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Gas Flushing as a Reservoir Formation Mechanism in the Ordovician Reservoirs, Tazhong Field, Tarim Basin, China: Evidence from Fluid Inclusion, Fluorescence and Hydrogen Isotope Data

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The Tazhong Field is one of the most important liquid oil producing provinces within the Tarim Basin with combined oil and gas reserves estimated to be close to 10 billion bbl of oil equivalent. The produced oils in the Tazhong uplift area are extremely diverse, ranging from condensates, very light oil, to very waxy oils, through normal black to heavy oils, all of which are believed to be sourced primarily from the Cambrian and Ordovician strata (Zhang et al., 2000; Li et al., 2010). The Ordovician carbonate reservoirs in the Tazhong area have been the primary producing interval and have been the focus of recent exploration. The diverse range of liquid hydrocarbons in the area have been primarily attributed to hydrocarbons progressively charged with increasing source rock maturity with multiple hydrocarbon charge events documented (e.g. Xiao et al., 1996; Lü et al., 2004; Pan and Liu, 2009).

Gas washing (flushing) or gas de-asphaltene has been recognized as a mechanism for the accumulation of some gas condensate in the Tarim Basin, especially in the Tabei area (e.g. Wang et al., 2007; Zhang et al., 2011). However, to date, there has been no direct, unequivocal evidence suggesting that gas flushing plays an important role in oil migration and accumulation within the Ordovician reservoirs in the Tazhong Field.

Recent investigation on the charge history of the Ordovician reservoirs in the Tazhong Field has revealed widespread co-occurrences of relatively immature (yellow), mature (blue), condensate and solid bitumen-bearing hydrocarbon fluid inclusions in both current and palaeo reservoirs (Fig. 1). The fluid inclusion petrographic and microthermometric data indicate that the immature oil was charged first followed by either a light/mature oil and/or large quantity of gas. The co-occurrences of the varieties of hydrocarbon fluid inclusions and their trapping sequence suggest that gas flushing may have played an important role in the (palaeo) reservoir accumulation process. The homogenization temperatures of the fluid inclusions (~80-125ºC, Fig. 1) indicate that the co-existence of solid-bitumen bearing and condensate inclusions could not be caused either by biodegradation or by in situ pyrolysis.

Total Scanning Fluorescence (TSF) and hydrogen isotope data of 29 selected oil samples from the Ordovician reservoirs in the Tazhong area also indicate that the current reservoir oils may have undergone varying degrees of gas flushing (Fig. 2, see Nomenclatures). Two distinct “inverse isotope fractionation” trends (i.e. progressive enrichment of lighter hydrogen isotope with decreasing maturity and API gravity) can be identified in Figure 2, typical of isotope fractionation via the progressive vaporization process (Wang and Huang, 2001). The δD values of the oils analysed are in the range between -90‰ and -140‰, somewhere in-between the δD values for CH4 (-125‰ to -163‰) from the Tazhong reservoirs (Liu et al., 2007) and δD values for oils from the nearby Lunnan Field (-60‰ to -120‰, CSIA) (Lu et al., 2004).

Both the fluid inclusion data and the TSF-hydrogen isotope data of current day oils indicate that gas flushing played an important role in the reservoir formation process in the Ordovician reservoirs in the Tazhong area, Tarim Basin.

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Nomenclatures

<u>Total Scanning Fluorescence (TSF)</u>

TSF measures the 3D fluorescence excitation-emission spectral response of oil diluted in solvent (Dichloromethane). TSF spectrograms provide fingerprints of oil and empirical API gravity and maturity information (Barwise and Hay, 1996). The TSF Parameter R1, defined as the ratio of the emission intensities at 360 nm over that at 320 nm when excited with a 270 nm UV light, correlates well with thermal maturity and API gravities of oils. In general the smaller the R1 value is, the more mature and the lighter the oil would be.

<u>Inverse hydrogen isotopic fractionation</u>

For oils derived from similar sources the δD values are believed to become lighter with increasing maturity or API gravities. However, during their progressive vaporization experiments Wang and Huang (2001) found that the hydrogen isotope fractionation is opposite to the general expectation inferred from kinetic isotopic fraction with heavier component evaporated rather than preserved. They attributed the phenomenon of ‘‘inverse isotopic fractionation’’ during vaporization to the process of being primarily controlled by an equilibrium isotopic process relating to the P/T conditions during the experiment. They further suggested that gas flushing may result in similar isotope fractionation trend as the progressive vaporization experiments, quite different from the biodegradation process.

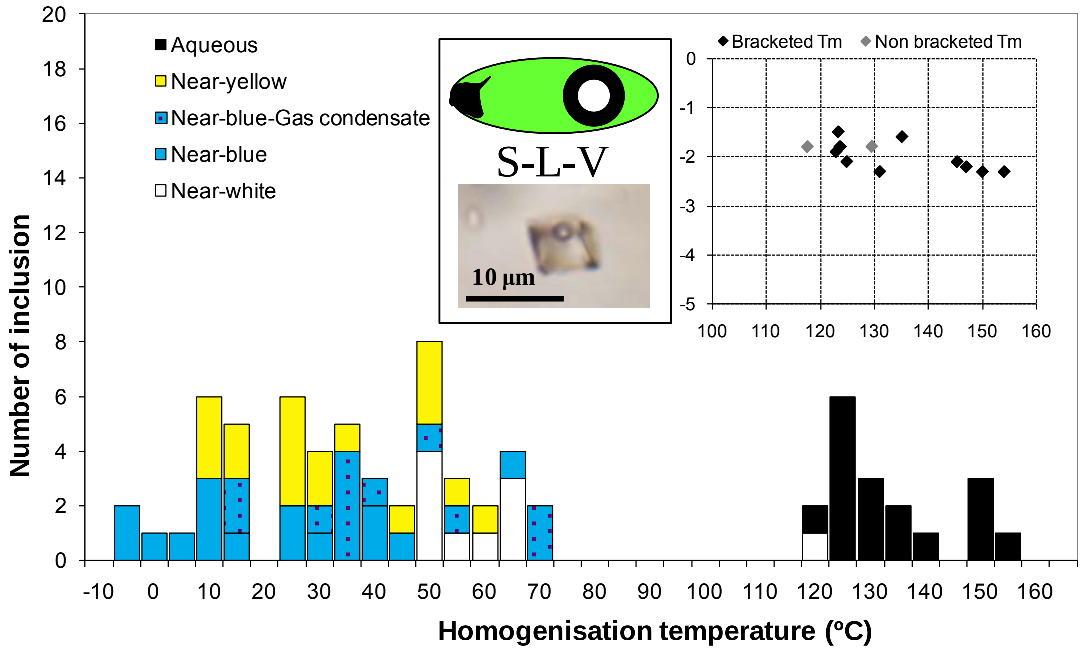

Figure 1 Fluid inclusion microthermometric results of the TZ-822 (5676.9m) sample, frequency histogram of homogenization temperature by inclusion type and fluorescence color; top right: Plot of Th and salinities (ice melting temperature, Tm) on aqueous inclusions; middle inset: a hydrocarbon inclusion with solid (S) bitumen, liquid (L) oil and Vapor (V). The anomalously low Th values of the blue, yellow and condensate hydrocarbon inclusions are interpreted to be caused by trapping under over-pressure settings according to Pironon and Bourdet (2008).

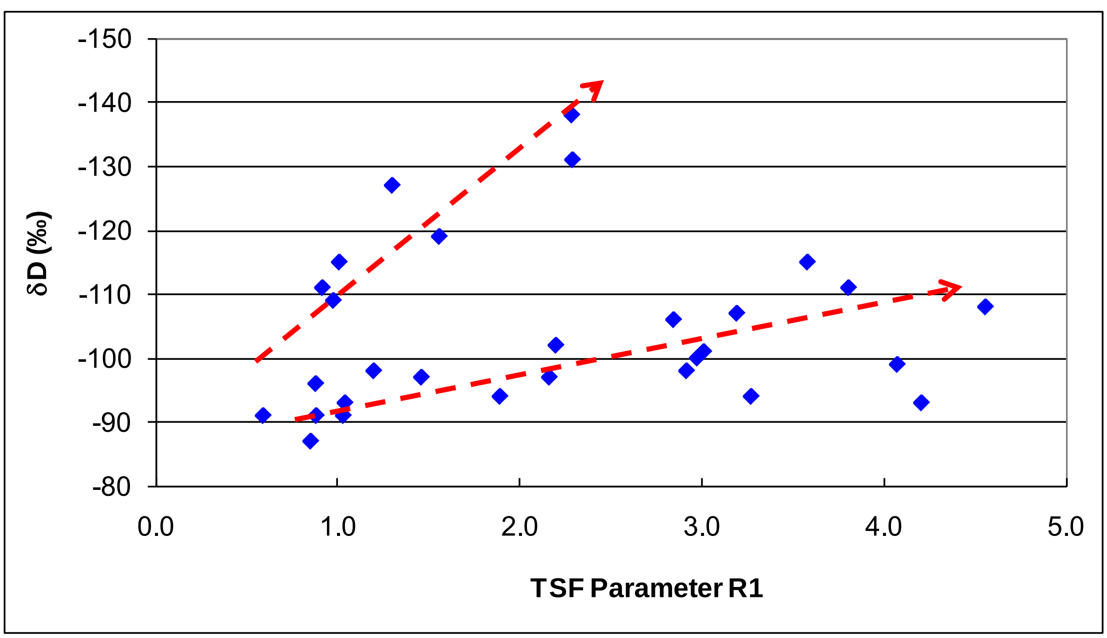

Figure 2 Cross plot of δD vs Total Scanning Fluorescence (TSF) Parameter R1 of whole oil samples from the Tazhong Field, Tarim Basin showing two trends of progressive enrichment of light hydrogen isotope with decreasing maturity or API gravity. The difference in the trends is interpreted to reflect the varying degree of gas flushing.