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In situ stress heterogeneity induced by weak natural fractures and faults with high slip-tendency

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In situ stress measurements typically conducted using several geotechnical methods (hydraulic fracturing and overcoring) often show quite scattered and inconsistent stress magnitudes. Would they be artifacts from test errors or genuine stress signals in the crust? I report two field examples of stress measurements, in which lateral stresses represented by maximum (SHmax) and minimum (Shmin) horizontal principal stresses scatter quite widely, to investigate the cause of the observed stress heterogeneity. Hydraulic fracturing stress measurements were conducted in vertical boreholes at two different locations in South Korea. The boreholes are 300 and 400 m deep, respectively, both penetrating granites. Several isolated intervals of intact rocks over depths in the boreholes were vertically fractured by injecting water. Magnitudes of Shmin were determined from shut-in pressures. Magnitudes of SHmax were estimated based on the Hubbert-Willis (1957) equation using reliably determined hydraulic fracturing tensile strengths. The stress states in both locations are in reverse faulting stress regimes, in which vertical stress (Sv) is the least principal stress. The magnitudes of SHmax are generally within or close to stress range limited by frictional coefficients of 0.6-1.0 of nearby faults. However, SHmax do not increase consistently with depth, but rather scatter quite significantly. Over only a few tens of meter depth interval, the SHmax magnitudes jump up and down by an order of $\sim$10 MPa, often resulting in lower SHmax values at deeper depths. Near the depths of relatively low stress, natural fractures and faults with wide apertures (for instance, wider than $\sim$10 mm, observed from borehole image logs) are abundant, and near those of relatively high stress, those wide discontinuities are scarce. Such wide discontinuities are inferred to be filled with weak gouges or rock fragments, and thus tend to have relatively low frictional coefficients. In particular, the wide fractures and faults are oriented predominantly in the directions of high slip-tendency. If excessive stress is exerted, those weak fractures and faults would slip to release the stress, which would reduce the stress magnitudes to the values that can only be sustained by the discontinuities. This observation suggests that stress magnitudes are constrained quite locally by such weak, high slip-tendency discontinuities. Although the remote stress field might be uniformly applied, the stress state in the crust seems inherently heterogeneous because of the heterogeneous distribution of weak natural fractures and faults.