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SILICIC SEGREGATIONS IN SUBVOLCANIC INTRUSIONS: CLUES TO THE ORIGIN OF BIMODAL BASALT-RHYOLITE ASSOCIATIONS IN THE NORTHERN PARANÁ MAGMATIC PROVINCE?

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Resumo – Segregações ricas em SiO_2 (70-74%) são encontradas em alguns corpos subvulcânicos de composição basáltica na porção setentrional da Província Magmática Paraná sob a forma de fragmentos de vidro, veios riolíticos e ocelos, todos cristalizados a partir de líquidos ricos em voláteis, como mostrado pelos elevados conteúdos de amígdalas e pela associação com vênulas hidrotermais. Essas segregações se formaram pela extração "in situ" de líquido residual, auxiliada por instabilidades gravitacionais na câmara magmática em cristalização e/ou pelo transporte para cima associado com vesiculação. Embora de pequeno volume, essas feições indicam que, como mostrado pela literatura recente, hiatos composicionais são uma feição comumente gerada no fracionamento cristal-líquido, especialmente nos líquidos evoluídos, de maior viscosidade. A existência desses hiatos não pode portanto ser usada como um argumento principal para negar que este mecanismo tenha sido responsável pela geração das rochas vulcânicas ácidas tipo Chapecó.

Palavras-Chave: riolito; basalto; gap composicional; sill; Formação Serra Geral

Abstract – Silica-rich (70-74 wt% SiO_2) segregations are found in some subvolcanic bodies in northern Paraná Magmatic Province as glass patches, rhyolite veins and occelli, all of which crystallized from a volatile-rich melt, as shown by high contents of amygdales and association with hydrothermal veinlets. These segregations were formed by "in situ" extraction of residual melt, aided by gravitational instabilities in the solidifying magma chamber and/or by upward transport associated with vesiculation. Although of small volume, these features indicate that, as increasingly shown in literature, compositional gaps are a feature of crystal-liquid fractionation, especially as evolving liquids become more viscous. The existence of such gaps cannot therefore be used as a main argument to deny this mechanism as responsible for the generation of the Chapecó-type acid volcanics.

Keywords: rhyolite; basalt; compositional gap; sill; Serra Geral Formation

1. Introduction

Acid volcanic rocks from the Paraná Magmatic Province (PMP) show significant modal, textural and geochemical diversity, and were formed by varied mechanisms in several episodes that apparently occurred over most of the Province´s lifespan.

Geochemical modeling suggests that the associated and by far more abundant tholeiitic basalts may be connected to the generation of the acid magmas in different ways: as parent melts that evolved to more felsic compositions through fractional crystallization (combined with different degrees of crustal contamination); as lower crustal underplates that were the main source for remelting; or as a source of heat for melting of older mafic granulitic crust (e.g., Garland et al. 1995; Kirstein et al. 2000).

Although fractional crystallization models seem to fit better the geochemical behavior of high-Ti (Chapecó-type) dacites from the NNW PMP (Bellieni et al. 1986; Freitas & Janasi 2007), the existence of a wide (~10 wt%) SiO_2 gap has being pointed as a major obstacle to such processes, and an origin by remelting of basalt underplates is the preferred model in literature (Bellieni et al., 1986; Garland et al., 1995).

Recent studies (Marsh 2002; Brophy & Dreher 2000) indicate, however, that compositional gaps appear to be an inherent feature of the crystallization history of basalt sills and lava lakes, and justify a reappraisal of the role of crystal fractionation in the genesis of the Chapecó dacites.

Structural and textural features indicative of *in situ* formation of silicic segregations are found in some diabase sills and dikes from northern PMP, and are currently being studied using petrography and geochemistry to investigate their bearing on the general petrologic problem of acid-basic magma connection.

2. The Chapecó-type acid volcanics

Acid volcanic rocks occurring as lavas in the NW PMP are distinguished from equivalents in the south (the Palmas-type) by porphyritic textures and higher contents of Ti and incompatible elements such as P, Zr, Ba, Sr and LREE. Field-based estimates (Luchetti et al. 2005) show that they presently occupy a volume (~1,000 km^3) that is more than an order of magnitude lower as compared to Palmas (22,000 km^3).

Our recent detailed work in the northernmost occurrence of acid volcanic rocks in the PMP (Ourinhos subtype; (Janasi et al. 2007) has confirmed that these rocks correspond locally to the first flows, and are chemically very homogeneous, showing a major chemical gap to the younger basalt flows (54-64 wt% SiO_2; 4-1.5 wt% MgO).

3. Silicic segregation structures in northern PMP intrusive bodies

Silica-rich segregations are found as mostly subvertical veins cutting host diabase and as cm-sized occelli near the roof of a sill south of Limeira (SP) (cf. Faria & Janasi 2007) and as up to dm-sized highly vesiculated glass fragments in some portions of "dikes" in the neighborhood of Brotas (SP) (Fig. 1).

Chemical analyses show the Limeira veins and Brotas glass fragments to correspond to highly silicic compositions (respectively, 71 and 74 wt% SiO_2; both ~0.2 wt% MgO). Plagioclase and pyroxene crystals from both types of segregations have very evolved compositions as compared to those found in host diabase, consistent with growth in equilibrium with a silica-rich melt.

A high volatile content is evident in all cases. In Limeira, the rhyolite veins are often associated with thin veinlets showing a hydrothermal assemblage of quartz, zeolites, calcite and/or apophylite, whereas the ~1 m thick occelli-bearing horizon has abundant zeolite-filled amygdales that become more abundant (while the occelli tend to disappear) towards the roof. In Brotas, the vesicles are typically filled with chalcedony, and are often distributed asymetrically in features suggestive of outward movement

4. Significance of the silicic segregations and implications for magma evolution

As pointed out by Marsh (2002), a differentiated melt resides interstitially in the solidification fronts of cooling magma bodies of basalt composition, and becomes increasingly more fractionated deeper within these fronts. Significant silica enrichment begins only after ~50% crystallization, when a rigid crystal network has formed, and crystal settling becomes impossible. In Marsh´s model, silicic segregations form by infilling of tears formed during gravitational instability of the upper solidification front.

Other mechanisms are recognized in the literature as capable of segregating interstitial silica-rich melts from magma mushes. Costa et al. (2006) argue that during vesiculation of low P or high water content melts, evolved interstitial melt may escape from the cumulus pile of a magma chamber, intruding the main body of magma as vesicle cylinders or other segregation features. A similar mechanism may explain the formation of occelli and glass patches in the cases studied here.

That silica-rich interstitial melts can segregate from shallow-level intrusive bodies in the PMP (and possibly also from thick lava flows, as demonstrated in other provinces) is clear from field and geochemical evidence, but is this relevant for the genesis of the Chapecó-type acid volcanics? The high-silica segregations described here and in other shallow-level basalt bodies do not appear to be able to leave the magma chamber and form large independent bodies; moreover, they are much more evolved than the typical Chapecó dacites. By recognizing the limited volumes of silica-rich segregations generated in a given magma chamber (accordingly referred to as a "silicic noise" introduced into basalt systems), Marsh (2002) proposed that subsequent "reprocessing" of the host would be necessary to form volumetrically important masses of silicic magma.

An important consequence of the findings reported here is that compositional gaps are a feature of "in situ" crystal-liquid fractionation during the evolution of basalt systems in the PMP; furthermore, as shown by Oliveira et al. (1998), they are not restricted to silica-rich compositions, as "pegmatitic gabbro" layers possibly extracted from a basalt melt after <35% crystallization (cf. Philpotts et al. 1996) are found close to the top of a sill near Campinas (SP). It follows that the existence of a compositional gap alone can not be accepted as a major argument to favor melting of basalt underplates over crystal-liquid fractionation as the mechanism responsible for the generation of the Chapecó-type acid volcanics. The extraction of large volumes of residual melts from crystallizing granitic magma mushes is currently a major research topic and may help explain several important features in both plutonic and volcanic systems (e.g., Bachmann & Bergantz 2004; Eichelberger et al. 2006).

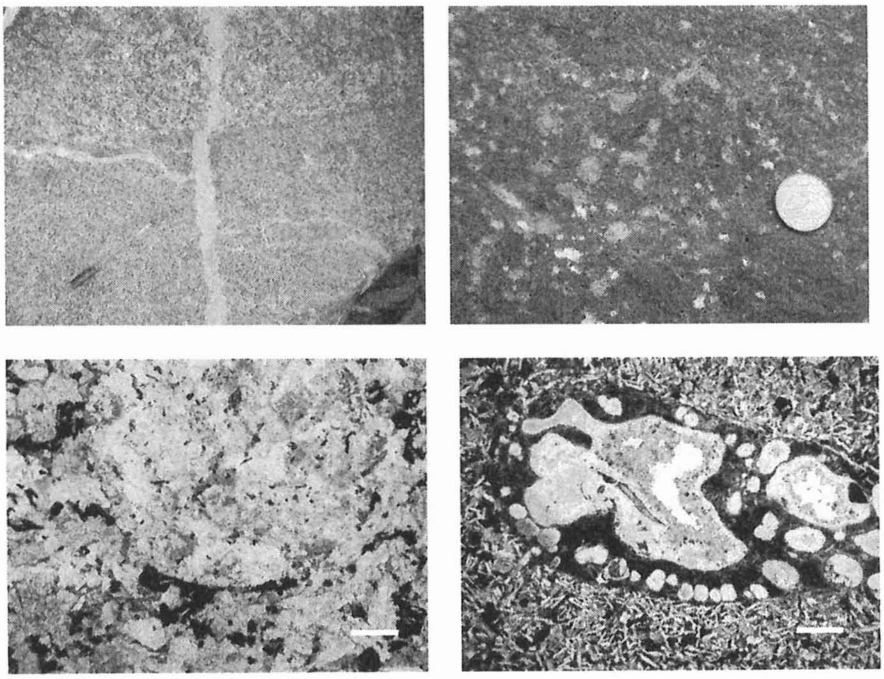

Figure 1. Structural and textural aspects of silicic segregation from subvolcanic bodies in Northern PMP: (a) branching rhyolite vein (white) cutting boundary between two varieties of diabase; (b) rhyolite occelli (light gray) and calcite-filled amygdales (whitish) near roof of sill; (c) photomicrograph of a round-shaped occelus (contacts delineated by curve opaque mineral in lower portion) within diabase; (d) photomicrograph of a highly vesiculated fragment of glass (dark-brown) in fine-grained basalt; vesicles are infilled by chalcedony; note plagioclase laths contouring glass fragment. (a, b, c) from Limeira, SP; (d) from Brotas, SP. Both photomicrographs in plane-parallel light; white bar is 0.5 mm long.

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