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Primary origin of some trachytoid magmas: Inferences from naturally quenched glasses in hydrothermally metasomatized gabbroic xenoliths (Hyblean area, Sicily)

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ABSTRACT

Hydrothermally-modified gabbroic xenoliths from the Hyblean tuff-breccia deposits (Sicily) consist of albitized plagioclase, Fe–Mg-rich clays, aegirine–augite, ±zeolites, titanite, apatite, magnetite, and hydrothermal zircon. Pockets of silicate glass with perlitic cracking occur in some samples forming 15–20% (by volume) of the rock modal assemblage. Electron microprobe analyses show the trachytic composition of the glass, with generally peralkaline sodic affinity [molar $Al_2O_3/(Na_2O+K_2O)$~0.8 (average value); molar $Al_2O_3/(Na_2O+K_2O+CaO)$~0.7 (average value); Na_2O/K_2O (wt.%) = 1.7–2.3]. The glass trace element abundances, obtained by secondary ion mass spectrometry (SIMS) analyses are consistent with those of world-wide trachytes (e.g. Zr/Ti = 0.15–018; Nb/Y = 0.73–1). Relatively high abundances of Cl (700–1600 ppm) and F (>500 ppm) were also detected in the glass.

Careful macroscopic and microscopic observations exclude the possibility that external silicate melt infiltrated the xenolith. The occurrence of glass pockets between the mafic clay assemblages and the feldspar grains, along with comparisons between chemical compositions of the glass and the surrounding minerals, suggest that the glass is due to the melting of a eutectoid system consisting of Na-rich alkali feldspar, Fe–Mg-rich clays and aegirine–augite. Halogens had probably played an important role in the partial melting process by decreasing the melting temperature of modal minerals, especially feldspar.

The occurrence of these trachytic glasses lends support to petrologic models suggesting that partial melting of a hydrothermally altered, brine-rich oceanic crust induced by shallow-seated basic intrusions can produce primary trachytoid melts. This may explain the "Daly-gap" characterizing some oceanic within-plate volcanoes.

1. Introduction

A number of within-plate volcanoes from oceanic and continental geodynamic settings erupts modest amounts of alkaline-intermediate to felsic products, particularly trachytes. Since the pioneering experimental work by Bowen (1945), Hamilton and MacKenzie (1965), and Bailey and Schairer (1964, 1966), trachytes have been considered the result of the fractional crystallization of alkaline-mafic magmas. This process has been proved to be consistent with mass–balance calculations and melt inclusion geochemistry (e.g., Tanguy et al., 1997; Fedele et al., 2003). On the other hand, in some oceanic islands, fractional crystallization fails to account for the odd volumetric relationship between trachytes and their supposed parent basalts, especially when taking into account the absence of intermediate members throughout the differentiation suite (i.e. the "Daly-gap" introduced by Chayes, 1977 on the basis of an early geological report on the Ascension Island by Daly, 1925). Apart from a few dismissive accounts considering this compositional gap an artifact due to limitations of subaerial sampling (Harris, 1963; Baker and Mv Reath, 1972) or misleading petrochemical calculations (Clague, 1978), petrologists have offered different explanations for the paucity of intermediate differentiates. Some theories invoke complex physico-chemical perturbations in the differentiating magma reservoir which interrupt the liquid line of descent, leading to the formation of end members rather than the intermediate ones (e.g. Bonnefoi et al., 1995; White et al., 2009). Mixing between already differentiated liquids in an anomalously stratified magmatic chamber was also suggested (Ferla and Meli, 2006).

On the other hand, near-solidus differentiation due to (hydrous) partial melting of mafic intrusive rocks has repeatedly been proposed as a possible mechanism for generating felsic primary melts in oceanic and continental geodynamic settings (e.g., Chayes, 1977; Bohrson and Reid, 1995; Bohrson et al., 1996; Bohrson and Reid, 1997, 1998; Avanzinelli et al., 2004; Martin and Sigmarsson, 2007; Koepke et al., 2007). Furthermore, open-system processes, such as brine-induced partial

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melting of hydrothermally-modified oceanic crust or assimilation of altered wall rocks by basaltic magmas, can account for the isotope systematics and trace element distributions of some OI-type trachytes (e.g., Lassiter et al., 2002; Gagnevin et al., 2003; Legendre et al., 2005).

Since the first discovery (Scribano, 1986) of deep-seated xenoliths in the Hyblean area (Southeastern Sicily, Italy), investigations on them have aimed at obtaining insights into the nature of the unexposed lithospheric basement. In addition to providing the principal information on regional geology, Hyblean xenoliths have sometimes supplied indications regarding petrological problems of broad interest, such as mechanisms of metasomatic processes in the lithospheric mantle and lower crust, as well as their bearing on the origin of different magma compositions (e.g. Tonarini et al., 1996; Scribano et al., 2009). Specifically, Scribano and Manuella (2007) mentioned the intriguing occurrence of glasses with trachytic compositions found in some hydrothermally altered mafic xenoliths from Valle Guffari (VG in Fig. 1). These authors briefly noted that such an occurrence may pertain to the primary origin of some trachytoid magmas, including peralkaline types. The present paper attempts to substantiate this hypothesis on the grounds of newly acquired ion microprobe data on the same glass compared with published trachyte compositions from various oceanic islands and the neighboring sites of Pantelleria and Mt. Etna.

2. Geological setting

The Hyblean Plateau is an uplifted emerged portion of the Pelagian–Ionian foreland area in southeastern Sicily, Italy (Fig. 1). This plateau is bounded to the east by the northernmost segment of a

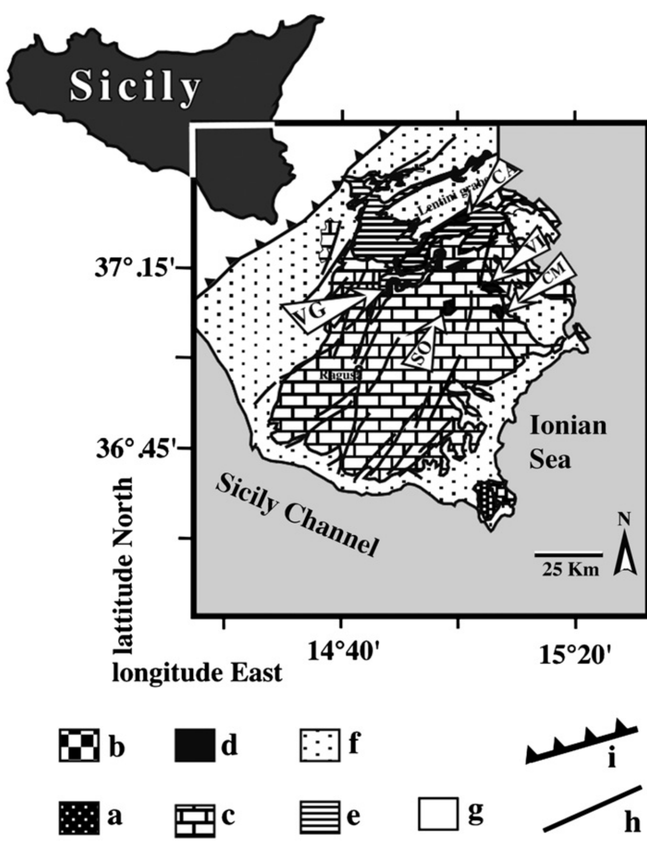

Fig. 1. Geological sketch map of the Hyblean area (after Lentini et al., 1994, mod.) and location of the main xenolith occurrence (VG-Valle Guffari; CM-Cozzo Molino; CA-Carlentini; VI-Vallone Iuso; SO-Sortino. Legend: a) Upper Cretaceous limestones; b) Upper Cretaceous OIB-type lava and hyaloclastite; c) Cenozoic limestones; d) Xenolith-bearing Miocenic diatremes and/or related tuff-breccia deposits; e) Plio-Pleistocenic OIB-type and E-MORB-type lavas and hyaloclastite; f) Neogene–Quaternary open-shelf clastics; g) Allochtonous sediments of the Maghrebian units; h) Main faults; i) Limit of the Maghrebian thrust belt.

steep and long submarine slope, the Hyblean–Malta Escarpment, which separates the Pelagian shelf from the Ionian abyssal plain (~3000 m b.s.l.). The Hyblean Plateau is down-faulted to northwest, forming the Gela–Catania foredeep, which is filled by silico-clastic sediments of the Apennine–Maghrebian thrust belt front (Butler et al., 1992). Two main fault systems cross-cut the Hyblean area. One, trending NE–SW, is extensional; the other, trending NNW–SSE, mostly consists of strike–slip faults (Grasso and Reuther, 1988). The exposed part of the Hyblean stratigraphic succession consists of Upper Cretaceous to Cenozoic deep-water carbonate rocks, Neogene to Quaternary open-shelf terrigenous rocks and various levels of basic volcanic rocks (Bianchi et al., 1987). The deepest subsurface levels inferred by deep wells drilled for hydrocarbon prospecting consist of dolomitic limestones and basic volcanic rocks middle Triassic in age (e.g. Rocchi et al., 1998). No direct evidence on the nature of the pre-Triassic basement has been reported so far, except for xenoliths brought to the surface by diatremic eruptions (e.g. Scribano, 1986; Scribano et al., 2006a).

Oil wells drilled in the Hyblean sedimentary succession recorded a nearly continuous, dominantly effusive magmatism from Middle Triassic to Late Cretaceous, with an estimated magma effusion rate ranging from 10 to 100 $km^3\ Ma^{-1}$. The Mesozoic subsurface volcanic rocks consist of basalts with OIB affinity (Rocchi et al., 1998). Upper Cretaceous volcanic rocks crop out in the southernmost area of Sicily (Fig. 1) and hence they form scattered, small outcrops along the Ionian coast, from Siracusa to Augusta. Most of the Hyblean volcanic rocks crop out in the northeastern part of the Plateau occupying an area of about 350 km^2. They are generally Pliocene to Pleistocene basaltic volcanics (lavas and hyaloclastites), often submarine, with both Na-alkaline and tholeiitic affinity (e.g., De Rosa et al., 1991; Tonarini et al., 1996; Schmincke et al., 1997; Trua et al., 1998). It is important to note that the interpretation of the Sr–Nd–Pb isotopic data for the Upper Miocene and Plio-Pleistocene lavas from the Hyblean area has excluded the presence of continental crust contamination (Trua et al., 1998).

3. The Hyblean xenoliths and their bearing on the nature of the unexposed basement

Although lava flows fed by fissure activity represent the main volcanic feature of the Hyblean area, there are also some alkaline-mafic diatremes in the central-eastern part of the plateau (Carbone and Lentini, 1981). The diatremic activity occurred during the Upper Miocene (Tortonian) and bore to the surface an important suite of deep-seated xenoliths the study of which has greatly improved our knowledge of the underlying, unexposed lithosphere. Specifically, the xenoliths consist of mantle-derived ultramafic rocks, minor gabbroic rocks representing the unexposed crustal basement, and various sedimentary and volcanic rocks coming from the Meso-Cenozoic succession. To date, no typical continental crust rocks have been found among the Hyblean xenoliths.

Mantle xenoliths consist of spinel-facies, four-phase peridotites and different pyroxenite types. The former are composed of spinel-harzburgite exhibiting both protogranular and porphyroclastic texture. The $Mg/(Mg+Fe^{2+})$ values (Mg#) of the harzburgite olivine vary from 0.90 to 0.92 (0.91 is the most common value), with NiO = 0.2–0.5 wt.%. The Cr/(Cr + Al) ratio (Cr#) of spinel ranges from 0.25 to 0.45 and Mg# from 0.7 to 0.8. The Mg# values of orthopyroxene vary between 0.87 and 0.91 with CaO < 0.9 wt.%. Minor Cr-diopside exhibits a narrow range of compositional variations ($En_{52}Wo_{47}Fs_1$–$En_{50}Wo_{43}Fs_7$). Major element compositions in peridotites also suggest a moderate to high degree of depletion (whole rock $Al_2O_3 < 2$ wt.%, $TiO_2 < 0.2$ wt.%). Their initial $^{143}Nd/^{144}Nd$ (0.51256–0.51277) is similar to that of the average Late Paleozoic–Early Mesozoic MORB (Tonarini et al., 1996). This time interval is that estimated for the formation of the adjoining Ionian lithosphere (Vai, 2003).