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Detection of seismic frictional heat using scanning ESR microscopy

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The estimate of seismic frictional heat is important to evaluate the total earthquake energy budget. The frictional heat strongly depends on the width of heat generation, so that we need to determine it to exactly estimate the frictional heat from a fault rock. In addition, we must sequentially detect the index of the frictional heat at a resolution of 1 mm or less. In this study, I will explain how to detect the frictional heat from the ESR signals as indices of frictional heat and how to determine the width of heat generation using scanning ESR (electron spin resonance) microscopy. The fault rocks studied are a crushing-originated pseudotachylyte distributed in the Nojima fault zone, Hyogo Prefecture and a melting-originated pseudotachylyte in the Uchinoura shear zone, Kagoshima Prefecture, and besides indurated black materials in the Taiwan Chelungpu fault deep drill Hole B cores (Ma et al., 2006).

The target signals for the detection of frictional heat are FMR (ferrimagnetic resonance) signals produced from iron-bearing minerals and a paramagnetic organic radical produced from organic materials by thermal decomposition during frictional heating. A distinctive FMR signal is detected from the Nojima pseudotachylyte, whose source rock is the granitic fault gouge. Its magnetic source was considered to be maghemite (gamma-Fe_2O_3) with low crystallinity produced by the thermal dehydration of lepidocrocite (gamma-FeOOH) in the fault gouge on the basis of its g-value and lineshape (Fukuchi et al., 2007). However, detailed analyses of ESR spectra indicate that magnetite (Fe_3O_4) with low crystallinity produced by instantaneously thermal decomposition of siderite ($FeCO_3$) also shows the similar g-value and lineshape. If taking account of the initial temperature (about 200 degree C) at the time of formation of the Nojima pseudotachylyte, lepidocrocite cannot stably exist under such high temperature. Therefore, the magnetic source of the FMR signal may be derived from magnetite with low crystallinity produced by thermal decomposition of siderite. The Uchinoura pseudotachylyte whose source rock is the granitic rock also shows a distinctive FMR signal. Since thermal experiments revealed that magnetite can be produced by thermal decomposition of biotite, the magnetic source of the FMR signal may be derived from the biotite-originated magnetite (Fukuchi, 2012). On the other hand, no prominent FMR signal is detected from the black material in the Taiwan Chelungpu fault zone, so that I use a paramagnetic organic radical (g=2.004), which may be produced by thermal decomposition of organic materials in muddy stone.

The scanning ESR microscope used for the detection of frictional heat has a TE_{111} mode cavity with a pinhole of 1.6-2.6mm in diameter and an internal 100kHz modulation coil that improves the detection sensitivity. At this stage, the resolution of detection is estimated at 0.1 mm. 2-Dimensional ESR analyses indicate that the multiple peaks of FMR signal intensity having resulted from ancient frictional heating events are detected from the Nojima pseudotachylyte and the width of heat generation is estimated at 0.5-1.0 mm. In case of the Uchinoura pseudotachylyte, the contacting part with an intrusion vein shows very high FMR signal intensity, while the inner part of the intrusion vein has almost uniform and low signal intensity. Since FMR signals disappear just at the moment their magnetic source minerals melt, we can judge the origin of pseudotachylyte (melting or crushing) from the FMR signal intensity and distribution inside the pseudotachylyte vein. On the other hand, the black material in the Chelungpu fault zone shows a higher 2-D intensity of organic radical than its source rock.

Keywords: electron spin resonance, ferrimagnetic resonance, ESR microscopy, organic radical, earthquake, frictional heat