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Deciphering viscous flow of frictional melts with the mini-AMS method

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A B S T R A C T

The anisotropy of magnetic susceptibility (AMS) is widely used to analyze magmatic flow in intrusive igneous bodies including plutons, sills and dikes. This method, owing its success to the rapid nature of measurements, provides a proxy for the orientation of markers with shape anisotropy that flow and align in a viscous medium. AMS specimens typically are 25 mm diameter right cylinders or 20 mm on-a-side cubes, representing a volume deemed statistically representative. Here, we present new AMS results, based on significantly smaller cubic specimens, which are 3.5 mm on a side, hence~250 times volumetrically smaller than conventional specimens. We show that, in the case of frictional melts, which inherently have an extremely small grain size, this small volume is in most cases sufficient to characterize the pseudotachylyte fabric, particularly when magnetite is present. Further, we demonstrate that the mini-AMS method provides new opportunities to investigate the details of frictional melt flow in these coseismic miniature melt bodies. This new method offers significant potential to investigate frictional melt flow in pseudotachylyte veins including contributions to the lubrication of faults at shallow to moderate depths.

1. Introduction

The anisotropy of magnetic susceptibility (AMS) provides invaluable insights into flow kinematics, deformation and emplacement of magmatic materials ranging from mafic to silicic melts as well as pyroclastic deposits (e.g., Ernst and Baragar, 1992; Archanjo et al., 1995; Cañón-Tapia et al., 1996; Ferré and Améglio, 2000). Like all petrofabric methods, the AMS method requires the analysis of a large enough number of grains (s.l., ferromagnetic particles as well as paramagnetic silicate minerals) to obtain statistically significant results (e.g., Borradaile and Henry, 1997). Because the average grain size in most igneous rocks ranges from a few millimeters to hundreds of microns in dimension, the volume of AMS specimens typically is about 10 cm^3.

Fault pseudotachylytes generally form relatively thin generation veins, 0.1–10 mm in thickness (e.g., Sibson, 1975; Passchier, 1982; Di Toro and Pennacchioni, 2004), along which melt forms and rapidly quenches during or shortly after an earthquake. AMS could be very useful for determining viscous flow in pseudotachylytes. However, because of their limited volumetric occurrence, the standard sample size of 10 cm^3 is not suitable for AMS studies of pseudotachylytes. Previous attempts to use AMS of fault pseudotachylytes were performed on 10 cm^3 (Nishioka et al., 2005) or ~1 cm^3 (Molina Garza et al., 2009) specimens. These investigations proved somewhat inconclusive most likely because specimens were not small enough to completely exclude host-rock material adjacent to the vein. Recently, Ferré et al. (2015), successfully isolated the AMS fabric in the Val Gilba pseudotachylytes (Italian Alps) from that of the host-rock by measuring 1 cm^3 specimens. These pseudotachylyte veins were relatively thick (>10 mm), which is unlike most of the reported pseudotachylytes in nature that are generally < 10 mm in thickness and consist of ultra-comminuted clasts embedded in an extremely fine-grained quenched matrix. Therefore, to continue these types of investigations a method that

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measures AMS in very small specimens of pseudotachylyte is needed. In this paper, we measure AMS from 3.5 mm cubes ($\approx$0.04 cm^3 volume; 250 times smaller than standard size) and test the consistency of AMS fabric indicative of coseismic slip kinematics.

2. Geologic settings

The fault pseudotachylytes of this study come from four well-studied localities and are hosted by different rock types (Fig. 1).

2.1. Hoping river, Taiwan

The Hoping River pseudotachylyte veins cut across the Tananao mylonitic gneiss complex, in eastern Taiwan, and formed less than 4.1 Ma ago (Chu et al., 2012). The host-rock consists of a quartz-ofeldspathic phengite, biotite and muscovite medium grained high-grade gneiss. The main slip plane forms a generation vein that varies in thickness from 0.1 to 10 mm, extends over 10 m length and records 0.22 m of seismic displacement (Korren et al., 2016). The overall orientation of this generation vein is 025°, 35° W. This vein also displays a clear slip direction, marked by offset piercing points and pseudotachylyte brushline striations at 292°, 35° (Ferré et al., 2016). The oriented sample of this study (HP010P) comes from this vein where the local vein orientation is 146°, 38° SW. The normal sense of seismic slip is determined using offset pinning points and, as shown elsewhere (Ngo et al., 2012), by the obliquity of injection veins with respect to the slip plane. The pseudotachylyte – host rock contact is very sharp over a few microns. Widely dispersed feldspar microcrystallites (0.5–10 μm) generally display a

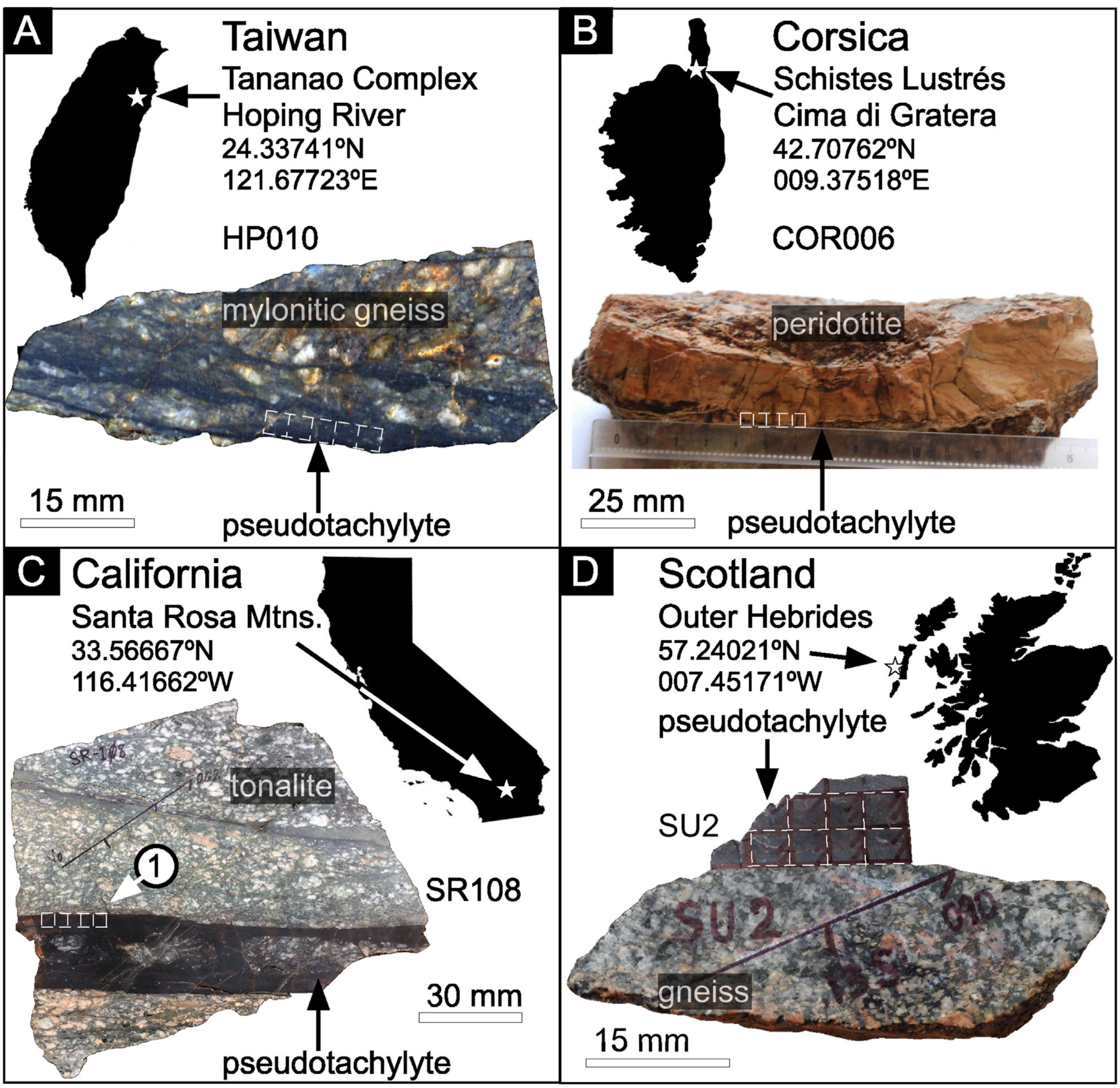

Fig. 1. Location with GPS coordinates of the four pseudotachylyte localities and samples investigated in Taiwan (A), Corsica (B), California (C), and Scotland (D). The white dash lines on the sample show where mini-cube specimens were taken from. The mini-cubes were cut from 3 successive and parallel rows in the direction perpendicular to the plane of the photograph, hence all mini-cubes are at the same distance from the vein margin, except for Scotland where the 7 mini-cubes were stacked as shown.