SHORT COMMUNICATION

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Augelite and cerian crandallite in dumortierite quartzites, Vaca Morta quarry, Vereda range, Macaúbas, Bahia, Brazil

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AUGELITE, $Al_2PO_4(OH)_3$, is a very rare Al-phosphate in relatively high-temperature Al-rich hydrothermal deposits, tin- and/or lithium-bearing pegmatites, hydrothermally altered andesites and Al-rich meta-quartzites (Maijer, 1965; Wise and Loh, 1976; Hoffmann, 1979; Duggan *et al.*, 1990; Ek and Nysten, 1990). In this communication we report a new occurrence of augelite and its association with cerian crandallite, $(Ca,Ce,Sr)Al_3(PO_4)(PO_3OH)(OH)_6$, in dumortierite quartzites from the Vaca Morta Quarry, Vereda range, Macaúbas, Bahia, Brazil.

The Vereda range in the northwest of the state of Bahia is well known for the occurrence of dumortierite quartzites (Cassedanne and Franco, 1966; Cassedanne *et al.*, 1989). The dumortierite--quartzites belong to the Proterozoic Santo Onofre Group, which consists of several quartzite units, schists and a thin amphibolite band. Cassedanne *et al.* (1989) described chemically complex lazulites, $(Mg,Fe,Sr,Pb)Al_2(PO_4)_2(OH)_2$, as halos surrounding hematite pebbles and lenses which occur scattered among the dumortierite quartzites.

The granoblastic quartzite contains abundant muscovite and dumortierite, and minor amounts of kyanite, crandallite, augelite, hematite, rutile and zircon. The rock shows a distinct microscopic layering expressed by variable amounts of quartz and muscovite. Muscovite (up to 0.35 mm) in the studied samples is orientated randomly. However, other samples from the quarry show a distinct foliation made up by muscovite. Muscovite has sometimes been replaced by kaolinite. Kyanite (up to 0.1 mm) occurs intergrown with muscovite, but the mutual age relationship is not clear from the textures. Euhedral, acicular, blue dumortierite (up to 0.2 mm) occurs as a late mineral dispersed over the entire rock and is especially abundant in the muscovite-rich layers, giving the rock a blue-banded appearance. Occasional trillings of dumortierite are also observed.

TABLE 1. Selected microprobe analyses of the augelite-crandallite-bearing dumortierite–kyanite–muscovite quartzite, Vaca Morta, Vereda range, Macabas, Bahia

	Ms	Ky	Hem	Dum	Kln	Agl	Cran
SiO_2	46.15	37.43	0.17	30.55	47.50	0.00	0.00
TiO_2	0.10	0.00	0.38	1.37	0.00	0.00	0.00
Al_2O_3	33.86	62.83	0.00	61.33	39.22	49.68	33.37
Fe_2O_3	–	0.23	99.64	–	0.33	–	–
FeO	3.16	–	0.45	0.35	–	0.00	1.12
MnO	0.09	0.00	0.07	0.00	0.00	0.00	0.00
MgO	0.00	0.00	0.00	0.15	0.00	0.00	0.13
CaO	0.00	0.00	0.00	0.00	0.08	0.00	7.66
SrO	n.a.	n.a.	n.a.	n.a.	n.a.	0.00	2.31
Ce_2O_3	n.a.	n.a.	n.a.	n.a.	n.a.	0.00	10.02
Na_2O	0.09	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	9.70	0.00	0.00	0.00	0.15	0.00	0.00
P_2O_5	0.00	0.00	0.00	0.00	0.00	34.89	28.45
SO_3	0.13	0.00	0.00	0.00	0.27	0.00	0.52
Total	95.28	100.49	100.71	93.75	87.55	84.57	83.58

Y, Cl and F below detection limit. n.a. – not analysed. La, Pr and Nd not detected in augelite and crandallite. Mineral abbreviations after Kretz (1983) except for Dum = dumortierite, Agl = augelite and Cran = crandallite.

Colourless crandallite occurs as clusters of numerous very small (2–10 μm) corroded or irregular grains. Most clusters are irregular and cut across the boundaries of three or four quartz grains. In several clusters the crandallite grains are grouped together to form a nearly continuous layer outlining quartz grains or a layer along the contact of two adjacent quartz grains. Crandallite grains are always completely rimmed by subhedral colourless to grey augelite (10–30 μm). Small hematite grains (up to 40 μm) may occur intergrown with both crandallite and augelite. Augelite is also present as irregularly distributed large (up to 100 μm across) subhedral colourless grains adjacent to quartz, kyanite and dumortierite and as inclusion in muscovite. The presence of both phosphates has been confirmed by XRD analysis of a HF-treated sample. Apatite was not detected in any of the samples.

Mineral analyses have been obtained using a Jeol JXA-8600 Superprobe at the University of Utrecht. During a first session the concentrations of Si, Ti, Al, Fe, Mn, Mg, Ca, Na, K, P, S, Cl and F were established at operating conditions of 15 kV, a sample current of 10 nA and a counting time of 30 seconds. The *REE*, La, Ce, Nd, Pr and Y were measured during a separate session together with Al, Fe, Mn, Ca, Sr, P and S. Operating conditions were 25 kV, 40 nA and a counting time of 40 seconds. The analytical procedures of the *REE*-analysis are similar to those in Lieftink *et al.* (1994). Raw data were corrected with a Tracor Northern PROZA computer program. Wollastonite (Si, Ca), diopside (Si, Ca, Mg, Fe), jadeite (Si, Al, Na), quartz (Si), periclase (Mg), corundum (Al), halite (Na, Cl), pyrite (Fe, S), potassium-titanium-phosphate (KTP; K, Ti, P), Cl-apatite (Ca, P, Cl), fluorite (Ca, F), celestite (Sr), metal (Mn) and synthetic oxides (La, Ce, Nd, Pr and Y) were used as standards. Selected analyses are listed in Table 1.

Augelite is a pure phase with no other elements detected but P and Al. Crandallite, $(CaAl_3(PO_4)(PO_3OH)(OH)_6)$, shows significant solid solution with florencite, $(CeAl_3(PO_4)(PO_3OH)(OH)_6)$, and goyazite $(SrAl_3PO_4)(PO_3OH)(OH)_6)$. Other analysed *REE* (La, Pr and Nd) were not detected. Using the abbreviations for the end-members Cn = crandallite, Fc = florencite and Gz = goyazite, the mineral can be described as $Cn_{53-64}Fc_{29-36}Gz_{6-17}$, representing a cerian crandallite. Calcium, cerium and strontium contents range 7.30–8.80 wt.% CaO, 9.62–11.45 wt.% Ce_2O_3 and 1.21–3.49 wt.% SrO. Minor components are Fe ($\leqslant$ 1.29 wt.% FeO), Mg ($\leqslant$ 0.13 wt. %) and S (0.12–2.40 wt.% SO_3). FeO in muscovite is variable ranging 1.70–3.40 wt.%. Phengite and paragonite components in muscovite are low. Kyanite contains 0.23–0.43 wt.% Fe_2O_3. Dumortierite contains low amounts of FeO (0.21–0.58 wt.%) and MgO (0–0.29 wt.%). Titanium contents are moderate ranging 0.85–1.37 wt.% TiO_2. Phosphorus, an important minor component in dumortierite (e.g. Willner and Schreyer, 1991; Taner and Martin, 1993), was not detected.

Hematite contains trace amounts of Ti (0.10–0.38 wt.% TiO_2).

Many studies show that intense weathering of primary phosphates (e.g. apatite) in the presence of clay minerals may produce crandallite (Flicoteaux and Lucas, 1984, and references therein) and various other Al-rich phosphates including augelite. The textures displayed by the cerian crandallites resemble the ones described in the sublitharenites and greywackes of the Helikan Athabasca Group, Alberta, Canada (Wilson, 1985), for which a very early diagenetic origin of the crandallites is proposed. Similarly, Cassedanne *et al.* (1989) proposed a late-diagenetic or metamorphic origin of lazulite in the Serra da Vereda quartzites, by a process of disassociation and re-equilibration of primary phosphates (apatite).

Augelite developed after crandallite as a result of continued transformation of the new formed phosphates during the diagenetic process or due to an increase in temperature and pressure. During this stage Ca, Sr and Ce are partly removed from the rock. Some of the Sr is still incorporated in lazulite (up to 5.30 wt.% SrO; Cassedanne *et al.*, 1989). The clay minerals were transformed to muscovite and probably pyrophyllite which produced kyanite at a later stage. The intergrowth of augelite with quartz, kyanite and muscovite provides a useful $P-T$ indicator for this assemblage. Based on the experimental data of Wise and Loh (1976) the association of augelite + kyanite in the presence of excess silica is stable at conditions T 380–475°C and $P > 2$ kbar. The intergrowth of dumortierite with kyanite and augelite suggests that the formation of dumortierite at a later stage proceeded at simlar $P-T$ conditions.

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