Determining source mechanism types of the underground event

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Abstract. We consider problem determination of focal mechanism and identification the type of source of underground event. This is a typical problem for observing microseismic events, which arise during the reservoir prospecting or hydraulic fracturing. The article presents of recovery of impulse from explosive cord by surface data and application a Hudson plot to determine type of the source.

1. Introduction
The procedure hydraulic fracturing lead to increase pore pressure in the medium and stress-strain state in area around the injection well also changes. This is the cause of microseismic activity, which is associated not only with growing fracture, but also with the re-opening of natural fractures [3, 4, 7]. At the stage of interpretation of hydraulic fracturing, there is problem of recognizing correct microseismic events that are caused by the opening of a fracture.

A microseismic event can be described by the seismic moment tensor, which shows the scale of the seismic event, orientation fracture plane, stress-strain state of medium at the in the place of origin [1].

In order to identify which type of seismic source there is a decomposition of the moment tensor into three basic mechanisms of movement: volume isotropic expansion/compression (ISO); compensated linear vector dipole (CLVD); double-couple (DC) [5, 6].

Any microseismic event can be attributed to one of these types of sources, or described by their combination in the case of a complex source.

\[
M = M_{ISO} + M_{CLVD} + M_{DC} = M_{ISO} M_{ISO} + M_{CLVD} M_{CLVD} + M_{DC} M_{DC},
\]  

(1)

where \( E_{ISO}, E_{CLVD}, E_{DC} \) can take the form:

\[
\begin{align*}
E_{ISO} &= \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}, \\
E_{CLVD} &= \begin{pmatrix} 2 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & -1 \end{pmatrix}, \\
E_{DC} &= \begin{pmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & -1 \end{pmatrix}.
\end{align*}
\]  

(2)

wherein:

\[
M_{ISO} = \frac{1}{3} (M_1 + M_2 + M_3), M_{CLVD} = \frac{2}{3} (M_1 + M_2 - 2M_3), M_{DC} = \frac{1}{2} (M_1 - M_2 - [M_1 + M_3 - 2M_2]).
\]  

(3)

at \( M_1 \geq M_2 \geq M_3 \).
The ISO component characterizes the change in volume, while the CLVD, DC components symbolize the deviator part. The contribution of each component is more clearly estimated as a percentage, we will make normalization:

\[
\begin{bmatrix}
C_{\text{ISO}} \\
C_{\text{CLVD}} \\
C_{\text{DC}}
\end{bmatrix}
= \frac{1}{M'}
\begin{bmatrix}
M_{\text{ISO}} \\
M_{\text{CLVD}} \\
M_{\text{DC}}
\end{bmatrix},
\]

where \(M' = |M_{\text{ISO}}| + |M_{\text{CLVD}}| + M_{\text{DC}}\), and:

\[|C_{\text{ISO}}| + |C_{\text{CLVD}}| + C_{\text{DC}} = 1.\]

So if \(C_{\text{ISO}} = 100\%, C_{\text{CLVD}} = 0\%\) and \(C_{\text{DC}} = 0\%,\) this will mean that the source represents a uniform isotropic expansion.

Hudson [2] proposed a graphical decomposition of the moment tensor in the coordinate plane of the \(u\) and \(v\) axes (Fig. 1).

**Figure 1.** Decomposition of the moment tensor via Hudson-plot

Where:

\[
u = \frac{2}{3} \left( M_1 + M_2 - 2M_3 \right), \quad \lambda = \frac{1}{3} \left( M_1 + M_2 + M_3 \right).
\]

The upper and lower poles of the graph (Fig. 1) are responsible for the type of displacement of the form of volume tension and compression, respectively. The 2nd quadrant shows the events of the “tensile crack”, and moment tensor is:

\[
M_{\text{crack}} = \begin{pmatrix}
\lambda & 0 & 0 \\
0 & \lambda & 0 \\
0 & 0 & (\lambda + 2\mu)
\end{pmatrix}.
\]

Such sources are formed during the opening and growth of hydraulic fractures, therefore they are of practical interest for these tasks. The process of closing a crack is also important; such events will be located in the 4th quadrant. Thus, the Hudson-plot system allows you to visually determine focal mechanism of the source.
2. Recovery of impulse from explosive cord

In this work, data of surface microseismic monitoring of a detonating cord explosion (DTSH), performed at a depth of 2682 m, at a given known time was processed.

For the area of space that covers the location of the detonating cord, a discrete grid is specified. The nodes of this grid are the points at which the intensity of microseisms will be restored. For each of these points, shape of the impulse is calculated, which arrives at each of the sensors on the surface. Further, for each time step, the most probable amplitude of the microseismic event that occurred at that moment is restored. Synthetic signals and field data were compared using the maximum likelihood method. Such an amplitude of the microseismic event was selected, at which the likelihood function reached its maximum. The intensities reconstructed at each point of the grid form a three-dimensional dynamic (evolving in time) cube of microseismic events in the studied area.

As a result of processing, components of the seismic moment tensor were restored. The maximum likelihood method also allows one to estimate the signal-to-noise ratio of the recovered tensor for the entire observation time interval.

\[
\text{SNR}(\mathbf{M}) = \mathbf{M}^\top \text{cov}(\mathbf{M})^{-1} \mathbf{M},
\]

where \( \mathbf{M} \) – seismic moment tensor.

The event corresponding to the moment of detonation appeared on the time axis in the SNR. Figure 2 shows a high SNR amplitude, symbolizing the recovered pulse.

![Figure 2. Restored ratio SNR](image)

The decomposition of the found components according to equation (5) gives the following results: \( C_{\text{ISO}} = 78\% \), \( C_{\text{CLVD}} = 15\% \) and \( C_{\text{DC}} = 7\% \). A graphical representation of the components of the seismic moment tensor, through the Hudson-plot system, defines the event in the 2nd quadrant (Fig. 3). That allows you to determine the focal mechanism of movement as the center of "explosion" with anisotropic predominance towards the "tensile crack". 
3. Conclusion
The graphical decomposition of the reconstructed event at Hudson plot made it possible to determine the focal mechanism as explosion source with a predominance to the “tensile crack”. This is consistent with expectations and the physical interpretation of the underground impulse from explosive cord, in an anisotropic environment, as the center of an uneven increase in volume.

The result obtained shows the fundamental applicability of using the Hudson plot for interpreting microseismic events in surface monitoring. This will allow to reject false events, which is very important for the tasks of monitoring hydraulic fracturing.

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