Geophysical Research Abstracts
Vol. 15, EGU2013-13799, 2013
EGU General Assembly 2013

A new three-dimensional method of fault reactivation analysis : Application to the 2011 Tohoku-Oki earthquake sequence

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The determination of the state of stress around fault is of fundamental importance to understand fault reactivation and earthquake triggering. During the last decades, the determination of the stress state in the crust has been improved thanks to deep borehole stress measurements and the development of stress inversion methods. However, the influence of the stress tensor on the ability of faults to be reactivated remains unclear. The use of the reduced stress tensor given by most stress inversion methods to estimate the ability of fault to be reactivated is possible with only a few methods.

We developed a new 3-D fault reactivation method to evaluate the reactivation potential of fault planes. The method is based on the Mohr-Coulomb theory and can be applied to cohesive or noncohesive faults whatever their orientations and without any conditions on the regional stress field. It allows computation of the effective stress ratio σ_3'/σ_1' required to reactivate any fault plane and to determine whether the plane is favorably oriented, unfavorably oriented or severely misoriented with respect to the ambient stress field. The method also includes a graphical sorting tool that involves plotting poles of fault planes on stereoplots for which the boundaries separating the three domains corresponding to favorable orientations, unfavorable orientations and severe misorientations cases are shown. The delineation of these domains is based on the value of the σ_3'/σ_1' ratio that depends on the orientation of the fault plane with respect to the principal stress axis orientations, the stress ellipsoid shape ratio, the coefficient of static friction μ_s of the fault, and the fault cohesion C_0.

The method is then applied on 145 focal mechanisms of the 2011 March 11^{th} Tohoku-Oki (Japan) earthquake sequence. This application delineates, along or in the vicinity of the Pacific-Okhotsk plate interface, three types of domains characterized by favorable orientations, unfavorable orientations or severe misorientations of mainshock/aftershock fault planes. Aftershock focal mechanisms that plot in the 'severe misorientation' domains are interpreted to have occurred because of pore fluid pressures exceeding the regional minimum principal stress at those locations. The distribution of these 'severe misorientation' domains partly overlaps the asperities or the low-velocity anomalies mapped on the plate interface off NE Japan. The 3-D fault reactivation analysis appears complementary to geophysical investigations.