Geophysical Research Abstracts
Vol. 13, EGU2011-4663-1, 2011
EGU General Assembly 2011

Spatial distribution and characteristics of fracture zones in heterogeneous lithologies and long-term, multiple, fault re-activations

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Development of fracture zones has a substantial impact on long-term changes in the underground environment because fracture zones have the potential to become major water conducting feature, as well acting as a locus for continued mechanical disturbance by fracturing. In order to understand their development, we surveyed the spatial distribution and characteristics of fracture zones in areas around the Atotsugawa Fault, a long-lived active fault in central Japan. The Atotsugawa Fault extends for approximately 60 km along strike in an ENE-WSW direction, with a dextral strike-slip displacement and northwest uplift. Geological survey was carried out in the area covering 4 km to the north and 6 km to the south of the western part of the Atotsugawa Fault.

Although fracture zones are sparsely distributed in the study area, the number of exposed fracture zones decreases sharply with increasing distance, especially 500 m or more from the Atotsugawa Fault trace. Most facture zones greater than 2 m width occur within 500 m from the main Atotsugawa Fault trace. Numerous fractures and breccia are characteristic of the fracture zones along the Atotsugawa Fault and width of low permeable fault gouge is less than 1 m. This suggests that the fracture zones act as a major water conducting feature controlling regional groundwater flow. Results of the XRD analysis of fault clays collected from the fracture zones show that secondary minerals such as smectite and kaolinite formed at many locations in the fracture zones, indicating that water-rock interactions occurred at several locations in the fracture zones.

Based on the specific locations where fracture zones developed, fracture zones in the study area are subdivided into the following five types: re-fractured and weathered along foliated cataclasite (Type 1), fractured along andesite dikes (Type 2), fractured along hydrothermal veins (Type 3), fractured and weathered with displacement along joints, schistosities or lithological boundaries (Type 4), and others such as fracture zones difficult to identify due to poor exposure (Type 5).

Foliated cataclasite associated with the Type 1 fracture zones likely originated from sinistral tectonics related to the initial development of the Atotsugawa Fault between the Cretaceous and the Paleogene. Spatial distribution and characteristics of the Type 1 fracture zones indicate that epigenetic deformation was concentrated in the ancient shear zones, once the major foliated cataclasite zones had formed.

Andesite dikes in the Type 2 fracture zones intruded from the Oligocene to the Miocene and are related to NW-SE extension during the opening of the Japan Sea. The distribution and orientation of the Type 2 fracture zones suggest that fault-related shearing along the andesite dikes after intrusion is restricted to the area in and near the Atotsugawa Fault.

The Types 3 and 4 fracture zones show brittle fracturing with network-patterned cracks and simple fragmentation without ductile shearing. These indicate that deformation in the zones post-date the formation of the foliated cataclasite in the Type 1 fracture zones. The Types 3 and 4 fracture zones are widely distributed and sparsely exposed in the study area, even away from the Atotsugawa Fault. However, they have narrow width (most of their widths are less than 2 m) and lack continuity, and mean density of their spatial distribution is less than one per several hundred meters square.