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The mafic dikes from the Panticosa pluton (Pyrenean Axial Zone): petrology and mineral chemistry

Los diques máficos del plutón de Panticosa (Zona Axial Pirenaica): petrología y química mineral

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ABSTRACT

The Panticosa pluton is one of multiple granitic plutons cropping out in the Pyrenean Axial Zone, which corresponds to the Palaeozoic core of the Pyrenees. Mafic dikes cut both the Panticosa pluton and its Devonian metasedimentary country rocks. According to their mineralogy and mineral composition, these dikes can be classified into two different groups, with little textural variations: a calc-alkaline group and an alkaline group. The calc-alkaline rocks (spessartites and calc-alkaline diabases) include calcic to sodic Pl, slightly Ti-rich Amp and substantial Qz. In contrast, the alkaline rocks (camptonites and alkaline diabases) are composed of calcic Pl, Ti-rich Cpx, Ol pseudomorphs and inherited constituents (megacrysts and enclaves). The composition of Pl and the main ferromagnesian phase (Amp in calc-alkaline group and Cpx in alkaline group) is coherent with the geochemical affinity assigned to both groups. The megacrysts in the alkaline group are predominantly Krs and Ts, with a deep-origin according to thermobarometric calculations. A detailed mineral chemistry study of the phases observed inside the enclaves is necessary to better comprehend the petrogenesis of the magmas which generated these alkaline rocks.

Key-words: *Dike, alkaline, calc-alkaline, Pyrenees, Variscan.*

RESUMEN

El plutón de Panticosa es uno de los múltiples plutones graníticos variscos que afloran en la Zona Axial Pirenaica, núcleo paleozoico de la Cordillera de los Pirineos. Cortando al granitoide y a su encajante devónico metasedimentario, existe un conjunto de diques de rocas ígneas melanocráticas. En función de su mineralogía y de la composición de sus fases minerales, estas rocas pueden clasificarse en dos litotipos principales, con cierta variedad textural: un litotipo de afinidad calcoalcalina y un litotipo de afinidad alcalina. Las rocas calcoalcalinas (espesartitas y diabasas) están caracterizadas por Pl cálcica a sódica, Amp ligeramente titanado y Qz apreciable. Por contra, las rocas alcalinas (camptonitas y diabasas) presentan: Pl cálcica, Cpx titanado, pseudomorfos de Ol y elementos heredados (núcleos cristalinos y enclaves). Las composiciones de la Pl y de la fase ferromagnesiana principal (Amp en las calcoalcalinas y Cpx en las alcalinas) se corresponden con las afinidades geoquímicas definidas para ambos litotipos. Los megacristales en los diques alcalinos son mayoritariamente Krs y Ts de origen profundo, según las estimaciones termobarométricas realizadas. Un estudio detallado de la química mineral de las fases minerales observadas en los enclaves sería necesario para un mayor conocimiento petrogenético de los magmas que dieron lugar a estas rocas alcalinas.

Palabras clave: *Dique, calcoalcalino, Pirineos, Varisco.*

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Introduction

The Panticosa pluton is a granitic intrusion located in the Pyrenean Axial Zone. It is the southernmost pluton of the Cauterets-Panticosa granitoid complex (Fig. 1). Its emplacement age is not well defined up to present. This emplacement could be subsequent (Debon, 1980) or coincident (Gleizes *et al.*, 1998) with the main deformational phase of the Variscan Orogeny (Pennsylvanian in age). Several intermediate and mafic dike swarms can be recognized cutting both the pluton and its metasedimentary Devonian country rocks (Debon and Zimmermann, 1993). These dikes have been classified as lamprophyres (Lago *et al.*, 2004; Galé, 2005) even though they have been also cited as doleritic dikes (Santana *et al.*, 2006) or simply as mafic dikes (Debon and Zimmermann, 1993). The assumed dike age is Permian (Debon and Zimmermann, 1993; Galé, 2005). In this work, we combine previous data with new petrological and chemical data for the main mineral phases of the dikes.

Petrology

The dikes from the Panticosa pluton are melanocratic igneous tabular intrusions, up to 7 m thick. They intrude both the pluton and the Devonian country rock. Contacts between the dikes and the host rocks are sharp and quite straight. Chilled margins and deformation structures (Riedel fractures caused by shear) have sometimes been observed in the contacts.

To the naked eye, some of these dikes are porphyritic, with large crystals of Pl and/or Amp or less frequently Cpx (mineral abbreviations in this work follow recommendations by Whitney and Evans, 2010), whereas many of them correspond to fine grained equigranular rocks.

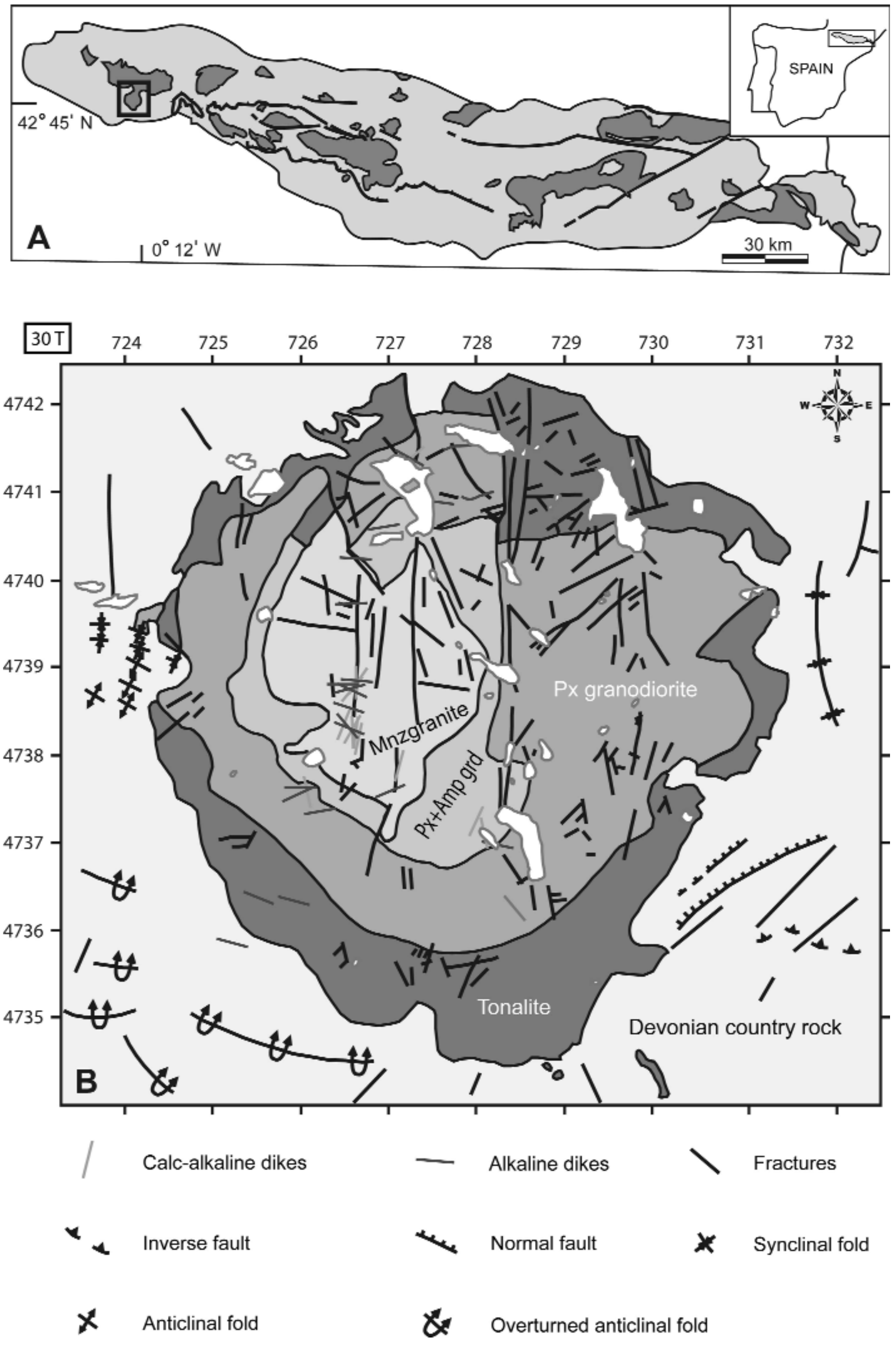

Fig. 1.- Geological setting of the Panticosa mafic dikes. A) Simplified map of the Pyrenean Axial Zone, including the location of the Panticosa pluton (black square). B) Geological map of the Panticosa pluton referenced to the UTM coordinate system.

Fig. 1.- Contexto geológico de los diques máficos de Panticosa. A) Mapa sintético de la Zona Axial Pirenaica en el que se incluye la localización del plutón de Panticosa (cuadrado negro). B) Mapa geológico del plutón de Panticosa, referenciado en coordenadas UTM.

According to their mineralogy and geochemistry (Le Maitre, 2002), two main groups of dikes can be defined: a calc-alkaline group (CA) and an alkaline group (ALK). When cutting situations occur, the ALK dikes always cut the CA dikes, indicating that CA dikes were emplaced first. The CA dikes show a microporphyritic to intergranular texture, composed of Pl microcrysts (50-75%) and Amp micro-phenocrysts (25-40%), intergranular and xenocrystalline Qz (3-10%), Opq (0-3%), Bt (0-5%) and acicular Ap (2%). Alteration phases, as Chl (5-15%) and Ttn (0-8%), have also been observed. Given their mineral assemblage and texture, they can be classified either as spessartite (microporphyritic), or calc-alkaline diabase (with intergranular texture).

The alkaline dikes show a mainly doleritic or less commonly microporphyritic texture with a mineral assemblage including micro- and phenocrysts of Pl (40-70%) and Ti-rich-Cpx (10-30%), Chl pseudomorphs after olivine (3-15%), Opq (3-10%), Amp (1%), Bt (1%) and Ttn (1%). Vesicles, filled by Chl ± Cal, are common (0-12%). Moreover, macro- (< 1 cm) and megacrysts (> 1 cm) of Amp, Ap, Pl and Opq are common in some of these alkaline rocks, thus making them appear porphyritic to the naked eye. Under the microscope, Amp megacrysts are anhedral, displaying oval or ameboid morphologies. They usually have reaction rims and also permeated zones, filled by the rock groundmass. Enclaves are also frequent in these alkaline rocks. Several enclave types can be defined, according to their mineral assemblages (Pl+Bt megacrysts, Pl+Ap macrocrysts, Pl+Amp macrocrysts and others) and size (up to decimetric).

These ALK rocks are classified either as camptonite (microporphyritic texture, macro and megacrysts) or alkaline diabase (doleritic texture).

According to the crystallization sequences, in both the CA and ALK rocks, the ferromagnesian minerals are the first phases to crystallize (Amp in CA and Cpx in ALK). The sequences continue with the crystallization of Pl, in competence with Amp or Cpx. The crystallization of Pl ends after that of the main ferromagnesian phase. The crystallization of Opq takes place throughout the whole crystallization process.

Mineral chemistry

The main mineral phases (Pl, Cpx and Amp) were analysed in 12 samples of the Panticosa dikes using a JEOL JZA-8900M electron microprobe at the *Centro Nacional de Microscopía electrónica* of the *Universidad Complutense de Madrid*.

Plagioclase

According to their composition, four principal Pl types have been discriminated (Fig. 2):

1. Microcrysts in CA rocks: this group shows a wide compositional range (An_{65} – An_{15}).
2. Microcrysts in ALK rocks, with a limited compositional variation (An_{66} – An_{56}) and some Ab compositions, probably related with subsolidus recrystallization.

3. Phenocrysts in ALK rocks: this group includes unzoned phenocrysts and phenocryst rims in some samples. Their compositions cover a wider range (An_{67} – An_{46}) than the microcrysts in the same samples.

4. Inherited Pl in ALK rocks (this group includes Pl macrocrysts, Pl inside enclaves and antecrystic cores in some type-3 phenocrysts). Their compositions define a common trend from An_{61} (less calcic than the micro- and phenocrysts in the same rocks) to An_{22} (more sodic than the phenocryst rims).

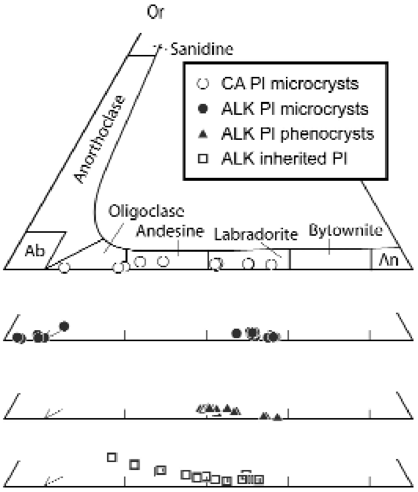

Fig. 2.- Composition (An-Ab-Or) of Pl crystals in the two dike groups.

Fig. 2.- Composición (An-Ab-Or) de los cristales de Pl en los dos grupos de diques.

The compositional evolution is different for the Pl crystals of the two dike types (Fig. 2). The increase of the proportion of Ab molecule in Pl in the alkaline dikes is correlated with a sligth increase in the K content (Or molecule). This evolution path is a common feature of Pl in alkaline magmas. This feature is absent, in contrast, in the Pl compositions in CA rocks, supporting their subalkaline affinity.

Clinopyroxene

This mineral is only present in the alkaline rocks. According to the obtained results, 2 main types of Cpx can be differentiated. The most common Cpx type is formed by microcrysts of Ti-rich augite and diopside. The second type of Cpx consists of zoned phenocrysts with augite cores and Ti-rich augite and diopside rims.

In a Ti *vs* Ca+Na (per formula unit) plot, the whole of the data define a Ti-increase trend, coincident with the the typical alkaline trend defined by Leterrier *et al.* (1982) (Fig. 3).

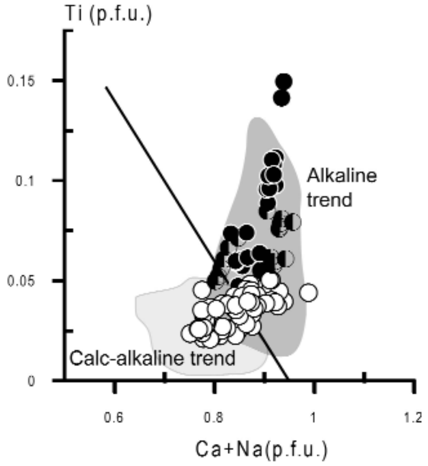

Fig. 3.- Ti vs Ca+Na diagram (Leterrier *et al.*, 1982) for Cpx compositions in ALK rocks. White circles: phenocryst cores; half-filled black circles: phenocryst rims; black circles: microcrysts.

Fig. 3.- Diagrama Ti vs Ca+Na (Leterrier** et al.**, 1982) para las composiciones de Cpx en rocas alcalinas. Círculos blancos: núcleos de los fenocristales; círculos negros partidos: bordes de fenocristales; círculos negros: microcristales.

The Ti-rich rims in zoned Cpx show compositions similar to those in microcrysts of the rock groundmass. Therefore, phenocryst rims and groundmass microcrysts were coeval and probably crystallized at the emplacement level. In contrast, phenocryst cores present low Ti concentrations and greater Mg contents, in agreement with their early crystallization. Besides, the crystallization pressures calculated according to the Al^{IV} and Al^{VI} distribution (Aoki and Shiba, 1973) and the Ti content (Shaw and Eyzaguirre, 2000) point out a greater pressure (depth) for the crystallization of the phenocryst cores with respect to the phenocryst rims and the groundmass microcrysts.

Amphibole

This mineral is found in both groups (CA and ALK). Four types of Amp have been chemically discriminated, namely: 1. Microphenocrysts in the CA rocks, 2. Green Amp in some type-1 phenocryst marginal zones, 3. Isolated macro/megacrysts of Ti-rich Amp in some ALK rocks, and 4. Crystals of Ti-rich Amp inside enclaves within some ALK rocks.

All the obtained analyses are calcic amphiboles, according to the nomenclature proposed by Leake *et al.* (1997). The first group is mainly classified as Mg-hastingsite with moderate TiO_2 contents (up to 3.36%), which are representative of sub-alkaline Amp. Their differentiation range is relatively large, according to the Mg# values (from 0.5 to 0.7).

The second group is composed of Mg-hornblende. Its composition is very different from that of type-1 Amp, as it is observed in diverse elements like titanium (lower Ti contents than Mg-hastingsite). Given their textural position (around type-1 Amp phenocrysts) and the fact that their composition differs from the proposed ranges for igneous Amp (Czamanske and Wones, 1993), this type of Amp can correspond to a late-magmatic phase.

The third group is exclusively formed by kaersutite (TiO_2 up to 6.13%). The Mg# values are clustered between 0.78 and 0.71. The alkaline affinity of these Krs is clear, although taking into account their resorption features, big size and different composition, they must be interpreted, at least, as an early mineral phase (probably antecrystalline).

Finally, the fourth Amp type is very similar in texture and optical features to type 3 Amp. They are classified as tschermakite, according to their $(Na+K)_A$ contents (minor to 0.5 pfu). They are also interpreted as antecrystalline and chemically related to type-3 Amp.

The pressure (Hammarstrom and Zen, 1986) and temperature (Otten, 1984) estimated for the Amp compositions suggest a deep origin for the Amp antecrysts found in the ALK group (about 8 kbar -25 km depth- and 1100ºC).

Discussion and conclusions

The Panticosa mafic dikes can be divided, according to their mineral parageneses and the chemical composition of their mineral phases, into two groups: one group with calc-alkaline affinity and another group with alkaline affinity. The calc-alkaline dikes are classified either as spessartites or calc-alkaline diabases, attending to their textures. Using the same criterion, the alkaline dikes are classified either as camptonites or alkaline diabases.

The calc-alkaline dikes contain Pl defining a sub-alkaline geochemical trend (Fig. 2) and Amp with contents in Ti (and other elements) similar to those described in other spessartites from the Pyrenees (Arranz, 1997). In contrast, the alkaline dikes present Pl with a typically alkaline evolution, characterized by a relative K-enrichment as the differentiation advances (Fig. 2). Moreover, the Cpx compositions in this group are equivalent to those typical of Cpx in alkaline rocks (Leterrier *et al.*, 1982) (Fig. 3).

The CA dikes are intermediate rocks, according to their mineralogy (substantial Qz -up to 10%- and very abundant Pl, from calcic to relatively sodic members -An_{15}-). On the contrary, the ALK dikes are basic rocks with Ol pseudomorphs, Ti-rich Cpx and predominantly calcic Pl (labradorite).

Apart from some examples of xenocrystalline Qz, the CA dikes do not show other xenocrystic phases. The wide range of differentiation displayed both by the calc-alkaline Pl (Fig. 2) and the calc-alkaline Amp (according to the Mg# index), suggests an extended crystallization process.

However, in the ALK dikes, antecrysts (e.g. Krs megacrysts) and/or enclaves have been recognized. They do not represent the crystallization of the alkaline melt, which is mainly represented by the Cpx and Pl groundmass microcrysts.

The Cpx phenocryst cores formed during the early stages of the alkaline magma crystallization. Their low Ti and high Mg contents can be linked to the Cpx microcryst compositions by a normal differentiation trend in alkaline magmas (Fig. 3). Cpx phenocryst cores probably crystallized before the emplacement of the magma. In contrast, phenocryst overgrowths and groundmass microcrysts crystallized at the emplacement level.

The Krs megacrsyts are diagnostic of alkaline rocks; in the Panticosa alkaline dikes they are interpreted as antecrysts transported by the alkaline magmas during their ascent to the emplacement level. This interpretation is supported by their rounded, anhedral morphologies, reaction rims, permeated zones and chemical composition. Furthermore, geobarometric calculations indicate higher depths for the crystallization of these antecrysts (ca. 7-8 kbar, that is, a 23-26 km depth). This implies that their host magma was likely stagnated and fractionated at lower crustal levels.

Finally, the enclaves show diverse mineralogies and represent rock fragments incorporated by the alkaline magma during its ascent. A detailed chemical study of the mineral phases forming these enclaves would be necessary to acquire better comprehension of the deep magmatic system related to the generation and ascent of the alkaline magmas.

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