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Apatite and zircon fission-track dating from the Hirabayashi-NIED borehole, Nojima Fault, Japan: Evidence for anomalous heating in fracture zones

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Abstract

Fission-track (FT) analysis using apatite and zircon was performed on samples from two fracture zones (FZ) at the depths of 1140 and 1310 m within the 1838 m borehole core penetrating the Ryoke Granitic Rocks in the Nojima Fault at Nojima-Hirabayashi, Awaji Island, Japan, drilled just after the 1995 Hyogo-ken Nanbu earthquake. Clear discordance in apatite and zircon FT age was found for two samples located at ~2 m below the central part of each FZs where the presence of pseudotachylyte and/or fault gouge would predict the largest amount of slip. Asymmetric distribution was identified by discordant ages with respect to the central part of FZs. These very local discordant ages in the fault reflect thermal anomalies caused by secondary heating with an inferred maximum temperature in the region between apatite and zircon closure temperatures at a time post-48 Ma. As a source of the secondary heating, heat transfer or dispersion via geothermal fluids caused presumably the observed similarity in asymmetric distribution of discordant FT ages at two different FZs. Other samples yield concordant FT zircon and apatite ages and these indicate rapid cooling within the bounds of two closure temperatures of these minerals at ~60 Ma of the Ryoke Granitic Rocks.

Keywords: Thermal anomaly; Fault; Fission track; Nojima fault; Geothermal fluid; Frictional heat

1. Introduction

Thermochronological analysis around active faults using radiometric dating methods may reveal the history of heat generation and transport associated with fault activity in and around fracture zones (FZs), which is important in understanding the dynamics of active faults. There have been several attempts to use thermochronology to demonstrate thermal anomalies around natural faults (e.g., Scholz, 1979; Tagami et al., 1988; Xu and Kamp, 2000; Comacho et al., 2001; d'Alessio et al., 2003), focusing mainly on the broad anomalies produced by the accumulation of heat over geologic time scales. Of various radiometric dating methods, the fission track (FT) method has several merits for thermochronological analysis around active faults (e.g., Gallagher et al., 1998). (1) Environmental factors on minerals such as pressure and fluid acidity other than temperature do not affect FT annealing significantly. (2) Minerals commonly used minerals for analysis (i.e.,

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apatite, zircon) are relatively resistant to weathering so that it is likely to survive under the hydrothermal conditions around FZs. (3) Closure temperatures for FT methods are relatively low (~110 and 240 °C for apatite and zircon, respectively; e.g., Gallagher et al., 1998.) so that they can serve as sensitive indicators for thermal events in the upper crust. (4) FT length measurement allows quantitative analysis of the heating or cooling behavior of rocks by means of inverse modeling of thermal history using laboratory based annealing kinetics. (5) Recent laboratory annealing experiments have confirmed that the zircon FT system is reset under the extreme short-term heating at 1000 °C for one second at which pseudotachylyte is supposed to be formed (Yamada et al., 2003, 2006; Murakami et al., 2006).

Zircon FT thermochronologic analyses were carried out on Cretaceous granitic rocks around the Nojima Fault, activated during the 1995 Hyogo-ken Nanbu earthquake. Tagami et al. (2001) found indication for an ancient thermal anomaly that significantly reduced the mean FT length of samples in the vicinity of the fault plane. Murakami et al. (2002) attributed the reduced mean FT length for samples less than 10 m away from the fault to heat transfer or dispersion via fluids in the deep crustal interior. Murakami and Tagami (2004) measured a zircon FT age of the pseudotachylyte sample collected in the surface trench of the fault. In another study, apatite FT analysis was performed for samples from adjacent to and within the San Gabriel fault zone in southern California by d'Alessio et al. (2003), who concluded no frictional heating along this fault by quantitative investigation of history of the fault activity history, although they found some variability in apatite FT ages adjacent to the fault.

We performed FT dating using both zircon and apatite on granitoid samples around the FZs to assess the possibility of earthquake-related thermal anomalies based on the different thermal property of FTs in two minerals. Samples were collected from the 1838 m borehole core

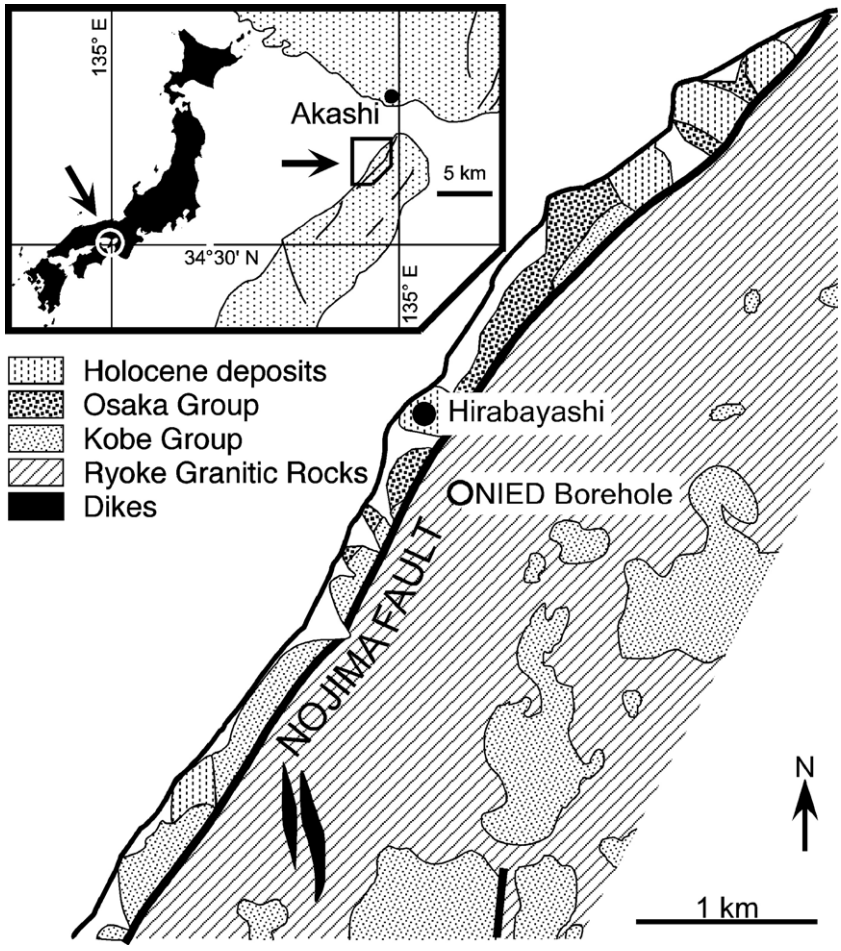

Fig. 1. Geological map showing the Nojima Fault and the drilling site location (34° 34′ 42.9″ N, 134° 58′ 23.6″ E, 65 m altitude). Modified from Mizuno et al. (1990).