

## **U-Pb and Re-Os Geochronology of REE-rich Breccia Pipes and Magnetite Ore from the Mesoproterozoic Pea Ridge Fe-REE-Au Deposit, St. Francois Mountains, Missouri, USA**

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The Pea Ridge iron oxide-apatite (IOA) deposit in the ~1.47 to 1.44 Ga Mesoproterozoic St. Francois Mountains terrane of southeast Missouri, USA, is an endmember type in the global spectrum of iron oxide-copper-gold (IOCG) deposits, which constitute important Fe, Cu, Au, U, and rare earth element (REE) resources. The Pea Ridge deposit contains REE-rich breccia pipes along its footwall zone that have a reported endowment of 600,000 t @ 12% total REO. Previous underground mapping (workings are now flooded) showed that the breccia pipes (ca. 15 × 60 m in plan view) cut the host rhyolite, magnetite ore, and alteration zones associated with the iron ore system. Monazite ((Ce,La,Th)PO<sub>4</sub>) and xenotime (YPO<sub>4</sub>) are the main REE-bearing minerals in the breccia pipes. Two varieties of breccia pipes are recognized: “soft” (SBP) and “hard” (HBP). Although small in size and currently sub-economic, the breccia pipes are enriched in heavy REEs relative to other REE occurrences; these pipes are the focus of isotopic and geochemical studies by the USGS designed to determine their origin and aid assessments of similar undiscovered resources.

SHRIMP U-Pb geochronology was used to date zircon from two samples each of host rhyolite and crosscutting late aplite, and monazite and xenotime from samples of SBP and HBP. Apatite from magnetite ore was dated by SHRIMP, TIMS, and LA-ICP-MS U-Pb methods. Zircon from two host rhyolite samples yielded ages of  $1473.6 \pm 8.0$  (2 $\sigma$ ,  $n = 20$ ) and  $1472.7 \pm 5.6$  Ma ( $n = 20$ ). Euhedral prismatic zircon grains in late aplite dikes have a range of ages and are regarded as xenocrysts. Two totally dissolved apatite samples from magnetite ore yielded TIMS ages of  $1461.3 \pm 8.3$  ( $n = 3$ ) and  $1466.2 \pm 4.0$  Ma ( $n = 9$ ). Micrometer-sized monazite inclusions in the apatite form both crystallographically controlled euhedral acicular grains and equant, randomly oriented grains. The LA-ICP-MS age of the larger, equant monazite inclusions is  $1442 \pm 12$  Ma ( $n = 10$ ).

Monazite crystals within the REE-rich breccia pipes have two distinct morphologies: (1) coarse-grained yellow grains (similar to typical igneous and metamorphic monazite) with distinct cores and rims in SEM-BSE images, and (2) granular grains, composed of numerous small (<50  $\mu$ m) crystallites, which are pieces of the matrix that surrounds coarse breccia rock fragments. The granular matrix also contains rare, fine-grained xenotime (both as isolated intact grains and as rims around monazite), thorite, apatite, and magnetite. The weighted average of all monazite ages is  $1462.5 \pm 1.5$  Ma ( $n = 111$ ), whereas the age of matrix xenotime is  $1462.7 \pm 9.3$  Ma ( $n = 15$ ). Molybdenite, which is intergrown with quartz, monazite, and xenotime in HBP, yielded a Re-Os age of  $1440.6 \pm 9.2$  Ma.

Although textural evidence in monazite suggests the possibility of multiple hydrothermal events (perhaps at ca. 1465 and ca. 1445 Ma), better analytical precision is required to fully resolve potential age differences. However, our results indicate that the hydrothermal activity responsible for IOA mineralization at Pea Ridge post-dated volcanism by up to 10 Ma and may have continued for several tens of m.y.