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Anomaly of magnetic susceptibility produced by high velocity friction test from the Chelungpu fault in Taiwan

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Seismic slip induces the mechanical crushing and the frictional heating within the fault zone, which can cause the chemical and magnetic anomalies of the fault core materials. It might be possible to evaluate the shear strength and heating history of the fault from the detailed core analyses. The sequential TCDP (Taiwan Chelungpu-fault Drilling Project) Hole B core analysis found the anomaly of bulk magnetic susceptibility around the center of fault zone that the black ultra cataclasite is developed. 1) The grain fining of ferromagnetic minerals caused by the mechanical-crushing, 2) newly formation of ferromagnetic minerals by mechano-chemical reaction, and 3) thermal decomposition and newly formation of ferromagnetic minerals caused by the frictional heating, are the possible mechanisms that increased the magnetic susceptibility during and after the seismic slip. Therefore, we performed high-velocity frictional tests, simple heating tests and milling tests on crushed fault gouge from the Hole B core samples, and then grain size analysis, XRD analysis, thermomagnetic susceptibility analyses, and color measurement were carried out using samples after experiments to investigate the cause and origin of high magnetic susceptibilities in the fault core.

We carried out high velocity frictional tests using dry gouges (less than 0.2 mm of grain size) under 0.5 to 1.5 MPa of axial stress and at 1 m/s of slip velocity. Black ultracataclasite resembling that observed in Hole B were formed during the experiments, even under low axial stress. The bulk magnetic susceptibility of the tested samples was proportional to the frictional work applied and increased as slip increased. Simple heating test also caused the increase of magnetic susceptibility above the 300 $_o$C of the maximum heating temperature, and the susceptibility was proportional to heating temperature up to 700 $_o$C. However, the generated susceptibility was lower than that after high velocity frictional test. Thermomagnetic susceptibility analyses of natural fault rocks revealed that magnetization increased at maximum heating temperatures above 400 $_o$C in the heating cycle, and showed three step increases, at 600 to 550 $_o$C and at 300 $_o$C during the cooling cycle. These behaviors are consistent with the presence of pyrite and siderite, suggesting that TCDP gouge originally included these minerals, which contributed to the generation the magnetic susceptibility by thermomechanical reactions. A kinetics model analysis based on the slip behaviors and physical parameters of the 1999 Chi-Chi earthquake confirmed that frictional heating can cause thermal decomposition of siderite and pyrite.

Furthermore, we observed the relationship between magnetic susceptibility and milling time so as to investigate the influence of mechanochemical reaction on the susceptibility change. Magnetic susceptibility was changed with milling time, though the change was very small compared to other tests. A large increase of the magnetic susceptibility was observed after heating using the milled samples. Milling of iron-bearing minerals for a long time caused the transition to the other minerals such as hematite by the mechanochemical reaction.

Above these results, the thermally induced formation of ferrimagnetic minerals by high velocity friction that was also promoted by the grain fining due to mechanical crushing might have caused a magnetic susceptibility anomaly. Our experimental results also support the assumption that heat generation of short duration, even if it is below the melting point, can increase magnetic susceptibility. The decomposition of siderite and, to some extent, pyrite to magnetite is the probable reaction mechanism explaining the magnetic anomaly within the Chelungpu fault zone.