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ESR thermochronological studies on frictional heating events in the Taiwan Chelungpu fault drilling project Hole B cores

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The Taiwan Chelungpu Fault Drilling Project (TCDP) was launched in 2002 after the 1999 Chi-Chi earthquake to elucidate the rupture process caused in a subduction seismogenic zone, and continuous drill cores were collected from two main boreholes (Holes A and B) penetrating through the Chelungpu fault plane at depths [Ma et al, 2006]. In the Hole B cores, there exist three major fault zones at about 1136 m, 1194 m and 1243 m depths [Hirono et al., 2007]. As a result of the close investigations using various analytical methods, the black fault gouge zone distributed at about 1136 m depth (BGZ1136) is considered to have been most likely active in the Chi-Chi earthquake. Some preceding studies reported that high magnetic susceptibility and low inorganic-carbon content detected from the BGZ1136 may have been caused by coseismic frictional heating [Ikehara et al., 2007; Hirono et al., 2007]. On the other hand, X-ray diffraction analytical data clearly indicated that smectites, chlorites and illites exist in the BGZ1136 [Hashimoto et al., 2008; Hirono et al., 2008]. Especially the content of illites has been extremely increased as compared with that in the surrounding fault rocks, implying the occurrence of smectite-illitization in the BGZ1136 [Hirono et al., 2008]. However, since frictional heating is considered to cause an instantaneously dry state, hydrothermal reaction under a state of thermal equilibrium like smectite-illitization cannot occur at the same time as frictional heating. Thus, we carried out thermal analyses of the 1136m major fault zone in the Hole B cores using the electron spin resonance (ESR) technique. As a result, we obtained no evidence of the striking generation of frictional heat such as the anomaly of ferrimagnetic resonance (FMR) signal from the BGZ1136. Instead, we detected small FMR signal of maghemite from it. Magnetic analyses indicated that the black gouge has much higher coercive force than the surrounding fault rocks, suggesting the transformation of maghemite produced by ancient frictional heating into hematite due to hydrothermal reaction.

We have newly carried out thermochronological studies using the E_1' center, which is a paramagnetic signal associated with unpaired electrons trapped at vacancies in quartz [Fukuchi & Imai, 2001]. According to our step-by-step (5 minutes) heating experiments, the E_1' center commonly grows at 200-300 degree C, is saturated at 300-350 degree C and is almost annihilated at 450 degree C. The E_1' center in the BGZ1136 has been strikingly decreased, compared with those in the surrounding fault rocks, so that the black gouge may have been subjected to heat over 400 degree C. The only heat source is most probably frictional heating, because no igneous or metamorphic rock exists around the 1136m major fault zone. On the other hand, the E_1' center in the black gouge strikingly increases by heating at 250 degree C or more and has a maximum intensity at about 350 degree C. This means that the BGZ1136 was not subjected to heat over the heating for 5 minutes at 250 degree C in the Chi-Chi earthquake. This conclusion from the E_1' center is consistent with that from the FMR signal of maghemite. The E_1' center exactly suggests that frictional heat over 400 degree C detected from the BGZ1136 may have been generated earlier than the Chi-Chi earthquake. Moreover, thermochronological analyses using the E_1' center reveal that the black gouge may have been produced by ancient frictional heating older than 50 ka. The ESR thermochronology may allow us to identify coseismic frictional heating events of ~1 ka in deep drill cores.

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