Study of apatites in the Les Guilleries lamprophyre dykes: Insights into their parental magmas

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INTRODUCTION

Les Guilleries Massif is located at the northeastern Variscan domain of the Catalan Coastal Ranges in the NE of the Iberian Peninsula. The studied area is comprised of metamorphic and igneous rocks from Cambrian and Ordovician ages. They are intruded by a variety of calc-alkaline igneous dykes emplaced during the Hercynian orogeny. A mesh of lamprophyre dykes (LD) crosscut all of the above at 262 ± 7 Ma (Mellado et al., 2021), and mark the end of Variscan magmatism prior to the Triassic extension and fragmentation of Pangea. The LD derived from basic parental magmas, an amphibole-phlogopite-bearing melt rich in K and fluids. They represent the least modified magmas –and deepest source of heat– from the subcontinental lithospheric mantle source (Mellado et al., 2021).

In the present study, apatite has been used as a tool for unraveling petrogenetic processes from the LD parental magma, as well as secondary processes related to remobilization of elements and metasomatism. Although apatite is usually found in accessory proportions, it is ubiquitous in igneous rocks and can incorporate a variety of incompatible elements, such as U, Th, REEs, and the volatiles F, Cl, and OH. Its characterization, grain size distribution, (micro)textures, and compositions can provide additional insights into processes that are not well characterized yet.

SAMPLES AND ANALYTICAL TECHNIQUES

The LD samples were extracted from an upper area compared to Mellado et al. (2021) location, emplaced in marble. Two polished thin sections (4 x 2.5 mm) of the least altered LD from Les Guilleries, numbered GUI-40 and GUI-41, have been studied using optical light microscopy and backscattered electron (BSE) imaging on a Field Emission SEM (FE-SEM) Zeiss Merlin Geminis II, equipped with energy-dispersive spectroscopy (EDS) X-ray analysis, at the Geology Department and Serveis de Microscòpia of the Universitat Autònoma de Barcelona. Quantitative chemical analyses of apatite grains were performed using electron probe micro-beam analyses (EPMA) at the Centres Científics i Tecnològics of the University of Barcelona. Finally, a FIB section was extracted from a representative apatite grain in GUI-40 using a Zeiss Gemini 2 Crossbeam 550 L FEG-SEM/FIB instrument at the Centro Nacional de Microelectrónica (CNM-CSIC). Transmission electron microscopy (TEM) analyses were conducted at the Catalan Institute of Nanoscience and Nanotechnology (ICN2) using a FEI Tecnai G2 F20 field emission gun (FEG) high resolution (HR) scanning TEM (STEM), operated at 200 kV.

RESULTS

The GUI-40 thin section corresponds to a weakly altered LD that exhibits a homogeneous, microcrystalline texture consisting of K-rich feldspar, amphibole, ilmenite, titanomagnetite, chlorite, albite, apatite, and quartz. A few phlogopite grains occasionally occur throughout, and larger assemblages, up to ~1 mm in size, of amphibole and chlorite are also distinguished. Apatite grains in GUI-40 range from a few µm to ~35 µm in size, they are mostly subhedral to anhedral, and randomly oriented (Fig. 1a). Some apatite grains exhibit convoluted margins and porosity (Fig. 1a). They are mainly associated with amphibole, alkali-feldspar (albite and/or orthoclase), and chlorite.

In contrast, GUI-41 thin section is dominated by large, irregular chlorites, which appear to replace previous amphibole and titanomagnetite crystals. Albite is the predominant feldspar and makes up the groundmass between larger crystals. Isolated, large phenocrysts of amphiboles (up to 200 µm in size) are affected by significant alteration, and calcite is present throughout. Other phases include titanomagnetite, silica, and apatite. Apatite grains in this sample are abundant, euhedral, highly acicular (up to 100 µm long), randomly oriented, homogeneously distributed, and crosscut other minerals (Fig. 1b).

Halogen content in both populations of fluorapatite are distinct. GUI-40 apatite is F-richer and OH-poorer (mean of 78 mol% F, 2 mol% Cl, and 20 mol% OH in the X site) compared to GUI-41 apatite (mean of 64 mol% F, 5 mol% Cl, and 31 mol% OH in the X site). In addition, apatite in GUI-40 shows a higher S content that is consistently associated with an increase of Fe (Fig. 1c).

TEM work on an apatite grain in GUI-40 reveals the presence of abundant, hexagonal nano-inclusions within the core of the apatite, occupying about 40% of the crystal (apatite is a single crystal). The interface between the area filled with inclusions and the inclusion-free apatite is sharp (Fig. 1d). Most of the inclusions are bimodal, consisting of a high-Z phase and a low-Z phase, they range from ~10 to 50 nm in size (only a few inclusions exceed 50 nm), and are similarly oriented. SAED patterns and HR TEM show they consist of pyrrhotite and an amorphous C-rich phase (Fig. 1d).

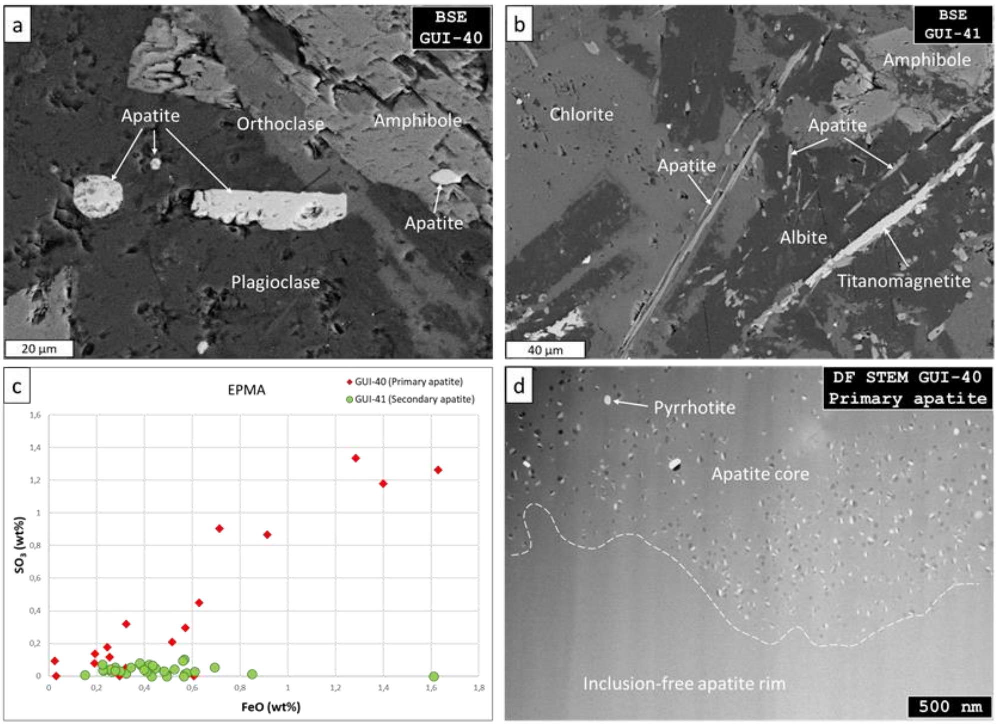

***Fig 1**. BSE images showing apatit*e grains *in GUI-40 (a) and GUI-41 (b); corresponding SO3 versus FeO contents in different individual apatite analyses from the two samples (c); and a dark field STEM image of an apatite grain in GUI-40 showing the presence of abundant nano-inclusions.*

DISCUSSION AND CONCLUSIONS

Based on petrographic observations and apatite compositions, we argue that apatite from GUI-40 is primary, formed during crystallization of the lamprophyre dyke, whereas apatite in GUI-41 is secondary, formed under metasomatic/hydrothermal conditions. The nano-inclusions of pyrrhotite within the primary apatite may have contained a gaseous phase and could be indicative of liquid immiscibility under reducing conditions; otherwise S would have been incorporated into the apatite structure. Alternatively, the presence of high Fe content in the parental magma prevented S to form ellestadite domains in apatite. EPMA results also indicate that some mobilization of light rare-Earth elements (LREE) took place during the secondary alteration event.

REFERENCES

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