

THE PHOSPHATE MINERALS ASSEMBLAGES FROM JOCÃO PEGMATITE, MINAS GERAIS, BRAZIL

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In Brazil occurs one of the most important pegmatite provinces in the world, the Eastern Brazilian Pegmatite Province (EBPP). This province is located at the Eastern side of the São Francisco craton, mainly in the state of Minas Gerais. The Conselheiro Pena district forms part of the EBPP where two intrusions crosscut the basement rocks and its cover: the Galiléia and Urucum magmatic suites which correspond to metaluminous and peraluminous magmas, respectively. The Galiléia suite consists in granodiorite and tonalite and the Urucum suite is composed of four different facies of granite. In August 2008 and July 2010, we visited several pegmatites located in the Conselheiro Pena district in order to investigate the petrography of phosphate minerals and their relationships with associated silicates.

Among these pegmatites, the João pegmatite, also called Cigana or Boa Vista Cigana pegmatite, is intruded in the garnet-, biotite-, and sillimanite-bearing schists of the São Tomé Formation (Rio Doce group, Late Proterozoic). Although the pegmatite was under water when we visited, we were able to collect phosphate minerals and associated silicates from the dumps. According to their macroscopic features, three types of phosphate occurrences may be distinguished. After the magmatic stage during which the primary phosphates crystallized, each type of occurrence was altered by pegmatitic processes, under different physico-chemical conditions, leading to different phosphate mineral assemblages. The petrographic observations, X-ray diffraction measurements, and electron-microprobe analyses that were performed on these minerals allowed us to characterize these three different phosphate minerals assemblages.

The first assemblage (I) consists of dendritic and skeletal textures involving feldspar (generally albite) and triphylite (Figs 1a, 1b). This triphylite may also form complex intergrowths with associated garnet, quartz, and apatite (Fig. 1b). Then triphylite evolved under poor oxidizing conditions. The first hydrothermal stage was a hydroxylation stage during which triphylite was only replaced by hureaulite along its cleavage planes. In some rare cases, hureaulite is associated with barbosolite. The second alteration stage corresponds to meteoric processes,

which are responsible for the formation of ludlamite and vivianite replacing triphylite. These two minerals are ferrous iron bearing phosphates with high water content.

The second assemblage (II) occurs as a nodule (15 cm in diameter) covered by oxides. The only primary mineral of this assemblage is triphylite, which evolved under more oxidizing conditions. The first hydrothermal transformation is the progressive oxidation of this triphylite, $\text{Li}(\text{Fe}^{2+}, \text{Mn}^{2+})\text{PO}_4$, coupled with a simultaneous Li-leaching, yielding to ferrisicklerite, $\text{Li}_{-1}(\text{Fe}^{3+}, \text{Mn}^{2+})\text{PO}_4$, and heterosite, $(\text{Fe}^{3+}, \text{Mn}^{3+})\text{PO}_4$, successively. This oxidation mechanism corresponds to the so-called "Quensel-Mason" sequence. The second hydrothermal stage corresponds to a hydroxylation process; the mineral species which are formed during this stage depend on the species they alter. For example, in Fig. 1c, we see the contact between triphylite and ferrisicklerite in the same optical orientation. Nevertheless, triphylite is altered by barbosolite and hureaulite, while ferrisicklerite is altered by janhsite and/or frondelite *s.l.* All these hydroxylated species occurred in the cleavages planes of the previous unaltered minerals (Fig. 1c). The last alteration stage lead to the formation of meteoric phosphate species, like phosphosiderite, leucophosphite and whitmoreite, and of Fe-Mn bearing oxides, which result in the disappearance of former petrographic texture.

The third assemblage (III) also occurs as an elliptic nodule reaching 70 cm x 50 cm x 50 cm. This nodule presents intergrowths between ferrisicklerite/ heterosite and a reddish massive beusite (Fig. 1d). Garnet may also be present in this assemblage. The textural relationships between the lamellae of ferrisicklerite and heterosite in beusite, $(\text{Mn}, \text{Fe}, \text{Ca})_3(\text{PO}_4)_2$, correspond to exsolutions lamellae, which are formed at the expense of high temperature homogenous Ca-Li bearing graftonite-beusite-like phase: when the temperature decreased, Li migrate into triphylite (which are later altered to ferricklerite and heterosite) and Ca into the larger M1 site of beusite. Intergrowths of triphylite in beusite are less common than exsolution of triphylite in graftonite or lithiophilite in beusite. The bulk composition of the high temperature homogenous

phase and the partition coefficient allow us to better understand these exsolutions lamellae of triphylite in beusite. After this magmatic process come the hydrothermal stages. The first one corresponds to the "Quensel-Mason" sequence; this oxidation stage does not alter beusite. Nevertheless, the second hydroxylation stage more strongly affects beusite than ferrisicklerite and heterosite lamellae. The replacement of beusite by an intimate polygranular mixture of orange pleochroic hureaulite and tavorite progressed from the contact with the exsolutions, leaving the latter almost unaltered. However, heterosite is replaced by OH-rich fluorapatite and staněkite. After this stage, another stage is characterized by an increase of Ca^{2+} and H_2O activities, indicated by the replacement of hureaulite and tavorite by minerals of the mitridatite-robertsite series. In the border of the nodule, beusite and heterosite are completely replaced by intimate polygranular intergrowths mainly constituted by frondelite, robertsite-mitridatite and oxides. Phosphosiderite and leucophosphite are scarcer. In the inner part of this border, lamellae of heterosite are only replaced by (Mn-Fe)-bearing oxides and beusite by the intimate intergrowths. However, in the external part of the border, the exsolution texture is completely obscured by other secondary mineral species. In assemblage III a rare silico-phosphate mineral also occurs, harrisonite $\text{Ca}(\text{Fe}^{2+}, \text{Mg})_6(\text{SiO}_4)_2(\text{PO}_4)_2$, which was previously reported in only one pegmatite from Czech Republic

(Skoda *et al.*, 2007). According to the textural relationship with associated minerals, it seems that harrisonite has a hydrothermal origin. This mineral was probably formed after dissolution of garnet by Ca-Fe and P-rich hydrothermal fluids. Apatite, which replaces heterosite, is often associated with harrisonite and may be formed simultaneously or shortly before the formation of this phase because the crystallization of phosphates and silicates is considered as a sequential crystallization.

As we have seen above, the primary phosphate minerals occur in different type of assemblages. In assemblage I, triphylite is dendritic and show intergrowths with silicates (albite Fig. 1a, garnet, Fig. 1b); in assemblage II, triphylite occurs as massive nodules; and in assemblage III triphylite forms exsolution lamellae in massive beusite. Moreover, the oxidation affecting the whole nodules of each assemblage increases from the core to the border. In assemblage II a mineral zonation occurs, which is underlined by the different colour of the Quensel-Mason sequence minerals: greenish for triphylite (core), brownish for ferrisicklerite (transition zone), purple for heterosite (external zone) and, finally a dark colour for the oxides (cover). In assemblage III, lamellae of ferrisicklerite only occur in the core of the nodule, while they take the purplish colour of heterosite on the border (Fig 1d). These features will be discussed and the different nodules will be chronologically positioned in the global setting of the pegmatite.

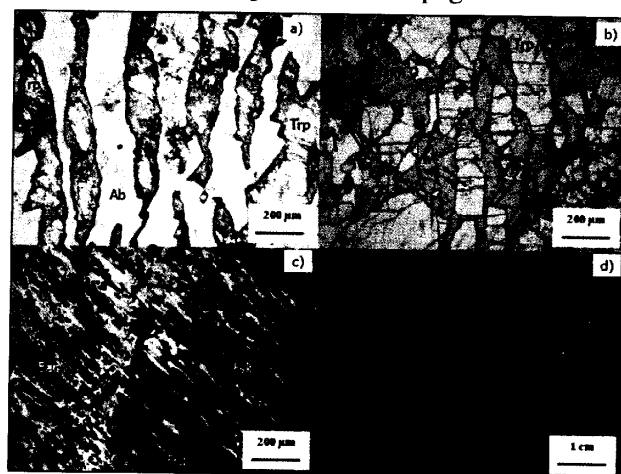


Fig. 1: The three different phosphate assemblages. a, b: assemblage I; c: assemblage II; d: assemblage III. Trp: triphylite; Ab: albite; Viv: vivianite; Sps: spessartine; Chm: chamosite; Qtz: quartz; Hur: hureaulite; bar: barbosolite; Frd: frondelite; Fsk: ferrisicklerite.

Reference

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