

## RELATIONSHIPS BETWEEN MAFIC AND FELSIC MAGMATISM AT PANTELLERIA: A PETROLOGICAL STUDY ON INTERMEDIATE TRACHYTE MAGMAS

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### INTRODUCTION

Pantelleria island (Strait of Sicily) is the type locality for pantellerite (a Fe-rich peralkaline rhyolite) and it is well known in the petrological literature for the presence of a bimodal suite including slightly hy-normative transitional basalts/hawaiites to ne-normative alkali basalts as mafic end member ( $\text{SiO}_2 = 45\text{-}52$  wt.%) and metaluminous to peralkaline trachytes and pantellerites as felsic end member ( $\text{SiO}_2 > 62$  wt.%). Rocks of intermediate composition such as mugearites, benmoreite and mafic trachytes have been found only as xenoliths (Villari, 1974; Ferla & Meli, 2006). The lack of intermediate composition in bimodal suite (Daly Gap) is a common feature in the alkaline/peralkaline volcanism in continental rift and oceanic island settings.

The origin of the peralkaline silicic end members at Pantelleria, and more in general in the continental rift zones where the Daly Gap is present, remains a puzzling issue in the volcanological literature. Although some recent experimental petrology studies (Scaillet & Macdonald, 2001, 2003; Di Carlo *et al.*, 2010) and petrological papers (White *et al.*, 2005, 2009) shed light on several aspects regarding the phase equilibria, the assessment of T-P pre-eruptive conditions, and the role of dissolved  $\text{H}_2\text{O}$  and  $f\text{O}_2$ , some questions still remain unanswered. There is a general consensus that pantellerite is most likely deriving from trachyte *via* fractional crystallization of an assemblage dominated by alkali feldspar at relatively low pressure and  $f\text{O}_2$  ( $\leq$  FMQ; White *et al.*, 2005, 2009; Di Carlo *et al.*, 2010), whereas two contrasting models have been proposed for the origin of the trachytes:

(i) protracted fractional crystallization from an alkali basalt parental magma (Civetta *et al.*, 1998) to trachyte and then to pantellerites (after removal of 90% of solid); this model has been developed purely on geochemical grounds, whereas more recently White *et al.* (2009), added valuable petrological constraints to the fractional crystallization model;

(ii) no direct consanguinity between mafic and felsic magmas; following this hypothesis, trachytes are the result of a two-step process that encompasses the low-degree partial melting of alkali-rich mafic cumulates followed by fractional crystallization at low-pressure (Lowenstern & Mahood, 1991; Avanzinelli *et al.*, 2004).

At Pantelleria, pantellerites were erupted either as pyroclastic density currents or as pumice fall deposits or else as lava flows and lava domes. On the contrary, trachytes were erupted almost exclusively as lava flows and, to a lesser extent, are found as enclaves in some young pantelleritic pumice fall and lava flows. Trachytes are the less evolved erupted felsic composition and, consequently, represent the crucial rock-type to investigate the relationships among mafic (parental) magmas and felsic (derivative) melts.

The principal aims of this study were: (i) to explore petrographic variability within the lava pile of Montagna Grande, that consists of metaluminous to slightly peralkaline trachytes; (ii) to focus on detailed petrological determinations, including trace elements in key mineral phase (*e.g.* clinopyroxenes); (iii) to perform thermodynamic modelling (MELTS code) in order to explore the viability of fractional crystallization process and its adherence to the natural products; (iv) to perform a few focused crystallization experiments, in order to more tightly constrain the pre-eruptive conditions.

### BULK ROCK COMPOSITION, PETROGRAPHY AND MINERAL CHEMISTRY

The mafic rocks collected at C. Mursia and C. Bruciata show porphyritic textures with phenocrysts of labradoritic plagioclase ( $\text{An}_{54-68}$ ), clinopyroxene ( $\text{Wo}_{40-45}\text{-Fs}_{12-16}$ ), olivine ( $\text{Fo}_{73-79}$ ), and microphenocrysts of

Fe-Ti oxide. They are alkali basalts (Fig. 1), with trace elements abundance typical for the basalts younger than 50 ka as discussed in Civetta *et al.* (1998).

Trachytic samples range from metaluminous trachytes (Peraalkalinity Index =  $Na + K / Al = 0.97-1.00$ ) to comenditic trachyte (PI = 1.1-1.2). They have porphyritic texture with, up to 45 vol.% phenocrysts of anorthoclase ( $An_{1-20} Ab_{64-73}$ ), clinopyroxene ( $Fs_{25-39}$ ) and minor olivine ( $Fo_{8-30}$ ) and oxides. The metaluminous trachytes show poorly variable contents of incompatible trace elements (ITE) in the following ranges: Rb = 53-77 ppm; Zr = 300-615 ppm; Nb = 58-128 ppm. They also show nearly constant content of Ba (1048-1128 ppm) and Sr (177-187 ppm) and correspond to the High-ITE metaluminous rocks of White *et al.* (2009).

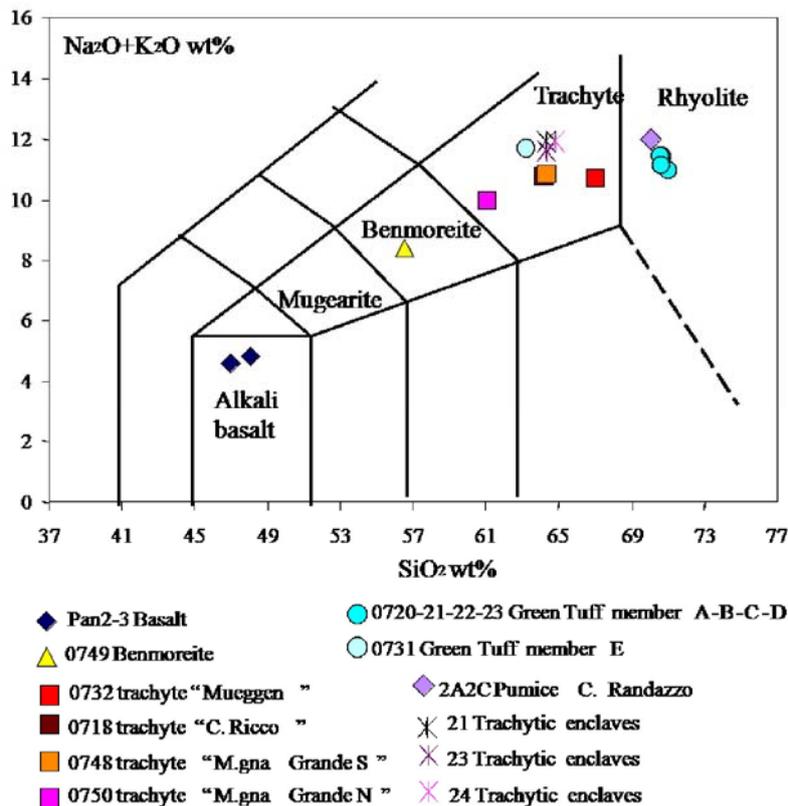


Fig. 1 - Total-alkali versus silica (TAS) diagram for the classification of volcanic rocks at Pantelleria.

The peralkaline trachytes have incompatible trace elements, such as Rb, Zr, Nb, lower than the previous ones, for the same  $SiO_2$  content. Based on the Ba content, the peralkaline group can be further divided in two groups: High-Ba (Ba = 1940-2160 ppm) and Low-Ba (Ba < 500 ppm).

The most evolved rocks are Fe-rich peralkaline rhyolites (pantellerites) with PI = 1.6-1.8. Typical phenocrysts are anorthoclase, with nearly homogeneous composition ( $Or_{32-38}Ab_{60-68}$ ;  $An < 1.6$ ), and aenigmatite associated with minor hedenbergitic clinopyroxene, ilmenite ± magnetite ± fayalite.

A single intermediate rock found among the lavas of Montagna Grande, shows benmoreitic bulk composition with  $SiO_2 = 55.6$  wt.% and alkalis = 8.2 wt.%. However, textural characteristics and mineral chemistry, such as the presence of

resorbed phenocrysts, reversely and directly zoned crystal with resorbed cores along with microphenocrysts showing textural equilibrium with the groundmass, point to the occurrence of different mineral paragenesis mixed together in the rock.

Trace elements in clinopyroxenes have been analyzed in seven samples which include rocks with different degree of evolution and trachytes with different geochemistry. REE increase steadily from basaltic to silicic rocks following nearly parallel trends *i.e.* without any relevant change in slope, for basalt to trachyte, whereas clinopyroxenes from pantellerite show a marked increase in HREE (Fig. 2)

The variations of Zr and Nd vs. Mg# in pyroxene highlight two distinct trends which intersect at the basaltic end-member: an ITE-rich trend which includes the metaluminous trachytes, and an ITE-poor trend which includes peralkaline rocks.

The trace elements in pyroxene hosted in the sample with benmoreitic bulk composition show the occurrence of three populations of crystals: 1) diopsidic pyroxene with the same chemistry than the pyroxene in

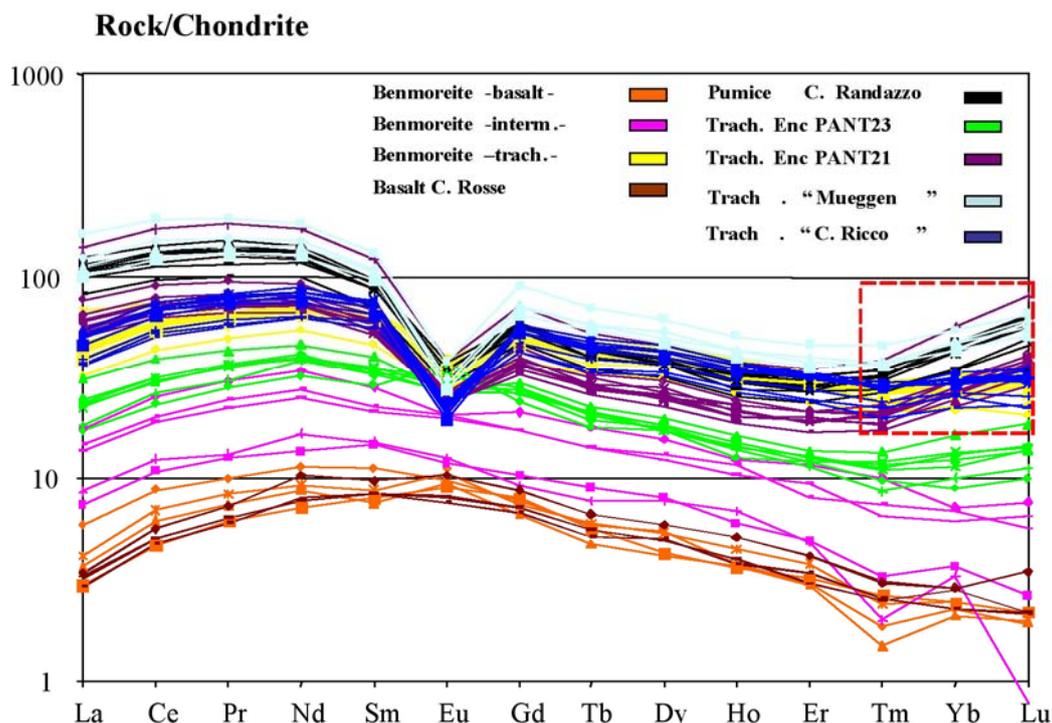


Fig. 2 - Chondrite-normalized REE patterns for clinopyroxene in alkali basaltic, trachytic and pantelleritic rocks from Pantelleria.

the alkali-basalts; 2) Fe-rich pyroxene with the same chemistry than the pyroxene in trachytes; 3) pyroxenes with intermediate composition, mainly found as microphenocrysts. This suggests that intermediate sample results from mixing between alkali basaltic and trachytic magmas.

#### EXPERIMENTAL PETROLOGY

The sample chosen for crystallization experiments is a porphyritic trachyte lava with phenocrysts of alkali feldspar (31 vol.%), clinopyroxene (2 vol.%), olivine (2 vol.%), and Fe-Ti oxides (2 vol.%), set in a microcrystalline groundmass. Whole rock SiO<sub>2</sub> and K<sub>2</sub>O are 64.0 wt.% and 4.2 wt.% respectively, with a PI = 0.97. The starting sample was melted and the resulting glass was ground and loaded in Au capsules together with a variable amount of H<sub>2</sub>O and silver oxalate.

Experimental conditions were varied in the range 900-950°C, 1-1.5 kb, 1.6-4.0% H<sub>2</sub>O<sub>melt</sub>, *f*O<sub>2</sub> ca. FMQ. Experiments were carried out at CNRS - Institute des Sciences d'Orleans.

#### RESULTS

Chemical and mineralogical study of the samples from Montagna Grande lava pile and trachytic enclaves in more recent explosive products (Randazzo eruptive unit) allow to focus on some aspects of the magma history in the past 50 ka at Pantelleria island. The results can be summarized as follow:

i) the occurrence of a benmoreite lava flow within the trachyte lava pile and well within the caldera limit (mafic magmas outcrop only north of the young caldera) is the result of mixing processes between a mafic melt and the resident trachyte magma. The mafic end member shows characteristics close to those of the alkali basalts erupted outside the caldera in the past 50 ka. This argues for basaltic magmas intruding the trachytic magma chamber when this latter was almost emptied at the end of the eruptive event and can be regarded as a physical

evidence of a strict relationship between basaltic and trachytic magmas.

ii) the whole rock geochemistry and the trace elements distribution in clinopyroxenes, suggest that trachytes can derive from alkali basalts via crystal fractionation. Different conditions, of oxygen fugacity and crystallization of accessory mineral phases, can determine different evolutionary trends, leading to trachytic magmas with different chemistry, as the two groups of trachytes that were here recognized: a) metaluminous trachytes high in incompatible trace elements and b) peralkaline trachytes low in incompatible trace elements; they possibly depict two distinct petrogenetic trends.

iii) the crystallization experiments allow to place some further constraints (Fig. 3):

- pre-eruptive conditions: trachyte magma T-P-H<sub>2</sub>O<sub>melt</sub> conditions are closely reproduced by two experimental runs that match phase abundance and phase composition of the natural sample. Thus we propose as the most likely storage/crystallization conditions for trachyte magma at: T = 950°C, P = 1.5 kb, H<sub>2</sub>O<sub>melt</sub> = 2.5- 2.8 wt.%.

For what concern the derivative melts, we were able to produce a pantellerite liquid (PI = 1.24) at the following conditions: T = 950°C, P = 1 kb, H<sub>2</sub>O<sub>melt</sub> = 1.6 wt.%, at a total crystal content of 73 wt.%. These

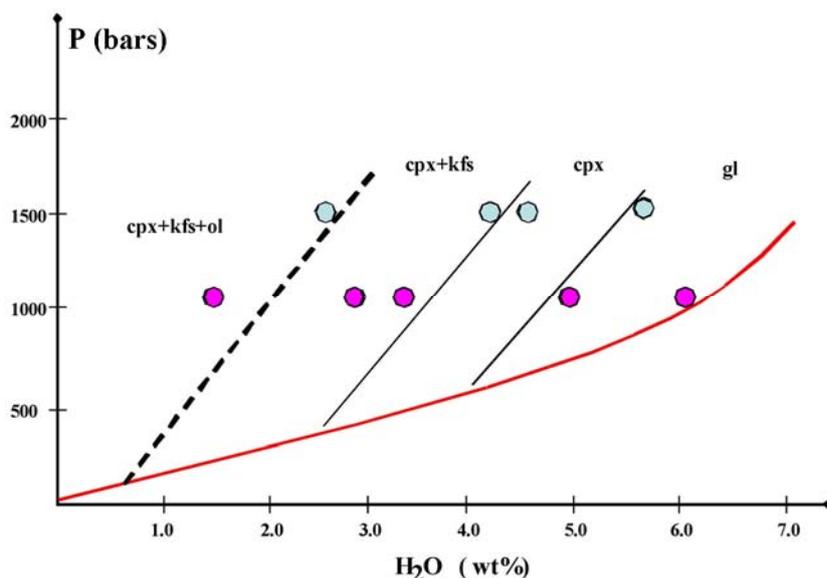


Fig. 3 - P-H<sub>2</sub>O<sub>melt</sub> phase equilibria at 950°C for trachyte composition. H<sub>2</sub>O in the melt was determined by coupling FT-IR and “by difference” method at the EMP. The lower curve is the water saturation for a trachyte melt.

conditions are very different from the inferred pre-eruptive T-P-H<sub>2</sub>O of pantellerite magma (Di Carlo *et al.*, 2010), being much higher in temperature and at an H<sub>2</sub>O<sub>melt</sub> unrealistically low.

Thus, more experiments are needed to better address this argument, focused to explore the low-T and H<sub>2</sub>O-rich region. Nevertheless, we are allowed to assess that pantellerites are derivative of parental trachyte magma after 70% of crystal fractionation, and this agrees with independent estimates, either geochemical or *via* thermodynamical modelling.

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