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Recognition and characterisation of high-grade ignimbrites from the Neoproterozoic rhyolitic volcanism in southernmost Brazil

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ABSTRACT

Neoproterozoic magmatism in southern Brazil is associated with translithospheric shear belts and strike-slip basins in a post-collisional setting related to the last stages of the Brasilian-Pan African Orogenic Cycle. It evolved from an association of high-K calc-alkaline, leucocratic-peraluminous and continental tholeiitic magmas, to an association with shoshonitic magmas and, eventually, to an association with magmas of the sodic mildly alkaline series. This magmatism varies from metaluminous to peralkaline and exhibits alkaline sodic affinity. A large volcanism is related to this alkaline sodic magmatism and is named the Acampamento Velho Formation. This unit was coeval with subaerial siliciclastic sedimentation in post-collisional basins preserved in the region. The Acampamento Velho Formation consists of pyroclastic and effusive volcanic deposits, which are mainly silicic, emplaced under subaerial conditions. The best exposures of this volcanism occur on the Ramada and Taquarembó plateaus, located southwest of Rio Grande do Sul in southernmost Brazil. The pyroclastic flow deposits are composed mainly of juvenile fragments such as pumices, shards and crystal fragments. Welding is very effective in these units. High-grade ignimbrites occur at the base and intermediate portions of the deposits and rheoignimbrites are observed at the top. The pre-eruptive temperature calculations, which were obtained at the saturation of zircon, revealed values between 870 °C and 978 °C for Taquarembó Plateau and 850 °C–946 °C for Ramada Plateau. The calculated viscosity values vary from 6.946 to 8.453 log η (Pas) for the rheoignimbrites and 7.818 to 10.588 log η (Pas) for the ignimbrites. Zr contents increase toward the top of the pyroclastic sequence, which indicates an increase in peralkalinity and determines the reduction in viscosity for clasts at the upper portions of the flows. The patterns of the structures of the ignimbrites and rheoignimbrites in the Taquarembó and Ramada plateaus accords well with successive pyroclastic flows that halts en masse. In this model the entire pyroclastic flow halts en masse, so complex vertical changes in grain size and composition are interpreted as recording deposition from successive discrete pyroclastic flows. The stratification observed in intermediate units in Taquarembó Plateau might reflect in this case variation in eruptive dynamics and short pauses.

1. Introduction

Welding in eruptive volcanic products is an efficient deformation mechanism that involves the simultaneous sintering of vesicular and partially melted fragments in high-temperature flow deposits (Smith, 1960b; Guest and Rogers, 1967; Riehle et al., 1995). Welding results in definite textural and physical features (occurrence of fiamme, eutaxitic or parataxitic fabric, low porosity, deformation or pyroclastic particles) which are sometimes observed in ignimbrites (Smith, 1960a, 1960b, 1979; Ross and Smith, 1961; Ragan and Sheridan, 1972; Peterson, 1979; Streck and Grunder, 1995; Quane and Russell, 2005). Several authors involving theoretical and experimental aspects have considered that welding may be influenced by interactions between the

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eruption, flow dynamics and cooling of volcanic deposits. The welding process can be extreme for high-grade pyroclastic flow deposits (Walker, 1983), where certain portions, called lava-like ignimbrites, are texturally indistinguishable from lava flows (Ekren et al., 1984; Henry et al., 1988). During and/or after deposition, the structures are formed by deformation caused by non-particulate flows, which is a continuous process known as rheomorphism (Schmincke and Swanson, 1967; Chapin and Lowell, 1979; Wolff and Wright, 1981; Branney et al., 1992).

High-grade ignimbrites occur in many volcanic settings and are sustained by alkali-rich magmas and encompass a wide compositional spectrum, which varies from basalts to rhyolites (Chapin and Lowell, 1979; Branney et al., 1992; Freundt, 1998). However, the most documented examples, which are from systems with high magmatic temperatures and elevated amounts of viscosity-reducing elements, have a peralkaline rhyolitic composition and also low lithic content (Schmincke and Swanson, 1967; Schmincke, 1974; Wolff and Wright, 1981; Mahood, 1984; Kobberger and Schmincke, 1999).

In Brazil, welded deposits were spotted in several ancient volcanic sequences, from Paleoproterozoic to Neoproterozoic volcanic settings. They are normally associated with silicic volcanism, where high-grade and rheomorphic ignimbrites are common (Sommer et al., 1999, 2003, 2005, 2006; Barros et al., 2001; Pierosan et al., 2011; Barreto et al., 2013).

In this work, we discuss the welding significance of the rhyolitic ignimbrites of the Neoproterozoic Acampamento Velho Formation in southernmost Brazil. We also combine and integrate detailed fieldwork descriptions of this unit with petrography and lithochemistry. The terminology adopted to the characterization of the ignimbrite lithofacies is similar to Branney and Kokelaar (2002), combining grain size, depositional structures and fabric. The facies association was defined on the basis of volcanic units as pyroclastic flow (Table 1).

The Acampamento Velho Formation is characterised by a non-deformed and non-metamorphosed silicic volcanic succession situated in the western portion of the Sul-Rio-Grandense Shield. The un-altered preservation of the volcanics and previous detailed characterisation of the deposits and their regional context (e.g. Ribeiro et al., 1966; Wildner et al., 1999, 2002; Sommer et al., 1999, 2003, 2005, 2006; Almeida et al., 2002), has facilitated this further detailed investigation of the emplacement and welding characteristics of the ignimbrites in the Acampamento Velho Formation.

2. Analytical procedures

The lithochemical studies are based on chemical analyses of ignimbrites that represent different lithotypes. The major and trace elements were analysed at Activation Laboratories Ltd., in Ontario, Canada, by using the ICP technique (Inductively Coupled Plasma) for major elements and ICP-MS (Inductively Coupled Plasma Microspectrometry) for trace and rare earth elements.

Temperature data were calculated using Watson (1979) and Watson and Harrison (1983) methodologies that involve whole-rock chemical composition (major elements and Zr), which were applied to compositions of H2O >2% and M parameter values between 0.9 and 2.1 [$M = (Na + K + 2 \times Ca)/(Al \times Si)$] (Hanchar and Watson, 2003). Other temperature data were obtained by the Sisson and Grove (1993) methodology, which involves only compositions of the major elements.

Viscosity data were calculated using the model of the Giordano et al. (2008). This model predicts the non-Arrhenian Newtonian viscosity of silicate melts as a function of T and melt composition, including the volatile constituents (H_2O and F). This model was based on experimental measurements of viscosity at T (K) on melts of known composition at atmospheric pressure (10^5 Pa). It is continuous in composition- and temperature-space and predicts the viscosity of natural volatile-bearing silicate melts (SiO_2, Al_2O_3, TiO_2, FeO_{tot}, CaO, MgO, MnO, Na_2O, K_2O, P_2O_5, H_2O, F_2O^{-1}) over fifteen log units of viscosity (10^{-1}–10^{14} Pa s). This model is capable of accommodating strong and fragile behaviour of silicate melts (respectively, near- and non-Arrhenian T-dependences) and it reproduces observed relationships between melt composition and transport properties (i.e. glass transition temperature and fragility).

3. Geological setting

The Neoproterozoic lithologic section in southernmost Brazil is characterised mainly by plutonism along major translithospheric shear belts and by plutonism, volcanism and sedimentation in strike-slip basins such as the Camaquã. This volcano-sedimentary section is situated in relatively non-deformed areas and positioned on a basement of older igneous and metamorphic terrains (Fig. 1). The basin was formed during the post-collisional stages (Liégeois, 1998) of the Brasiliano-Pan-African orogeny and is considered a strike-slip basin, although controversies exist regarding its classification and mechanism of generation (Almeida et al., 1981; Brito-Neves and Cordani, 1991; Fernandes et al., 1992; Chemale, Jr., 2000; Paim et al., 2000). In this work, the post-collisional stage was considered as tectonically complex period, subsequent to the main collision stage that includes great movements along the shear zones, oblique collision, lithospheric delamination, rifting, subduction of small oceanic plates and volcanism associated with the basin sedimentation (Liégeois, 1998; Bonin, 2004).

Regarding the geological evolution, the basin can be interpreted as a depositional locus characterised by alternating depositional events and erosive intervals. The depositional episodes were dominated by the accumulation of sedimentary and volcano-sedimentary sequences with kilometric thickness. In the filling phases, the volcanic units are predominant at the base of the units followed by the predominant deposition of siliciclastic sediments. This dynamic context, which involved igneous, sedimentary and deformational events, generated a complex filling pattern represented by a series of stratigraphic units (Paim et al., 2000).

The Neoproterozoic-Ordovician magmatism of the Camaquã Basin evolved from tholeiitic and high K calc-alkaline magmas to shoshonitic and sodic alkaline magmas. The crustal contribution is represented by peraluminous granitoids (Wildner et al., 2002; Sommer et al., 2006; Lima et al., 2007) (Fig. 1).

The older volcanic rocks have compositions that are predominantly intermediate with shoshonitic affinity, with minor basic and acid compositions (Hilário Formation – Ribeiro and Fantinel, 1978

Table 1
Terminology adopted to the characterization of the ignimbrite lithofacies of the Acampamento Velho volcanism.

Facies cod.	Lithofacies description
rheom LT	Massive, poorly sorted, vitriclastic matrix; strong flattening, rotational structures and high stretching
sLT(nl-ip)	Stratified lapilli-tuff, poorly sorted, normal grading of lithic fragments and reverse grading of pumice fragments
LT(nl)	Massive poorly sorted ignimbrite; normal graded lapilli-sized lithic fragments in ash-sized matrix
eLT	Lapilli-tuff with eutaxitic texture
mLT	Massive lapilli-tuff
//bpL	Welded rhyolitic ignimbrite with vitroclastic matrix; pumices lapilli flattened and aligned, defining a planar foliation subparallel to bedding
crLT	Crystal rich lapilli-tuff
sLl	Stratified lapilli-tuff, rich in lithic fragments

Modified from Branney and Kokelaar, 2002.