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Fault–valve action and vein development during strike–slip faulting: An example from the Ribeira Shear Zone, Southeastern Brazil

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Abstract

Fluid inclusion microthermometry and structural data are presented for quartz vein systems of a major dextral transcurrent shear zone of Neoproterozoic–Cambrian age in the Ribeira River Valley area, southeastern Brazil. Geometric and microstructural constraints indicate that foliation–parallel and extensional veins were formed during dextral strike–slip faulting. Both vein systems are formed essentially by quartz and lesser contents of sulfides and carbonates, and were crystallized in the presence of CO_2–CH_4 and H_2O–CO_2–CH_4–NaCl immiscible fluids following unmixing from a homogeneous parental fluid. Contrasting fluid entrapment conditions indicate that the two vein systems were formed in different structural levels. Foliation–parallel veins were precipitated beneath the seismogenic zone under pressure fluctuating from moderately sublithostatic to moderately subhydrostatic values (319–397 °C and 47–215 MPa), which is compatible with predicted fluid pressure cycle curves derived from fault–valve action. Growth of extensional veins occurred in shallower structural levels, under pressure fluctuating from near hydrostatic to moderately subhydrostatic values (207–218 °C and 18–74 MPa), which indicate that precipitation occurred within the near surface hydrostatically pressured seismogenic zone. Fluid immiscibility and precipitation of quartz in foliation–parallel veins resulted from fluid pressure drop immediately after earthquake rupture. Fluid immiscibility following a local pressure drop during extensional veining occurred in pre-seismic stages in response to the development of fracture porosity in the dilatant zone. Late stages of fluid circulation within the fault zone are represented dominantly by low to high salinity (0.2 to 44 wt.% equivalent NaCl) H_2O–NaCl–$CaCl_2$ fluid inclusions trapped in healed fractures mainly in foliation–parallel veins, which also exhibit subordinate H_2O–NaCl–$CaCl_2$, CO_2–(CH_4) and H_2O–CO_2–(CH_4)–NaCl fluid inclusions trapped under subsolvus conditions in single healed microcracks. Recurrent circulation of aqueous–carbonic fluids and aqueous fluids of highly contrasting salinities during veining and post-veining stages suggests that fluids of different reservoirs were pumped to the ruptured fault zone during faulting episodes. A fluid evolution trending toward CH_4 depletion for CO_2–CH_4–bearing fluids and salinity depletion and dilution (approximation of the system H_2O–NaCl) for aqueous–saline fluids occurred concomitantly with decrease in temperature and pressure related to fluid entrapment in progressively shallower structural levels reflecting the shear zone exhumation history.

Keywords: Fluid inclusion; Fault-related veins; Fault–valve action; Fluid pressure fluctuation; Fluid immiscibility; Earthquake cycle

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1. Introduction

Hydrothermal vein systems are common features in ancient shear zones, and frequently form mineral deposits of economic importance, particularly lode–gold deposits (*e.g.* Bonnemaison and Marcoux, 1990; Ronde et al., 1992). In the past the faults were considered only as passive channels or barriers for fluid percolation. Sibson et al. (1975) were the first to relate hydrothermal veining with earthquake cycles demonstrating that seismic faults have an active role in the transport and precipitation of veins. Nowadays, extensive veining such as the gold-bearing quartz veins in mesothermal gold deposits (*e.g.* Cox et al., 1986, 1991; Boullier and Robert, 1992; Robert et al., 1995; Dugdale and Hagemann, 2001) has been related to coupled cyclic variations in tectonic stress and fluid pressure correlated with earthquake cycles. This mechanism, denominated seismic pumping (Sibson et al., 1975) or fault–valve behavior (Sibson et al., 1988), has been corroborated by several studies (*e.g.* Sibson, 1990; Parry and Bruhn, 1990; Parry et al., 1991; Boullier and Robert, 1992; Robert et al., 1995; Cox, 1995; Sibson, 1996; Henderson and MacCaig, 1996; Nguyen et al., 1998; Sibson and Scott, 1998; Sibson, 2000; Dugdale and Hagemann, 2001; Montomoli et al., 2001; Sibson,

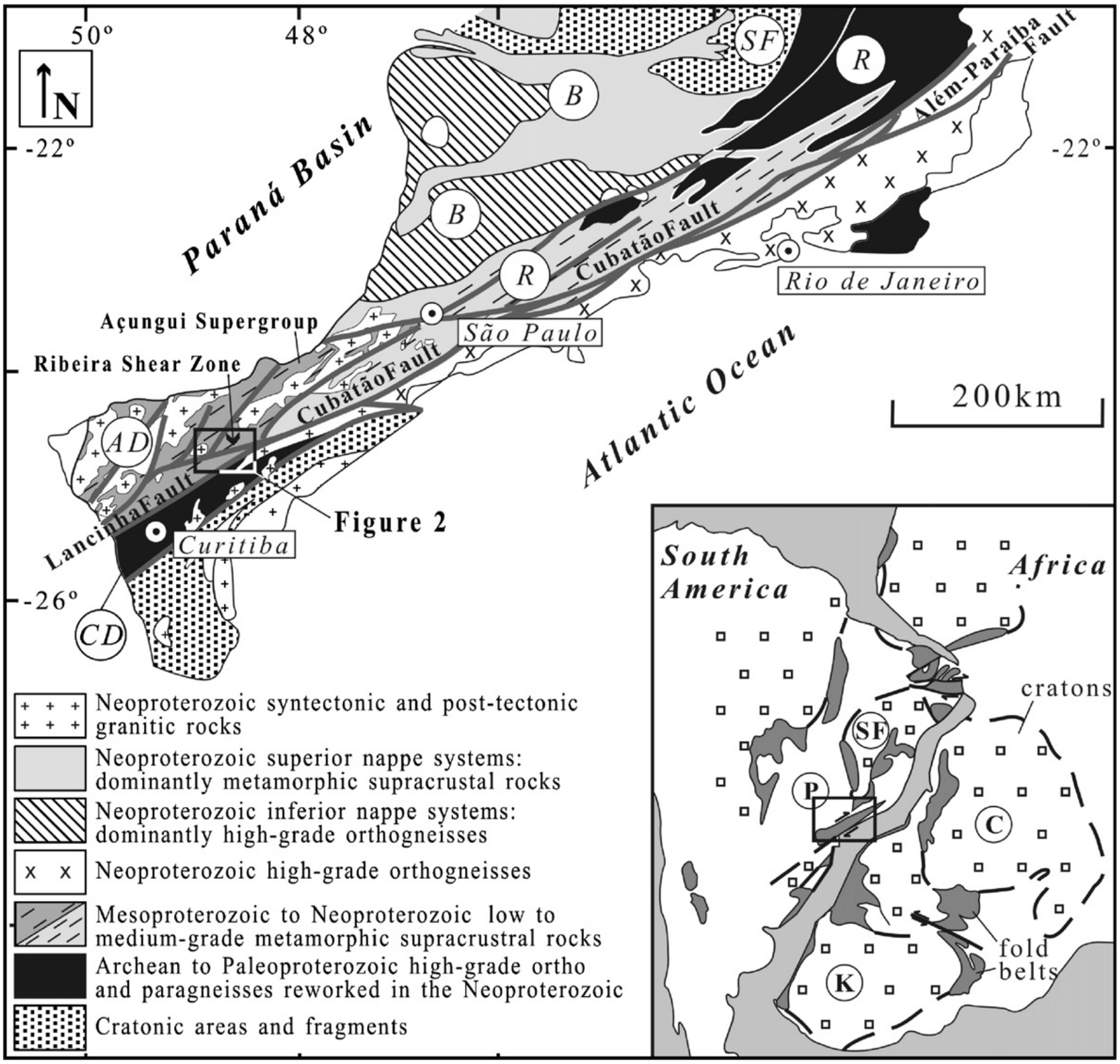

Fig. 1. Geotectonic sketch map of the Southeastern Brazil (modified after Campanha and Sadowski, 1999). Cratonic areas: São Francisco (SF); Paranapanema (P); Congo (C); Kalahari (K). Neoproterozoic fold belts: Ribeira Belt (R) including the Apiaí Domain (AD) in its southern portion; Brasília Belt (B). The Curitiba Domain (CD) comprises mainly Paleoproterozoic high-grade orthogneisses intensely reworked in the Neoproterozoic.