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Geological controls of copper, gold and silver in the Serra Geral Group, Realeza region, Paraná, Brazil

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ABSTRACT

The Serra Geral Group has high Cu concentrations in southern Brazil, including the Realeza (Paraná) region where Au and Ag also occur. The basalts (46.7–50.8 wt.% SiO_2) have breccias at the top of 10 out of 31 studied flows in the Realeza section and at the top of 5 out of 7 analyzed flows in the Capanema section. Sand injectites occur at the top of basalts in 18 out of 23 flows from the Realeza section. The average content of Cu in three samples of mineralized breccias is 3788 ppm. One sample from a silicified sandstone sill intruded at the top of a basalt flow has up to 0.66 ppm Au. K_2O was not leached during basalt alteration. The hydrothermal breccias, particularly when sand is present, show enrichment in U which leads to higher values of scintillometry (rate of emission of K, U and Th). In the basalts, breccias and sandstones, Pd (17.5 ± 8.4 ppb) is higher than Pt (12.5 ± 5 ppb), suggesting a hydrothermal remobilization of the metals. The Serra Geral Group is thus shown to have high potential for precious and base metal deposits.

1. Introduction

The basaltic Cretaceous rocks from the Paraná volcanic province are mostly contained in the Serra Geral Group in southern Brazil and are well known as host rocks of amethyst and agate mineralization and occurrences of native copper. The Serra Geral Group is the host of world class amethyst and agate deposits and may also contain large deposits of metals. What makes the group special is its association with the underlying Guarani aquifer, the sands of the Botucatu Formation and a higher geothermal gradient. These factors established favorable conditions for the generation of hydrothermal mineralization.

Extensive studies in the volcanic group described an intense paleohydrothermal system, which originated in the Guarani aquifer. As a result, metals were deposited in the host basalts; silicon deposited as valuable silica minerals (e.g., amethyst), and copper as a native metal (Hartmann et al., 2010; Pinto et al., 2011). The present investigation described the presence of gold and silver in the same system. These processes were described as three main events (H1, H2, H3) by Hartmann et al. (2012a). H1 filled vesicles and microfractures with zeolites and smectite that caused the sealing of porosity, H2 resulted in seal failure and the injection and effusion of fluidized sand during the event caused by increase in pore pressure, and H3 was responsible for the opening of giant protogeodes and their filling with amethyst and agate. The main deposits of amethyst and agate (Duarte et al., 2009; Hartmann et al., 2012a) and occurrences of native copper and associated minerals (Pinto et al., 2011) have been described as the result of hydrothermal processes with temperatures of <150 °C.

The source of the mineralizing fluids (Gilg et al., 2003; Morteani et al., 2010) is commonly considered the Guarani aquifer (Araújo et al., 1999), based on stable isotope analyses. According to Jolly and Lonergan (2002), sandstone intrusions are found in all sedimentary environments but have been reported most commonly from deep-water settings. Hartmann et al. (2012a,b, 2013a) made extensive studies on the geological relationships between the basalt flows and interleaved sandstone layers and concluded that fluidized sand (Botucatu Formation) was injected into overlying cool lavas because the basalts (Serra Geral Group) acted as seals for fluid ascent from the heated Guarani aquifer and its vapor for the hydrothermal processes responsible for the injection and effusion of sand. The authors observed that although the hydrothermal temperature in the Paraná volcanic province was high (~130 °C) compared with offshore basins (30–70 ºC), the resultant structures are similar in the two environments (Hurts et al., 2011; Jonk et al., 2005). Evidence of intrusion of fluidized sand from the underlying Botucatu paleoerg into the overlying basalts is recorded in the dikes and sills of silicified sandstones and hydrothermal breccias with a sandstone matrix (Hartmann et al., 2012b). These breccias were formed before and along the entire metal mineralizing event. Sand extrudites (1–2 m thick) and sills (up to 5 m thick) occur as partly silicified layers in

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the volcanic sequence (Hartmann et al., 2013a). The interaction of hot water from the huge Guarani aquifer with the extensive Paraná volcanic province resulted in an especially great mineral potential. The purpose of this work is to establish the geological controls of the mineralization in the study area (Realeza, southwestern Paraná state).

2. Geological setting

The Paraná volcanic province covers an extensive area of approximately 917,000 km^2 (Frank et al., 2009). Wildner et al. (2007) proposed an internal stratigraphy for the Serra Geral Group that contains all volcanic rocks from the province. Sixteen formations were described and proposed, changing the status of the Serra Geral Formation into Serra Geral Group, as here accepted. The Serra Geral Group has a thickness of 500–1000 m (maximum of 1750 m) in the Paraná Basin depocenter (Milani, 1997, 2003) (Fig. 1). The thickness of individual flows is estimated at 5–80 m with an average of 20 m (Peate et al., 1999). According to Peate et al. (1992) and Turner et al. (1999), the generation of the basaltic province and the opening of the South Atlantic Ocean occurred under the thermal influence of the Tristan plume in the Lower Cretaceous.

The interpretation of a large number of chemical analyses of rocks from the volcanic province (Bellieni et al., 1983, 1984a,b) led to grouping of the basalts and andesitic basalts into two major divisions that are distinguished by either high or low contents of titanium. The high-Ti ($TiO_2 \geq 2\%$) group has relatively high concentrations of phosphorus (P_2O_5) and incompatible trace elements such as Sr, Zr, Hf, Ba, Ta, Y and light rare earths compared to the low-Ti group ($TiO_2 < 2\%$). Peate et al. (1992), based on the concentrations of less-mobile major, minor and trace elements (high field strength elements such as Ti, Zr, Y), divided the volcanic group into six basaltic magma types, namely the low-Ti Gramado, Esmeralda and Ribeira types, and the high-Ti Urubici, Pitanga and Paranapanema types. To this subdivision, Nakamura et al. (2002) added an intermediate-Ti type. Several investigators (e.g., Hawkesworth et al., 1986) have evaluated extensively the isotopic geochemistry of the province. Peate (1997), Ernesto et al. (1999) and Marques et al. (1999) showed that several subgroups have different isotopic signatures and characterize magmas-type generated from different sources in the mantle. An updated revision of the geochemical evolution of the province is presented by Hartmann et al. (2010).

Stratigraphically, the Serra Geral Group is positioned above the paleo-erg of the Lower Cretaceous Botucatu Formation and is covered by the Bauru Group (Cretaceous) eolian, fluvial and lacustrine sandstones. The Botucatu Formation contains the large Guarani aquifer, whereas other continental volcanic provinces (e.g., Columbia River, Karoo, Deccan) are underlain by weak aquifers. The volcanic group covers approximately 75% of the area of the Paraná Basin (Nardy et al., 2002). Peate et al. (1999) correlated flows using rock geochemistry; a similar technique was integrated with gamma spectrometry by Hartmann et al. (2010, 2013b) to correlate flows over long distances up to 50 km. Thus, the Paraná volcanic province offers a unique opportunity to study the tectonic and hydrothermal interaction of a large aquifer with basalts.

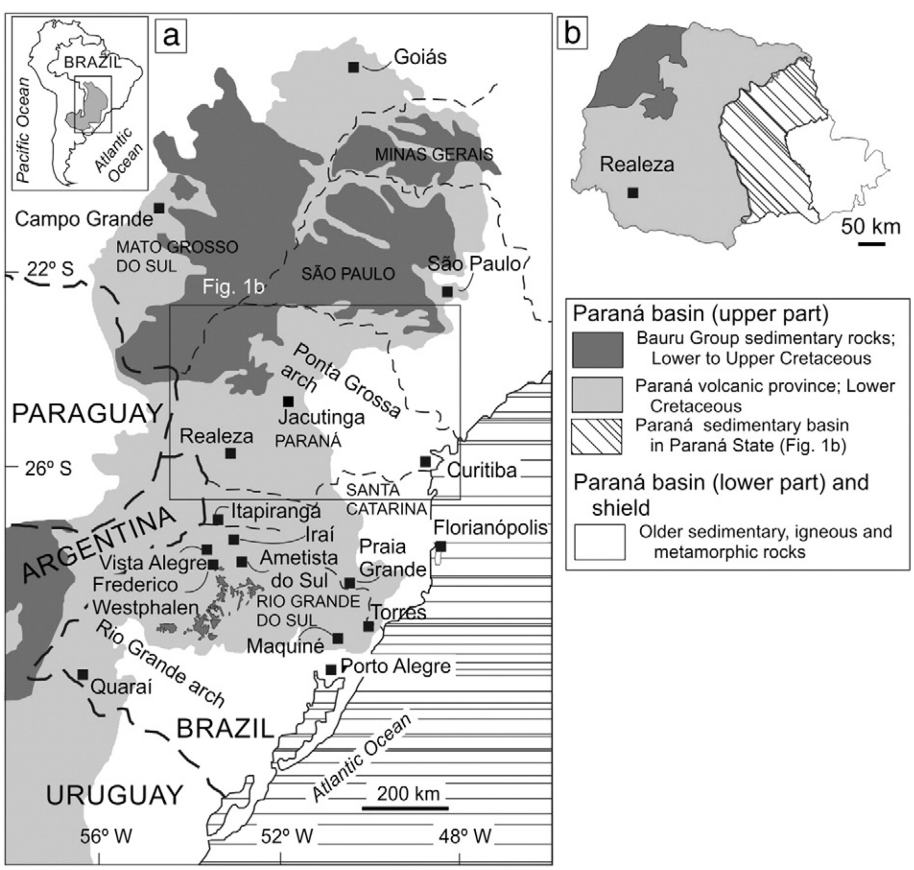

Fig. 1. Geological map of the Paraná volcanic province; Serra Geral Group undivided. Inset shows location of Paraná basin in South America. (a) Highlight of basin depocenter in southwestern Paraná state; some locations indicated (e.g., Vista Alegre) with occurrences of native copper; (b) Simplified geological map of Paraná state.
Modified from Peate et al. (1992) and Iwashita et al. (2011).