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Evidence of Ediacaran glaciation in southernmost Brazil through magmatic to meteoric fluid circulation in the porphyry–epithermal Au–Cu deposits of Lavras do Sul

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ABSTRACT

The Lavras do Sul Au–Cu mining district, southern Brazil, hosts an Ediacaran plutonic–volcanic association with hydrothermal alteration. This association is interpreted as a *ca.* 600–580 Ma tilted porphyry–epithermal system, where the main ore occurs in phyllic and intermediate argillic halos around quartz veins.

In this paper we used detailed field mapping, fluid inclusion microthermometry, oxygen and hydrogen isotope measurements of whole-rocks, feldspars, clay minerals and quartz from propylitic, phyllic and intermediate argillic alteration to reconstruct the hydrothermal fluid temperatures and compositions. The results showed that the deeper zones of the hydrothermal system were predominantly influenced by magmatic fluid and its shallower zones by meteoric water with very negative $\delta^{18}O$ compositions. Our data support a model of mixing between magmatic-derived fluids with meteoric waters of glacial origin. Based on stable isotope data we propose indirect evidence of high latitude position for the study area during Brasiliano/Pan-African convergence of the Kalahari and Rio de La Plata cratons.

1. Introduction

There are no current references in the literature dealing with Neoproterozoic Brazilian porphyries and their epithermal deposits formed during the Ediacaran Period (630–542 Ma). Known examples of similar deposits in North and South Brazil include respectively the *ca.* 1.8 Ga porphyry and epithermal deposits from Tapajós Gold Province (Juliani et al., 2005), as well as epithermal deposits from the Castro basin (Seoane and Silva, 1999) dated at *ca.* 543 Ma (Cordani et al., 1999).

In the Lavras do Sul (LS) mining district (Rio Grande do Sul State, southern Brazil) crops out over hundred square kilometers of very well preserved, undeformed and unmetamorphosed Ediacaran plutonic–volcanic association with numerous hydrothermal Au–Cu mineralizations (Fig. 1). These magmatic events occurred during the late- to post-collisional stages of the Brasiliano/Pan-African Orogeny (e.g. Chemale, 2000; Gray et al., 2008; Fig. 1) associated with the amalgamation of western Gondwana (Trompette, 1997; Cawood et al., 2001; Meert, 2003). Based on descriptions of possible glaciogenic diamictites nearby Lavras do Sul, Bocchi (1970) and Eerola (2007) suggested previously that the study area was influenced by cold climate conditions between *ca.* 600 and 580 Ma.

Ore exploration studies at LS area focused on N40°E to E–W lineaments, which host numerous quartz veins/breccias associated with wall-rock alteration halos in both granitic and volcanic rocks, containing "sericite", chlorite, pyrite, chalcopyrite and Au–Cu ore (Carvalho, 1932; Teixeira and Leinz, 1942; Kaul and Rheinheimer, 1974). Bongiolo et al. (2008) indicated that hydrothermal ore deposition followed the main stage of magmatic activity in the studied area (606–595 Ma; Gastal et al., 2006). Based on the overall distribution of phyllic and intermediate argillic (IA) mineralogy in fracture-controlled sites, the LS district was interpreted by Bongiolo et al. (2008) as tilted porphyry containing epithermal deposits with

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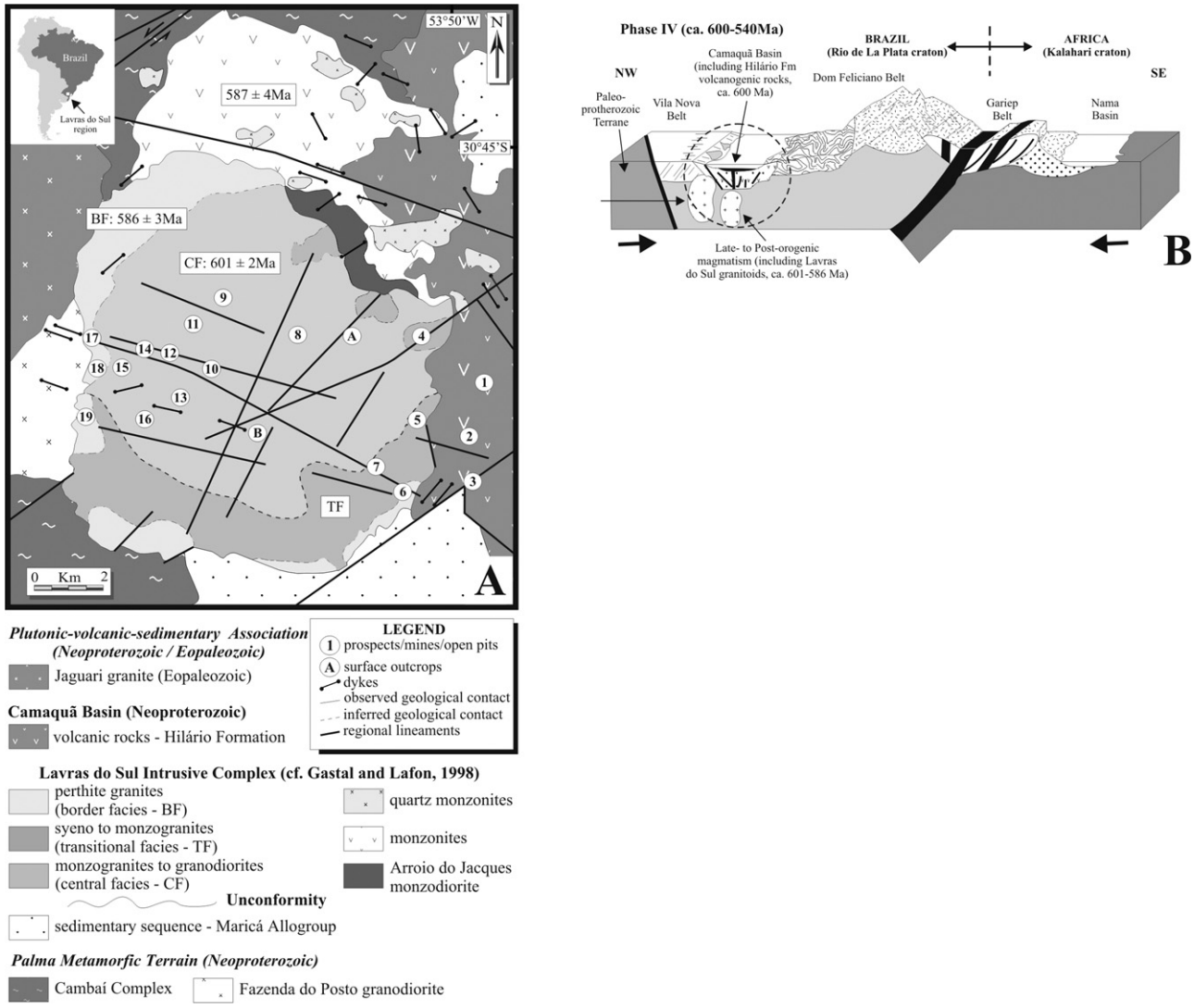

Fig. 1. Location of the studied area and geological setting. (A) Simplified geological map of the Lavras do Sul region. Prospects/Mines: (1) Aurora, (2) Bloco do Butiá, (3) Caneleira, (4) Cerrito, (5) Dourada, (6) Galvão, (7) Mato Feio, (8) Olaria, (9) Paredão, (10) Pitangueira, (11) Santo Expedito, (12) São José, (13) Taruman, (14) Valdo Teixeira, (15) Virgínia, (16) Zeca Souza, (17) Cerro Rico, (18) Saraiva and (19) Volta Grande. Sampling was performed in most prospects (except for 3, 9, 13 and 18) and outcrops (A and B). Modified from Gastal and Lafon (1998). Geochronological data from Liz (2008) and Gastal et al. (2006). (B) The late- to post-tectonic granitoids from Lavras do Sul are coeval with the volcanic rocks (Hilário Formation) from Camaquã basin. They occur in a hinterland environment developed due to the amalgamation of Kalahari (Africa) and Rio de La Plata cratons during the Neoproterozoic Ediacaran Period. Tectonic model (not to scale) from Chemale (2000).

telescoped alteration features developed during the waning phase of a large hydrothermal system.

We used mineralogical data, fluid inclusion microthermometry and stable isotope (O, H) data of unaltered and altered rocks, clay minerals and quartz veins to reconstruct temperature and isotopic composition of fluids responsible for hydrothermal alteration and associated Au–Cu ores in the Lavras do Sul area.

2. Geological setting

The southernmost Brazilian shield is compartmented in four geotectonic units: (i) Taquarembó Block, composed of Archean rocks which were metamorphosed in amphibolites to granulite facies during the palaeoproterozoic; (ii) São Gabriel Arch, comprising intercalation of gneisses, amphibolites, granitoids and low-grade metamorphic rocks (900–700 Ma); (iii) Porongos Belt, composed of palaeoproterozoic metamorphic rocks of greenschist to amphibolites facies, which were reworked at *ca.* 660–580 Ma and covered by the volcano-sedimentary rocks from Camaquã basin (640–450 Ma); and (iv) Pelotas Batolith, comprising granites (630–550 Ma) and subordinate metamorphic rocks.

The magmatic rocks from the Lavras do Sul region include volcanic rocks from the base of the Camaquã volcanic-sedimentary basin (Chemale et al., 1995) which were intruded by several plutonic and subvolcanic bodies (Fig. 1). Plutonic and volcanic rocks of Lavras do Sul were probably derived from a parental shoshonitic basaltic magma mostly through crystal fractionation from decompression melting of a metasomatized mantle (Lima and Nardi, 1998; Nardi and Lima, 2000; Gastal et al., 2005). This magmatic event occurred in late- to post-collisional stages (606–580 Ma; Gastal and Lafon, 1998; Gastal et al., 2005; Raposo and Gastal, 2009; Liz, 2008) of the Brasiliano/Pan-African Orogeny (660–550 Ma; Chemale et al., 1995; Gray et al., 2008; Fig. 1).

The Lavras do Sul granitic complex shows a zonation of its petrographic and geochemical features consisting of a so-called central, transitional and border facies (Nardi, 1984). The central facies – CF (601 ± 2 Ma; Gastal et al., 2006) comprises medium to coarse-grained shoshonitic granodiorites to monzogranites with seriate to porphyritic textures (locations 8–16; Fig. 1), consisting of