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Timing of Deformation and Gas Generation and Migration in the Foothills Region of the Eastern Brooks Range Fold-Thrust Belt (Arctic National Wildlife Refuge, Alaska)

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In the foothills region of the eastern Brooks Range fold-thrust belt (Arctic National Wildlife Refuge), surface vitrinite reflectance data (Ro> 2.0%) indicate high thermal maturity, and suggest that the region is primarily gas prospective. These data do not address, however, the timing and conditions of gas generation and migration relative to structural trap formation associated with Brooks Range deformation- a critical exploration issue in this frontier setting. We address these issues through detailed petrographic, SEM-cathodoluminescence , fluid inclusion, and stable isotope analyses of cemented fractures collected, in part, from important source rocks in northern Alaska. The analyses document the temperature, pressure, and fluid composition conditions under which fluid flow, including gas, occurred. Results of these analyses are integrated with zircon fission track data, which establishes the relative and absolute timing of deformation and gas generation and migration.

Samples come from the Triassic Fire Creek and Shublik Formations and Jurassic Kingak Shale, the latter two of which are source rocks. Cemented fractures are exposed in a thrusted anticlinorium along the Aichilik River at Leffingwell Ridge, which is the northernmost outcrop of the Brooks Range fold-thrust belt along the Aichilik River. Fractures are cemented primarily with quartz and smaller amounts of chlorite and ankerite. Crack-seal textures, healed microcracks, and bent crystals and fluid inclusion populations in quartz suggest that cement growth and deformation occurred close in time, and in many cases, deformation influenced cement growth processes.

Homogenization temperatures (175°-250°C) and temperature trends among aqueous fluid inclusion populations suggest that fracture cements grew at 7 to 10 km depth (assumed geothermal gradient= 25°C/km and surface temperature= 0°C) during the transition from burial to uplift. Oxygen isotope values of fracture pore fluids, calculated using measured mineral isotope values and homogenization temperatures, are mostly enriched ($\delta^{18}0_{SMOW}$ = 6-13‰). Along with salinity data taken from fluid inclusion final ice melting temperatures (2.5-5.7 wt.% NaCl equivalent), the data suggest that fracture pore fluids were rock-buffered formation fluids.

The presence of gas-rich CH_4 and CH_4-CO_2 inclusions in the Shublik and Kingak, respectively, is consistent with inclusion entrapment at high thermal maturity at the time of fracturing. Low temperature phase changes (i.e. CH_4 homogenization, CO_2 final melting) were modeled in the CH_4-CO_2 system to estimate composition (X_{CH4}=0.79-0.9) and molar volume (47-65 cm^3/mole). Entrapment pressures were calculated using the composition and molar volume data, a modified Redlich-Kwong equation of state, and homogenization temperatures of aqueous inclusions coeval with the gas-rich inclusions. Pressure estimates range from 1000 to 2000 bars, with most in the range of 1100 to 1600 bars. At inferred cementation depths based on homogenization temperatures, the estimated pressures suggest that fracture pore fluids exceeded hydrostatic and approached lithostatic at the upper end of the range. Furthermore, detailed analysis among fracture cement generations and in a single quartz crystal suggests remarkable pressure variations on the order of 100's of bars.

Zircon fission track data, with a closure temperature of 240°C, record early uplift associated with Brooks Range deformation in the area at 65 to 70 Ma. The zircon closure temperature overlaps homogenization temperatures of coeval aqueous and gas-rich inclusions in the Shublik and Kingak fracture cements. The overlap provides a direct link between deformation timing and the generation and migration of gas. Development of overpressures, inferred from the inclusion modeling, is thus likely due to lateral compression associated with thrusting during Brooks Range deformation.

The presence of dry gas inclusions and absence of oil-bearing inclusions strongly suggests that dry gas was the dominant hydrocarbon phase present during the early stages of Brooks Range deformation. The corollary to these observations is that development of trapping structures associated with early Brooks Range deformation occurred after source rocks were buried through the optimum oil and gas generation window (~90°-190°C) in the eastern Brooks Range foothills. From a general exploration strategy viewpoint, this study underscores the potentially important contribution that fracture diagenesis and fluid inclusion studies can have in evaluating source rock maturation and deformation timing in fold-thrust belts, where burial histories based on stratigraphic restoration can contain significant uncertainty.