Experimental Determination of Phase Equilibrium and Pre-eruptive Conditions of Phonolitic Magmas from Tenerife (Canary Islands)

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INTRODUCTION.

Volcanoes and their eruptions play a major role in shaping the thermal and chemical structure of the Earth, its landscape and climate, and may have direct hazardous effects on society. The style, duration, explosivity, and hazards of a given eruption is a function of many different variables. This includes the magma flux from depth, the magma storage time, and the values of the thermodynamic variables at which magma is stored prior to eruption. These latter are the so called-pre-eruptive conditions, and include the pressure (P), temperature (T), volatile fugacities (fO_2, fH_2O, fSO_4, etc) and composition of the magmas, and are the main topic of this communication.

The pre-eruptive conditions can be in some cases determined by studying the natural rocks. Calibrated equilibrium reactions between minerals- silicate melts and fluids combined with glass inclusion studies can provide information about some intensive variables (e.g., T, fO_2, more rarely P). However, for many magmas, mineral or fluid compositions there is not enough thermodynamic data that allow for such determinations. Moreover, large uncertainties are associated to key parameters like pressure which gives information about the depth of the magmatic system. The alternative or complementary approach is to perform phase equilibria experiments on the natural rock of interest. The experimental method allows for testing the effects of the different environmental parameters and in many cases they can be varied until a match between the experimental and natural products is found. Although this approach can be time consuming, it allows a precise determination of the intensive variables and contributes to the calibration numerical algorithms of free energy minimisation based on thermodynamic databases.

In this work, we use the phase equilibrium experimental technique for constraining the pre-eruptive conditions of phonolite magmas erupted in Tenerife Island. We chose to investigate two of the most relevant eruptions for volcanic hazards. One is the product of the last caldera collapse (El Abrigo eruption) and associated with the explosive eruption that produced about 20 km^3 of ignimbrite at about 200 kyr ago. The other is the effusive event of Lavas Negras which is the last eruption of Teide volcano and which occurred at about 900 yr AD. We have found that these two phonolitic magmas which are similar in composition, and also similar water contents, they were stored at different depths. The difference in storage depth could be related with the change in the eruptive dynamic from explosive to effusive observed during the last 200 kyr.

SAMPLES AND METHODS.

The phonolite of El Abrigo contains with about 7 vol% of phenocrysts, mainly sanidine, magnetite, biotite, clinopyroxene, titanite and traces of sodalite and apatite. In contrast, the last eruption of pico Teide (Lavas Negras), contains about 33 vol% of phenocrysts, mainly anorthoclase with lesser amounts of clinopyroxene and magnetite.

The experimental laboratory.

Crystallization and reversal experiments were performed in the new experimental laboratory SIMGEO (UB-CSIC, Barcelona, Spain), using 3 cold seal pressure vessels (CSPV) working vertically with rapid-quench system attached to the bombs (Fig. 1). We have investigated

fig 1.General view of the SIMGEO experimental laboratory where can be observed the three cold seal vessels, their furnaces and the accessory equipment.

pressure ranges from 50 to 250 MPa, temperatures of 700-925ºC, water contents in the melt from 1.5 to ca. 10 wt %, and oxygen fugacity (fO_2) from 1 log unit above the Ni-NiO solid buffer to the fayalite -magnetite- quartz (FMQ) buffer. We use de-ionized water as a pressure medium. Pressure is recorded by Bourdon gauges with an accuracy of ± *10 MPa*. Temperatures are recorded by using K-type thermocouples with an accuracy of ±*5ºC*.

Experimental procedure.

Variable amounts of water were added to the rock powder and loaded into $Ag_{70}Pd_{30}$ capsules spanning from water-saturated to largely under-saturated conditions. The capsules were inserted in the furnace and pressurised till a half value of the target pressure. After that, temperature was increased to 900 or 925ºC and left for 4-5 hours for completely melt the sample. Later, temperature and pressure were decreased until achieving the target values. Experiments were left for 7-15 days at the desired conditions and then they were quenched. Run products were included in epoxy resin and mounted and polished in a thin section.
Thin sections were studied under the petrographic and electron microscope. Phase proportions of the experimental

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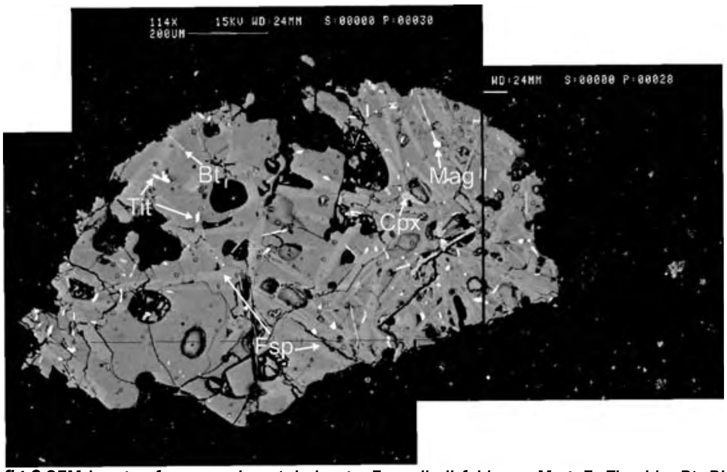

fig 2.SEM image of an experimental charge. Fsp: alkali feldspar; Mag: Fe-Ti oxide; Bt: Biotite; Tit: Titanite.

charges were determined by analysis of backscattered electron images (Fig. 2). The different experimental phases were analysed using the electron microprobe with an accelerating voltage of 20 kV, sample current of 6 nA for glasses and 10 nA for minerals, beam size of 10 µm for minerals and 20 µm for glasses. Na and K were analysed first with counting times for glass analyses were 20 s for Na and 10 s for other elements; in mineral analyses counting times were 10 s for all elements.

EXPERIMENTAL RESULTS.

The shape, distribution, and lack of zoning of the experimental phases suggest that equilibrium was achieved to a high degree. This was confirmed by the small variations of phase compositions within a single experimental charge and by the fact that we obtained the same results in forward and reversal runs. In total, the results of more than 100 experiments are used to display the phase equilibrium relations at different conditions of T, P, H_2O using different variables in variation diagrams.

In the case of El Abrigo, the experimental products were magnetite, biotite, clinopyroxene, titanite, alkali feldspar, a feldspathoid, and apatite. These phases include the mineral assemblage of the ignimbrite. Detailed comparison between natural and experimental phase assemblage, proportions, and compositions indicate that the magma was stored at 800-850ºC, 130MPa, and water contents in the melt of about 3 wt% (Fig. 3).

The experimental runs from lavas Negras contained alkali feldspar, magnetite, clinopyroxene, and biotite, and also reproduce the natural phase assemblage. The comparison between the natural and experimental phase proportions and mineral assemblage constrain the pre-eruptive parameters to be 900ºC, 200MPa and water contents in the melt ca. 3 wt%.

DISCUSSION.

The main results and topics to be discussed from this work are:

(1) Despite the similar bulk major element composition of both samples, the experimental phase assemblages are not the same. For example, the feldspatoid mineral present in the experimental and natural products of El Abrigo and which is crucial to determine its storage pressure is absent in the Lavas Negras. This indicates that there is a high sensibility of the phase equilibria on the bulk composition of the system and it implies that results from one system can not be universally extrapolated. It is worth noting that there is also a significant difference between the two compositions in terms of their trace element data. El Abrigo is more differentiated (e.g. containing higher abundances of incompatible trace elements) than Lavas Negras. The coupled observations of sensitivity of phase equilibria and trace element variation to the bulk composition can be explained if both systems are close to an eutectic. In this situation, a small variation of major elements can cause large variation of crystallinities and incompatible trace elements and thus explain our observations.

(2) The difference in explosivity between the two phonolites (ignimbrite of El Abrigo vs. lava for Lavas Negras) can not be simply explained by the amount of volatiles, since both magmas were stored with similar water contents in the melt. The difference in eruptive behaviour is probably related to the difference in storage depth, although it could also be due to differences in eruptive fluxes or total volumes, aspects that can not be resolved by the phase equilibra results.

(3) The shift from a depth of about 4 km for the large explosive eruption of El Abrigo to about 6 km for the last eruption of Teide indicates that a the storage level of phonolite magmas has changed with time. This probably reflects the reorganization of the magmatic system after the catastrophic event of caldera collapse that should be accounted for in numerical models of the volcanic evolution of Tenerife.

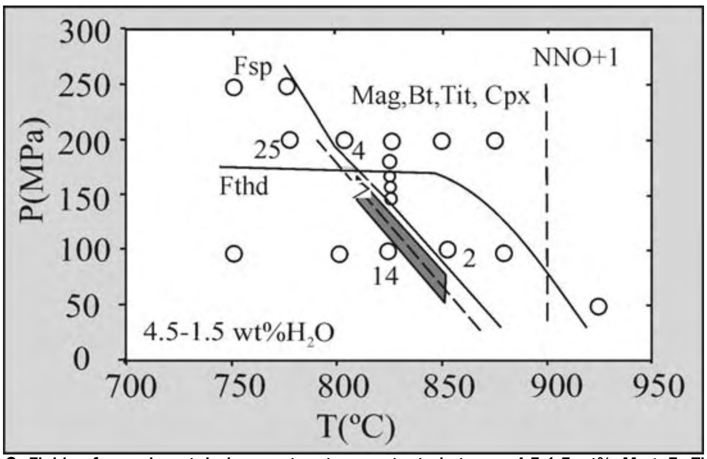

fig 3. Fields of experimental phases at waters contents between 4.5-1.5 wt%. Mag: Fe-Ti oxide; Bt: biotite; Tit: titanite; Cpx: clinopyroxene; Fsp: alkali feldspar; Fthd: feldspathoid. Numbers below circles indicate crystal content of the charge in vol%. Grey region indicates the pre-eruptive conditions where the crystal content and mineral assemblage of the El Abrigo phonolite are reproduced.