Sr-Nd isotope systematics of fluorite in the world-class Xiangshan uranium deposit, SE China: Evidence for ore-forming fluid derivation from the local enriched mantle source

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Xiangshan mine, located in Jiangxi Province, SE China, is one of the largest uranium ore deposits in China. The deposit occurs in a Mesozoic central volcano-tectonic collapse basin, with a basement composed of Early-Middle Proterozoic and Sinian metamorphic rocks. The volcanic rocks are of late Jurassic age (135-149Ma), with major rock types of rhyolitic tuff and lava, porphyroclastic lava, and subvolcanic rocks. Nd-Sr isotope signature indicates that the volcanic rocks were likely derived from partial melting of Middle Proterozoic metamorphic rocks at depth.

The late dikes of lamprophyre intruded in the volcanic rocks at 109Ma. The lamprophyre shows $\varepsilon_{Nd}(T)$ value of -7.2 and initial $^{87}Sr/^{86}Sr$ ratio of 0.709004, and has high contents of transition metal elements, LREE, LILE and high ratios of Nd/Sm and Rb/Sr, and shows apparent negative Ce anomaly, implying the metasomatic event associated with subducted sediments in local lithospheric mantle source region.

The uranium mineralization (98Ma) postdates the volcanic activity and takes the form of replacement hydrothermal veins in the volcanic rocks and Sinian metamorphic rocks. Fluorite is a common gangue mineral in the Xiangshan uranium ore veins. These fluorites have variable Sr contents of 295-1136ppm and initial $^{87}Sr/^{86}Sr$ ratios of 0.71447-0.72072, and show a positive linear correlation between $^{87}Sr/^{86}Sr$ and 1/Sr, which can only be attributed to reaction between the local enriched mantle-derived fluid with $^{87}Sr/^{86}Sr$ ratio of 0.71060 and high Sr contents, and the Early-Middle Proterozoic parametamorphic rocks with high $^{87}Sr/^{86}Sr$ ratios of 0.723424-0.77200 and low Sr contents of 38.0-299.6ppm. In contrast, the initial $^{143}Nd/^{144}Nd$ ratios of the fluorites are relatively uniform (0.51209-0.51217, avg0.51212), similar to that of the lamprophyre (0.51214), and show no correlation with 1/Nd. This suggests that the ore fluid Nd was dominantly of local enriched mantle origin.

Our isotopic results are consistent with a new model for fluorite and uranium ore deposition that the ore-forming fluid may have mainly derived from the local enriched mantle source, and this deep-seated fluid obtained some Sr from basement metamorphic rocks during its ascent along deep fault, and then precipitated in fractures of volcanic rocks and Sinian metamorphic rocks at shallow crust level.

Isotopic biosignatures from the intermediate-mass range

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The search for isotopic biosignatures reflects recognition of the ubiquitous role that biology plays in cycling many elements in near-surface environments, and the fact that “biological processing” of elements may produce isotopic fractionations which are distinct from those produced by inorganic processes. Although biologically-produced isotopic fractionation may reflect kinetic effects, equilibrium fractionations may also exist in biologic systems that are unique relative to those in “equivalent” inorganic systems if bonding environments are distinct. Quantification of isotopic biosignatures requires experimental studies in both biologic and inorganic systems, as well as an assessment of the role biology plays in sequestering isotopically distinct reservoirs that might be unlikely to occur in abiotic systems.

In the intermediate mass-range, Fe isotope variability in nature and experiment indicates that $^{56}Fe/^{54}Fe$ ratios may vary by ~5 ‰. In the case of dissimilatory Fe reduction, the $\delta^{56}Fe$ values of $Fe(II)_{aq}$ are ~2.2 ‰ lower than the starting ferric oxy/hydroxide when Fe reduction rates are fast (independent of bacteria species and in the absence of biogenic mineral products), whereas at rates 10^3 lower, $\Delta_{Fe(II)aq\text{-}Ferric\ Oxide}$ appears to be constant at -1.3 ‰, suggesting isotopic fractionation under equilibrium conditions. If the -1.3 ‰ fractionation reflects equilibrium partitioning between soluble Fe(II) and Fe(III) components, the isotopic fractionation is half that measured in abiotic systems associated with a range of inorganic complexes, suggesting that an Fe isotope “vital effect” may exist during dissimilatory Fe reduction. Production of biogenic Fe carbonates and magnetite produces significant Fe isotope fractionations, which vary depending upon Fe reduction rates, but it is not yet clear if unique isotopic fractionations are associated with these biological systems because we lack experimental determinations of equilibrium Fe isotope fractionation in the abiotic system Fe(II)-magnetite-siderite. Anoxygenic phototrophic Fe(II) oxidation produces significant Fe isotope fractionation, where hydrous ferric oxide precipitates are enriched by ~1.5 ‰ in $^{56}Fe/^{54}Fe$ ratios, apparently independent of overall oxidation rate. Although somewhat comparable to the results of abiotic experiments, kinetic issues remain unresolved in biologic and abiologic systems that involve Fe(II) oxidation. It seems clear, however, that investments made in experimental studies of isotopic fractionations that are associated with new isotope systems such as Fe are likely to produce new insights into biogeochemical cycling of a diverse range of elements.