Fluids implicated in hydrocarbon migration: Identifying the perpetrators in rifted margins

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Hydrocarbons travel together with aqueous fluids as they are expelled from source rocks, migrate, and accumulate in reservoirs. Simple models suggest that aqueous fluids are derived from the source rocks themselves and/or connate waters in permeable rocks along the migration pathway. Isotopic tracers offer a test for such models. Using the osmium isotope tracer, we show that deep faults dissecting the crust in rift environments tap primitive fluids, affirming the importance of these structures in localizing oil fields and challenging long-standing models for hydrocarbon maturation and mobility.

Rhenium (Re) and osmium (Os) comprise a parent-daughter isotopic pair, offering both geochronology and an isotopic tracer. ^{187}Re decays to ^{187}Os with a half-life of 41.6 Ga. Despite the long half-life, commonly high Re/Os ratios produce enough radiogenic Os for precise measurements even in very young rocks. Because Os is compatible in mantle mineral assemblages, whereas Re is mildly incompatible, Re/ Os ratios in the crust are far higher than those in the mantle. Over time, therefore, mantle ^{187}Os/^{188}Os remains low (~0.13 today), while crustal ^{187}Os/^{188}Os may range from ~1 (e.g. modern seawater) to extreme values in Re-rich materials. Organic-rich sedimentary rocks typically have ^{187}Re/^{188}Os ratios in the 100s to 1000s, generating ^{187}Os/^{188}Os ratios of 0.5 to >5 over time. Many oils derived from these source rocks have broadly similar ratios, suggesting minimal elemental or isotopic fractionation during maturation and migration.

Among other localities, the AIRIE Program has analyzed a variety of oils from the rifted Norwegian Continental Shelf. In certain fields, measured ratios for both ^{187}Re/^{188}Os and ^{187}Os/^{188}Os are extremely low (<10 and <0.2, respectively). Such data interrogate our present thinking on oil generation. A chapter in hydrocarbon generation models must include fluids carrying primitive (mantle-derived) Os interacting with kerogen and/or its expelled products. That is not to say oil is abiogenic, but that oil generation processes go beyond burial of sedimentary rocks with their connate basin fluids. We have coupled case studies with experimental work to show the effect water-oil interaction on different oils. Importantly, isochron ages for asphaltene-crude-maltene triplets are preserved whereas the Os tracer identifies fluids involved in hydrocarbon migration history.

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