Available online at www.sciencedirect.com
SCIENCE DIRECT®
Tectonophysics 402 (2005) 3–20
TECTONOPHYSICS
www.elsevier.com/locate/tecto

Can pseudotachylytes be used to infer earthquake source parameters? An example of limitations in the study of exhumed faults

Giulio Di Toro[a,*], Giorgio Pennacchioni[a,b], Giordano Teza[a]

[a]Universita' di Padova, Dipartimento di Geologia, Paleontologia e Geofisica, Via Giotto 1, 35137 Padova, Italy
[b]CNR Istituto di Geoscienze e Georisorse (Sezione di Padova), Italy

Received 28 April 2004; received in revised form 9 August 2004; accepted 25 February 2005
Available online 29 April 2005

Abstract

Tectonic pseudotachylytes might be used to constrain earthquake source parameters, such as dynamic shear stress resistance, average dynamic friction and slip-weakening distance. Estimation of dynamic shear stress resistance and dynamic friction from field studies is based on the assumption that the volume of melt produced during coseismic slip is proportional to the frictional work converted to heat on the fault surface. Conditions conducive to a realistic estimate of dynamic shear resistance are: (i) the presence of large outcrop exposures that allow for estimation of the volume of pseudotachylyte; (ii) the presence of structural markers offset by faults in order to relate the displacement accommodated by the fault with the volume of melt produced; (iii) data that provide an estimate of the initial melt temperature; and (iv) determination of host-rock temperature and pressure conditions that may have existed during seismic faulting. An independent indication that steady-state friction in the presence of melts might be achieved during coseismic slip arises from the dependence of the fractal dimension of the fault profile (intersection of the fault surface with the outcrop surface) with displacement. This relation could also indicate the slip-weakening distance (Hirose, T., Shimamoto, T., 2003. Fractal dimension of molten surfaces as a possible parameter to infer the slip-weakening distance of faults from natural pseudotachylytes. Journal of Structural Geology 25, 1569–1574).

The above conditions are all satisfied in the case of the Gole Larghe Fault Zone, which consists of hundreds subparallel strike-slip faults that cut tonalites of the Adamello batholith (Italy). The thickness of pseudotachylyte-bearing faults increases with displacement. From displacement/thickness ratios and energy balance calculations, we determined the dynamic shear resistance for several pseudotachylyte-bearing faults. In the same faults, the fractal dimension of the fault profile increases from 1.0 to 1.16 with displacement. This was also observed in experiments where steady-state friction in the presence of melt was achieved (Hirose, T., Shimamoto, T., 2003. Fractal dimension of molten surfaces as a possible parameter to infer the slip-weakening distance of faults from natural pseudotachylytes. Journal of Structural Geology 25, 1569–1574). However, we will show that the estimate of the dynamic shear stress resistance, average dynamic friction and slip-weakening distance in the studied faults is limited by the uncertainties to attribute the measured displacement to a single seismic rupture. Since many

* Corresponding author. Tel.: +39 049 8273941; fax: +39 049 8272070.
E-mail address: giulio.ditoro@unipd.it (G. Di Toro).

doi:10.1016/j.tecto.2004.10.014

pseudotachylytes in the upper seismogenic crust overprint preexisting cataclasites, it is suggested that future field and experimental work should be addressed to determine microstructural indicators (i.e. evolution of cataclastic fabric with displacement) within cataclasites, which might constrain the contribution of the cataclastic, pre-pseudotachylyte displacement to the total displacement accommodated by the fault.

Keywords: Pseudotachylyte; Earthquake; Dynamic shear stress; Slip-weakening; Fractal surface; Thickness–displacement ratio

1. Introduction

In earthquake mechanics, the estimate of the dynamic shear stress τ_f during coseismic slip is difficult since its absolute value cannot be determined by seismological methods (Kanamori, 1994). The magnitude of τ_f determines the amount of coseismic dynamic stress drop (e.g. Scholz, 1990; Kanamori, 1994; Bouchon, 1997; Kanamori and Heaton, 2000) and of seismic energy dissipated during earthquakes (e.g. McGarr, 1999). A low value for τ_f might also explain the debated weakness of some major mature faults (e.g. Brune et al., 1969; Lachenbruch and Sass, 1980; Chester et al., 1993; Scholz, 2000; d'Alessio et al., 2003). Several dynamic weakening mechanisms have been invoked to explain low τ_f during coseismic slip, such as thermally induced pore pressure rise (Lachenbruch, 1980), normal interface vibration (Brune et al., 1993), acoustic fluidization (Melosh, 1996), hydrodynamic lubrication (Brodsky and Kanamori, 2001) and thixotropic behavior of silica gels (Di Toro et al., 2004). The local presence of pseudotachylytes along exhumed fault zones suggests that friction-induced melts can be produced during an earthquake (Jeffreys, 1942) and that fault weakening may also result by melt lubrication (Sibson, 1975; Spray, 1993).

Experimental simulation of earthquake conditions is difficult given the high slip rates (i.e. 1–3 m s^{-1}), the high normal stresses (e.g. 50–500 MPa) and the large displacements (up to 10 m) attained during coseismic slip. In experiments conducted at about seismic slip rates (0.85–1.60 m s^{-1}), but lower normal stresses (<2 MPa) than in real earthquakes, values of the friction coefficient μ of 0.5–0.6 were measured in gabbro and monzodiorite concomitant with the production of friction-induced melts (Tsutsumi and Shimamoto, 1997; Hirose and Shimamoto, 2003). Actually, these values for μ are only slightly lower the those (0.6–0.85) measured in experiments conducted at low sliding speeds (<10 μm/s) and short displacements (<10 mm) over a wide range of pressures and temperatures in different rock types (Stesky et al., 1974; Byerlee, 1978). The slight decrease in the μ observed from the high slip rate (pseudotachylyte-producing) experiments to the low slip rate ones apparently suggests that friction-induced melts cannot produce large fault weakening and that friction-induced melts only partially lubricate fault surfaces. In these experiments, however, rock samples were not confined laterally and melt could escape from the sliding surface leading to rock–rock interaction. In nature, values of μ lower than 0.6 may potentially be achieved when friction-induced melts are produced and remain along the fault surface. In their experiments conducted at coseismic slip rates, Hirose and Shimamoto (2003) observed that the fractal dimension of a melt-decorated sliding surface increased from 1.0 to 1.1 when, with increasing slip, a steady-state value of μ of 0.6 was achieved. This correlation between the fractal dimension of fault surface and the critical displacement necessary to achieve a constant μ may provide a method to constrain the slip-weakening distance (d_c), which is a critical parameter for earthquake instability (e.g. Scholz, 1990).

Pseudotachylytes consist of lithic clasts suspended in a glassy-cryptocrystalline matrix (Shand, 1916). The bulk composition of most pseudotachylytes is slightly more mafic than the parent host rock (e.g. Shand, 1916; Philpotts, 1964; Maddock, 1992) and, in many cases, the matrix of pseudotachylytes has an andesitic/basaltic composition (e.g. Sibson, 1975; Maddock, 1992; Spray, 1993). This would imply a low melt viscosity and, as a consequence, a low value of the shear resistance during sliding along a fault plane lubricated by a friction-induced melt, although the presence of lithic clasts or vapor bubbles may significantly increase the melt viscosity by several