

Mineralogical and geochemical characteristics of gabbros in the Los Molinos area, Fuerteventura (Canary Islands)

Características mineralógicas y geoquímicas de los gabros del área de Los Molinos, Fuerteventura (Islas Canarias)

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ABSTRACT

Gabbros of Los Molinos area crop out in the northwest part of Fuerteventura (Canary Islands). They are formed by different types of gabbros, and their mineralogy and geochemistry are presented in this work. The results indicate that the most fractionated gabbros are leucogabbros situated in the upper parts of the intrusion, whereas the most primitive (olivine-rich) gabbros occur in the lower parts. Crystallization temperatures range from 1116 to 836°C. Whole rock geochemistry is partly controlled by modal mineralogy and shows moderate alkalinity suggesting, in principle, a higher affinity with miocene volcanic rocks from the Central edifice than with those from the North one. In situ crystallization mechanism followed by progressive segregation of a slightly more differentiated liquid and volatile concentration is proposed.

Key-words: Fuerteventura, gabbro, crystallization sequence, geochemistry.

RESUMEN

Los gabros del área de Los Molinos afloran en la zona noroeste de la isla de Fuerteventura (Islas Canarias). Está formada por diferentes tipos de gabros de los que la mineralogía y la geoquímica se presentan en este trabajo. Los resultados indican que los gabros más fraccionados son leucogabbros situados en las partes más altas de la intrusión, mientras que los más primitivos (ricos en olivino) aparecen en las partes más bajas. Las temperaturas de cristalización quedan comprendidas entre 1116 y 836°C. La geoquímica de roca total está en parte controlada por la mineralogía modal y muestra una alcalinidad moderada, lo que sugiere, en principio una mayor afinidad con las rocas volcánicas miocenas del Edificio Central que con las del Edificio Norte. El mecanismo de cristalización que se propone es cristalización in situ seguida de la separación progresiva de un líquido un poco más diferenciado con concentración de volátiles.

Palabras clave: Fuerteventura, gabro, secuencia de cristalización, geoquímica.

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Introduction

Fuerteventura is one of the most singular islands of the Canary archipelago because in it, it is possible to observe outcrops of intrusive rocks, which allow us to study the subvolcanic processes that took place in different stages of growth and development of the island. These stages have been grouped into four magmatic episodes: alkaline-carbonatitic, subalkaline-transitional, alkaline and volcanic-subvolcanic Betancuria Edifice (Muñoz *et al.*, 2003; Muñoz and Sagredo, 2004), and part of them are probably reflected in the different phases of construction of the Miocene volcanic edifices defined by Ancochea *et al.* (1996). Thus, in-

trusions to the north of the island (Fig. 1) (Milocho-Blanca intrusions) have been associated with the Northern Volcanic Complex (Tetir Edifice) (De Ignacio, 2008) while those in the central-west part (Pájara intrusion) have been related to the Central Volcanic Complex (Gran Tarajal Edifice) (Muñoz *et al.*, 2003).

In the overlapping area between the Northern and Central Volcanic Complexes (Fig. 1), a small (~6.5 Km²), group of intrusive outcrops occur. The main focus of this work is to describe the mineralogical and geochemical characteristics of one of these intrusions in order to consider, in a preliminary way, if it could be related either to the Northern or to the Central Volcanic Com-

plexes proposed by Ancochea *et al.* (1996). Galindo (1978) performed the first study in the south part of this sector (Morro Negro area) focusing on temperature and depth of emplacement, from transformations observed in the host rock and therefore this was the basis for the present work.

Geologic setting

The gabbros in the south part of Los Molinos area are cut by ~15% dikes of basalt to trachybasalt compositions and showing N 010° E to N 040° E trend directions. Surrounding this intrusion, heterolithological matrix-supported breccia (comprising mainly fragments of dikes, but

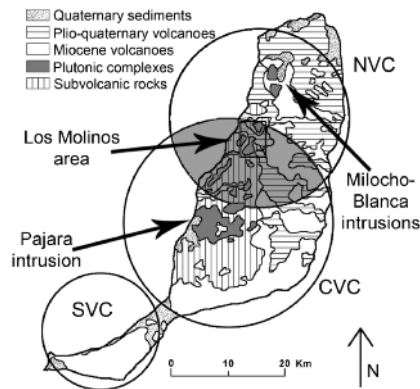


Figure 1.- Geological sketch of Fuerteventura with location of the main intrusive bodies and three major Miocene volcanoes reconstructed by Ancochea et al. (1996). NVC: Northern Volcanic Complex. CVC: Central Volcanic Complex. SVC: Southern Volcanic Complex.

Figura 1.- Esquema geológico de Fuerteventura con la localización de los principales cuerpos intrusivos y los tres grandes volcanes miocenos reconstruidos por Ancochea et al. (1996). NVC: Complejo Volcánico Norte. CVC: Complejo Volcánico Central. SVC: Complejo Volcánico Sur.

also of plutonic and volcanic rocks) is present.

The gabbros are melanogabbro, gabbro and leucogabbro. The first two lithologies occur in the lower parts of the intrusion, are coarse-grained and are always moderately altered. The upper-central parts are occupied

by gabbros and some leucogabbros, both of which are mainly medium-grained. The uppermost part of the intrusion is occupied by leucogabbros locally showing microrhythmic, modal layering. The layering trends range between N-S and NE-SW. The contacts between all lithologies are always gradual and progressive. It is also common to find pegmatoid gabbro facies near the leucogabbros.

Petrography and mineral chemistry of the gabbros

Mineral chemistry analyses were performed using an electron microprobe at the Centro Nacional de Microscopía Electrónica, Universidad Complutense de Madrid.

Petrographically, four types of gabbros can be distinguished: olivine melanogabbros, olivine gabbros, gabbros s.s. and leucogabbros. However, minerals show broadly similar chemistry in all groups (Table I), so that differences imply variations in texture and mode, probably reflecting magma chamber processes.

Olivine gabbros and melanogabbros are coarse-grained rocks composed of plagioclase, clinopyroxene, olivine, amphibole and Fe-Ti oxides as essential minerals, and mica and apatite as accessory minerals.

Gabbros and leucogabbros are

medium-grained rocks mainly, and their mineralogy is similar to that of olivine gabbros and melanogabbros, but without olivine (or with it as an accessory mineral). Layering described in the field is also observed in the presence of igneous lamination (thin section scale) marked by the orientation of plagioclase.

Table I summarizes the main petrographic and mineralogical features for the four types of gabbros in the south part of the Los Molinos area.

Geothermometry

Considering the amount of Ca in olivine it is possible to calculate its temperature of crystallization (De Hoog et al., 2010). Thus temperatures between 950°C and 1116°C were obtained.

Equilibrium temperatures between plagioclase rims and amphibole cores have also been established through the thermometer proposed by Blundy and Holland (1990). In this way, mineral equilibrium temperatures span a range between 836-938°C in all rock types.

Ernst and Liu (1998) created a semi-quantitative thermometer based in ^{IV}Al contents of synthetic Ca-amphiboles. With this method, we obtained temperatures of 880-950°C for kaersutites in these gabbros.

	Olivine melanogabbro	Olivine gabbro	Gabbro s.s.	Leucogabbro
Plg.	Bytownite-labradorite in cores and labradorite-andesine in rims			
	Euhedral prisms		Subhedral prisms	
Clpx	Normally zoned. Di ₇₃₋₇₇ Hd ₂₀₋₂₃ Aeg ₂		Normal zoned. Di ₇₀₋₇₅ Hd ₂₅₋₂₇ Aeg ₂₋₄	
	Large subhedral to anhedral crystals			
	Inclusions of Plg., Ol and Fe-Ti oxides. Totally or partially surrounded by Amph.			
Olivine	Large euhedral to subhedral crystals. Fo ₇₀ Fa ₃₀			
	Moderately altered along fractures and rims		Almost totally replaced by iddingsite	
	Sometimes including minute oxides and secondary fluid inclusions			
Fe-Ti oxides	Exsolutions. Mt ₇₆₋₉₁ Usp ₉₋₂₄ Ilm ₈₅₋₈₉ Gk ₁₀₋₁₄ Php ₁		Exsolutions. Mt ₆₀₋₇₉ Usp ₂₁₋₄₀ Ilm ₈₄₋₉₇ Gk ₃₋₁₀ Php ₁₋₂	
	Poor in NiO, Nb ₂ O ₅ and Cr ₂ O ₃ , though the latter can reach 19 wt% in oxides included in Ol.			
Amph.	Kaersutite (titanium rich pargasite with 6-7 wt% TiO ₂)			
	Poikilitic crystals. Intergrowth textures with Clpx.		Totally or partially surrounded by Fe-Ti oxides and or Clpx	
Mica	Titanium-rich (7-9 wt%) phlogopite (Ann ₀₋₂₅ Phl ₇₅₋₁₀₀) with low water contents (1,5-3,5 wt%)			
	Totally or partially surrounded by oxides and/or Amph.		Totally or partially surrounded by oxides	
Apatite	Fluorapatite (2-3 wt%) with some chlorine (0-1 wt%) and strontium (0,1-0,2 wt%)			
	From large subhedral prisms with fluid inclusions to small and acicular crystals			

Table I.- Main petrographic and mineralogical features of gabbros in south part of the Los Molinos area. Abbreviations: Plg: plagioclase; Clpx: clinopyroxene; Ol: olivine; Amph: amphibole.

Tabla I.- Principales características petrográficas y mineralógicas de los gabros en la parte sur del área de Los Molinos. Abreviaturas: Pgl: plagioclasa; Clpx: clinopiroxeno; Ol: olivino. Amph: anfíbol.

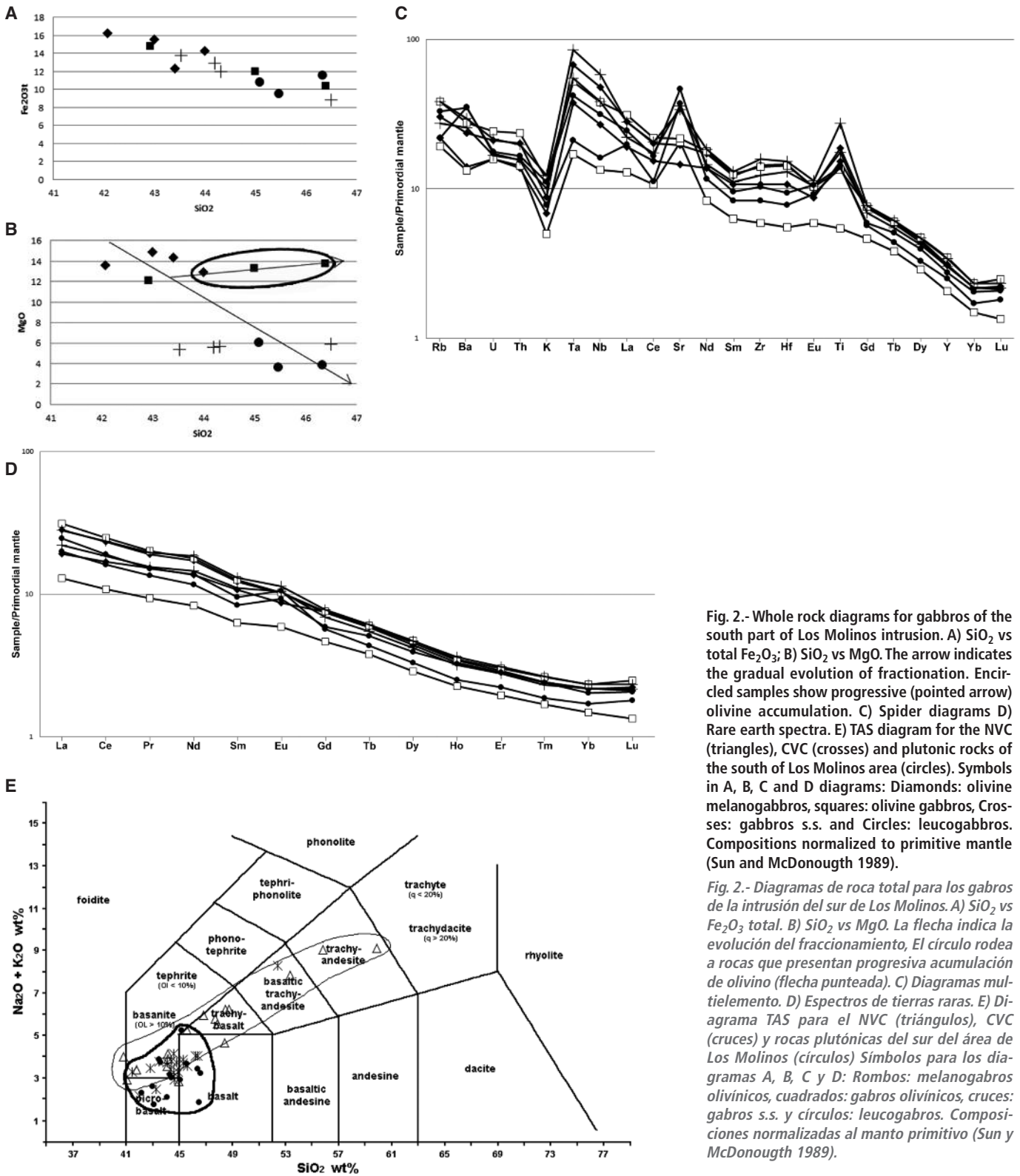


Fig. 2.- Whole rock diagrams for gabbros of the south part of Los Molinos intrusion. A) SiO₂ vs total Fe₂O₃; B) SiO₂ vs MgO. The arrow indicates the gradual evolution of fractionation. Encircled samples show progressive (pointed arrow) olivine accumulation. C) Spider diagrams D) Rare earth spectra. E) TAS diagram for the NVC (triangles), CVC (crosses) and plutonic rocks of the south of Los Molinos area (circles). Symbols in A, B, C and D diagrams: Diamonds: olivine melanogabbros, squares: olivine gabbros, Crosses: gabbros s.s. and Circles: leucogabbros. Compositions normalized to primitive mantle (Sun and McDonough 1989).

Fig. 2.- Diagramas de roca total para los gabros de la intrusión del sur de Los Molinos. A) SiO₂ vs Fe₂O₃ total. B) SiO₂ vs MgO. La flecha indica la evolución del fraccionamiento, El círculo rodea a rocas que presentan progresiva acumulación de olivino (flecha punteada). C) Diagramas de tierras raras. D) Espectros de tierras raras. E) Diagrama TAS para el NVC (triángulos), CVC (cruces) y rocas plutónicas del sur del área de Los Molinos (círculos) Símbolos para los diagramas A, B, C y D: Rombos: melanogabbros olivínicos, cuadrados: gabros olivínicos, cruces: gabros s.s. y círculos: leucogabbros. Composiciones normalizadas al manto primitivo (Sun y McDonough 1989).

Geochemistry

Whole rock geochemistry was performed at Activation Laboratories (Act Labs), Canada. These data have been complemented with some analyses by Galindo (1978).

Gabbros of the south part of Los Molinos area are ultrabasic to basic, silica-saturated and metaluminic rocks with subalkaline affinities.

Harker diagrams reveal positive correlations of Al₂O₃, NaO and CaO and negative correlations of MgO, Fe₂O₃ and TiO₂

with SiO₂ (Fig. 2A, B). The first pattern indicates the progressive fractionation of ferromagnesian-minerals, whereas the second one suggests plagioclase concentration. In the MgO vs. SiO₂ diagram (Fig. 2B), it is possible to observe the control exercised by the mineralogy, in this case, by olivine. Sam-

ples enclosed by a circle show a Mg excess proportional to modal olivine percentage. Furthermore, it is possible to affirm that whole rock geochemistry is controlled by the nature and abundance of the minerals that make up the different gabbro facies.

This control is also shown by spider diagrams and REE spectra (Fig. 2C, D). Thus, e.g., rocks rich in amphibole + Fe-Ti oxides have more pronounced positive Ti, and Ta-Nb anomalies, and a general enrichment in HFSE. On the other hand, slight positive Eu anomaly in leucogabbros not only reflects their high modal plagioclase content but also indicates a change from higher to lower oxygen fugacity conditions as crystallization proceeds.

Discussion

With the above data it is possible to establish a crystallization sequence: the earliest minerals to crystallize were olivine and Fe-Ti oxides, followed shortly after by clinopyroxene and some calcic plagioclase in a temperature range from 1116 to 950°C. This first crystallization stage removes MgO, FeO and TiO₂ from the initial magma, while concentrating SiO₂, Al₂O₃, CaO and Na₂O, which stabilizes plagioclase. In a second crystallization stage, plagioclase dominates the paragenesis while clinopyroxene rim compositions are enriched in Al₂O₃ and TiO₂. Progressive concentration of volatiles and incompatible elements in the magma stabilizes kaersutite as the main ferromagnesian phase, apatite as a host for REEs, and finally mica that retains K₂O and BaO. This stage would develop between 950°C and roughly 800°C.

Crystallization mechanism of the Los Molinos intrusion would have probably started as in situ crystallization in the margins and floor of the body, followed by progressive segregation of a slightly more differentiated liquid. Volatile concentration could have been produced as a result of the

fractional crystallization process itself, through retrograde boiling, thus explaining the tight association between amphibole and clinopyroxene, as well as the occurrence of small pegmatoid pods associated to the leucogabbros.

The microrhythmic layering observed in the latter could be explained by small alternative shifts in saturation of cotectic plagioclase and clinopyroxene/amphibole produced either by local increases or decreases in volatiles, changes in fO₂ or both, in a similar way as proposed by Boudreau and McBirney (1997).

Plotting on a TAS diagram (Fig. 2E) of the Los Molinos gabbros together with whole rock data from the lower parts of both the Central and Northern Volcanic Edifices of Ancochea (1993) and Ancochea *et al.* (1997), suggests that this intrusion is more related with the lower part of the Central Volcanic Complex than with the Northern one, as a first approximation.

Conclusions

Mineral chemistry in the south part of Los Molinos area is relatively simple, suggesting crystallization from a single magma batch. Whole-rock geochemistry indicates progressive fractionation from olivine-rich to leucogabbros. Crystallization conditions would comprise: a range of temperatures between 1116 and 836°C, some variation in fO₂, decreasing as fractionation proceeded and volatile saturation below 950°C, in a basaltic system of moderate alkalinity.

The Los Molinos intrusion seems to be related, as a first approximation, to the Central, Miocene Volcanic Edifice.

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