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On the anatomy of magma chamber and caldera collapse: The example of trachy-phonolitic explosive eruptions of the Roman Province (central Italy)

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ABSTRACT

Textural and compositional features of pyroclastic products erupted during caldera-forming events often reveal the tapping of different portions of variably zoned magma chambers due to changing geometries of the conduit/vent systems. Here we report on ultrapotassic trachytic–phonolitic explosive eruptions of the Roman Province (central Italy), which show remarkable changes of textural features and glass compositions in the juvenile material, even if the bulk chemical composition is essentially constant. In each example, the lower eruption sequence contains whitish, crystal-poor (leucite-free), highly vesicular pumice, emplaced by early Plinian fallout and/or pyroclastic currents; upsection, the eruption sequence contains black, low porphyritic (sanidine + leucite-bearing), moderately vesicular, scoria or spatter, emplaced by major pyroclastic flows (red tuff with black scoria) and associated co-ignimbrite, coarse lithic-rich breccias. This suggests a shift from a central feeder conduit, tapping the central part of the magma chamber, to a ring fracture vent system, tapping the peripheral portions of the magma chamber, during caldera collapse. Key features of these evacuating magma chambers are the thermal and volatile concentration (X_{vol}) gradients that produce the observed textural and compositional spectrum of trachy-phonolitic rock types. In particular, the degrees of freedom during the crystallization of these ultrapotassic magmas are increased by the variation of the leucite stability field at different P_{H2O} conditions. Both leucite-free and leucite-bearing differentiated ultrapotassic rock types can be produced in the course of individual eruptions, as a result of pre-eruptive conditions in the feeder magma, with no need to invoke different differentiation suites related to mantle source heterogeneities of parental magmas.

1. Introduction

Different types of juvenile clasts (pumice, scoria, spatter) with different textures and/or crystal contents often co-exist in the deposits of major explosive eruptions, with variable proportions upsection. Commonly, textural/mineral changes are accompanied by bulk chemical changes and are attributed either to the tapping of different portions of compositionally zoned magma chambers (e.g., the 0.2 Ma Cão Grande phonolitic eruption, Cape Verde Islands; Mortensen et al., 2009), or to mixing of different magma batches (e.g., the 16th century AD phonolitic eruption of Haruna Volcano, Japan; Suzuki and Nakada, 2007), or to a combination of both (e.g., the phonolite–tephriphonolite, 79 A.D. Plinian eruption of Somma–Vesuvius; Carey and Sigurdsson, 1987; Cioni et al., 1995). Crystal-poor, H_2O-rich, differentiated magma portions may develop in the upper parts of zoned magma chambers (Blake, 1984; Blake and Ivey, 1986; Dunbar and Hervig, 1992; Wallace et al., 1999; Wark et al., 2007) due to crystal fractionation (e.g., Miller and Mittlefehldt, 1984). Other processes may explain the transition from poorly to highly crystallized juvenile components, including syn-eruptive decompression–crystallization (Mastrolorenzo and Pappalardo, 2006; Humphreys et al., 2008; Brophy, 2009; Freda et al., 2011) or volatile-zoning of the magma chamber induced by CO_2 flux from carbonate wall rocks (Freda et al., 1997).

In some cases, contrasting textures of juvenile clasts are not accompanied by bulk compositional variations. For example, several major trachytic–phonolitic explosive eruptions from the Quaternary potassic Roman Province, central Italy (e.g., the Campanian Ignimbrite, Signorelli et al., 1999; the Sovana eruption at Vulsini; Vezzoli et al., 1987; Palladino and Taddeucci, 1998; the Tufo Giallo della Via Tiberina eruption at Sabatini; Masotta et al., 2010) show juvenile clast changes upsection from crystal-poor (subaphyric–vitrophyric), highly vesicular, whitish pumice to crystal-rich, moderately vesicular, dark scoria. In many examples, textural changes are accompanied by the appearance of leucite in late-erupted dark scoria. Compared to chemically zoned cases, these compositionally homogeneous eruptions have been less investigated.

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Masotta et al. (2010), in light of phase equilibria of phonolitic magma systems, attributed the changing textural features in the Tufo Giallo della Via Tiberina to the tapping of a thermally and volatile-zoned magma reservoir, where variable H_2O concentrations and thermal gradients essentially controlled variably crystallized magma portions (the low density contrast between a phonolitic melt and K-feldspar crystals making it unlikely an efficient zoning due to crystal fractionation). In their view, whitish pumice and dark scoria represent respectively the early erupted inner portion and the late erupted peripheral portion of the magma chamber.

Here we report four case studies of caldera-forming explosive eruptions from the Roman Province, which show analogous textural variations in the juvenile component, thus providing additional evidence that thermal- and volatile-zoning is a general mechanism acting in trachy-phonolitic pre-eruptive systems, with broad implications on: (1) the dynamics of magma withdrawal and "catastrophic" caldera collapses during major explosive eruptions; (2) the controlling factors for the origin of leucite-bearing vs. leucite-free rock-types from ultrapotassic differentiated magmas; and (3) the characterization of major explosive eruptions of the Roman Province, also relevant for tephrostratigraphic correlations in distal settings of the Apennine Chain and central Mediterranean. We show how changing juvenile component reflects the tapping of different portions of thermally and volatile-zoned trachy-phonolitic magma chambers due to changing geometry of magma withdrawal during syn-eruptive caldera collapse.

2. Geological setting

The four case studies are products of trachy-phonolitic explosive eruptions from the Vulsini, Vico and Sabatini Quaternary volcanoes, located north of Rome (Fig. 1). These form the northern part of the Roman Province (Peccerillo, 2005), the NW–SE-trending potassic volcanic belt developed along the Tyrrhenian coast of central Italy, related to the Tyrrhenian back-arc extension (Malinverno and Ryan, 1986).

2.1. The Vulsini Volcanic District

The Vulsini Volcanic District (Fig. 1), the northernmost and largest volcanic district in the Roman Province, developed along the southern termination of the NNW–SSE trending Mio-Pliocene Siena-Radicofani Graben (Barberi et al., 1994; Chiarabba et al., 1995). It comprises five major volcanic complexes: Paleovulsini, Bolsena–Orvieto, Vulsini Fields (including the previously defined Southern Vulsini), Latera and Montefiascone, partially overlapping in space and time (Vezzoli et al., 1987; Nappi et al., 1991, 1995; Palladino et al., 2010 and references therein). The early stages of activity (Paleovulsini complex) emplaced Plinian pumice fall horizons (~0.59 Ma; Cioni et al., 1987; Barberi et al., 1994) and large-scale, low- to high-grade pyroclastic flow deposits ("basal ignimbrites" or "Nenfri" *Auct.*; ca. 550–490 ka; Nicoletti et al., 1981; Cioni et al., 1989; Barberi et al., 1994; Nappi et al., 1995) and resulted in caldera collapse in the northern sector of the present-day Bolsena Lake (Acocella et al., 2012). Between 490 and 330 ka, volcanism acquired an areally widespread character along the rims of the protocaldera. Effusive and moderately explosive activity, mostly documented in the northeast (Bolsena–Orvieto) and south (Vulsini Fields; Palladino et al., 2010) sectors of the district, contributed to the subsidence of the present Bolsena caldera (Acocella et al., 2012). Volcanic activity reached a climax in the NE sector, with trachy-phonolitic Plinian eruptions and the emplacement of the Orvieto–Bagnoregio Ignimbrite (hereafter WOB; one of our case studies, see below). The onset of explosive activities at Montefiascone and Latera complexes took place at ~280 ka, in the southeast and west sectors of the district, respectively (Metzeltin and Vezzoli, 1983; Nappi et al., 1995; Brocchini et al., 2000). While volcanic activity in the east and southeast sectors waned at 240–220 ka (Nappi et al., 1995), highly explosive activity at Latera occurred up to ~166 ka; several Plinian and pyroclastic flow-forming eruptions (Sparks, 1975; Vezzoli et al., 1987; Palladino and Valentine, 1995; Palladino and Agosta, 1997), including the Sovana event (SVK) resulted in polygenetic caldera collapse (Nappi et al., 1991; Palladino and Simei, 2005). The late activity at Vulsini was characterized by small-scale explosive and effusive eruptions from several monogenetic

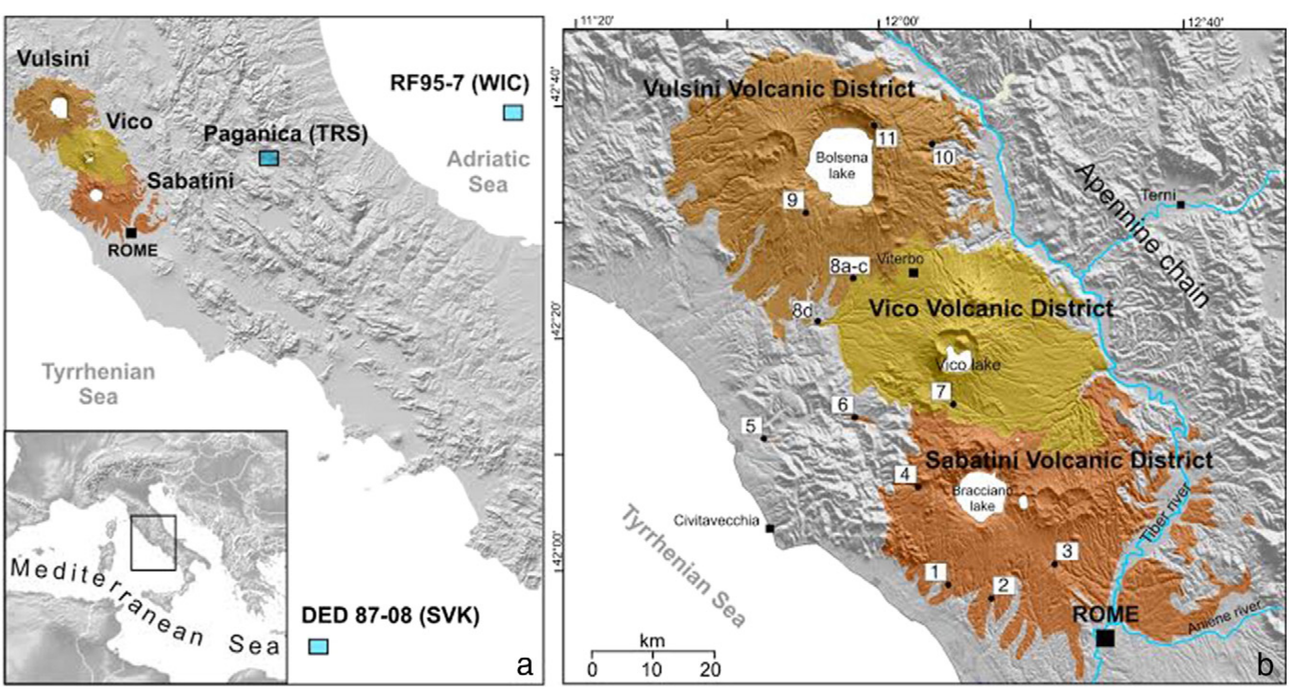

Fig. 1. a) Reference map with location of the study area and of the distal tephrostratigraphic records; b) sketch of the Northern Latium volcanic districts (Roman Province), showing the sample localities for this study: 1 = Ceri, 2 = Borgo Tragliata; 3 = Isola Farnese; 4 = Terme di Stigliano; 5 = Ficoncella; 6 = Pian della Dogana; 7 = Capranica; 8a = Road Vetralla-Tuscania; 8b = Casale Quarticciolo; 8c = Castello del Cardinale; 8d = La Rocca; 9 = La Rocchetta; 10 = Bagnoregio: road to Civita; 11 = Bolsena–Il Giglio.