

GEOCHEMICAL EVOLUTION OF PHOSPHATES AND SILICATES IN THE SAPUCAIA PEGMATITE, MINAS GERAIS, BRAZIL: IMPLICATIONS FOR THE GENESIS OF THE PEGMATITE

Maxime Bajiot^{1§}, Frédéric Hatert¹,
André-Mathieu Fransolet¹ & Simon Philippo²

¹ Laboratory of Mineralogy, University of Liège, B18, B-4000 Liège, Belgium §mbajiot@doct.ulg.ac.be

² National Museum of Natural History of Luxembourg, Section of Mineralogy, rue Münster, 24, L-2160, Luxembourg, Luxembourg

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INTRODUCTION

One of the most important pegmatite provinces in the world, the Eastern Brazilian Pegmatite Province (EBPP), occurs in Brazil. This province is located at the East side of the São Francisco craton, mainly in the state of Minas Gerais. Among these pegmatites, the Sapucaia pegmatite was selected for detailed sampling. This pegmatite was probably discovered around 1920-1930 and was initially exploited for beryl and muscovite (Pecora *et al.* 1950, Cassedanne & Baptista 1999). Sapucaia pegmatite is especially famous for its complex phosphate mineral associations, among which six new phosphate mineral species were first described: frondelite, faheyite, moraesite, barbosalite, tavorite, and lipscombite (Atencio 2000). The discovery of these new mineral species leads to a good knowledge of the Sapucaia mineralogy; however, only a brief description of the pegmatite body exists.

The aims of this work are (i) to describe the variations of the mineral assemblages corresponding to the different zones of the pegmatites, (ii) to investigate in detail the petrographic relations among phosphates as well as their chemical compositions in order to better understand the transformation sequences which affected these minerals, and (iii) to shed some light on the genesis of the Sapucaia pegmatite throughout the geochemical evolution of the phosphate minerals and their associated silicates.

GEOLOGICAL SETTING AND DESCRIPTION OF THE PEGMATITE BODY

GEOLOGICAL SETTING

The Eastern Brazilian Pegmatite Province (EBPP) is divided into several districts, among which the Conselheiro Pena district (Pedrosa-Soares *et al.* 2009) in which the Sapucaia pegmatite occurs. During the Brazilian orogeny (700-450 Ma), several pre-, syn-, and post-tectonic granitoids took place in the EBPP (Bilal

et al. 2000), originating most of the pegmatites (Bilal *et al.* 2000; Morteani *et al.* 2000). Two of these intrusions crosscut the cover and the basement rocks of the Conselheiro Pena district: the Galiléia and Urucum magmatic suites which belong to the G1 and G2 supersuites, respectively (Pedrosa-Soares *et al.* 2001). The Galiléia granitoid (595 Ma) is a metaluminous suite characterized by a polydiapiric batholith consisting mainly of granodiorites and tonalites with minor granites. These rocks are associated with the precollisional magmatism of the Brazilian orogeny and have calcalkaline affinities (Nalini *et al.* 2000; Pedrosa-Soares *et al.* 2001). The Urucum suite (582 Ma) is composed by four different types of rocks: a feldspar megacrystal-bearing granite (Urucum facies), a medium to coarse grained granite (Palmital facies), a tourmaline-bearing granite and a pegmatitic granite (Nalini *et al.* 2000). These rocks mainly have a peraluminous composition (S-type granite) due to the syn-collisional character of the orogeny (Nalini *et al.* 2000; Pedrosa-Soares *et al.* 2001).

DESCRIPTION OF THE PEGMATITE BODY

The Sapucaia pegmatite is located 14 km NE of the Galileia town (18°54'038''S ; 41°29'061''W). The pegmatite occurs in the São Tome formation consisting in subvertical sillimanite-staurolite-garnet-micas-bearing schists and has an elliptic shape of 80 m length, 40 m width and 50 m height. Different zones are observed in the pegmatite (Fig. 1). A border zone of 5 cm width, in direct contact with the host schists, has a granular texture and consists of an interbedding of dark bands of schorl + quartz, and light bands of quartz + albite ± greenish apatite. Muscovite is an accessory mineral in the two types of layers. The wall zone is characterized by K-feldspars showing occasionally coarse graphic texture, associated with biotite and muscovite (M2). Muscovite is coarser than biotite, and shows a fishbone-like habit, in which the crystals can reach 20 cm in length. Accessory schorl, reaching 1 to 2 cm in length, occurs in the matrix as well as in the muscovite flakes. In this wall zone,

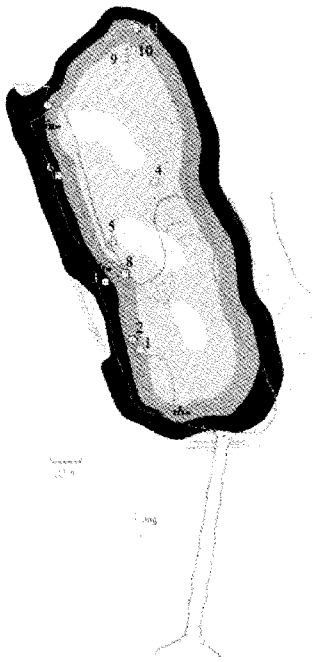


FIGURE 1. Schematic map of the Sapucaia pegmatite showing the zonation and the location of the phosphate nodules (numbers). Black zone = M2 zone: quartz + feldspars + two micas ± small schorl; Dark grey zone = M1 zone: graphic feldspars + muscovite + schorl ± Beryl; Light grey zone = S zone: Spodumene + quartz + yellow mica ± beryl; White zone: Q zone: quartz cores

biotite disappears one or two meters before entering into the intermediate zone, and the paragenesis is then characterized by K-feldspar (sometimes showing graphic textures), large schorl crystals reaching 10 cm long, accessory muscovite and beryl (M1). In the intermediate zone, many large spodumene crystals reaching 2 meters in length are surrounded by yellow mica in a quartz matrix. Beryl and small schorl crystals (2 cm maximum) can be present; larger tourmaline crystals sometimes appear perpendicular to the spodumene crystals. Finally, the quartz core (Q) appears, which can locally contain a few smaller spodumene crystals. The M1, S, and Q zones can be partially albitized.

Phosphate minerals were observed in the M1 and S zones, in which they form nodular masses reaching 2 meters in diameter (Fig. 1). Nine nodules were sampled directly in place in the pegmatite (samples 3 and 6 are not in place), and three different types of phosphate associations occur:

I) Masses showing dendritic or/and skeletal textures involving feldspar and several secondary phosphate minerals.

II) Fresh massive triphylite altered by vivianite, which give its bluish colour to the phosphate.

III) Rim of phosphate minerals and oxides

surrounding a white core of albite; the external feldspar directly in contact with the rim takes a greenish colour

Petrographic observations, X-ray diffraction measurements, and electron-microprobe analyses were performed on the phosphates, to confirm their identification, to calculate their unit-cell parameters, and to characterize their chemistry.

PHOSPHATE MINERALOGY AND CHEMICAL VARIATION

The only primary phosphate mineral is triphylite, $\text{Li}(\text{Fe}^{2+}, \text{Mn}^{2+})\text{PO}_4$. In association I, this mineral progressively oxidizes to ferrisicklerite, $\text{Li}_{<}(\text{Fe}^{3+}, \text{Mn}^{2+})\text{PO}_4$, and to heterosite, $(\text{Fe}^{3+}, \text{Mn}^{3+})\text{PO}_4$, following the so-called "Quensel-Mason" sequence (Quensel 1937; Mason 1941). Ferrisicklerite is frequently replaced by several secondary phosphates like leucophosphite, phosphosiderite, minerals of the jahnsite group, and minerals of the rockbridgeite-frondelite series. In association II, triphylite is directly replaced by vivianite along cleavage planes under reducing conditions. The association III needs more investigations.

As it was already observed in the literature (Mason 1941; Fontan *et al.* 1976; Fransolet *et al.* 1986), the contents in Fe, Mn and Mg do not show significant variation during the "Quensel-Mason" sequence. For example, ferrisicklerite and heterosite of sample Sap-1 are located close to each other in the $\text{Fe}_{\text{tot}}\text{-Mn-Mg}$ ternary diagram (Fig. 2). So we can also use the $\text{Fe}_{\text{tot}}/(\text{Fe}_{\text{tot}} + \text{Mn})$ and $\text{Mg}/(\text{Fe}_{\text{tot}} + \text{Mn} + \text{Mg})$ ratios in ferrisicklerite and heterosite to estimate the differentiation degree of the pegmatites (Keller *et al.* 1994a, 1994b). The electron-microprobe analyses of samples from Sapucaia show variations of the $\text{Fe}_{\text{tot}}/(\text{Fe}_{\text{tot}} + \text{Mn})$ ratio in these phosphates of the "Quensel-Mason" sequence, with a decrease from sample Sap-1 (around 0.74) to sample Sap-4 (0.71). The $\text{Mg}/(\text{Fe}_{\text{tot}} + \text{Mn} + \text{Mg})$ ratio also decreases, from 0.18 for Sap-1 to 0.13 for Sap-4.

These chemical modifications are due to variations of the differentiation degree, from the border to the centre of the pegmatite: the phosphates from the inner zone, in which Sap-4 is located, show a decrease in Fe and Mg, when compared with the less differentiated phosphates from the outer zone, where Sap-1 and Sap-7b are located. These observations are in agreement with the geochemical evolution of pegmatites described by Ginsburg (1960). Sap-6b was not in place but its Mg-Fe-Mn ratio suggests that this sample has a similar differentiation degree than Sap-1 (Fig. 2). Moreover, the Mn-rich triphylite sample Prb-1b, which was not located on the map, probably corresponds to a second generation of triphylite that crystallized at lower temperature (Fig. 2).

This geochemical trend must be further



FIGURE 2.

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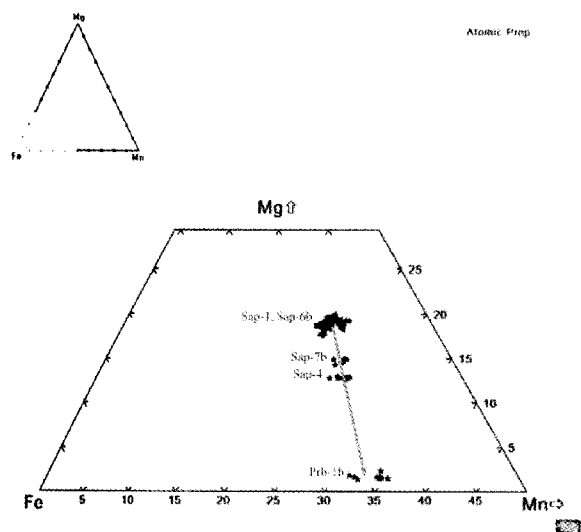


FIGURE 2. Chemical composition of triphylite (star), ferrisicklerite (square) and heterosite (triangle) from different phosphates nodules in a ternary plot Mg-Fe_{tot}-Mn.

confirmed by the investigation of the phosphate samples collected during the last fieldtrip in July 2010, as well as by analyses of the associated silicates.

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