Geophysical Research Abstracts
Vol. 13, EGU2011-13237, 2011
EGU General Assembly 2011

Does stress drop of small earthquakes depend on non-shear components?

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The occurrence of crack opening became recently a focus of many seismological studies that search for the non-double-couple or non-shear components of the seismic moment tensors. However, the results are ambiguous – the studies of fluid related earthquakes like earthquake swarms and industrial injection-induced seismicity shows source moment tensors of both pure shear and hybrid shear-tensile type. Besides, lacks of data are available to verify if the source scaling relations hold for tensile earthquakes similarly as for their shear counterparts.

Based on stress analysis we find that crack opening is possible only for negative effective normal stress, which can occur due to high fluid pressure on fractures trending close to $\sigma 1$ direction if the differential stress is small enough. In the presence of preexisting fractures of various orientations, the increasing fluid pressure would cause a shear failure of the optimally oriented fractures followed by a possible hybrid shear-tensile failure of non-optimally oriented fractures. Interestingly, the small shear traction resolved on hybrid fractures limits the maximum possible stress drop of shear-tensile events.

We test our approach on data of the earthquake swarm, which occurred in West Bohemia in 1997. We use 70 events for which full moment tensors were determined. While the first swarm period was characterized by shear events with small compressive component, in the second period tensile events with large positive volumetric and CLVD components occurred. Using stress analysis we find that the tensile events occurred on faults oriented closer to $\sigma 1$ direction than the shear events and that they occurred at smaller shear traction than the shear events.

We further analyze the pulse width of the P-waves to determine the stress drop of these events. We find a slight increase of the stress drop with increasing double-couple component of the moment tensors and the corresponding decrease of the stress drop with increasing volumetric component. This finding is in agreement with the expected decrease of the upper limit of stress drop with increasing tensile component of these fluid-related earthquakes.