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Cracked and full of sand: microstructural insights into how oil gets into a crystalline basement reservoir

Bob Holdsworth, Ken McCaffrey, and Eddie Dempsey
University of Durham, Dept of Earth Sciences, Durham, United Kingdom (r.e.holdsworth@durham.ac.uk)

The fractured Neoarchaean orthogneisses forming the 200km long, NE-SW trending Rona Ridge lie offshore along the southeast margin of the Faroe-Shetland Basin (FSB). The basement ridge was uplifted during Cretaceous-age normal faulting and is flanked and immediately overlain by Devonian to Cretaceous cover sequences. Basement-hosted oil is known to occur in significant volumes in at least two fields (Clair, Lancaster). Re-Os dating of bitumen samples from the Clair Field suggests that oil was generated in the period 64-72Ma.

A new microstructural study of basement cores was carried out to assess the mechanisms and timing of oil charge and other fracture-hosted mineralization. Oil charge is everywhere associated with quartz-adularia-calcite-pyrite mineralization and is hosted in a complex mesh of interconnected shear and tensile fractures that formed during a single protracted episode of brittle deformation. This association is recognized in all basement cores containing oil and also in locally overlying well-cemented Devonian (Lower Clair Group) and Jurassic (Rona Sandstone) sequences.

Mineralization and oil charge is everywhere associated with clastic sedimentary infillings which occur either as vein-hosted injected slurries, or as little deformed laminated infills in mm to dm-scale open fractures. The latter preserve delicate way-up criteria and geopetal structures. The largest accumulations of oil are found either in these poorly-cemented sedimentary infills, or in fracture-hosted vuggy cavities up to several cm across. All these features, together with the widespread development of zoned mineral cements and cockade textures suggest a low-temperature hydrothermal system that likely formed in a near surface (<1-2km depth) environment. It appears that highly dilated, open fractures developed in relatively strong basement or overlying well cemented sedimentary rocks and were able to act as long-lived fluid channel-ways. There is no textural evidence for reactivation and it seems likely that oil saturation ultimately shut down fracture cementation.

The widespread preservation of dilational pull-apart features, together with the development of injected sediment-mineral slurries, and at least one possible silica gel along a fault, suggests that seismogenic faulting drove fluid flow through the basement fracture systems. Such a ‘dilatancy-pumping’ process may have also helped to drive oil migration from the Jurassic source rocks located to the west in the FSB, through the basement ridge and up into the overlying Clair Group and other cover sequences during the 64-72Ma time period.

Our findings have major implications for the development of fractured basement reservoirs in the UKCS and worldwide. They also suggest that near-surface sesimogenic faulting and dilatancy in strong crystalline rocks such as basement, igneous intrusives/extrusives and some carbonates may help drive fluid flow and trigger hydrocarbon migration during rifting.