

## **Mineralogy, paragenesis, and mineral chemistry of REEs in the Olserum-Djupedal REE-phosphate mineralization, SE Sweden**

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### **ABSTRACT**

The rapidly growing use of rare earth elements and yttrium (REE) in modern-day technologies, not least within the fields of green and carbon-free energy applications, requires exploitation of new REE deposits and deposit types. In this perspective, it is vital to develop a fundamental understanding of the behavior of REE in natural hydrothermal systems and the formation of hydrothermal REE deposits. In this study, we establish a mineralogical, textural, and mineral-chemical framework for a new type of deposit, the hydrothermal Olserum-Djupedal REE-phosphate mineralization in SE Sweden. An early, high-temperature REE stage is characterized by abundant monazite-(Ce) and xenotime-(Y) coexisting with fluorapatite and subordinate amounts of (Y,REE,U,Fe)-(Nb,Ta) oxides. During a subsequent stage, allanite-(Ce) and ferriallanite-(Ce) formed locally, partly resulting from the breakdown of primary monazite-(Ce). Alteration of allanite-(Ce) or ferriallanite-(Ce) to bastnäsite-(Ce) and minor synchysite-(Ce) at lower temperatures represents the latest stage of REE mineral formation. The paragenetic sequence and mineral chemistry of the allanites record an increase in Ca content in the fluid. We suggest that this local increase in Ca, in conjunction with changes in oxidation state, were the key factors controlling the stability of monazite-(Ce) in the assemblages of the Olserum-Djupedal deposit. We interpret the alteration and replacement of primary monazite-(Ce), xenotime-(Y), fluorapatite, and minor (Y,REE,U,Fe)-(Nb,Ta) oxide phase(s), to be the consequence of coupled dissolution-precipitation processes. These processes mobilized REE, Th, U, and Nb-Ta, which caused the formation of secondary monazite-(Ce), xenotime-(Y), fluorapatite, and minor amounts of allanite-(Ce) and ferriallanite-(Ce). In addition, these alteration processes produced uraninite, thorite, columbite-(Fe), and uncharacterized (Th,U,Y,Ca)-silicates. Textural relations show that the dissolution-precipitation processes affecting fluorapatite preceded those affecting monazite-(Ce), xenotime-(Y), and the (Y,REE,U,Fe)-(Nb,Ta) oxide phase(s). The mineralogy of the primary ore mineralization and the subsequently formed alteration assemblages demonstrate the combined mobility of REE and HFSE in a natural F-bearing high-temperature hydrothermal system. The observed coprecipitation of monazite-(Ce), xenotime-(Y), and fluorapatite during the primary REE mineralization stage highlights the need for further research on the potentially important role of the phosphate ligand in hydrothermal REE transporting systems.

**Keywords:** Rare earth elements, hydrothermal, monazite, xenotime, allanite, apatite, Olserum, Sweden