

An Agentic AI Framework for Data-Driven Paragenetic Reconstruction of the Mount Weld REE Laterite Deposit, Western Australia

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The Mount Weld carbonatite complex (Yilgarn Craton, Western Australia) hosts one of the world's highest-grade rare earth element (REE) deposits, with concentrations exceeding 580,000 ppm total lanthanides due to intense weathering of a Proterozoic carbonatite. Despite its significance, the integrated temporal and geochemical evolution, from primary crystallization through lateritization to secondary REE redistribution, has not been quantitatively reconstructed within a unified framework. We present an agentic artificial intelligence pipeline that integrates four datasets: (1) $^{40}\text{Ar}/^{39}\text{Ar}$ step-heating geochronology of cryptomelane ($n = 18$; 269 steps); (2) LA-ICP-MS trace element and isotopic analyses of REE-bearing phases ($n = 291$); (3) EPMA of cryptomelane-group minerals ($n = 31$); and (4) powder XRD phase characterization ($n = 8$). The system comprises four agents: A-1 performs cross-dataset feature engineering; A-2 classifies paragenetic stages using UMAP, HDBSCAN, and LLM-based reasoning; A-3 generates and tests geochemical hypotheses via a ReAct loop; and A-4 constructs a temporally constrained evolution model. Results identify two statistically distinct lateritization episodes (36.1 ± 2.2 Ma and 28.4 ± 1.8 Ma; Mann–Whitney $p = 0.0006$), corresponding to Eocene and early Oligocene weathering pulses. LA-ICP-MS data show extreme LREE/HREE fractionation ($(\text{La}/\text{Yb})_N = 916$) and a Ce/Ce* anomaly (mean = 0.86), indicating reducing to mildly oxidizing conditions during REE phosphate formation. EPMA data reveal progressive K to Ba substitution in cryptomelane ($\text{K}/(\text{K}+\text{Ba}) = 0.12$ to 0.98) with strong negative correlation ($\rho = -0.670$, $p < 0.0001$), reflecting fluid evolution. PCA explains 94.6% of variance, with PC1 capturing fractionation intensity and PC2 fluid redox state. The resulting model defines five paragenetic stages, from pre-lateritization remobilization (Lu–Hf constrained) to Paleogene weathering pulses. This framework demonstrates that agentic AI can generate reproducible, geologically constrained paragenetic models from complex datasets, with direct applicability to REE exploration in analogous cratonic systems.