

## Paragenesis and precipitation stages of Nb-Ta-oxide minerals in phosphorus-rich rare-element pegmatites

Fernando Prado Araujo<sup>1\*</sup>, Niels Hulsbosch<sup>1</sup>, and Philippe Muchez<sup>1</sup>

<sup>1</sup>KU Leuven, Department of Earth and Environmental Sciences, Division of Geology, Celestijnenlaan 200E - Box 2410, 3001 Leuven, Belgium

(\*corresponding author: [fernando.pradoaraujo@kuleuven.be](mailto:fernando.pradoaraujo@kuleuven.be))

### Supplementary material S1

**Table S1: Petrographic description of minerals from the Buranga pegmatite**

| Facies             | Stage           | Mineral name [formula]  | Textural information   |
|--------------------|-----------------|---|--|
| Phosphatic nodules | Early primary   | Rutile<br>[(FeNbTa) <sub>x</sub> Ti <sub>1-x</sub> O <sub>2</sub> ]                                   | See the “Ore Minerals” section in Results of main manuscript   |
|                    |                 | F-rich montebrasite<br>[LiAl(PO <sub>4</sub> )(OH,F)]   | Euhedral to subhedral. Forms massive coarse to medium grains commonly fractured and replaced by several secondary phosphates.  |
|                    |                 | Wyllieite<br>[Na <sub>2</sub> (Fe,Mn)FeAl(PO <sub>4</sub> ) <sub>3</sub> ]                            | Euhedral to subhedral. Occurs as fine to medium inclusions in montebrasite, trolleite, augelite, and brazilianite. These inclusions, especially within augelite and brazilianite are rimmed and altered by scorzalite or whiteite, respectively.   |
|                    |                 | Fluorapatite<br>[(Mn,Ca) <sub>5</sub> (PO <sub>4</sub> ) <sub>3</sub> (F,OH,Cl)]                      | Anhedral to subhedral. Mainly corroded fine to medium crystals with a turbid appearance. In most cases, apatite occurs as anhedral “islands” in prismatic pseudomorphs. These pseudomorphs are commonly replaced with eosphorite, samuelsonite, augelite, scorzalite, and a secondary apatite  |
|                    |                 | Rosemaryite<br>[□Na(Fe,Mn)Fe <sup>3+</sup> Al(PO <sub>4</sub> ) <sub>3</sub> ]                        | Subhedral to anhedral. Medium to fine-grained, it is commonly altered by a range of later phases, such as scorzalite, samuelsonite, and eosphorite. The strongly altered rosemaryite crystals are usually accompanied by bertossaite, although no replacement textures are evident between these two minerals, and bertossaite mostly seems to encircle the rosemaryite crystals.  |
|                    | Late primary    | Trolleite<br>[Al <sub>4</sub> (PO <sub>4</sub> ) <sub>3</sub> (OH) <sub>3</sub> ]                     | Subhedral to anhedral, sometimes euhedral. Fine crystals are subhedral to euhedral and sometimes overgrown by scorzalite. Scorzalite commonly surrounds trolleite creating a distinct dark-blue rim to this mineral, which can be much thicker in the contacts with rosemaryite. Coarse crystals are commonly fractured and surrounded by brazilianite, low-F montebrasite, quartz, and bertossaite, but the latter can also locally show straight contact with trolleite. |
|                    |                 | Muscovite<br>[KAl <sub>2</sub> (Si <sub>3</sub> Al)O <sub>10</sub> (OH,F) <sub>2</sub> ]              | Subhedral. Forms fine to medium-grained blades which are partially replaced by augelite, scorzalite, and quartz.   |
|                    |                 | Quartz<br>[SiO <sub>2</sub> ]   | Anhedral medium crystals with interstitial aspect and forming clusters in the groundmass, also included in montebrasite and trolleite.   |
|                    | Early secondary | F-poor montebrasite<br>[LiAl(PO <sub>4</sub> )(OH)]   | Anhedral medium crystals replacing the earlier montebrasite and in some places trolleite. In all cases, it can be associated with lamellae of lacroixite [NaAl(PO <sub>4</sub> )F], which in turn commonly follows the crystallographic orientations of the host phase   |
|                    |                 | Bertossaite<br>[Li <sub>2</sub> CaAl <sub>4</sub> (PO <sub>4</sub> ) <sub>4</sub> (OH) <sub>4</sub> ] | Subhedral to anhedral. Occurs as medium to coarse crystals full of minute inclusions and altered by later phases, such as apatite, brazilianite, burangaite, and other minor phases. Sometimes showing optical zonations.  |
|                    |                 | CGM<br>[(Fe,Mn)(Nb,Ta) <sub>2</sub> O <sub>6</sub> ]  | See the “Ore Minerals” section in Results of main manuscript   |

|   |                |   |  |
|---|----------------|---|--|
|   |                | Scorzalite<br>[(Fe,Mg)Al <sub>2</sub> (PO <sub>4</sub> ) <sub>2</sub> (OH) <sub>2</sub> ]                             | Anhedral fine crystals usually occurring around or in fractures of earlier phases, or their contact zones, but single subhedral crystals are somewhat available isolated in the groundmass.                                |
|   |                | Augelite<br>[Al <sub>2</sub> (PO <sub>4</sub> )(OH) <sub>3</sub> ]  | Anhedral to subhedral. Fine to medium crystals replacing trolleite and muscovite, associated with quartz in the latter.  |
|   |                | Brazilianite<br>[NaAl <sub>3</sub> (PO <sub>4</sub> ) <sub>2</sub> (OH) <sub>4</sub> ]                                | Euhedral to anhedral. Coarse to medium crystals, commonly interstitial and poikilitic surrounding all previous minerals, but also partially replacing trolleite.   |
|   |                | Quartz<br>[SiO <sub>2</sub> ]   | Euhedral to subhedral. Medium to fine-grained, commonly surrounds other phases, such as trolleite, scorzalite, brazilianite, and secondary montebrasite. Can sometimes show inclusions of corroded trolleite.              |
|   | Late secondary | Childrenite-eosphorite<br>[(Fe,Mn)Al(PO <sub>4</sub> )(OH) <sub>2</sub> · H <sub>2</sub> O]                           | Anhedral to subhedral. Fine crystals commonly altering rosemaryite, bertossaite, augelite, and in pseudomorphs after apatite.  |
|   |                | Hydroxylapatite<br>[Ca <sub>5</sub> (PO <sub>4</sub> ) <sub>3</sub> (Cl,OH)]  | Subhedral very fine crystals with fibrous habit inside pseudomorphs after the primary prismatic apatite, or anhedral filling fractures of other earlier phases, such as bertossaite, augelite, and childrenite-eosphorite. |
|   |                | Samuelsonite<br>[Ca <sub>9</sub> Mn <sub>4</sub> Al <sub>2</sub> (PO <sub>4</sub> ) <sub>10</sub> (OH) <sub>2</sub> ] | Anhedral to euhedral very fine crystals showing plumose habit, commonly growing over pseudomorphs after apatite and on fractures at rosemaryite.   |
|   |                | Burangaite<br>[NaFeAl <sub>5</sub> (PO <sub>4</sub> ) <sub>4</sub> (OH) <sub>6</sub> · 2H <sub>2</sub> O]             | Euhedral to subhedral very fine alteration products of trolleite, bertossaite and scorzalite. Commonly occurs as radiated clusters of needle-shaped crystals.  |
|   |                | Wardite<br>[NaAl <sub>3</sub> (PO <sub>4</sub> ) <sub>2</sub> (OH) <sub>4</sub> · 2H <sub>2</sub> O]                  | Anhedral very fine crystals are mainly found nested in altered rosemaryite and the rims of trolleite.  |
|   | Albitized      | Early   | Beryl<br>[Be <sub>3</sub> Al <sub>2</sub> Si <sub>6</sub> O <sub>18</sub> ]  |
| Tourmaline (foitite)<br>[□(Fe <sub>2</sub> Al)Al <sub>6</sub> (Si <sub>6</sub> O <sub>18</sub> )(BO <sub>3</sub> ) <sub>3</sub> (OH) <sub>4</sub> ] |                |   | Euhedral prismatic and color-zoned fine crystals in the groundmass and included in albite  |
| Zircon<br>[ZrSiO <sub>4</sub> ]   |                |   | Anhedral fine crystals, with corroded rims and full of minute inclusions of U-bearing minerals.  |
| Fluorlapatite<br>[(Mn,Ca) <sub>5</sub> (PO <sub>4</sub> ) <sub>3</sub> (F,OH,Cl)]   |                |   | Subhedral to anhedral. Fine to medium corroded and rounded crystals, commonly surrounded by albite.  |
| Childrenite-eosphorite<br>[(Fe,Mn)Al(PO <sub>4</sub> )(OH) <sub>2</sub> · H <sub>2</sub> O]   |                |   | Anhedral fine crystals occurring as corroded and fractured inclusions in albite.   |
| Late  |                | Albite<br>[NaAlSi <sub>3</sub> O <sub>8</sub> ]   | Euhedral to subhedral. Coarse to fine with variable textures from lath-shaped oriented crystals to platy crystals, commonly shows plumose texture.   |
|   |                | CGM<br>[(Fe,Mn)(Nb,Ta) <sub>2</sub> O <sub>6</sub> ]  | See the “Albitized facies” section in Results of main manuscript   |
|   |                | Muscovite<br>[KA <sub>2</sub> (Si <sub>3</sub> Al)O <sub>10</sub> (OH,F) <sub>2</sub> ]                               | Euhedral to subhedral coarse to medium flakes surrounded by quartz and albite.   |
|   |                | Quartz<br>[SiO <sub>2</sub> ]   | Anhedral coarse to medium crystals of interstitial aspect with irregularly serrated rims, and forming pockets of medium-grained crystals.  |
|   |                | Mn hydroxides<br>[(Mn,Fe)(O,OH) <sub>2</sub> · nH <sub>2</sub> O]   | Anhedral, commonly forms masses of very fine crystals filling a network of fractures, and forming rounded millimetric spots  |
| Grain size: very fine = < 1 mm; fine = 1 to 5 mm; medium = 5 mm to 2.5 cm; coarse = > 2.5 cm  |                |   |  |