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Relevance of Hydrocarbon-Water Trace Metal Partitioning and Re-Os Geochronology for Sedimentary-Hosted Ore Deposits and Petroleum Systems

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Oil-producing basins commonly host sedimentary ore deposits and the same permeability networks are often utilized by formation waters, ore-forming fluids, and hydrocarbons. This results in a complex framework of fluid-rock-hydrocarbon interaction along fluid migration paths. The occurrence of hydrocarbons has been documented in a variety of ore-forming systems including sedimentary-hosted Pb-Zn(-Ag), U, Au, and platinum group elements deposits. The role of hydrocarbons for ore formation can vary widely from 1) hydrocarbons acting as reductants to facilitate sulfide precipitation from metalliferous basinal brines; 2) hydrocarbons indirectly contributing to ore formation by producing H₂S (sour gas) that can either mix with metalliferous fluids resulting in sulfide precipitation or oxidize on mixing with formation waters resulting in the formation of highly acidic brines; and 3) hydrocarbons acting as ore fluids by transporting metals. Hydrocarbons within ore deposits have elevated ore metal contents and are characterized by specific trace metal signatures reflecting brine-hydrocarbon or hydrocarbon-rock/mineral interaction. The Re-Os geochronometer has been used to date bitumen in sulfide deposits providing an accurate age for ore formation. It follows that water-hydrocarbon interaction may be an integral part of sedimentary-hosted ore formation and that hydrocarbons may provide important information on ore-forming processes.

In this study, we experimentally determined fundamental controls on trace metal fractionation during water-oil interaction for Cd, Co, U, As, Ag, Ni, Mo, Ba, Re, Os, V, and other trace metals (Figure 1). The experimental approach is based on the basic chemical principle that trace metals with different chemical properties fractionate across the water-oil interface and become variably enriched or depleted in hydrocarbons. Therefore, quantifying trace metal partitioning between water and hydrocarbons provides new insights for understanding what controls metal signatures in hydrocarbons. Experiments interacting waters and oils with varying initial compositions were conducted at 70°, 150°, and 220°C. In general, the behavior of different trace metals is highly variable with preferential partitioning of some elements (i.e., Ba, Fe) into the aqueous solution and retention and/or enrichment of other elements (i.e., Mo, U, Os, Re, Sb) in the oil. Increasing the salinity and pH of aqueous solutions results in stabilization of aqueous complexes and leaching of metals from the oil and limiting uptake of metals from the spiked aqueous solutions (Figure 1). The behavior of Re and Os during water-oil interaction is of special interest because the Re-Os geochronometer is invaluable for directly determining the timing of water-oil interaction. Results show that Re and Os fractionate across the water-oil interface with Os preferentially partitioning into the oils over Re. We further demonstrate that the Re-Os geochronometer can only be reset due to water-oil interaction for starting waters with sufficient Re contents and low pH at temperatures <220°C, underpinning the application of Re-Os dating of hydrocarbons associated with ore deposits in sedimentary basins.

Figure 1: Trace metal systematics of three different crude oils (black squares) and patterns for reacted crude oils that were equilibrated with trace metal spiked waters at different temperatures (colored circles). The y-axis represents metal concentration in the crude oil.

