Lead isotopes inform on crude oil migration processes

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While the geological settings of oil fields are usually well documented due to prospectivity interests, the process of oil migration from source rock to reservoir remains poorly constrained. As water-hydrocarbon mutual solubilities vary greatly with temperature [1], elemental concentrations in crude oil are affected by oil migration. Heavy isotopes, on the other hand, remain unaffected by these processes, and as U is found in abundance in organic-rich hydrocarbon-generating black shales, we focused on Pb isotopes as potentially promising tracers of oil genesis and migration. To this end, we developed an analytical protocol allowing high-precision isotopic measurements of Pb in small volumes of crude oil [2] and analyzed 195 crude oils from locations worldwide. Seventeen black shale source rocks also were analyzed. Lead, Th, and U concentrations were measured for all the black shales and a subset of the crude oils.

Lead isotopic compositions show that Pb in crude oil is derived from at least three distinct sources with Cenozoic, Paleozoic, and Proterozoic model ages. The Th/U ratios indicate that black shales are depleted in U relative to crude oil, and the Th/U ratio in crude oil is lowest near tectonic features associated with mantle thermal anomalies. Our data suggest that the process of oil migration from source rock to reservoir is triggered by hot waters circulating upwards within the sedimentary basin, carrying unradiogenic Pb from the underlying basement, and dissolving the oil, preferentially mobilizing U over Th. As water-hydrocarbon solubility depends on temperature, dissolution of oil by waters passing through the source rock followed by unloading of the oil below its final reservoir require strong temperature gradients, such as those found in plumes of hot fluids rising above mantle thermal anomalies.

[1] Griswold & Kasch (1942) *Ind. Eng. Chem* **34**, 804-806.
[2] Fetter *et al.* (2019) *Chem. Geol.* **511**, 212-122.