Dating faults, fractures and fluids with U-Pb calcite geochronology: Application to contrasting fracture and fluid-flow modes of the Cleveland Basin

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Fractures and faults act as important permeable pathways in the subsurface and are of great significance to the petroleum industry and for future Carbon Capture and Storage. Fractures allow fluid-flow through impermeable units such as mudrocks and can affect how these lithologies act as top seals, source rocks and/or unconventional reservoirs. Natural fractures within mudrocks can strongly influence top seal integrity, primary migration and the performance of unconventional (e.g. shale gas) reservoirs. This project studies the exhumed, early-mature, Jurassic mudrock succession of the Cleveland Basin, NE England, combining structural geology with isotope geochemistry and geochronology. The primary objective is to provide an absolute chronology of faulting and fracturing through novel U-Pb geochronology of fracture-fill calcite. The abundance of well-exposed, natural fractures with different orientations and failure modes provides an opportunity to investigate the properties of these fractures, and provide a basin-wide temporal and spatial framework of evolving deformation. The second objective is to use trace element, stable isotope, and clumped isotope analyses, to constrain fluid composition and temperature. In combination, these objectives will provide an integrated understanding of fracturing, faulting and fluid migration during burial and exhumation of a sedimentary basin.

Current fracture-fill dates from U-Pb geochronology provide intriguing insights into the history of the Cleveland Basin. We have identified and dated three phases of deformation and associated fluid-flow that have contrasting kinematics and fluid-flow regimes. The E-W trending Flamborough Head Fault Zone (FHFZ) bounds the basin to the south, and calcite preserved in one of the major extensional faults provides ages of 64-56 Ma. Calcite from N-S to NNW-SSE trending normal faults and associated fractures in the north of the Cleveland Basin provide ages of 44-25 Ma, revealing a previously unknown phase of Cenozoic faulting, which we speculatively relate to salt-related deformation. Structural and petrographic information suggest that the E-W and N-S trending faults have contrasting fracture-fluid-flow systems. Large (up to 30 cm), chalk hosted, vuggy calcite cements with geopetal sediment-fills in the E-W fault zone suggest it acted as an open fluid conduit with voluminous fluid-flow, linking the shallow sub-surface with deeper levels of the
stratigraphy. In contrast, typically thin (<5 mm) vein fills with varying crack-seal-slip type textures in the N-S mudstone-hosted fractures of the Cleveland Basin provide evidence of episodic slip of variable displacement (44-40 Ma); these fracture openings may partly be controlled by pore fluid pressures and pre-date fault movement along the regional Peak Fault and smaller scales N-S faults (40-25 Ma) which are characterised by damage zone calcite mineralisation and extensional jog structures. Initial stable isotopic results are giving indications of fluid temperatures and sourcing which will be built on further by clumped isotope and fluid inclusions work.