macla nº 11. septiembre ´09
revista de la sociedad española de mineralogía

Amphibole Trace Element Composition in a Magma Mixing Process

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INTRODUCTION.

Magma mixing processes are common in magma chambers and pipes feeding volcanic and plutonic systems. Sometimes, these processes are also recognized in composite mafic-felsic dykes, which are considered smaller equivalents of the former (Wiebe & Ulrich, 1997 and references therein). Mixing processes within composite dykes therefore represent scale models of the behaviour of larger-scale magmatic systems.

Several composite dykes have been mapped in the late-Variscan Maladeta Plutonic Complex (MPC, Pyrenean Axial Zone, Spain) (Charlet, 1972, 1979; Arranz, 1997). Two of them, located in the central area of the MPC are the subject of this study. In both, emplacement of a dioritic magma was followed by the injection of a leucogranitic (aplitic) magma into the same structural discontinuity. The two magmas were mingled, with fragmentation of the dioritic component within an aplitic matrix, and mixed, giving rise to a variety of hybrid compositions. Additionally, a variable portion of the solid phases carried by each magma before getting in contact was transferred (crystal transfer) to the hybrid magmas, where they suffered different modifications.

Field and petrographic observations, together with mineral and whole-rock compositions were used to characterize and quantify the mixing process (Ubide *et al.*, 2007).

Amongst the minerals present in the mafic hybrids, amphibole presents several textural varieties. It can appear either as single microcrystals, as rims bordering quartz ocelli or as polycrystalline aggregates (clots; Fig. 1). The latter are petrographically interpreted as transformed, by reaction with the melt, from a previous phase, likely pyroxene (Choe & Jwa, 2004, Castro & Stephens, 1992). Taking into account the aforementioned crystal transfer, these clots could represent early pyroxene crystals from the mafic magma, destabilized in the mixing process, when they got in contact with the water-rich felsic magma.

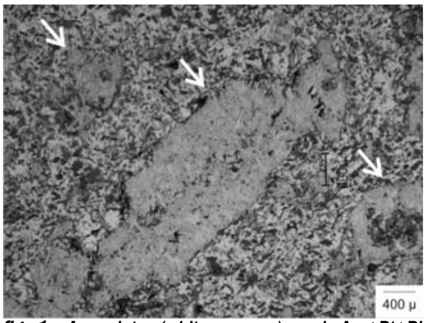

fig 1. Am clots (white arrows) and Am+Bt+Pl groundmass in a hybrid rock from the studied dykes. The central and biggest clot resembles the shape of a pyroxene crystal.

Trace element data of amphibole crystals are used to test our hypothesis for the formation of amphibole clots and, further, to check the influence of different proportions of felsic magma on the hybrids on the composition of their amphibole.

MATERIALS AND METHODS.

Mafic hybrids of both dykes (identified as dyke 1 and dyke 2, being 1 more mafic), can be grouped into two lithotypes: M, for the less mixed (more mafic), and H, for the more hybrid. None of the two dykes includes a pure (non-hybrid) mafic composition. As a reference pyroxene composition is needed for comparison, we have used crystals from a representative gabbro of the MPC, likely to correspond to the original mafic composition.

Six amphibole microcrystals, six amphibole clots and three pyroxene crystals were analyzed by LA-ICP-MS in the Centre for Scientific Instrumentation of the University of Granada. Microprobe compositions were used as internal standard and NIST SRM 610 international standard was used as the external one.

REE data have been normalized to the corresponding bulk rock composition. For amphibole, four average compositions have been calculated (one for each lithotype and each dyke). As a whole, trace element data have been treated statistically using a multivariate principal component analysis (PCA), performed on the symmetric correlation matrix.

RESULTS.

REE Data.

Normalized amphibole (Am) average compositions in the hybrids and pyroxene (Px) compositions in the gabbro are plotted in Fig. 2.

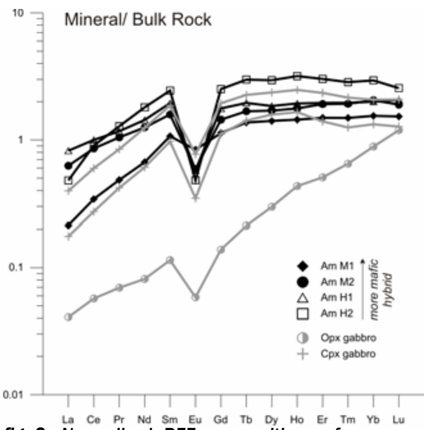

fig 2. Normalized REE compositions of pyroxene crystals in a MPC gabbro and amphibole in the different hybrid rocks (M and H) in both dykes (1 ad 2). Each amphibole pattern is an average of at least two LA-ICP-MS analyses.

All the amphibole patterns clearly agree with those of the Cpx, both in shape and height, and disagree with those of the Opx. Focusing on amphibole, the more

palabras clave: Anfíbol, REE, PCA, LA-ICP-MS, Mezcla.	*key words:* Amphibole, REE, PCA, LA-ICP-MS, Mixing.

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felsic the hybrid lithotype is, the higher the REE enrichment and the bigger its negative Eu anomaly.

Principal Component Analysis.

Fig. 3 shows the statistical PCA carried out with the 38 trace elements analyzed for each Am or Px. Am clots plot grouped all together, as they are thought to have the same origin. Am microcrystals are arranged in two separate groups, one for each lithotype (M and H), according to their igneous crystallization from different hybrid magmas. Finally, Cpx are separated from Opx.

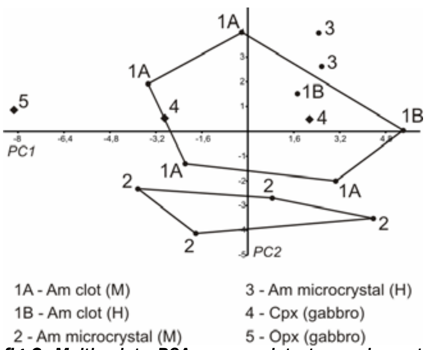

fig 3. *Multivariate PCA on complete trace element analyses of pyroxene in gabbro and amphibole crystals in the different hybrid rocks (M and H).*

Although all the compositions are, in general, rather similar, some differences can be noticed according to the statistical distribution of the groups defined above (polygons). First, the compositions for Am clots, define a polygon in which Cpx compositions are included. On the contrary, the Opx composition plots rather apart from the Am clots polygon. In addition to this, the compositions of Am microcrystals from M and H lithotypes form separated groups, non coincident either with each other, or with the Am clot polygon.

DISCUSSION.

Am REE patterns show a gradual compositional variation, consistent with the composition of the hybrid in which they are present (Fig. 2). This evidences the influence of the composition of the hybrid magmas on their minerals, including both igneous (microcrystals) and transferred (clots) amphibole. Thus, the higher REE contents and more noticeable Eu negative anomalies are consistent with progressively higher mixing rates with a felsic melt (Rollinson, 1993).

All Am REE patterns and contents in hybrids show a high similarity with those of Cpx in gabbro (Fig. 2). This compositional similarity is consistent with the origin of Am clots by Cpx destabilization. However, there are no significant differences in REE patterns between microcrystals and Am clots, but between Am from different lithotypes.

Statistical multivariate analysis, taking into account all analyzed trace elements, reveals some differences (Fig. 3). Although similar overall, Am clots (transferred) are discriminated from Am microcrystals (igneous). Moreover, the former are clearly related with Cpx compositions, nor the latter. This clearly supports the origin of Am clots from Cpx.

Finally, the PCA also supports an igneous origin for the Am microcrystals, different from the transferred Am. Actually, Am microcrystals from different lithotypes are not chemically related (Fig. 3), agreeing with their origin from different hybrid magmas.

CONCLUSIONS.

The petrological and mineralogical study of the mixing process, and especially the treatment of the mineral trace element data, support the following conclusions:

- Crystal transfer, which is a common process during magma mixing, has geochemical relevance on the composition of the hybrids.
- Am composition in hybrid lithotypes is conditioned, primarily by inherited Cpx composition from the original mafic magma and, also, by the proportion of felsic magma in the hybrid.
- Mineral trace element data support the origin of Am clots based on petrographical evidence: clots are a result of the destabilization of previously crystallized Cpx crystals, when they are transferred from the mafic magma in which they crystallized, to the hybrid (more felsic and water-rich) magma.
- Statistical multivariate principal component analysis (PCA) is a powerful tool for testing petrological and geochemical hypothesis. It takes into account every available parameter (e.g. all trace elements), therefore allowing easier detailed discriminations.

ACKNOWLEDGEMENTS.

This work is part of the project CGL-2008-06098. It is included in the objectives of the pre-doctoral grant BF106.189, Mod. AE, Gobierno Vasco (Teresa Ubide Garralda). Authors would like to thank Juan Rofes (Dpto. Cc. Tierra, Universidad de Zaragoza) for his help with the statistical analyses.

REFERENCES.

Arranz, E. (1997): Petrología del macizo granítico de La Maladeta (Huesca-Lérida): estructura, mineralogía, geoquímica y petrogénesis. Unpublished PhD thesis, Faculty of Sciences, Univ., Zaragoza, 320 p.

Castro, A. & Stephens, W.E. (1992): Amphibole-rich polycrystalline clots in calc-alkaline granitic rocks and their enclaves. Canadian Mineralogist, **30***, 1093-1112.*

Charlet, J.M. (1972): Étude geologique et petrographique du Massif Granitique de La Maladeta (Pyrénées centrales espagnoles). Mémoire présenté au concours de l´Academie Royale de Belgique, 115 p.

— (1979): Le Massif granitique de La Maladeta (Pyrénées centrales espagnoles), Synthese des donnees geologiques. Ann. Soc. Géol. de Belgique. T **102***, 313-323.*

Choe, W.H. & Jwa, Y.J. (2004): Petrological and geochemical evidences for magma mixing in the Palgongsan Pluton. Geosciences Journal, **8***, 4, 343-354.*

Rollinson, H. (1993): Using geochemical data: evaluation, presentation, interpretation. Pearson Education Limited, Harlow (England), 352 p.

Ubide, T., Arranz, E., Galé, C. & Lago, M. (2007): Mingling and mixing processes between compositionally contrasted magmas (Maladeta Massif, Central Pyrenees). VI Iberian Geochemistry Meeting (Portugal), 105-108.

Wiebe, R.A. & Ulrich, R. (1997): Origin of composite dikes in the Gouldsboro granite, coastal Maine. Lithos, **40***, 157-178.*