Age, petrochemistry, and origin of a REE-rich mineralization in the Longs Peak-St. Vrain batholith, near Jamestown, Colorado (U.S.A.)

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**Abstract**

An unusual rare earth element (REE) mineralization occurs at a locality known as the “Rusty Gold” within the anorogenic 1.4 Ga Longs Peak-St. Vrain monzo- to syenogranite Silver Plume-type intrusion near Jamestown, Colorado (U.S.A.). Irregular-shaped centimeter- to decimeter-sized mineralized pods and veins consist of zoned mineral assemblages dominated by fluorbritholite-(Ce) in a gray-colored core up to 10 cm thick, with monazite-(Ce), fluorite, and minor quartz, uraninite, and sulfides. The core zone is surrounded by a black, typically millimeter-thick allanite-(Ce) rim, with minor monazite-(Ce) in the inner part of that rim. Bastnäsite-(Ce), törnebohmite-(Ce), and cerite-(Ce) appear in a thin intermediate zone between core and rim, often just a few hundreds of micrometers wide. Electron microprobe analyses show that the overall REE content increases from rim to core with a disproportionate increase of heavy REE ($\Sigma_{HREE}$ increases 10-fold from 0.2 to 2.1%) compared to light REE ($\Sigma_{LREE}$ increases twofold from 21.3 to 44.3%). The fluorbritholite-(Ce) contains minor U, Th, Fe, Mn, and Sr (total 0.10 apfu), with Al, Mg, Na, K, Ti, Pb, S, and Cl below instrument detection limits. Cerite-(Ce) is a minor constituent of the thin zone between the inner rim and the core. The cerite-(Ce) is Fe-rich with low Ca, and minor Al, Mg, and Mn, whereas törnebohmite-(Ce) is Al-rich and Ca-poor. Monazite-(Ce) and uraninite U-Th-Pb microprobe ages yield 1.420(25) and 1.442(8) Ga, respectively, confirming a co-genetic relationship with the host ca. 1.423 Ga Longs Peak-St. Vrain granite. We suggest the origin of the REE mineralization is a F-rich and lanthanide-rich, either late-magmatic hydrothermal fluid or residual melt, derived from the granite. This late-stage liquid, when becoming progressively enriched in REE as it crystallized, could explain the observed concentric mineralogical and geochemical zoning.

**Keywords:** Fluorbritholite-(Ce), cerite-(Ce), törnebohmite-(Ce), allanite-(Ce), REE-speciation, Rusty Gold, peraluminous granite, Silver Plume, Colorado

**Introduction**

This study focuses on the petrology and geochemistry of a particular rare earth element (REE) mineralization, and aims to fully describe and discuss possible REE enrichment processes that led to this mineral assemblage. This mineralization occurs as both veins and pods (ovoid or amoeboidal pockets) within aplitic dikes related to the 1.4 Ga Proterozoic Silver Plume-type anorogenic and peraluminous Longs Peak-St. Vrain granite near Jamestown, Colorado, U.S.A. (Fig. 1; Anderson and Thomas 1985). Goddard and Glass (1940) were the first to publish a description of this locality, known as the “Rusty Gold” deposit. They described the REE mineralization, including what they analyzed to be “cerite,” “bastnäsite,” and “allanite,” as well as fluorite, quartz, uraninite, magnetite, and sulfide phases, from several localities along the contact between pegmatite/aplite bodies and metasediment lenses (Figs. 1c and 2). A misidentification of the cerite-(Ce) was first suggested based on an XRD analysis (Affholter 1987), and this mineral was later confirmed to be fluorbritholite-(Ce) by microanalysis (Affholter 1987; Affholter and Adams 1987) as it does not contain significant amounts of Fe or Al.

No such mineral assemblages associated with peraluminous granite as observed at this location have been reported in the literature from elsewhere in the world, and only a few papers discuss the occurrence of britholite-(Ce) and allanite-(Ce) with or without monazite-(Ce) in different geological contexts (e.g., Lira and Ripley 1990; Arden and Halden 1999; Hirtopanu et al. 2013). Despite its highly unusual mineralogical character, and its potential significance for the understanding of factors related to the concentration, transport, and deposition of REE, the Jamestown locality has not been investigated further since the works of Goddard and Glass (1940), Hanson and Pearce (1941), Rabitt (1952), and Gay (1957). In this paper, we present new whole-rock analyses of the REE-rich veins, details of their mineral assemblages, their spatial zonal variation, and electron microprobe analyses of the range of REE minerals they contain.

**Geological Setting**

The REE mineralization is related to the Longs Peak-St. Vrain batholith dated by Rb-Sr at 1.423 Ga (Peterman et al. 1968; Peterman and Hedge 1968). This batholith is part of the Silver Plume-type intrusions (Anderson and Thomas 1985),...