Effects of Various Clay Minerals on the Velocity Dependence and Healing Properties of Granite Fault Gouge: Postprint

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Abstract

Clay minerals, predominantly kaolinite, chlorite, illite, and montmorillonite, are widely distributed in faults. Clay minerals are characterized by small particle size, large specific surface area, and strong affinity for water and cation adsorption. The hydration swelling characteristic of clay minerals refers to their property of volume increase upon water absorption; the formation of water films around clay particles exerts a lubricating effect that reduces the friction coefficient. Additionally, clay minerals exhibit low friction coefficient, low healing rate, and velocity-strengthening behavior. The combined action of these multiple properties can significantly influence the strength and sliding stability of granite faults.

The South China region is located in the central part of the South China Block within the Mesozoic Eurasian plate tectono-magmatic belt, spanning the Yangtze and Cathaysia plates. Intense crustal tectonic movements caused by plate subduction have resulted in extremely abundant granite formations in South China. This paper focuses on the interaction mechanism between granite faults and clay minerals. While the influence of individual clay minerals on the frictional characteristics of granite faults has been extensively studied by previous researchers, the coupled effects of multiple clay minerals on the friction coefficient and velocity dependence of granite faults remain unclear. Therefore, this study specifically investigates the influence of multiple altered minerals acting in concert on the friction coefficient and velocity dependence of granite fault gouge and their underlying mechanisms. Montmorillonite, chlorite, and kaolinite powders were mixed in pairwise 1:1 ratios and a triple 1:1:1 ratio, then combined with granite powder in specific proportions to form experimental samples. Under constant normal stress of 20 MPa and constant water content of 5%, velocity-step tests and velocity-healing tests were conducted on the experimental samples using a direct shear apparatus, while simultaneously employing

Acoustic Emission (AE) technology to monitor the development of microcracks in the samples. The velocity dependence parameters and velocity-healing characteristics of the experimental samples were observed, and SEM microstructural observations were performed on the samples after testing. Experimental results indicate that cracks developed during the failure process of granite fault gouge differ from the tensile cracks dominant in intact granite, instead exhibiting pronounced shear cracks with well-developed Riedel shear bands at the microscale, among which R-shear bands are most common. The friction coefficient of fault gouge decreases bilinearly with clay mineral content, with a steeper slope in the first segment, indicating a more rapid decrease in friction coefficient with increasing clay content. Comparative analysis of the mechanical properties of granite fault gouge under the action of different clay mineral mixtures reveals that montmorillonite serves as the dominant mineral controlling the mechanical properties of granite fault gouge in both pairwise mixtures and triple mixtures.

Full Text

The Influence of Various Clay Minerals on the Velocity Dependence and Healing Characteristics of Granite Fault Gouge

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Abstract

Clay minerals—primarily kaolinite, chlorite, illite, and montmorillonite—are ubiquitous in fault zones. Characterized by fine particle size, large specific surface area, and strong affinity for water and cation adsorption, these minerals exhibit hydration-induced swelling that creates lubricating water films, thereby reducing friction coefficients. Furthermore, clay minerals display intrinsically low friction, low healing rates, and velocity-strengthening properties. The combined influence of these characteristics significantly impacts the strength and slip stability of granite faults.

The South China region, situated within the Mesozoic Eurasian tectono-magmatic belt at the center of the South China Block and spanning the Yangtze and Cathaysian plates, has experienced intense crustal deformation due to plate subduction, leading to extensive granite formation. This study investigates the interaction mechanisms between granite faults and clay minerals. While previous research has extensively examined individual clay mineral effects on granite fault frictional properties, the coupled influence of multiple clay minerals on friction coefficients and velocity dependence remains poorly understood. We therefore examine the combined effects of multiple alteration minerals on the frictional behavior and velocity dependence of granite fault gouge.

Experimental samples were prepared by mixing montmorillonite, chlorite, and kaolinite powders in binary (1:1) and ternary (1:1:1) combinations, then blending these clay mixtures with granite powder at specific proportions. Velocity-stepping and healing experiments were conducted using a direct shear apparatus under constant normal stress (20 MPa) and water content (5%), while acoustic emission (AE) monitoring tracked microcrack development. Post-experiment microstructural characterization was performed using scanning electron microscopy (SEM).

Our results demonstrate that fault gouge rupture is dominated by shear fractures rather than the tensile cracks typical of intact granite, with well-developed Riedel shear bands—particularly R-shears—observed at the microscale. The friction coefficient of fault gouge decreases biphasically with increasing clay content, showing a steeper initial slope that indicates rapid initial friction reduction. Comparative analysis reveals that montmorillonite consistently acts as the dominant mineral controlling the mechanical properties of granite fault gouge, regardless of whether it occurs in binary or ternary clay mixtures.

Keywords: Clay minerals; Granite fault gouge; Frictional properties; Water-rock interaction alteration minerals; Fault stability

Note: Figure translations are in progress. See original paper for figures.