

Geo-Temas



Sociedad
Geológica
de
España

Volumen 20

XI Congreso Geológico de España



Geochemical comparison of circular plutonic complexes with extrusive rocks from Sal Island (Cape Verde).

Comparación geoquímica de los complejos plutónicos circulares con las rocas extrusivas de la isla de Sal (Cabo Verde).

M. García-Rodríguez¹, C. Villaseca¹, C. de Ignacio¹, D. Orejana¹, J. Mata² y R. Caldeira³.

¹ Dpto. Mineralogía y Petrología, Facultad CC. Geológicas, Universidad Complutense de Madrid, C. José Antonio Novais, 12, 28040, Madrid, España. magarc40@ucm.es, granito@geo.ucm.es, cris@ucm.es, dorejana@ucm.es.

² Dpto de Geologia, Faculdade de Ciências, Universidade de Lisboa, Instituto Dom Luiz, C. Campo Grande, 1749-016 Lisboa, Portugal. jmata@ciencias.ulisboa.pt.

³ Unidade de geologia e cartografia geologica, Laboratório Nacional de Energia e Geologia (LNEG), strada da Portela Bairro do Zambujal, 2610-999. Amadora, Portugal. rita.caldeira@lneg.pt.

Abstract: *Sal island is located in the northeast and is the oldest of the Cape Verde archipelago, with magmatic activity starting ~25 Ma ago. It presents a series of circular plutons that could represent the subvolcanic roots of the exposed extrusive rocks. In this work we compare the geochemical characteristics of melagabbro-gabbro of circular (~16.3 Ma) intrusions in the Old Eruptive Complex, with basaltic and nephelinitic lavas of equivalent age (~15.8 and 14.2 Ma, Torres et al., 2010). This comparison allows observing a geochemical overlap between basalts and gabbros, and the similarity between trends of part of the samples in Harker-type diagrams and REE patterns. However, this compositional overlap is incomplete, with considerable differences and absence of fractionated (intermediate) lava types related to these terms of the circular complexes. This partial but incomplete overlap of the compositional fields of the plutonic and volcanic trends argues against the possibility of a direct genetic relationship between the two.*

Key words: *Circular Complexes, Genetic Relationship, Sal Island, Cape Verde Archipelago.*

Resumen: Sal se localiza en el noreste de Cabo Verde y es la isla más antigua del archipiélago, con actividad magmática que comenzó hace 25 Ma. Presenta una serie de plutones circulares que podrían representar las raíces subvolcánicas de las rocas extrusivas expuestas. En este trabajo comparamos las características geoquímicas de melagabros-gabros de los complejos circulares (~16.3 Ma) intrusivos en el *Old Eruptive Complex*, con lavas basálticas y nefeliniticas de edad equivalente (~15.8 y 14.2 Ma, Torres et al., 2010). Esta comparativa permite observar un solapamiento geoquímico entre basalts y gabros, y la similitud entre tendencias de parte de las muestras en diagramas tipo Harker y patrones de REE. Sin embargo, este solapamiento composicional es incompleto, existiendo diferencias considerables y una ausencia de lavas fraccionadas (intermedias) que se relacionen con estos términos de los complejos circulares. Esta superposición parcial pero incompleta de los campos composicionales de las rocas plutónicas y volcánicas complica la posibilidad de existencia de una relación genética directa entre ambos conjuntos magmáticos.

Palabras clave: Complejos Circulares, Relaciones genéticas; Isla de Sal, Archipiélago de Cabo Verde.

INTRODUCTION AND GEOLOGICAL SETTING

The relationship between volcanic and plutonic rocks can provide relevant information about the magmatic differentiation processes occurring in igneous systems. The comparison of mineral chemistry, whole-rock geochemistry and geochronological data allows the study of this relationship between intrusive and extrusive systems and helps to recognise genetic links. In this work we compare the petrological and geochemical characteristics of a set of plutonic samples with lavas of similar age from Sal Island in order to study a possible genetic relationship.

Sal is the northeasternmost island of the Cape Verde archipelago and forms part of the northern alignment along with São Nicolau, São Vicente and Santo Antão

islands. It is the oldest island of the archipelago with magmatic activity that started about 25 Ma ago (Torres et al., 2010). It has been mainly studied for its volcanic formations, and there are few studies addressing the circular intrusive complexes that could represent the subvolcanic roots of the extrusive rocks exposed in the island (Torres et al., 2010).

These intrusions are located in the central part of Sal and yielded a K-Ar age of 16.3 ± 0.6 Ma (belonging to the *Old Eruptive Complex: OEC* in Fig. 1) (Torres et al., 2010). Roughly contemporary volcanic units are found in the south-central part of the island (*Main Eruptive Formation*, 15.8 - 14.2 Ma) and in the north (the slightly younger *Ponta do Altar-Baleia Complex (PAB)*, 11.2 - 8.7 Ma) (Holm et al., 2008; Torres et al., 2002) (Fig. 1). Due to their relatively coeval intrusion we compare the

petrological and geochemical features of the different lithologies that make up the plutons with the basaltic lavas belonging to the *Main Eruptive Formation* (MEF).

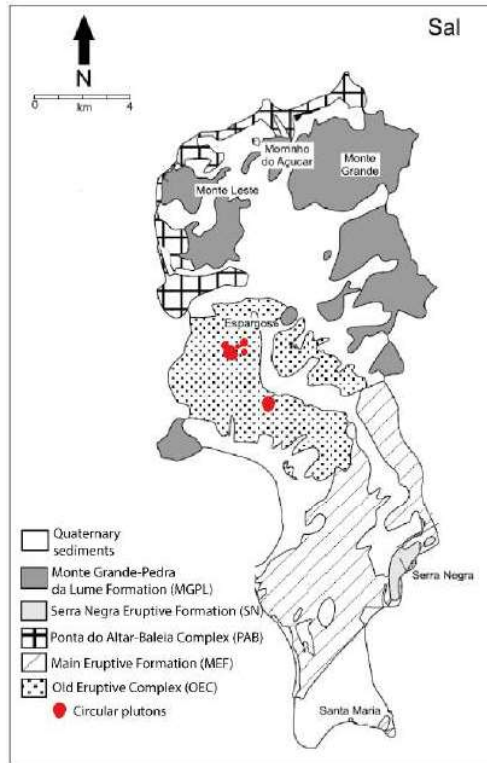


FIGURE 1. Schematic geological map of Sal Island with the location of the circular complexes (Silva et al., 1990).

PETROGRAPHY

The intrusions are plutons of circular morphology comprised by gabbro, melagabbro, monzogabbro and monzosyenite defining a normal zoning (i.e., mafic margin to felsic cores). The more felsic rocks usually appear in the highest topographic level of the pluton as a topping layer broadly defining a stratified intrusion. The larger complexes (1 and 2) are between 240 and 500 m in diameter, while the smaller one (complex 6) is between 60 and 130 m and is formed exclusively by the most differentiated terms (as are plutons 3, 4 and 5).

The classification of the samples has been carried out by modal and chemical characterization (Fig. 2). Thus, we have sampled a number of melagabbro, gabbro, monzogabbro (essexite) and monzosyenite from six circular complexes. Only two basalts from the *Main Eruptive Formation* have been sampled which added to previous data from this unit (Torres et al. 2010), to complete the comparison.

The most mafic types (mela-gabbros) are mostly cumulate rocks while gabbros *s.s.* are usually banded rocks with seriate inequigranular texture. Both have clinopyroxene, amphibole, plagioclase, phlogopite and magnetite, and gabbros also present olivine, nepheline, apatite and chromite (hosted by olivine).

Intermediate terms (monzogabbros and monzosyenites) also present a seriate inequigranular texture although with a lower proportion of mafic minerals and higher modal plagioclase, alkali feldspar and nepheline, plus apatite, spinel and titanite. In addition, some monzogabbros show accessory olivine and magnetite with ilmenite exsolutions.

Among the extrusive rocks, basaltic lavas are hypocrystalline to holocrystalline rocks, mainly porphyritic. They have olivine and clinopyroxene as phenocrysts, locally accompanied by amphibole. The groundmass consists mainly of plagioclase, clinopyroxene, Ti-magnetite, ilmenite and olivine, plus chromite inclusions (Torres et al., 2010). Locally, olivine nephelinite lavas with similar textural features to basalts appear in the MEF.

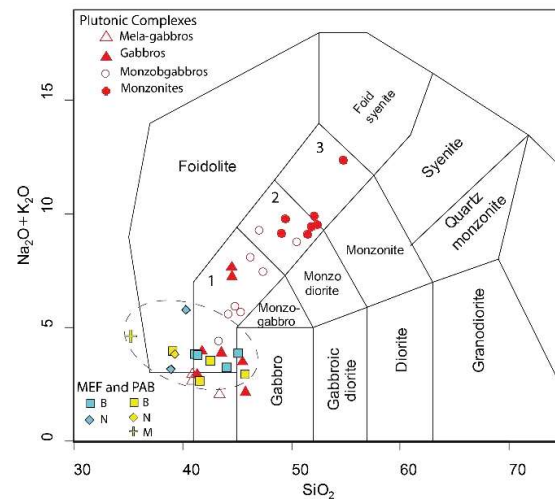


FIGURE 2. Classification of studied samples in the TAS diagram for plutonic rocks of Middlemost (1994). Fields: 1: foid gabbro (and cumulate melagabbro); 2: foid monzogabbro; 3: foid monzosyenite. Note that modal terms (legend) does not always coincide with chemical TAS classification for some rocks (cumulates). MEF (blue) and PAB (yellow symbols) lavas composition field has been marked: B= Basalts; N= Nephelinites and M= Melilitites.

MINERAL CHEMISTRY

Fo content of olivine in the OEC intrusive rocks shows a progressive decrease from the most mafic (gabbros, Fo_{81-61}) to the intermediate (monzogabbros, Fo_{49-39}) terms (Fig. 3). They show significant MnO contents (0.9-1.87 wt%) and a positive correlation with increasing FeO.

Clinopyroxene are classified as diopside, from gabbros to monzosyenites (Fig. 3) decreasing its Mg# (0.94 to 0.55). They show FeO_t and Na₂O contents that increase towards the intermediate terms (up to 14% and 1.2 % wt%, respectively), whereas Al₂O₃ and TiO₂ contents decrease.

Amphibole is mainly kaersutite-pargasite-Mg-hastingsite (Mg# 0.4 – 0.83), and the mica is biotite-phlogopite with Mg# that ranges from 0.54 to 0.96 (monzogabbros to gabbros).

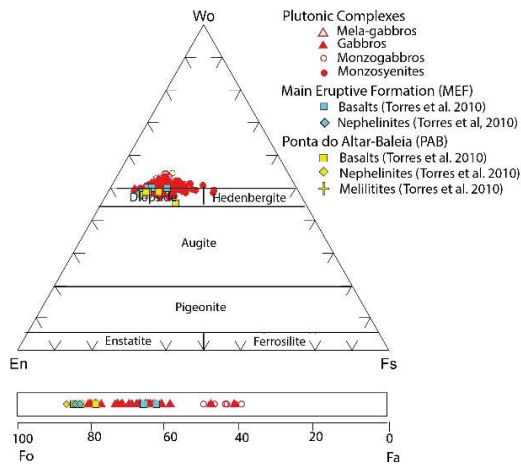


FIGURE 3. Chemical composition of clinopyroxene (top) and olivine (bottom) of samples from Sal island.

Plagioclase is bytownite-andesine showing direct zoning (An_{86-44} from core to rim) in gabbros, and labradorite-oligoclase in monzogabbros and monzosyenites (An_{66-16}). Alkali feldspar (anorthoclase to sanidine: Or_{20-98}) occurs only in monzogabbros and monzosyenites. Nepheline (Ne_{70-86}) becomes more potassic from gabbros to monzosyenites, and the main accessory phases are Ti-magnetite, chromite (as inclusions in olivine), titanite, apatite and ilmenite.

The basaltic lavas show a mineral chemical composition similar to gabbros of the circular complexes. Olivine ranges from low magnesian ($Fo < 70$) to high magnesian ($Fo > 77$) terms in nephelinites whereas it is Fo_{88-62} in basalts. Clinopyroxene are diopsides (Fig. 3) and displays zoning marked by a core to rim Ti enrichment ($TiO_2 = 1.23 - 2.51$ wt%) (with values in a similar range to that of gabbros). Plagioclase ranges from labradorite to bytownite (An_{73-57}) (Torres et al. 2010).

WHOLE ROCK GEOCHEMISTRY

Whole rock geochemistry (major and trace elements) of the different lithologies of the circular complexes has been compared with the MEF data (Torres et al., 2010, and unpublished data). This comparison allows to note the existence of a partial compositional overlap between basalts and gabbros (Fig. 4).

The volcanic rocks from the *Main Eruptive Formation* that plot close to the major and trace elements compositional field of the gabbros are mainly basalts (Figs. 4, 5). Nevertheless, the plutonic complexes show a progressive evolution from mafic to intermediate types, characterized by a linear decrease of MgO, TiO_2 , FeO_t , CaO, Ni and Cr, and a gradual increase in SiO_2 , Al_2O_3 , K_2O , Na_2O , Rb, Ba, Zr and Nb, suggesting a significant crystal fractionation evolution. By contrast, nephelinites from the MEF unit are displaced from general gabbro-monzosyenite trends towards higher MgO, CaO and most trace element (Ba, La, Y, Zr, Sr and Ce) contents. They also display broadly constant values of K_2O , Na_2O , FeO_t

and Rb similarly to data from Late Miocene lavas of the *Ponta do Altar-Baleia Complex* (Fig. 4).

Incompatible trace element patterns (primitive mantle-normalised) show a strong similitude between gabbros (specially circular complexes 1 and 2) and the MEF basalts. All of them show negative Th, U and Pb, as well as positive anomalies in Ba, Nb-Ta and Sr, typical features of OIB patterns (e.g., Akbary et al., 2023). Some samples show slightly positive Ti-anomalies due to the accumulation of ferromagnesian minerals and titanite (Fig. 5).

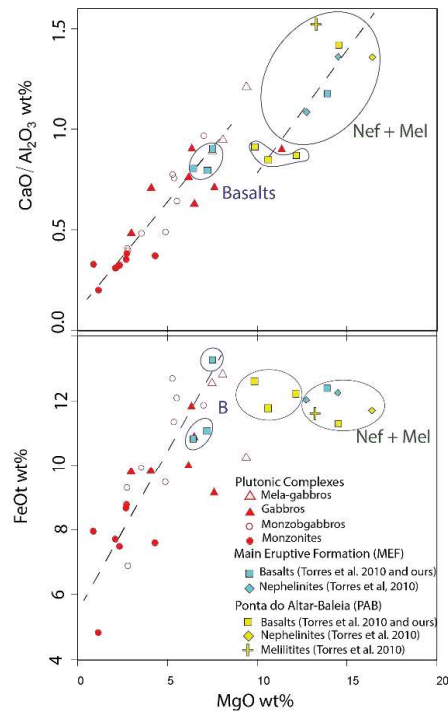


FIGURE 4. Chemical composition (CaO/Al_2O_3 and FeO vs MgO) of the sampled lithologies and those obtained from Torres et al. (2010). B= Basalts; Nef+Mel= Nephelinite and melilitite.

In REE (as in multitrace) diagrams the gabbros show similar trends to those of the MEF basalts. They show an enrichment of LREE with respect to HREE, typical of oceanic island basalts, indicative of their origin by low degree of partial melting (Mc. Donough and Sun., 1995) (Fig. 5).

Nephelinitic and melilitic rocks (not plotted in Fig. 5), on the other hand, show significant differences with respect to basalts and gabbros since they are characterized by marked negative anomalies of Rb, K and Hf (Torres et al. 2010). In addition, they present a progressive increase in REE fractionation with the degree of silica undersaturation, which is not shown neither by gabbros from circular complexes nor by basaltic lavas of the MEF (Torres et al., 2010).

DISCUSSION

The similarities in mineral chemistry (Fig. 3), along with similar whole-rock major and trace element

geochemical trends between the *Main Eruptive Formation* basalts and the gabbros of the circular plutons (Figs. 4 and 5), open the possibility of a genetic relationship between the two assemblages. Nevertheless, these are weak arguments as most of the OIB share similar chemical patterns (e.g., Akbari et al., 2023). In fact, most of the recent basaltic lavas from other northern Cape Verde islands show very similar multi-trace or REE element patterns to those here presented (e.g., lavas from Santo Antao, Holm et al., 2006; or basaltic lavas from Sao Nicolau, Millet et al., 2008). Nevertheless, geochemical trends of the MEF nephelinites indicate a greater affinity with the Late Miocene *Ponta do Altar-Baleia Complex* than with the plutonic rocks or associated MEF basaltic lavas.

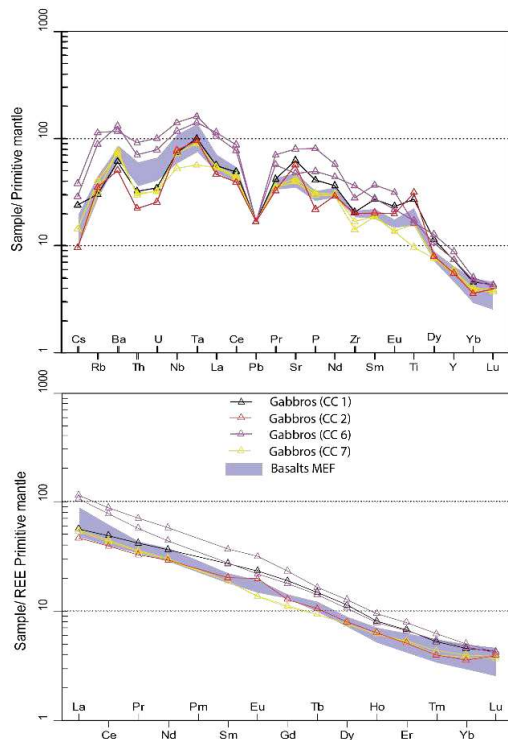


FIGURE 5. Multi-trace (top) and rare-earth element patterns (bottom) of gabbros from Sal island, normalized to primitive mantle values from McDonough and Sun (1995). The grey field are data from Torres et al. (2010) and unpublished data.

Some other arguments make unlikely the existence of a genetic relationship between these circular plutons and the *Main Eruptive Formation*. First, the absence of fractionated (intermediate) lava types within the MEF in comparison to the abundance of these terms in upper layers of stratified circular complexes, potentially the most easily eruptible magmas in a volcanic process. Second, the geochronological data is not conclusive on the coeval formation of studied plutonic and volcanic events. More precise and abundant geochronological studies on the plutonic complexes are needed to determine the age range of their formation. Finally, the scarce published isotopic data from MEF basalts ($^{87}\text{Sr}/^{86}\text{Sr} = 0.703350\text{-}0.703460$, and $^{143}\text{Nd}/^{144}\text{Nd} = 0.513029$) (Torres et al., 2010) do not overlap our preliminary data set on Sr-Nd isotope composition of

gabbros from circular complexes (Villaseca et al., 2024 in litt.) and this should also be revised in the future.

ACKNOWLEDGMENTS

We are grateful to Alfredo Fernández Larios for EMP analysis and R. Casillas, A. García-Casco and I. Novo for their helpful review. This study was funded by project PID2020-115980 GB-I00 of the Spanish Ministry of Science and Innovation and to Banco Santander-UCM predoctoral grant (MGR).

REFERENCES

- Akbari, M., Ghrobiani, M.R., Cousen, B.L., Graham, I.T. (2023): A robust discrimination scheme for ocean island basalts based on Ce/Rb, Tb/La, and Ba/Nb ratios. *Chemical Geology*, 628: 121486.
- Holm, P.M., Wilson, J.R., Christensen, B.P., Hansen, L., Hansen, S.L., Hein, K.M., Mortensen, A.K., Pedersen, R., Plesner, S., Runge, M.K. (2006): Sampling the Cape Verde mantle plume: Evolution of melt compositions on Santo Antao, Cape Verde islands. *Journal of Petrology*, 47: 145-189.
- Holm, P. M., Grandvuinet, T., Friis, J., Wilson, J. R., Barker, A.K. and Plesner, S. (2008): An $^{40}\text{Ar}\text{-}^{39}\text{Ar}$ study of the Cape Verde hot spot: Temporal evolution in a semistationary plate environment. *Journal of geophysical research*, 113: B08201.
- McDonough, W.F. and Sun, S.S. (1995): The composition of the earth. *Chemical Geology*, 120: 223-253.
- Middlemost, E. A. K. (1994): Naming materials in the magma/igneous rock system. *Earth Sciences Review*, 37: 215-224.
- Millet, M-A., Doucelance, R., Schiano, P., David, K., Bosq, C. (2008): Mantle plume heterogeneity versus shallow-level interactions: A case study, the Sao Nicolau Island, Cape verde archipelago. *Journal of Volcanology and Geothermal Research*, 176: 265-276.
- Silva, L. C., Serralheiro, A., Macedo, J. R., Gomes, M. Mota, A., Torres, P.C. (1990): *Carta geológica de Cabo Verde, Ilha do Sal*, folios 1 and 2, scale 1/25000, Inst. Invest. Cient. Trop./Inst. Coop. Econ., Lisbon.
- Torres, P., Silva, L.C., Serralheiro, A., Tassinari, C. Munhá, J. (2002): Enquadramento geocronológico pelo método K/Ar das principais sequências vulcano-estratigráficas da Ilha do Sal- Cabo Verde. *Garcia de Orta Ser. Geol.*, 18 (1-2): 9- 13.
- Torres, P., Silva, L.C., Munhá, J., Caldeira, R., Mata, J., Tassinari, C. (2010): Petrology and geochemistry of lavas from Sal Island: Implications for the variability of the Cape Verde magmatism. *Comunicações Geológicas*, 97: 35-62.
- Villaseca, C., Orejana, D., Huertas, M.J., Ancochea, E., de Ignacio, C., García-Rodríguez, M., Moreno, J.A. (2024, in litt.). Sr-Nd-Pb isotope geochemistry of magmatism from the Sal-Boavista-Maio ridge (Cape Verde archipelago): temporal evolution of its mantle sources. Geotemas XII SGE National Congress.