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Fluid transport properties of shale smear during fault development in sedimentary basin

Miki Takahashi[1]

[1] Institute of Geoscience, AIST

Smear sourced from shale or clay is thought to provide an across-fault barrier to fluid flow in sedimentary rocks. Permeability changes of this phenomenon were investigated using a triaxial testing machine which consisted of servo-controlled axial loading system, framework, confining and pore pressure intensifiers. Experimental specimens consisting of interlayered siltstone (low initial permeability, 10^-16 m^2) and sandstone (high initial permeability, 10^-13 m^2) were subjected to 20, 30 and 40 MPa of effective normal stresses on a pre-cut surface, dividing each specimen at a 30 degree angle to its axis, at axial shortening velocities between 0.14 and 1.41 micro m/sec. Permeability was measured by the oscillation method, and permeability changes categorized in three distinct regimes that indicated to progressively increasing rock deformation: (Regime 1) rapid reduction due to compaction of the siltstone layer prior to fault movement; (Regime 2) constant and minimum permeability while the smear developed; and (Regime 3) gradual permeability recovery caused by smear progressively thinning and loss of smear continuity. The duration of Regime 2 and of smear continuity recorded provide measures of the fault sealing potential produced by the smear. The shale smear factor SSF, defined as (fault throw)/(thickness of low-permeability layer), shows that there may be a positive correlation between seal potential and effective normal stress. Both factors in SSF can reach higher values when effective normal stress is 40 MPa than when that is less than 30 MPa.

Next, we compared the artificial shale smear by experiments to the natural smear. Area of field studies on natural shale smear is an outcrop along Airport Road in Miri, Sarawak, Malaysia (Upper Miri Formation in West Baram Delta Province, Middle Miocene), where the faults form dip-closure reservoirs of Miri oil field. From distribution of continuous and discontinuous smears for each normal fault, SSFcrt at which the continuity of shale smear is lost is various from 4.3 to 13.1. Except one fault showing SSFcrt = 4.3, all other faults (which were larger than 8.0) exhibit much larger values than those in the present experiments (SSFcrt = 6.6 for effective normal stress = 40 MPa and 4.9 for when that is less than 30 MPa) and in previous field studies (SSFcrt = 5 - 7). Both experimental and natural smears show wafer-thin feature, and thus, the shale smear mechanisms in these cases are thought as abrasion. At edge of the shale layer cut by the fault, both experimental and natural smears had the Riedel structure which have trapped a much amount of shale with maintaining the original lamination. Therefore, it suggests the mechanism to produce much amount smear entrained into the fault. Additionally, we plan to present the results of experiments using natural sandstone-shale layered rock sampled from Airport Road Outcrop in Miri.

The present studies indicate that natural shale smear can be reproduced by shearing experiments, that the fault-seal potential of shale smear can be evaluated by measuring permeability during fault slip, and that the critical shale smear factor, SSFcrt, of shale smear of a sedimentary basin can be estimated by conducting shearing experiments using shale and host sediments for a field. Applications of the present experiments are expected in many oil fields in the world. But also, the method will be useful in the studies of underground hydrology, large-scale fluid flow and material transport, and the contaminant transport in the earth as well.