The age and depth of exhumed friction melts along the Alpine fault, New Zealand

L.N. Warr
Centre de Géochimie de la Surface (CNRS-ULP), 1 rue Blessig, 67084-Strasbourg, France
B.A. van der Pluijm
S. Tourscher
Department of Geological Sciences, University of Michigan, Ann Arbor, Michigan 48109, USA

ABSTRACT

Laser-ablation $^{40}Ar/^{39}Ar$ step-heating analyses of 20 pseudotachylyte veins from a single location along the exhumed central portion of the active Alpine fault of New Zealand yield total gas age values between 1 and 19 Ma. Evidence shows that they are genetically related and were formed during coeval episodes of seismogenic melting at shallow crustal depth, contrasting with a spread in formation ages. The total gas ages show an exponential decrease with increasing proportion of melt matrix and K content, reflecting incomplete degassing and mixtures of radiogenic Ar sources. Calculation of intercepts for all–melted matrix and all–clast end-member components indicate ca. 570 ka (Quaternary) friction-melting ages of ca. 332 Ma (Lower Carboniferous) source rock. Assuming an average exhumation rate of 6–9 mm/yr for uplift and erosion, these results imply that friction melts were generated during major slip episodes at ~3.5–5 km crustal depth. We conclude that reliable dating of young pseudotachylyte can be accomplished by combining chronologic study with clast-matrix quantification of genetically related vein assemblages.

Keywords: $^{40}Ar/^{39}Ar$ dating, pseudotachylyte, coseismic faults, friction melt, Alpine fault.

INTRODUCTION

Pseudotachylyte, the product of friction melting during large-magnitude earthquakes, provides a unique opportunity to study the mechanism, age, and location of coseismic faulting (Sibson, 1975; Di Toro et al., 2006). These clast-ridden melts are known to form under a variety of conditions, ranging from deep-crustal faulting to landslides at the surface (Masch et al., 1985; Magloughlin and Spray, 1992). Despite their diverse occurrence, it remains a key challenge to isotopically date these melts and catalog large paleoseismic events of the geological record in time and space. In cases where the rate of fault exhumation is constrained, accurate age determinations of pseudotachylyte can also provide depth estimates for friction melting.

The principal method used for dating friction melts in crustal fault zones is the $^{40}Ar/^{39}Ar$ isotopic technique, determined by step-heating or laser-ablation methods (Merrihue and Turner, 1966; Magloughlin et al., 2001; Sherlock and Hetzel, 2001; Mueller et al., 2002; Di Vincenzo et al., 2004). Determining true formation ages requires that (1) all inherited radiogenic Ar is outgassed from both melt and clast components, (2) no radiogenic Ar is lost after quenching, and (3) no externally derived excess Ar gas accumulates in the sample following crystallization. In the case of natural pseudotachylytes, these conditions are commonly not fulfilled due to the incomplete and heterogeneous nature of flash melting and the trapping of Ar-bearing fluid inclusions in clasts (Di Vincenzo et al., 2004).

The complexities of interpreting "apparent age spectra" of friction melting is mirrored both by the relative rarity of simple degassing curves that show well-defined plateau ages and by the significant variations in total gas age measured on pseudotachylyte veins (Kohut and Sherlock, 2003). Despite these problems, significant age determinations have been obtained by laser-probe dating of melted matrix and assessment of mixed Ar sources as indicated by elevated Ca/K and Cl/K ratios (Sherlock and Hetzel, 2001; Mueller et al., 2002). The successful dating of young pseudotachylytes presents a particular challenge because the amount of radiogenic Ar is too low for effective laser probing of the vein matrix. Here, $^{40}Ar/^{39}Ar$ laser-ablation study of small matrix-rich rock fragments appears to be the best approach (Magloughlin et al., 2001; Warr et al., 2003).

In this study, we examine $^{40}Ar/^{39}Ar$ variations of 20 geologically young pseudotachylyte veins collected from a single location along the central section of the Alpine fault, New Zealand, in order to determine the true age and crustal depth distribution of friction melting. This area is of interest because previously analyzed pseudotachylytes have displayed a large range of isotopic ages in well-developed veins (Adams, 1981; Warr et al., 2003), and the region has a well-constrained exhumation history over the last 5 m.y. (Batt et al., 2000). Our objective was to test whether the friction melts of seemingly different ages were generated at various crustal depths or whether the melts were coeval and formed at a specific time and depth during the exhumation history of the fault. The latter would require an alternative explanation for the range in observed ages that is not related to variable-depth melting. Based on the mineralogic, isotopic, and geochemical variations found during this study, we demonstrate that all sampled pseudotachylytes are genetically related and formed during the Quaternary, within a single shallow-crustal generation zone along the Alpine fault.

GEOLOGICAL SETTING AND PSEUDOTACHYLYTE SAMPLES

The Alpine fault represents an active, oblique-slip segment of the Australia-Pacific plate boundary (Fig. 1A). The central section is characterized by a steep thrust geometry with high rates of dextral strike-slip displacement (27 ± 5 mm/yr) and rapid exhumation of Pacific hanging-wall rocks at rates as high as 10 mm/yr (Cooper and Norris, 1994; Norris and Cooper, 2001).

The 20 pseudotachylytes analyzed here were collected to the east of Hari Hari, mainly from boulder material washed down from the fault trace along Harold Creek (Fig. 1A). Fault zones exposed in large boulders typically contain parallel sets of thin planar melt-generation