Passive Seismic sources are directed by slips along a fault surface, while the tension at this surface remains continuous.
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 to the theoretical concepts developed in seismology, a seismic response is formed by superposition of the dipole sources, as is shown in this Slide.
The directional emission patterns are shown for source excitation along the X and Z axis, respectively.

Directivity graphs of P and S waves

\[ L_p = \frac{\cos^2 \theta}{2\pi V_p^3} \]
\[ L_{SV} = -\frac{\sin 2\theta}{4\pi V_S^3} \]

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

\[ m_{11} = c_{11} u_1 n_1 + c_{13} u_3 n_3 \]
\[ m_{13} = c_{55} (u_1 n_3 + u_3 n_1) \]
\[ m_{33} = c_{13} u_1 n_1 + c_{33} u_3 n_3 \]

\[ \lambda, \mu \quad \text{- Lame parameters} \]
\[ u_1 n_1 = \sin \theta_u \sin \theta_n \quad u_3 n_3 = \cos \theta_u \cos \theta_n \]
\[ u_1 n_3 + u_3 n_1 = \sin (\theta_u + \theta_n) \]
\[ c_{11} = c_{33} = \lambda + 2 \mu \quad c_{13} = \lambda \quad c_{55} = \mu \]
\[ \theta_u, \quad \theta_n \quad \text{- Angles between the vertical axis and vectors } u \text{ and } n \]

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

Directivity graphs of P and S waves

\[ L_P = \frac{\sin 2\theta}{4\pi V_P^3} \quad L_{SV} = \frac{\cos 2\theta}{4\pi V_S^3} \]
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.

\[ \begin{align*}
V_p &= 2000 \text{ m/s} \\
V_S &= 1150 \text{ m/s} \\
\rho &= 2010 \text{ kg/m}^3 \\
L_{SV} &= \frac{\sin^2 \theta \cos^2 \alpha}{8\pi \rho V_S^3} \\
L_{SH} &= \frac{\sin \theta \sin \alpha^2}{4\pi \rho V_S^3}.
\end{align*} \]

\( \theta \) - angle of inclination of slowness vector in vertical plane

\( \alpha \) - Azimuth of the slowness vector
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.
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.
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.