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Crystal fractionation in the friction melts of seismic faults (Alpine Fault, New Zealand)

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Abstract

Compositional variations are documented in friction melts along the Hari Hari section of the Alpine Fault, New Zealand, with multiple stages of melt injection into quartzo-feldspathic schists. Intermediate to felsic melts were heterogeneous in composition, but all fractions show a common trend, with a tendency for the younger melt layers and glasses to be more alkali – (Na+K) and Si-enriched, while being depleted in mafic (Fe+Mg+Mn) components. These changes are attributed primarily to crystal fractionation of the melt during transport. Farther traveled molten layers were on the whole less viscous, mostly due to a higher melt-to-clast ratio; however, compositional change, together with a decrease in volatile content, produced a progressively more viscous liquid melt with time. The glass phase is interpreted as a remnant of this high viscosity felsic residual melt that was preserved during final quenching. Following initial failure, the formation of largely phyllosilicate-derived, volatile-rich, lower viscosity melt corresponds with a phase of fault weakening. Subsequent rapid crystal fractionation during melt transport, the loss of volatiles and freezing of residual melt contributed to the strengthening of the fault during seismic slip.

Keywords: Pseudotachylyte; Friction melting; Crystal fractionation; Glass; Alpine Fault; Lubrication

1. Introduction

There is increasing realization that liquid melt generated by friction in the Earth's crust plays an important role in influencing the seismic and mechanical behavior of fault planes (e.g., Sibson, 1975). Frictional experiments in the laboratory have demonstrated how molten material can accumulate along a displacement surface to produce low viscosity melts that may lubricate the planes of displacement (Spray, 1993; Hirose and Shimamoto, 2003). Despite early recognition of the potential importance of the melt layer (e.g., Jeffery, 1942), we still know little about how it influences the behavior of faults.

One promising approach to reconstructing the properties of the molten material is to study the chemical composition of pseudotachylyte veins

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(Magloughlin and Spray, 1992). A significant number of studies have compared the compositional differences between host rock, veins and clast-free matrix, based on analyses of both major- and trace-element concentrations (Maddock, 1992; Magloughlin, 1992; O'Hara, 1992). Other investigations attempted to characterize the composition of material of a glassy appearance (Toyoshima, 1990; Bossière, 1991; Magloughlin, 1992), although the identification of true glass phases often remains ambiguous due to the extremely fine-grain size of pseudotachylyte material. Possibly the most convincing study of glass and its composition has been documented from the Fuyan Fault of northwest China (Lin, 1994).

In this paper, we investigate compositional changes in natural pseudotachylytes that occur in friction-induced melt along the Alpine Fault of New Zealand. Variations in composition are highlighted at a range of scales for multiple injections of melt and glass phases of two intermediate to felsic samples that intruded into quartzo-feldspathic host rocks. Such variations, in addition to crystallization textures observed by electron microscopy, indicate that crystal fractionation of the friction melt occurred during transport of the molten material. The resultant melt heterogeneities are discussed in terms of the frictional behavior of rocks in recent laboratory experiments (Tsutsumi and Shimamoto, 1997; Hirose and Shimamoto, 2003) and their influence on the mechanical behavior of seismic faulting is considered.

2. Alpine Fault pseudotachylyte (Hari Hari, NZ)

The two pseudotachylyte samples investigated were collected along the central part of the Alpine Fault, which crosses the South Island of New Zealand (Fig. 1a). This fault represents an active transcurrent segment of the Australian–Pacific plate boundary. The central section is characterized by a steep thrust geometry with high rates of oblique-slip displacement, and rapid exhumation of Pacific hanging wall-rocks at rates ~10 mm/year (Cooper and Norris, 1994; Norris and Cooper, 2001).

Examples of pseudotachylyte veins and their structural relationships along the Alpine Fault have been documented by Reed (1964), Wallace (1976), Sibson et al. (1979) and Bossière (1991). The samples

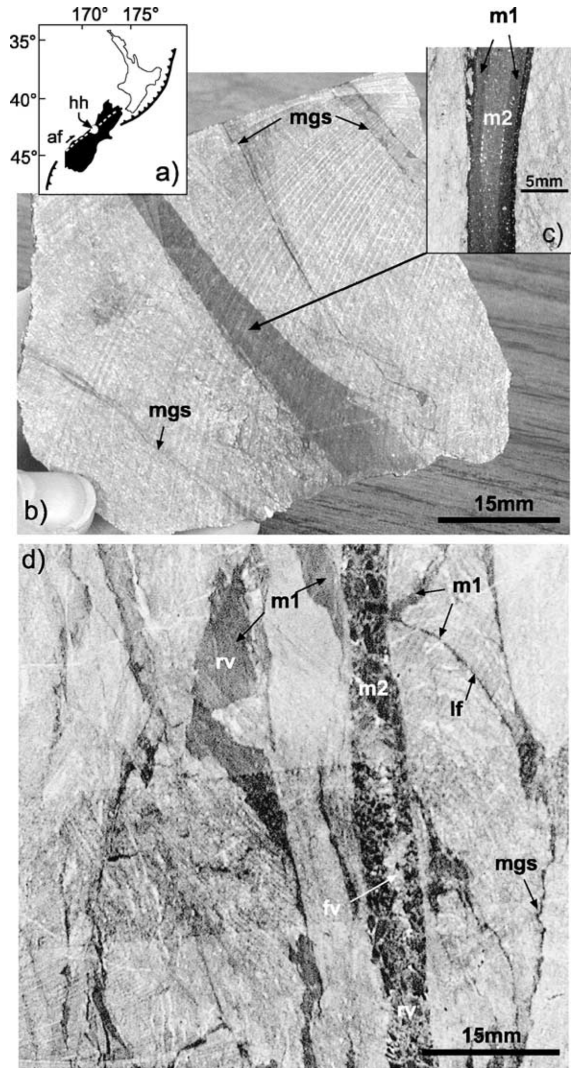

Fig. 1. (a) Map of New Zealand showing the location of pseudotachylyte veins (white point) along the Alpine Fault (af). hh = town of Hari Hari. (b) Photograph of a cut hand specimen of mylonitized quartzo-feldspathic, biotite–muscovite schist containing a layered vein structure studied in detail by Warr et al. (2003). (c) Thin section across the vein. The outer margins are considered to represent a more proximally derived melt layer (m1), which has been intruded by a more distally derived melt pulse (m2) characterized by cyclic frictional melting. (d) Foliated rock specimen of a green, mylonitized quartzo-feldspathic schist, containing cross-cutting vein structures. Note the mixture of melt generation surfaces (mgs), some of which are listric fractures (lf) that cross-cut the rock fabric. Reservoir veins (rv) are notably thicker and occasionally fractured (fv = fractured vein). The marks on the surface of the samples are cutting artifacts.