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Large molybdenum isotope variations in a continental rift setting

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Relatively little is known about the Mo-isotope variations in continental settings, where igneous and clastic sediment lithologies show a narrow range of $\delta^{97/95}$Mo values (0.0 $\pm$ 0.25 permil, relative to the Johnson-Matthey Mo plasma standard). In the present research we measured $\delta^{97/95}$Mo values of molybdenum-enriched low-temperature iron oxide veins in anticlines bordering the Dead Sea Rift. Potential source rocks for the Mo anomaly were also studied, including local igneous rock and Late Cretaceous organic-rich shales and phosphorites. The range of the $\delta^{97/95}$Mo values for the iron oxide veins was 2.6 permil (-0.4 $\pm$ 0.2 to 2.2 $\pm$ 0.07 permil). This range is larger than any other continental lithology measured to date. A unique feature of the results is that the highest $\delta^{97/95}$Mo values are associated with highest Mo concentrations. The variations are most easily interpreted in terms of a combination of mixing trends and isotopic fractionation. Two proposed mixing end-members are aqueous solutions containing Mo derived by congruent (i.e., non-fractionating) leaching of the isotopically-light igneous intrusion with a $\delta^{97/95}$Mo value = 0.12 $\pm$ 0.06 permil and the Cretaceous organic-rich shales with $\delta^{97/95}$Mo = 0.85 $\pm$ 0.15 permil. The highest $\delta^{97/95}$Mo values (1.1 - 2.2 permil) are obtained from Mo-enriched iron oxides in the anticlines located closest to the Dead Sea Rift. This geographical distribution suggests that the isotopically-heavy Mo end-member was located in the Rift. Molybdenum transport with hydrocarbons from oil shales buried in the Dead Sea Rift by infiltrating evaporative rift brines, and additional isotopic fractionation of Mo when thiosulphide complexes oxidized to form molybdate anions (MoO_4^{2-}) potentially could account for the high Mo-contents and $\delta^{97/95}$Mo values.