Dynamic mechanochemistry of seismic slip -nano spherules lubrication

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Abstract

The Chelungpu fault, which was activated during 1999 Chi-Chi Earthquake, had been drilled to penetrate and recover the earthquake slip zone materials at deeper level (1100 m depth) in the crust, from year 2004 to 2005. Three holes are drilled (Hole A, B and C) and recovered the drilled core materials. Identification of slip layers of Chi-Chi Earthquake, thermal property measurements across the slip zones, estimates of frictional heat energy during earthquake, and quantifications of true fracture energy have been conducted using Hole A and C core (Tanaka et al 2006, GRL, Ma, Tanaka et al., 2006, Nature, Tanaka et al 2007, GRL). We present here the results of nano-scale observations for slip zone materials by using HR-TEM and TXM technique and fundamental process of generating nano-grains is discussed. Hole C core contained slip concentration zone, which is 12 cm in thickness, in which four independent layers composed of fine crushed materials were identified. The zone is directly juxtaposed with lower undamaged host mudstone by planner surface. Each of four layers shows about 3 cm in thickness, which contains crushed grains with maximum diameter of 0.1 mm. Further, each layer contains ultra-fine grained layer at the bottom, about 1 cm in thickness, which contains no visible grains. XRD analysis clarified that the materials in this layer are mostly composed of quartz. Grain size distribution is measured under OM, SEM, and HR-TEM, from 100 nm to 100 um in grain diameter. The distribution follows the fractal model ($N(D) = 0.0045D2.3$; N: numbers of grains, D: grain diameter). Under SEM (SEI) observation, many of fractured grains are enveloped by viscous thin film, which extends from one side of fractured grains. This texture is similar with that observed by Otsuki for his samples after slip deformation experiments. Minimum size of grains observed under HR-TEM is 3 nm. The grain size distribution for grains larger than 100 nm in diameter follows the fractal law and grain shape is highly irregular. Grains smaller than100 nm show some specific characteristics, that is, smaller the grains, more the spherical shapes and more equi-granular. Thus, the grains smaller than 100 nm are no longer described by fractal distribution model. We refer tentatively these grains as nano spherules. By SAD and EDX analysis under HR-TEM, the nano spherules are mainly composed of crystallized quartz associated with minor amounts of carbonates (siderite) and

amorphous materials. The result corresponds well with that of XRD analysis. These observations lead following three conclusions, (1) nano spherules are not generated just by fracturing, based on their shapes and grain size distributions. (2) Considering the results of SEM observations, nano spherules would compose viscous materials enveloping larger fractured grains. (3) Mica clay minerals and feldspars, which are common in host mudstone rocks, are disappeared in ultra-fine grained layer. This implies that chemical process of dissolution -elements dissipation -SiO2 precipitation occurred associated with mechanical fracturing. Therefore nano spherules would be generated through mechano-chemical process during co-seismic slip. Dynamic shear strength drop are recently observed by rapid slip experiments (DiToro et al., 2004, Nature). Some experiments reported that the products contain gelled materials. Large differences of ultra-fine products between previous reports and our observations are existence of nano spherules and their crystallinity. If the nano-spherules are generated during seismic slip, dynamic weakening would be expected because mode of friction turns into rolling friction, which is 10 to 20% of shear friction, by huge amounts of equigranular and spherical grains. This may be alternative explanations for dynamic weakening. Quantitative process of dynamic fracturing -dissolution and precipitation of nano grains will be discussed in our presentation.