

## **Multi-stage formation of REE minerals in the Palabora Carbonatite Complex, South Africa**

**R. JOHANNES GIEBEL<sup>1,2,\*</sup>, CHRISTOPH D.K. GAUERT<sup>2,3</sup>, MICHAEL A.W. MARKS<sup>1</sup>, GELU COSTIN<sup>4,5</sup>,  
AND GREGOR MARKL<sup>1</sup>**

<sup>1</sup>Department of Geoscience, Eberhard Karls University, Wilhelmstrasse 56, 72076 Tübingen, Germany

<sup>2</sup>Department of Geology, University of the Free State, 250 Nelson-Mandela-Drive, Bloemfontein 9300, South Africa

<sup>3</sup>Department of Applied Geology and Geohazards, Geological Survey of Saxony-Anhalt, Köthener Str. 38, 06118 Halle (Saale), Germany

<sup>4</sup>Department of Geology, Rhodes University, PO Box 94, Artillery Road, Grahamstown 6140, South Africa

<sup>5</sup>Department of Earth Science, Rice University, 6100 Main Street, Houston, Texas, 77005, U.S.A.

### **ABSTRACT**

The 2060 Ma old Palabora Carbonatite Complex (PCC), South Africa, comprises diverse REE mineral assemblages formed during different stages and reflects an outstanding instance to understand the evolution of a carbonatite-related REE mineralization from orthomagmatic to late-magmatic stages and their secondary post-magmatic overprint. The 10 rare earth element minerals monazite, REE-F-carbonates (bastnäsite, parisite, synchysite), ancylite, britholite, cordylite, fergusonite, REE-Ti-betafite, and anzaite are texturally described and related to the evolutionary stages of the PCC. The identification of the latter five REE minerals during this study represents their first described occurrences in the PCC as well as in a carbonatite complex in South Africa.

The variable REE mineral assemblages reflect a multi-stage origin: (1) fergusonite and REE-Ti-betafite occur as inclusions in primary magnetite. Bastnäsite is enclosed in primary calcite and dolomite. These three REE minerals are interpreted as orthomagmatic crystallization products. (2) The most common REE minerals are monazite replacing primary apatite, and britholite texturally related to the serpentinization of forsterite or the replacement of forsterite by chondrodite. Textural relationships suggest that these two REE-minerals precipitated from internally derived late-magmatic to hydrothermal fluids. Their presence seems to be locally controlled by favorable chemical conditions (e.g., presence of precursor minerals that contributed the necessary anions and/or cations for their formation). (3) Late-stage (post-magmatic) REE minerals include ancylite and cordylite replacing primary magmatic REE-Sr-carbonates, anzaite associated with the dissolution of ilmenite, and secondary REE-F-carbonates. The formation of these post-magmatic REE minerals depends on the local availability of a fluid, whose composition is at least partly controlled by the dissolution of primary minerals (e.g., REE-fluorocarbonates).

This multi-stage REE mineralization reflects the interplay of magmatic differentiation, destabilization of early magmatic minerals during subsequent evolutionary stages of the carbonatitic system, and late-stage fluid-induced remobilization and re-/precipitation of precursor REE minerals. Based on our findings, the Palabora Carbonatite Complex experienced at least two successive stages of intense fluid–rock interaction.

**Keywords:** Rare earth minerals, Loolekop, monazite, britholite, anzaite, fluoro-carbonates, ancylite, cordylite, fergusonite, REE-Ti-betafite