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Direct evidence of gas flushing oil in deep reservoirs: Insight from integrated fluid inclusion analyses

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Gas-flushing-oil has been proposed as an essential process for forming some condensate gas reservoirs based on laboratory experiments and modeling but such a process has rarely been documented in subsurface reservoirs. Here we report a unique type of yellow-ringed oil inclusions (*YROIs*) discovered from a deep reservoir in the Kuqa foreland basin, western China that recorded the gas-flushing-oil process in subsurface. The occurrence, composition, phase state and conditions of *YROIs* during trapping were investigated using a suite of fluid inclusion analytical methods including fluid inclusion petrography, microthermometry, fluorescence spectroscopy, quantitative grains fluorescence, PVT modeling and molecular composition analysis.

YROIs found in the reservoir are three-phase (solid-liquid-vapor) fluid inclusions at room temperature with solid rings of 2~3 μm thick and estimated volume fractions varying between 5% and 15%. When heated the solid ring starts to melt at around 46 ºC and would homogenize with the liquid phase at or above their corresponding homogenization temperatures of the coeval aqueous inclusions. *YROIs* have fluorescence spectral peaks between 530 nm and 550 nm and an elevated spectral shoulder around 650 nm when measured under room temperature; but most spectra show a distinct “blue shift” and an absence of the 650 nm shoulder when measured under their homogenization temperatures. Molecular compositions derived from synchronous fluorescence and GC-MS analysis suggest that the compositions of *YROIs* are rich in polyaromatic and resin compounds. PVT modeling indicates that *YROIs* were trapped under high pressure conditions with a pressure coefficient of 1.5 or greater.

YROIs are interpreted to have been trapped under an elevated temperature and overpressure condition relating to an intensive (wet) gas flushing of an early-charged wax-rich oil. When light hydrocarbon components in the reservoir oil were partially removed by gas, the wax/resin components rich in polyaromatic hydrocarbon compounds may precipitate due to physio-chemical fractionation. *YROIs* were entrapped in subsurface from a heterogeneous hydrocarbon fluid containing variable amounts of wax/resin colloids, which subsequently coalesce to form solid rings adhering to the inner wall of oil inclusions at room temperature. The minimum homogenization temperature may approximate their trapping temperature.