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# The origin of high magnetic remanence in fault pseudotachylites: Theoretical considerations and implication for coseismic electrical currents

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## Abstract

Several examples of fault-related pseudotachylites display a significantly higher initial magnetic susceptibility than their granitic host rock (10:1 to 20:1). These higher values are attributed to the presence of fine magnetic particles formed during melt quenching. The hysteresis properties of the particles indicate a single domain (SD) to pseudo single domain (PSD) magnetic grain size. The Curie temperature (Tc) of the magnetic particles is close to 580 °C.

The natural remanent magnetization (NRM) of these pseudotachylites is also significantly higher than that of the host rock (up to 300:1). Such anomalously high remanence cannot be explained by a magnetization acquired in the Earth's magnetic field, regardless of pseudotachylite age.

Ground lightning and other strong electric pulses can cause anomalously high NRM intensities. A ground lightning explanation seems unlikely to explain the systematically high NRM intensities, particularly in the case of recently exposed samples that have been collected from active quarries. Alternatively, high NRM intensities could be explained by earthquake lightning (EQL), a seismic phenomenon occasionally reported in connection with large magnitude earthquakes ($M>6.0$).

The coseismic electrical properties of the pseudotachylite vein–host rock system are characterized by (1) a core of molten material (high conductivity), (2) vapor-rich margins of thermally and mechanically fractured host rocks (low conductivity) and (3) moderately fractured to undeformed host rock (normal conductivity). Such a core conductor bordered by insulating margins is potentially responsible for the propagation of EQL pulses.

The coseismic thermal history of pseudotachylite veins has been modeled in 2-D using conductive heat transfer equations. It shows that EQL can be recorded only during a brief time interval (less than 1 min) for a given vein thickness and host-rock

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temperatures. If the vein is too thick or if the host rock is too hot, the pseudotachylite remains above Tc after the electric pulse has lapsed.


*Keywords:* Pseudotachylite; NRM; Coseismic; Earthquake; Electrical current

## 1. Introduction

Pseudotachylites are dark fine-grained to glassy rocks formed by frictional melting along a fault plane during seismic deformation (e.g., Philpotts, 1964; Sibson, 1975; Spray, 1992), or at the sole of very large landslides (Legros et al., 2000; Lin et al., 2001) or by shock metamorphism and friction during asteroid impact on rocky planets (Shand, 1916; French, 1998; Spray, 1992). Our investigations are restricted to the first type, which form veins of a few millimeters to a few centimeters in width. Pseudotachylite veins related to seismic deformation are found mostly in the upper continental crust (e.g., McNulty, 1995) although examples of deep-seated veins have been reported (e.g., Austrheim and Boundy, 1994; Lin et al., 2003). Frictional melting depends primarily on the fault's slip rate, displacement, friction coefficient, normal stress and fault rocks physical properties (density, thermal conductivity, specific heat).

Many fault-related pseudotachylites and gouges exhibit distinctively high natural remanent magnetization (NRM) carried by single domain to pseudo single domain magnetite (e.g., Piper, 1981; Piper and Poppleton, 1988; Enomoto and Zheng, 1998; Enomoto et al., 2001; Nakamura and Nagahama, 2001; Nakamura et al., 2002). Subsequent alteration may lead to the formation of hematite (e.g., O'Hara and Sharp, 2001). The Earth's average magnetic field ($\approx 0.045$ mT) typically produces NRMs in the order of 0.15 A $m^2$/kg in basalts and basaltic glasses. In first approximation, in order to produce he high NRMs observed in many pseudotachylites ($J > 200$ A $m^2$/kg; references herein), a field intensity of about 60 mT would be required. This is clearly orders of magnitude larger than what has been generated by the terrestrial dipole source at any given time in the geologic record.

Very large fields can be generated by electrical arcs such as ground lightnings (e.g., Verrier and Rochette, 2002). Such events produce an isothermal remanent magnetization [IRM] (e.g. Dunlop and Özdemir, 1997). Nevertheless, it is statistically unlikely that most pseudotachylite veins would have been struck by lightning bolts, especially those exposed in recent quarries or tunnels. An alternative source of IRM might be earthquake lightnings which commonly occur during $M > 6$ earthquakes near the fault plane (Derr, 1973; Persinger and Derr, 1983; Ouellet, 1990; Tsukuda, 1997). These phenomena are white bluish glows and lights observed in the atmosphere right above a rupture surface during an earthquake. Such lights radiate in the visible range of the electromagnetic spectrum and last up to a few minutes. Earthquake lights have been observed in remote areas (e.g., Derr, 1973) and therefore cannot be systematically attributed to accidental failure of the power grid. The causative link between coseismic electric currents and earthquake lightnings has not been fully demonstrated yet but the presence of charred plant roots discovered near the surface, along the rupture surface of the Nojima fault, after the 1995 Kobe earthquake, suggests that an electrical bolt was involved (Enomoto and Zheng, 1998).

Regardless of the process responsible for their generation, coseismic electric currents should result in the acquisition of an isothermal remanent magnetization [IRM] (e.g. Dunlop and Özdemir, 1997) in the rocks along or near the fault plane. However, due to the transient nature of these natural currents, their record in the remanent magnetization may depend upon several factors including power of the source, distance to the fault, geometry of the veins, size and nature of the magnetic carrier(s) and temperature in the fault zone.

In the following, we propose a theoretical framework to evaluate the influence of some of these factors on the paleomagnetic record of coseismic currents in pseudotachylite veins.