Tracing circulating fluids in gas shales using noble gases and nitrogen

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Noble gases occur as free, adsorbed or dissolved components in shale. Nitrogen in shale occurs as a major constituent of organic matter or, can be adsorbed or fixed in the lattice of K-bearing clay minerals. Together, they can be used to trace gas loss/retention from shales. We measured He, Ne, Ar and N_2 concentration, $\delta^{15}N$ and $^{40}Ar/^{36}Ar$ isotopic ratios, along with $^{4}He/^{40}Ar^{*}$ (where $^{40}Ar^{*}$ is radiogenic ^{40}Ar), $^{20}Ne/^{36}Ar$, $^{20}Ne/N_2$ and $^{36}Ar/N_2$ from two well-preserved cores of Haynesville-Bossier formation, deposited during 156-145.5 Ma in the East Texas Basin [1]. The cores are well-characterised for their carbon isotopic composition [2,3]. Seven samples from 3540-3726 m of core 2 and five from 3490-3540 m of core 3 were analysed, the cores retrieved from wells about 220 km apart.

The $^{40}Ar/^{36}Ar$ ratios in both the cores are correlated with depth and range from atmospheric to ratios up to ~ 4000 indicating mixing between the atmospheric and the crustal components. The N concentration in core 2 varies between 300-750 ppm and $\delta^{15}N$ between +1 and +8 ‰. The total N concentration in core 3 is higher (900-1400 ppm) and $\delta^{15}N$ is lower and less variable (~ -2 to +0.3 ‰). The $^{36}Ar/N_2$ ratio in both the cores increases with depth, along with the ^{36}Ar concentration that, cannot be attributed to mechanical compaction during burial. The measured porosity in both the cores increases with depth as a consequence of mineral dissolution and/or precipitation or, related to the occurrence of over pressured zone. The thermal maturity of organic matter determined using Raman spectra also suggests a decrease with increasing depth. Hence, noble gases can be potentially used to track under compacted, over pressured zone in a hydrocarbon formation.

[1] Basu et al. (2020) J. Mar. Sci. Eng. 8(2), 136; https://doi.org/10.3390/jmse8020136 [2] Basu et al. (2018) Energy Procedia 146, 47-52. [3] Basu et al. (2019) Front. Earth Sci. 7, Article 297; https://doi.org/10.3389/feart.2019.00297