Journal of Volcanology and Geothermal Research 200 (2011) 91–98

Contents lists available at ScienceDirect

Journal of Volcanology and Geothermal Research

journal homepage: www.elsevier.com/locate/jvolgeores

Short communication

Lithology of the basement underlying the Campi Flegrei caldera: Volcanological and petrological constraints

Massimo D'Antonio *

Dipartimento di Scienze della Terra — University Federico II, L.go S. Marcellino 10, I-80138, and Istituto Nazionale di Geofisica e Vulcanologia, sezione di Napoli Osservatorio Vesuviano, Via Diocleziano 328, I-80124, Napoli, Italy

ARTICLE INFO

Article history:
Received 21 June 2010
Accepted 11 December 2010
Available online 23 December 2010

Keywords:
Campi Flegrei caldera
basement
fractional crystallization
syenite

ABSTRACT

A geologically reasonable working hypothesis is proposed for the lithology of the basement underlying the Campi Flegrei caldera in the ca. 4–8 km depth range. In most current geophysical modeling, this portion of crust is interpreted as composed of Meso-Cenozoic carbonate rocks, underlain by a ca. 1 km thick sill of partially molten rock, thought to be a main magma reservoir. Shallower magma reservoirs likely occur in the 3–4 km depth range. However, the lack of carbonate lithics in any Campi Flegrei caldera volcanic rocks does not support the hypothesis of a limestone basement. Considering the major caldera-forming eruptions, which generated widespread and voluminous ignimbrites during late Quaternary times, including the Campanian Ignimbrite and Neapolitan Yellow Tuff eruptions, the total volume of trachytic to phonolitic ejected magma is conservatively estimated at not less than 350 km^3. Results of least-squared mass-balance calculations suggest that this evolved magma formed through fractional crystallization from at least 2500 km^3 of parent shoshonitic magma, in turn derived from even more voluminous, more mafic, K-basaltic magma. Calculations suggest that shoshonitic magma, likely emplaced at ca. 8 km depth, must have crystallized about 2100 km^3 of solid material, dominated by alkali-feldspar and plagioclase, with a slightly lower amount of mafic minerals, during its route toward shallower magma reservoirs, before feeding the Campi Flegrei large-volume eruptions. The calculated volume of cumulate material, likely syenitic in composition at least in its upper portions, is more than enough to completely fill the basement volume in the 4–8 km depth range beneath the Campi Flegrei caldera, estimated at ca. 1250 km^3. Thus, it is proposed that the basement underlying the Campi Flegrei caldera below 4 km is composed mostly of crystalline igneous rocks, as for many large calderas worldwide. Syenite *sensu lato* would meet physical properties requirements for geophysical data interpretations, explain some geochemical and isotopic features of the past 15 ka volcanics, and justify the carbon isotopic composition of fumaroles at the Campi Flegrei caldera. This implies that Meso-Cenozoic limestones, if still present today beneath the Campi Flegrei caldera, no longer constitute significant portions of its basement.

1. Introduction

The lithology of the crust underlying an active volcano is a fundamental parameter to be known, for many reasons such as: (1) magmas pass through, stagnate within, and interact with the crust before feeding volcanic eruptions; (2) in volcanic areas most earthquakes are generated within the crust in response to magma and/or volatile injection; (3) the volcanic edifice itself rests on crustal rocks; and (4) the first few kilometers of crust beneath an active volcano host its hydrothermal system. Many direct and indirect techniques are available to investigate the lithology of the crust underlying a volcano, including crustal rock outcrops, deep boreholes, and geophysical surveys, such as those based on gravimetric and magnetic anomalies, and seismic tomography. However, when the crust deeper than a few kilometers is investigated, none of these methodologies can provide much information on the exact nature of the crust. Still, knowledge of the lithology of the crust several kilometers below an active volcano is critical because it hosts the magmatic feeding system.

The Campi Flegrei nested caldera (CFc; Orsi et al., 1996) located in the Campania region, South Italy, is part of the Phlegrean Volcanic District (PVD), which also includes the islands of Ischia and Procida (Orsi et al., 2004). The CFc, one of the largest known volcanic areas on Earth, is active as testified by resurgence phenomena in the past 15 ka, the last volcanic event occurred in AD 1538 (Monte Nuovo eruption), unrest episodes occurred in the past few decades, as well as diffuse fumaroles and hot springs. The caldera and its surroundings are inhabited by more than 1.5 million people; thus the volcanic risk is one of the highest in the world (Orsi et al. 2004, and references therein). The CFc was generated by two major collapses related to two high-magnitude eruptions, the Campanian Ignimbrite (CI; ca. 39 ka, De Vivo et al., 2001), and the Neapolitan Yellow Tuff (NYT; ca. 15 ka, Deino et al., 2004), fed by magmas of trachytic to phonolitic composition. Trachyte and phonolite

* Tel.: +39 081 2538323; fax: +39 081 5525611.
E-mail address: masdanto@unina.it.

0377-0273/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.jvolgeores.2010.12.006

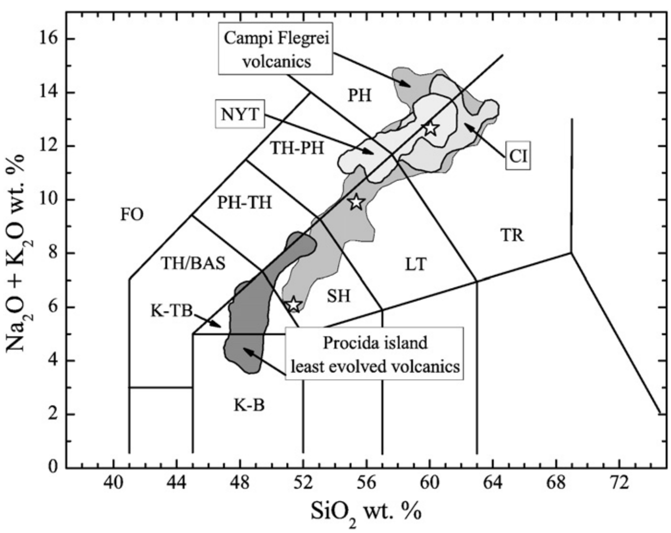

Fig. 1. Total alkalis vs. silica (TAS; Le Maitre, 1989) classification grid for volcanic rocks representative of the whole PVD volcanic activity of the past ca. 60 ka (data from: Melluso et al., 1995; Orsi et al., 1995; Civetta et al., 1997; Pappalardo et al., 1999, 2002a; D'Antonio et al., 1999a,b, 2007 and references therein; Di Renzo et al., 2007; Tonarini et al., 2009; Di Vito et al., 2010). Samples representative of the main caldera-forming eruptions (CI and NYT), and of the least evolved products from Procida island, are grouped as separate fields. The composition of the three volcanic rocks utilized for the least-squared mass-balance calculations are shown as white stars (data from Table 3).

are by far the most common volcanic rocks emplaced at CFc through time, whereas poorly evolved composition rocks such as latite and shoshonite are by far subordinate (Fig. 1; e.g., D'Antonio et al., 1999b, 2007).

Drilling data and geophysical investigations carried out within the Campi Flegrei (CF) volcanic area suggest that the caldera is filled down to 2 km depth by pyroclastic deposits with intercalated sandstone (Fig. 2). Denser pyroclastic and sedimentary rocks occur between 2 and 3 km depth (AGIP, 1987; Rosi and Sbrana, 1987). Temperature profiles measured in geothermal wells bored within the caldera floor give maximum values of about 350 °C at about 2.5 km depth (AGIP, 1987). Seismic reflection studies show that below 3 km depth there are thermo-metamorphic rocks bearing water and/or gas that overlie a basement, whose top is located at a depth of ca. 4 km (Judenherc and Zollo, 2004; Vanorio et al., 2005, 2006; Battaglia et al., 2008; Berrino et al., 2008; Zollo et al., 2008). This basement (Fig. 2), in the ca. 4–8 km depth range, is homogeneous in terms of density (2600–2650 kg/m^3; Battaglia et al., 2008; Berrino et al., 2008), whereas P wave velocity is variable with depth, from less than 4000 to more than 6000 m/s (Vanorio et al., 2005). Thus, on the basis of geophysical investigations, and geological evidence of Meso-Cenozoic limestones cropping out all around the Campania plain, this basement has been hypothesized to consist of carbonate rocks (e.g., Bruno et al., 2003; Zollo et al., 2003; Bruno, 2004; Judenherc and Zollo, 2004; Vanorio et al., 2005, 2006; Battaglia et al., 2008; Zollo et al., 2008). However, since the physical properties of limestone are similar to other lithotypes, for instance trachytic lavas, thermo-metamorphic and crystalline (i.e., plutonic) rocks, there is no consensus about the exact lithology of the basement lying in the ca. 4–8 km depth range below CFc. Given this uncertainty, some authors have hypothesized other lithologies for the basement, e.g. calc-alkaline volcanic rocks (Wohletz et al., 1999), skarn and feldspathoid-bearing syenites (Fowler et al., 2007), or left it undefined in their modeling (Marianelli et al., 2006; Berrino et al., 2008; Arienzo et al., 2010; Carlino and Somma, 2010; De Siena et al., 2010). At about 8 km depth the basement is underlain by a laterally extended, 1 km thick low velocity layer; this has been highlighted by seismic data, and interpreted as a partially molten rock zone (Zollo et al., 2008). That is in agreement with melt inclusion data, which provide evidence that CF magmas of shoshonitic composition stagnated at ca. 7–9 km depth, and equilibrated at progressively shallower depth up to ca. 3–4 km while differentiating to trachyte, in the past ca. 39 ka (Marianelli et al., 2006; Mangiacapra et al., 2008; Arienzo et al., 2010).

Since the crustal basement in the 4–8 km depth range represents the main location for magmas stagnating and rising below CFc, definition of its lithology is important for a better understanding of both magmatic and volcanic processes which occurred in the past, mandatory for inferring the present state of the magmatic feeding system, and assessing volcanic hazards. Thus, the aim of this work is to gather some volcanological and petrological lines of evidence to shed light on the lithological composition of the basement beneath the Campi Flegrei caldera.

2. Volcanological and petrological lines of evidence

The whole history of the Campi Flegrei volcanic area has been marked by high-magnitude explosive eruptions, whose products (ignimbrites) are widespread in the Campania region, and in some cases well beyond it (e.g., Rosi and Sbrana, 1987; Orsi et al., 1996; De Vivo et al., 2001; Rolandi et al., 2003). The beginning of activity in the CF volcanic area is not known with certainty. The oldest radiometrically dated volcanics, that can be confidently attributed to volcanic centers located in the CF area, have an age of 58 ± 3 ka (Pappalardo et al., 1999). They include pyroclastic flow deposits several tens of meters thick, whose areal distribution is unknown, due to scarcity of outcrops on land. For some of them, impact sags of ballistic clasts suggest a provenience from vents located outside the current CF caldera borders (Orsi et al., 1996). However, they testify to high-magnitude explosive eruptions, since they have been correlated to thick deposits buried undersea in the Gulf of Pozzuoli (volcanic unit V1; D'Argenio et al., 2004), and to pyroclastic units found in a deep borehole drilled South of Somma–Vesuvius (Di Renzo et al., 2007). Even older ignimbrites have been dated to the ca. 105–290 ka time span (De Vivo et al., 2001; Rolandi et al., 2003); also for these deposits, lack of stratigraphic relationships does not allow estimation of their areal distribution as well as a sure attribution to the CF volcanic activity. In any case, all these volcanological studies suggest that the CF area was affected by intense explosive volcanism fed by differentiated, K-alkaline magmas since late Quaternary times. The best known high-magnitude eruptions that occurred at CF are the Campanian Ignimbrite (CI; ca. 39 ka, De Vivo et al., 2001) and the Neapolitan Yellow Tuff (NYT; ca. 15 ka, Deino et al., 2004). The products of these eruptions are trachytic to phonolitic in composition (Fig. 1; Orsi et al., 1995; Civetta et al., 1997; Pappalardo et al., 2002a; Di Renzo et al., 2007). The latter are among the most evolved volcanics cropping out in the PVD. Intermediate and basic volcanics also occur at CF, but are much less abundant (Fig. 1); the least evolved, K-basaltic composition has been found only as lithic lava fragments in the 17 ka old Solchiaro eruption products at Procida island (D'Antonio and Di Girolamo, 1994; D'Antonio et al., 1999a). The occurrence in the PVD of a complete K-alkaline differentiation suite, from K-basalt through trachybasalt, shoshonite, latite, trachyte and (peralkaline) phonolite, suggests that all CF volcanics share a common genetic link (e.g., D'Antonio et al., 1999a,b, 2007, and references therein).

The inferred volume of the better known, highest magnitude eruptions that occurred at CF is noticeable: not less than 300 km^3 DRE (dense rock equivalent) for the CI (Fedele et al., 2003), and not less than 40 km^3 DRE for the NYT (Orsi et al., 1992). The deposits of older (>39–290 ka) ignimbrites of the Campania region are insufficient for an estimate of their volume (Pappalardo et al., 1999; De Vivo et al., 2001; Rolandi et al., 2003; D'Argenio et al., 2004; Di Renzo et al., 2007). Thus, a very conservative estimate of the total volume of differentiated magma emitted at Campi Flegrei in late Quaternary times, including at least part of that erupted before 39 ka, might be not less than 350 km^3 DRE, though very likely much more. That is a huge amount of magma, but it is a conservative estimate which does not