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Magma storage, ascent and recharge history prior to the 1991 eruption at Avachinsky Volcano, Kamchatka, Russia: Inferences on the plumbing system geometry

Marco Viccaro [a,*], Marisa Giuffrida [a], Eugenio Nicotra [a], Alexey Yu. Ozerov [b]

[a] *Dipartimento di Scienze Biologiche, Geologiche e Ambientali, Università di Catania, Corso Italia 57, I-95129, Catania, Italy*
[b] *Russian Academy of Sciences, Institute of Volcanology and Seismology, Piip Boulevard 9, 683006, Petropavlovsk-Kamchatsky, Russia*

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ABSTRACT

Textural and compositional features of plagioclase phenocrysts of the 1991 eruption lavas at Avachinsky Volcano (Kamchatka, Russia) were used to investigate the feeding system processes. Volcanics are porphyritic basaltic andesites and andesites with low-K affinity. A fractionation modeling for both major and trace elements was performed to justify the development of these evolved compositions. The occurrence of other magma chamber processes was verified through high-contrast BSE images and core-to-rim compositional profiles (An% and FeO wt.%) on plagioclase crystals. Textural types include small and large-scale oscillation patterns, disequilibrium textures at the crystal core (patchy zoning, coarse sieve-textures, dissolved cores), disequilibrium textures at the crystal rim (sieve-textures), melt inclusion alignments at the rim. Disequilibrium textures at the cores may testify episodes of destabilization at various decompression rates under water-undersaturated conditions, which suggests different pathways of magma ascent at depth. At shallower, water-saturated conditions, plagioclase crystallization continues in a system not affected by important chemical–physical perturbations (oscillatory zoning develops). Strongly sieve-textured rims, along with An increase at rather constant FeO, are evidence of mixing before the 1991 eruption between a residing magma and a hotter and volatile-richer one. The textural evidence implies that crystals underwent common histories at shallow levels, supporting the existence of a large magma reservoir whose top is at ~5.5 km of depth. Distinct textures at the outer rims in a hand-size sample are evidence that crystals mix mechanically at very shallow levels, probably in a small reservoir at ~1.8 km of depth.

1. Introduction

The bulk rock compositions at volcanoes sited on subduction zones are the result of superimposition of multiple differentiation processes that affect primary magmas after their segregation from the source. These processes include crystal growth with consequent fractionation from the melt, crustal assimilation, changes in the total volatile budget of the system, recharge by physically and chemically distinct magma batches and subsequent mixing. These processes may occur at the same time, thus the definition of their relative role on the final whole rock composition is a hard task. In order to get unambiguous information on the dynamics of natural magmas, several studies have focused their attention on the textural and compositional features recorded by plagioclase crystals of volcanic rocks (e.g., Anderson, 1984; Costa et al., 2003; Davidson and Tepley, 1997; Ginibre et al., 2002a; 2002b; Izbekov et al., 2002; Johannes, 1978; Johannes et al., 1994; Lofgren, 1980; Pearce et al., 1987; Ruprecht and Wörner, 2007; Ruprecht et al., 2008; Shcherbakov et al., 2011; Singer et al., 1995; Smith and Lofgren, 1983; Tsuchiyama, 1985). Indeed, the zoning patterns of plagioclase make available a record that reflects physical and chemical changes of the melt from which crystals grew. Plagioclase is very common in volcanic rocks and crystallizes over a wide range of magmatic temperatures and pressures. Furthermore, the original compositional zoning can be preserved because the CaAl–NaSi diffusion within the crystal structure is slow (Grove et al., 1984). Analytical approaches based on the investigation of plagioclase textural and compositional characteristics may therefore offer valuable information to understand magma dynamics in the plumbing system before the eruption, especially for volcanic systems scarcely known.

At Avachinsky Volcano (South-eastern Kamchatka, Russia), volcanological and geophysical studies began in '60s (Fedotov et al., 2007; Melekestsev et al., 1994a, 1994b and references therein). The scientific research has shown growing interest especially in the last decade, although the data available on the historical activity, the knowledge of magma dynamics and geometry of the feeding system are still fragmentary. The January 1991 eruption was the first event with an extensive documentation available on the eruptive dynamics and emitted products, which contributed to advance the awareness of the volcano.

Aim of this work is the identification of the feeding system processes and styles of magma ascent before the 1991 eruption at Avachinsky Volcano integrating whole rock geochemical data with the textural and compositional characteristics of plagioclase phenocrysts

* Corresponding author. Tel.: +39 095 7195741; fax: +39 095 7195760.
E-mail address: m.viccaro@unict.it (M. Viccaro).

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obtained through high-contrast BSE images and core-to-rim compositional profiles. Understanding of the magma recharge regimes from depth, the magma ascent and storage dynamics into the plumbing system of Avachinsky could be useful to evaluate the associated hazard, being the volcano less than 30 km far from Petropavlovsk, the largest city of Kamchatka.

2. Geological and volcanological background

2.1. Avachinsky Volcano in the framework of Kamchatka geodynamics

The Kamchatka Peninsula is located on the north-western border of the Pacific Ocean, where the Pacific plate north-westerly dips under the Euro-Asiatic and American plates (Gorbatov et al., 1997; 1999). This area is one of the most active over the world with about 30 active volcanoes and hundreds of monogenic volcanic systems distributed along belts of various age. From W to E three major volcanic zones are observed (Fig. 1): the Sredinny Ridge (SR), the Central Kamchatka Depression (CKD) and the Eastern Volcanic Front (EVF). During Late Eocene, the volcanic front was located on the accreted terrains of the SR (Auer et al., 2009; Volynets, 1994 and references therein). The growth of the intra-oceanic domain of the Eastern Kamchatka caused the blocking of the subduction zone with breaking-off and consequent sinking of the subducting slab (Avdeiko et al., 2006; Levin et al., 2002; Volynets, 1994). This caused the eastward migration of the subduction zone to its present location. As a consequence of this tectonic resettlement, the volcanism in the SR gradually decreased (Avdeiko et al., 2006; Volynets, 1994), while in Late Miocene the EVF and CKD started to form and Holocene volcanism was mainly concentrated at these sites (Auer et al., 2009 and references therein).

Avachinsky Volcano (2741 m a.s.l.) is an active volcano located in the EVF, ~200-km-far from the Kurili–Kamchatka trench (Fig.1). Together with Aag, Arik, Kozel'skyi and Koryakskyi volcanoes, it forms the so-called "Avachinsky volcanic group", a Middle Pleistocene–Holocene ridge crossing from northwest to southeast the southern sector of the EVF (Fig. 1; Masurenkov et al., 1991; Fedotov et al., 2007). These volcanoes are located above a Late Pliocene volcano-tectonic depression, constituted of a strongly dislocated Upper Cretaceous basement covered by Neogene–Quaternary volcanogenic deposits (Fedotov et al., 2007). Avachinsky Volcano has a typical Somma-Vesuvius structure and is composed of lava and pyroclastic rocks with compositions from basalts to andesites (Zavaritsky, 1977). The volcanic edifice is cut by a horseshoe-shaped caldera formed ~30 ka as a result of a sector collapse (Melekestsev et al., 1994b; Ponomareva et al., 2006). Inside this volcanic structure the active Young Cone is nested (Fig. 2a).

The volcanic activity at Avachinsky started about 60–70 ka (Fedotov et al., 2007), although its Holocene pyroclastic deposits cover the most ancient products. Starting from the Holocene, the volcanic history of Avachinsky Volcano is grouped in two stages (Braitseva et al., 1998; Melekestsev et al., 1989), which are separated by the formation of the Young Cone. The first period (7.2–3.5 ka) was dominated by voluminous Plinian eruptions that produced pumiceous ash-falls and pyroclastic flows with andesitic composition (Braitseva et al., 1997; Braitseva et al., 1998). An increase of the eruption frequency about 3.5 ka ago led to the formation of the Young Cone inside the Late Pleistocene caldera, with magma compositions that shifted to basaltic andesites (Braitseva et al., 1995, 1998; Puzankov et al., 2004). Alternating explosive and effusive eruptions characterized the activity of the Young Cone. Although the historical database shows several lacunas, fourteen eruptive events were recorded since 1737. The most recent known eruption, although

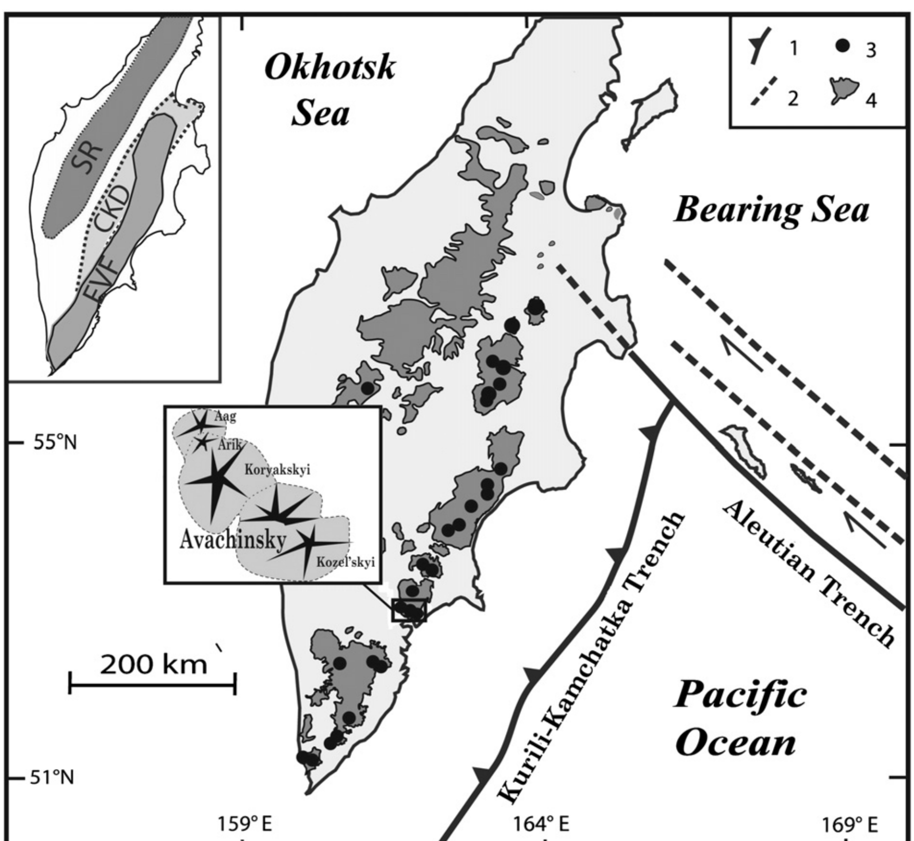

Fig. 1. Sketch map of the Kamchatka region showing the main geodynamic–tectonic structures and the location of the Avachinsky Volcanic Group. SR: Sredinny Ridge; CKD: Central Kamchatka Depression; EVF: Eastern Volcanic Front. Symbols in the up-right box are for: 1) Boundary of the active subduction zone; 2) Transform faults at the Aleutian–Kamchatka arcs junction; 3) Active volcanic centers; 4) Quaternary volcanic rocks.
Modified from Portnyagin and Manea (2008).