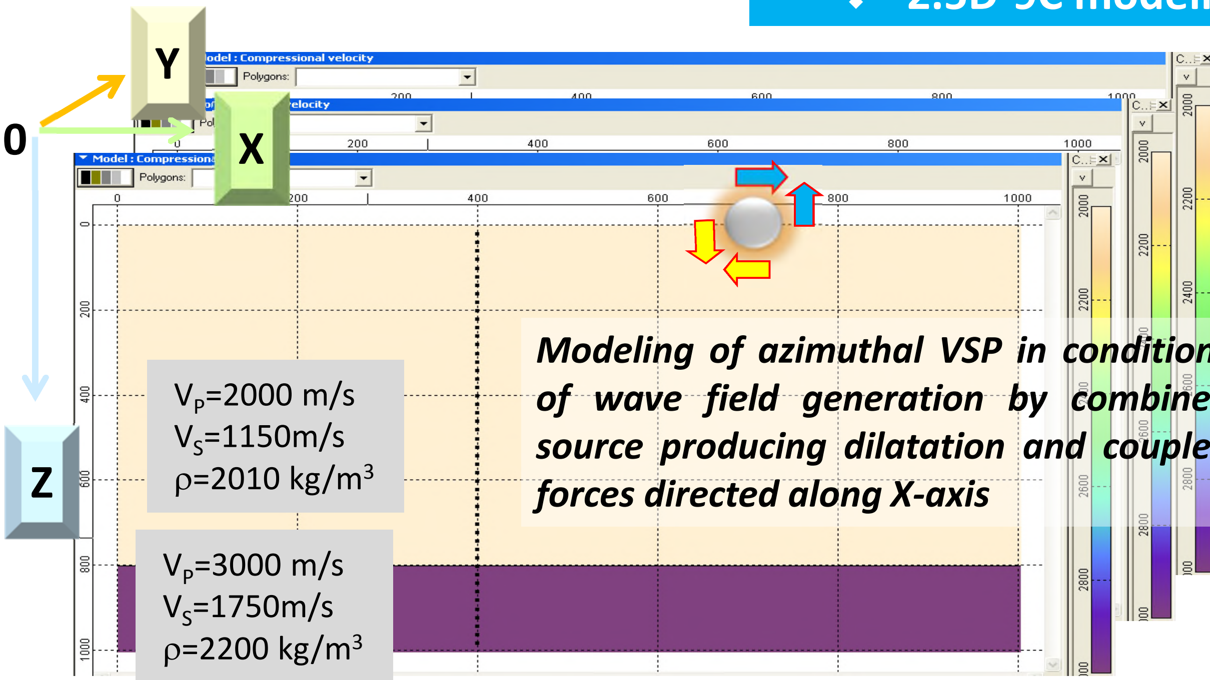




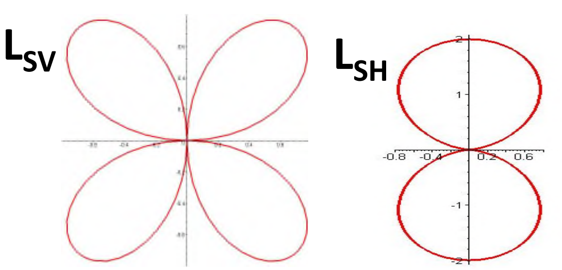
Directivity graphs of P and S waves

$$L_P = \frac{\sin 2\theta}{4\pi V_P^3} \qquad L_{SV} = \frac{\cos 2\theta}{4\pi V_S^3}$$

❖ 2.5D-9C modeling



3D Characteristics of directional source of coupled forces



$$L_{SV} = \frac{\sin 2\theta \cos^2\alpha}{8\pi\rho v_S^3}; \qquad L_{SH} = \frac{\sin\theta \sin^2\alpha}{4\pi\rho v_S^3}.$$

ϑ- angle of inclination of slowness vector in vertical plane

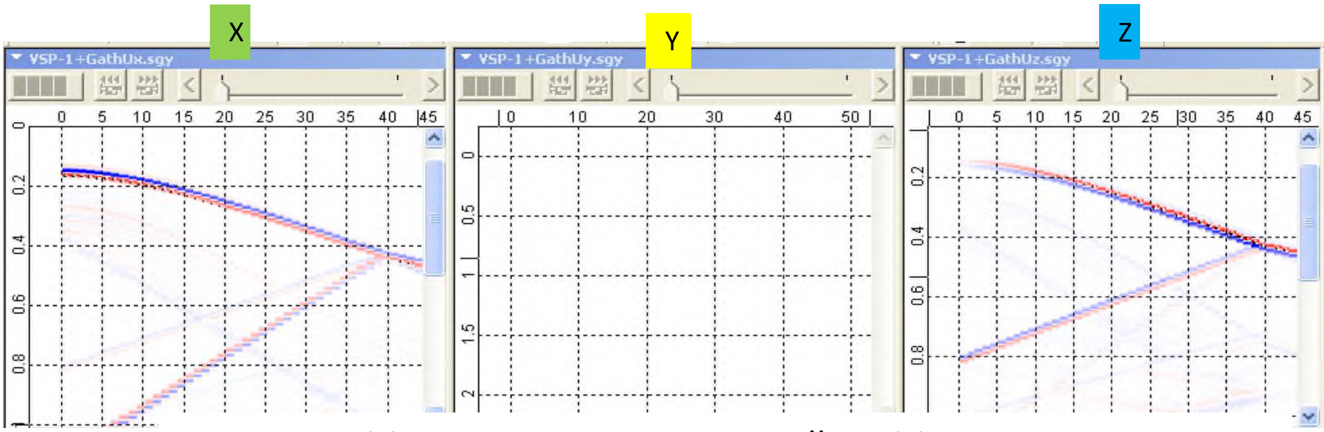
α- Azimuth of the slowness vector

Since the monitoring observations for *hydrofrac* are often done inside wells. The next example is for the VSP with source located in different Y offset (crossline offset).

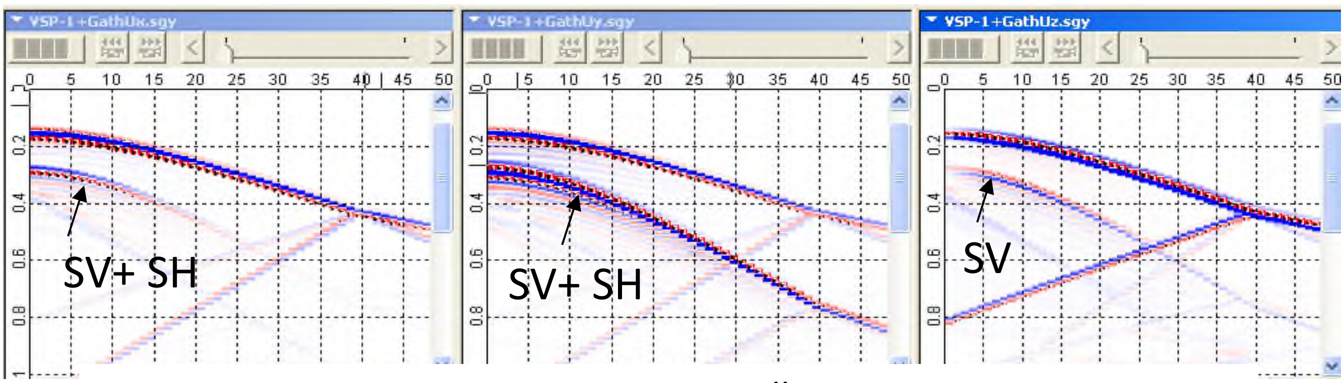
The model is shown in *this Slide*.

The S-wave azimuthal characteristics for the dipole source along the X axis are shown *below*.

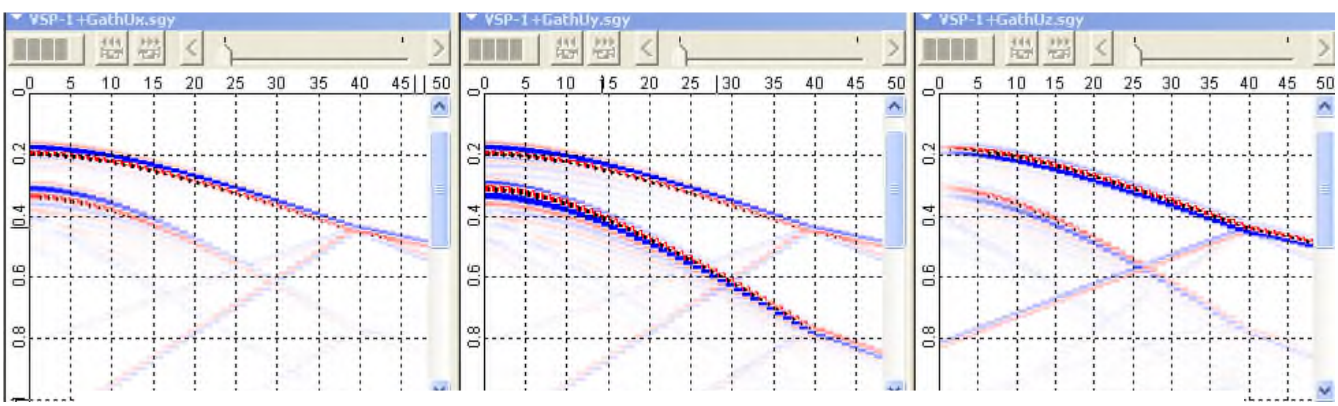
Three-component VSP synthetic shotgathers



Source position at X=700m, Y=0m; Well position at X=400m, Y=0m



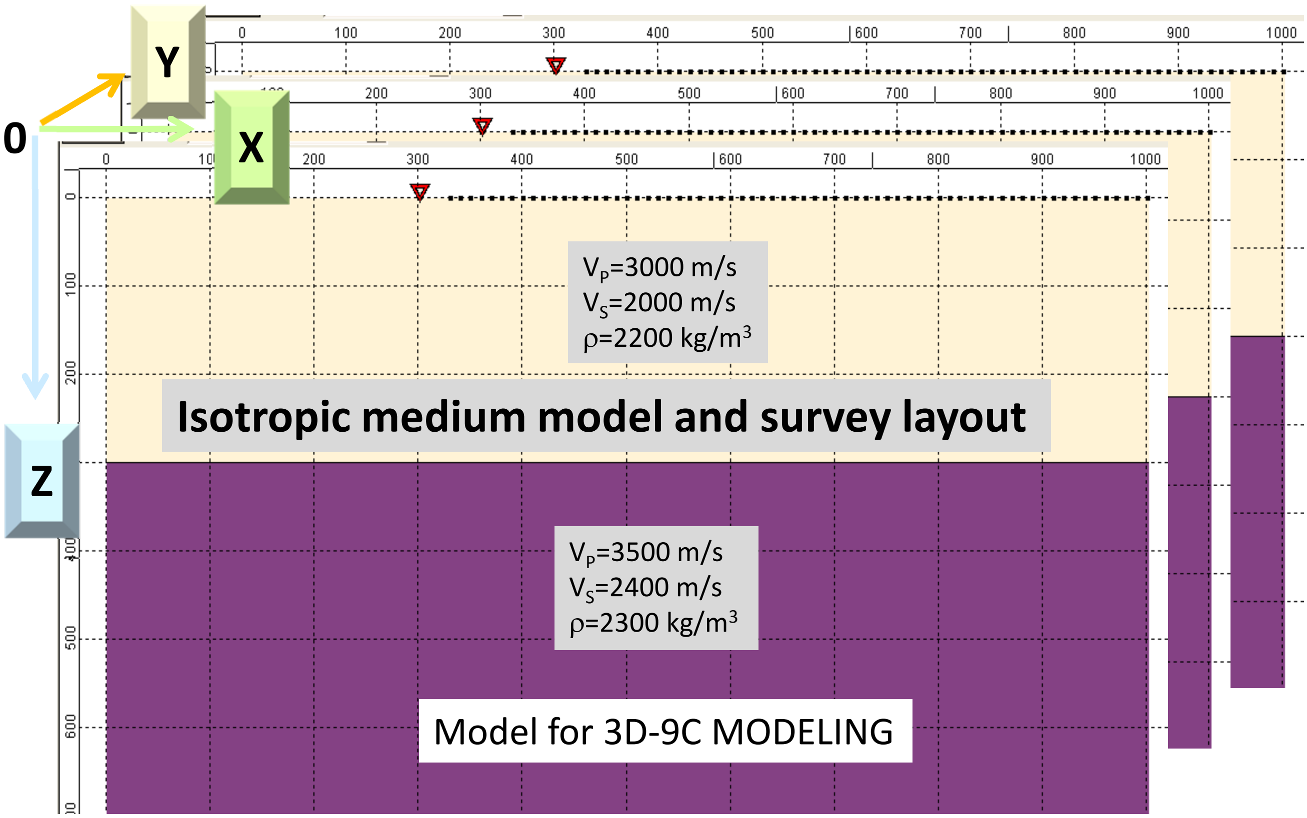
Source position at X=700m, Y=100m; Well position at X=400m, Y=0m



Source position at X=700m, Y=200m; Well position at X=400m, Y=0m

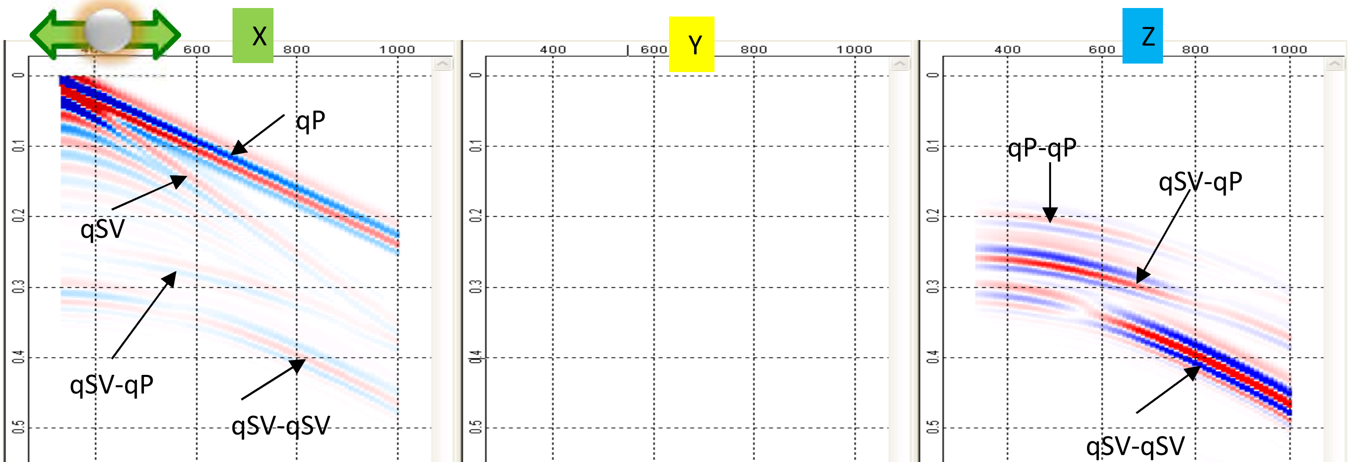
In *this and next Slide*, the gathers for a source with different Y offset are shown.

All types of waves can be observed, in full conformity to the source-array characteristics.

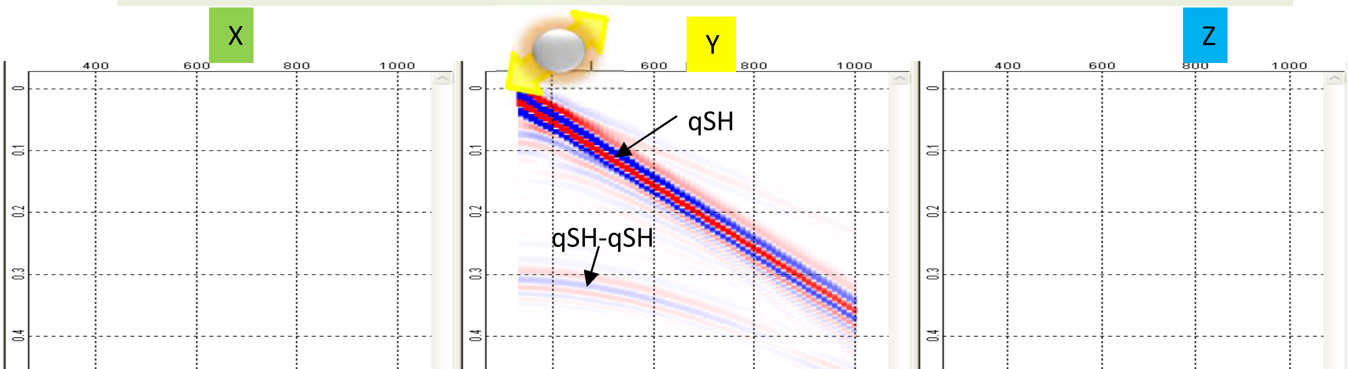


Many oil companies request 3D-9C survey, which is done by using 3-component receiver and 3-component excitation (concentrate source force along X, Y and Z directions, respectively). The initial isotropic model is shown.

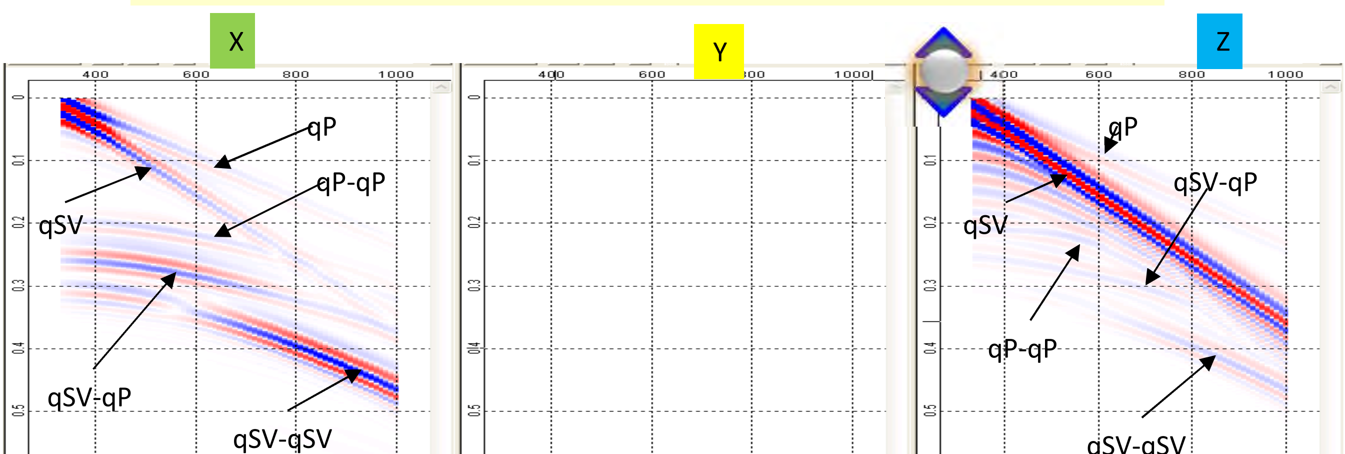
2.5D-9C modeling



Shotgathers of reflected waves for an excitation along OX axis



Shotgathers of reflected waves for an excitation along OY axis

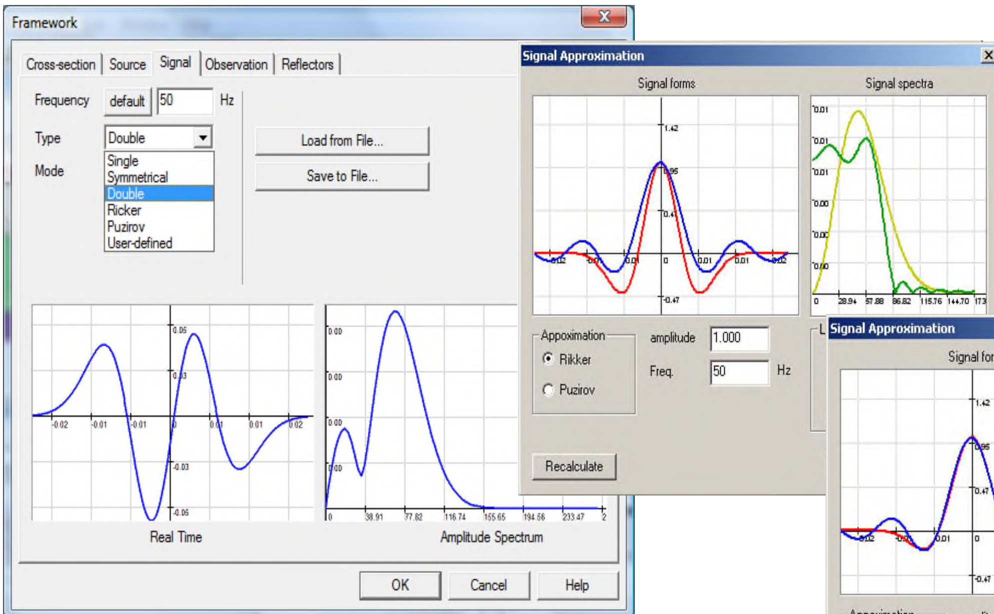


Shotgathers of reflected waves for an excitation along OZ axis

The 9C gathers (*from previous slide model*) are shown for source excitation along the X, Y, and Z axis, respectively.

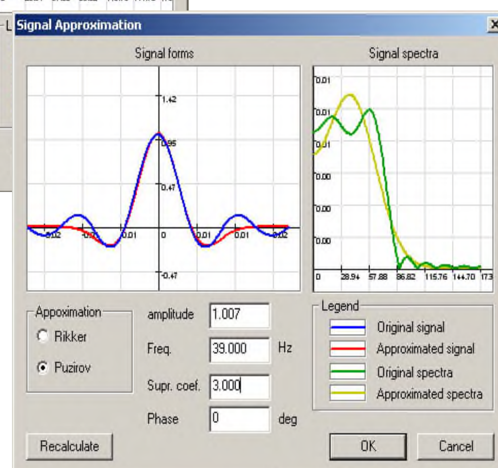
It is interesting to compare the X component of 3C observation for source excitation along X axis and Y axis. The latter generates a pure SH wave. As contrary to the SV wave, the SH wave does not have wave-mode conversions in isotropic medium.

What signals are used?



Approximation of user custom wavelet with Rikker wavelet

User custom wavelet in tabular form



Approximation of user custom wavelet with Puzirov wavelet

Approximate with wavelet ... list allows selecting one of standard wavelets. If corresponding box is checked and there is previously entered signal (***background signal***) for some standard wavelets (*<name-of wavelet>) will be made attempt to automatically *fit its parameters to background signal*. ***Signal Form*** *window* shows signal as it will be generated by the source. Depending on the form of the signal, it may be more or less distorted at its way through the (modeled) medium due to inherent conditions of the wave equation. *Background signal* is shown with dark grey color.

Signal Spectrum *window* shows spectral decomposition of the signal in relative amplitudes as function of frequency. Horizontal brown line corresponds to *median* (see *Median Gain*) of the signal, vertical (yellow and red) lines allow to estimate its (*median*) frequency band. Brown line corresponds to the *Peak Frequency* of the signal. *A background signal spectrum is* shown with dark grey color.

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