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Effusive eruption of viscous silicic magma triggered and driven by recharge: a case study of the Cerro Chascon-Runtu Jarita Dome Complex in Southwest Bolivia

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Abstract The Cerro Chascon-Runtu Jarita Complex is a group of ten Late Pleistocene (~85 ka) lava domes located in the Andean Central Volcanic Zone of Bolivia. These domes display considerable macroscopic and microscopic evidence of magma mixing. Two groups of domes are defined chemically and geographically. A northern group, the Chascon, consists of four lava bodies of dominantly rhyodacite composition. These bodies contain 43–48% phenocrysts of plagioclase, quartz, sanidine, biotite, and amphibole in a microlite-poor, rhyolitic glass. Rare mafic enclaves and selvages are present. Mineral equilibria yield temperatures from 640 to 750 °C and log $f_O^2$ of −16. Geochemical data indicate that the pre-eruption magma chamber was zoned from a dominant volume of 68% to minor amounts of 76% SiO$_2$. This zonation is best explained by fractional crystallization and some mixing between rhyodacite and more evolved compositions. The mafic enclaves represent magma that intruded but did not chemically interact much with the evolved magmas. A southern group, the Runtu Jarita, is a linear chain of six small domes (~1 km$^3$ total volume) that probably is the surface expression of a dike. The five most northerly domes are composites of dacitic and rhyolitic compositions. The southernmost dome is dominantly rhyolite with rare mafic enclaves. The composite domes have lower flanks of porphyritic dacite with ~35 vol.% phenocrysts of plagioclase, orthopyroxene, and hornblende in a microlite-rich, rhyodacitic glass. Sieve-textured plagioclase, mixed populations of disequilibrium plagioclase compositions, xenocrystic quartz, and sanidine with ternary composition reaction rims indicate that the dacite is a hybrid. The central cores of the composite domes are rhyolitic and contain up to 48 vol.% phenocrysts of plagioclase, quartz, sanidine, biotite, and amphibole. This is separated from the dacitic flanks by a banded zone of mingled lava. Macroscopic, microscopic, and petrologic evidence suggest scavenging of phenocrysts from the silicic lava. Mineral equilibria yield temperatures of 625–727 °C and log $f_O^2$ of −16 for the rhyolite and 926–1000 °C and log $f_O^2$ of −9.5 for the dacite. The rhyolite is zoned from 73 to 76% SiO$_2$, and fractionation within the rhyolite composition produced this variation. Most of the 63–73% SiO$_2$ compositional range of the lava in this group is the result of mixing between the hybrid dacite and the rhyolite. Eruption of both groups of lavas apparently was triggered by mafic recharge. A paucity of explosive activity suggests that volatile and thermal exchanges between reservoir and recharge magmas were less important than volume increase and the lubricating effects of recharge by mafic magmas. For the Runtu Jarita group, the eruption is best explained by intrusion of a dike of dacite into a chamber of crystal-rich rhyolite close to its solidus. The rhyolite was encapsulated and transported to the surface by the less-viscous dacite magma, which also acted as a lubricant. Simultaneous effusion of the lavas produced the composite domes, and their zonation reflects the subsurface zonation. The role of recharge by hotter, more fluid mafic magma appears to be critical to the eruption of some highly viscous silicic magmas.

Key words Lava domes · Recharge · Eruption mechanisms · Encapsulation
Introduction

Effusive eruptions of silicic lavas are common in the geologic record. Such events, generally accepted to be extrusions of gas-poor magma, constitute a significant proportion of silicic volcanism (e.g., Eichelberger 1995). Stimulated by such eruptions as Santiaguito, Guatemala (1920s to present), Mount St. Helens, USA (1980 to present), Unzen, Japan (1990–1995), and Soufrière Hills, Montserrat (1995 to present), much attention has focused on understanding the mechanisms that occur during the eruption and emplacement of such lavas. Considerable progress has been made in developing concepts concerning the initial or magma chamber conditions (e.g., Tait et al. 1989; Stasiuk and Jaupart 1997), the importance of rate of ascent and the possible role of syneruptive degassing (e.g., Eichelberger et al. 1986; Jaupart and Allegre 1991; Fink et al. 1992; Stasiuk et al. 1993), the eruption and growth of lava bodies (e.g., Huppert et al. 1982; Blake 1990; Fink and Griffiths 1990, 1992), and the role of mafic magma (e.g., Gibson and Walker 1963; Blake and Campbell 1986; Carrigan et al. 1992; Carrigan 1994; Rutherford et al. 1998). However, fundamental questions still remain, particularly about the triggering of an eruption and the movement and transport of extremely viscous crystal-rich silicic lavas, which form some of the largest individual lava bodies (e.g., de Silva et al. 1994; Manley 1996) and dominate the geologic record for this class of feature.

The role of recharge and attendant effects in the eruption of crystal-rich silicic lavas may be crucial. Numerous interdependent effects may occur during a recharge event that juxtaposes dense, hot, low-viscosity magma into a reservoir of cooler, less dense, viscous (crystal-rich) magma. The most important of these are:

1. Volume increase. A simple increase in the volume of magma may induce an increase in magmatic pressure that may exceed the minimum principal stress and tensile strength of the country rock; if so, magma may erupt. Bindeman (1993) argues that during recharge a 10% increase in volume might be the maximum expected. This may provide a limiting condition above which magmatic pressure induces failure and conduit formation.

2. Superheating. Superheating of magma can have several effects. Firstly, it may result in a reduction of viscosity and may promote convective motion. Furthermore, heating of the silicic magma may lower the solubility of the volatiles and promote volatile exsolution. During convective uprise of the silicic magma, decompression can cause further volatile exsolution. The subsequent increase in vapor pressure might trigger an eruption.

3. Volatile exchange during recharge. Thermal exchange at the interface between cooler silicic magma and hot, denser mafic magma promotes crystallization and second boiling within the mafic magma. Second boiling may result in an increase in the volume of the recharge magma that may generate vapor overpressures sufficient to trigger an eruption. Furthermore, crystallization could lead to a density decrease in the residual liquid of the mafic magma, which might promote intimate mixing of the two magmas. This process would promote vapor saturation of the mafic magma, which releases volatiles as a result, particularly water vapor. This may help further reduce the viscosity of the reservoir magma.

4. Transport of silicic magma. Mafic magma may act as a lubricant and as a transporting agent for viscous silicic magma through the development of core-annular zonation (Carrigan and Eichelberger 1990; Carrigan 1994). If two magmas of different viscosities are introduced at the entry end of a conduit system, the less viscous magma will migrate to the higher stress regions at the margins of the conduit (or dyke), producing a zoned system with a silicic core and mafic annulus. This lubricates the conduit (pipe-like or dyke) walls and reduces the forces required to move the silicic magma. The silicic magma is therefore transported by the mafic magma. An extension of this would be a portion of the silicic magma that was physically separated from the main reservoir as it was encapsulated and buoyed upward by the denser mafic magma.

 Whereas all of these effects are likely to occur during recharge (mafic into silicic), their relative importance would depend heavily on the nature and properties of individual systems. Here we present a case study of a superbly exposed group of silicic and composite lava bodies in the Andes of Bolivia: the Chascon-Runtu Jarita (CRJ) Complex. Using a combination of field observations, petrologic and geochemical data, and volcanologic analysis, we show that recharge by mafic magma probably triggered the eruptions at CRJ and also facilitated the transport and eruption of extremely viscous silicic magma.

Regional geologic context

The Chascon-Runtu Jarita Complex is one of a group of youthful effusive silicic centers within the Altiplano-Puna Volcanic Complex (APVC) of the Central Volcanic Zone (CVZ) of the Andes (Fig. 1; de Silva et al. 1994). The APVC covers approximately 70,000 km² between latitudes 21° and 24°S. It developed during the Late Miocene to early Pleistocene ignimbrite flare-up which produced voluminous silicic ignimbrites during massive caldera-forming eruptions (de Silva 1989a, 1989b). This flare-up has been argued to be the response to crustal thickening and subsequent thermal relaxation of the Central Andean crust augmented by the thermal input from mantle-derived magmas. Produc-