



Low-temperature alteration of basalts leading to world-class deposits of amethyst geodes in the Ametista do Sul mining district, southernmost Brazil

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The low-temperature alteration of basalts in the Ametista do Sul mining district, southernmost Brazil, led to the formation of a world-class deposit of amethyst geodes (400 ton/month). The basalts are part of the Paraná volcanic province, one of the largest continental flood volcanic provinces. The mining district is located in the northern part of Rio Grande do Sul state, where the prolate amethyst-bearing geodes in the pahoehoe lavas have cylindrical shapes up to 5 m x 1 m and are much prized by collectors and museums. Six Pitanga magma type flows (larger than 3 wt.% TiO₂) occur at the base and three Paranapanema flows (2-3 wt.% TiO₂) occur at the top of the stratigraphy. The amethyst-bearing geodes are contained in the uppermost three Pitanga flows and are known as the Veia Alta, Veia do Meio and Veia Baixa flows. The Veia Alta flow is the main producer in the mining district and is about 30 m thick, positioned between 400 and 430 m above sea level. The three amethyst geode hosting flows are classified as type I flows, showing no cooling joints in the central portion of the flow. The Pitanga magma type flows are highly altered, particularly the Pitanga geode producing flows (Veia Alta, Veia do Meio and Veia Baixa flows). The loss on ignition (LOI) content in the chemical analyses of rocks has a direct relationship with the presence and quantity of clay minerals (mostly smectites) in the rock. And, when compared with the Paranapanema flows, the average LOI in Pitanga flows is 2.55 wt.%, while the average LOI in Paranapanema flows is 1.7 wt.%. In thin sections, the microcrystalline matrix was altered to clay minerals and alteration pockets were formed in the rock structure. This alteration is an intense process that occurred along all rock components, mainly the fine grained crystals, such as the microcrystalline matrix and small rounded-shaped crystals of clinopyroxene. The pockets of alteration were formed as a consequence of the increment in alteration of the fine grained crystals. The alteration pockets are made up of anisotropic material, brownish to green, probably smectite (celadonite) and present irregular shapes and borders, sometimes with plagioclase crystals "floating" in the pocket. All this evidence of alteration leads to the interpretation that the rocks from the Ametista do Sul mining district, especially the geode producing flows, underwent a low temperature hydrothermal alteration process, delimited at smaller than 130 °C by the presence of clinoptilolite and by stable isotopes. The massive presence of clay minerals in the rock is an important component that controls the rheology of the rock, transforming the basalt in a very low grade smectite metabasalt, directly related to the geodes formation by a ballooning process.