Noble Gas Tracing of Fluid Transport in Shale Reservoirs

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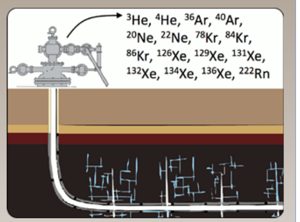
We investigate fluid transport mechanisms in a shale reservoir using natural noble gas tracers. Noble gas tracing is seeing increased attention in groundwater, geology of the deep earth, and hydrocarbon reservoirs (Farley and Neroda, 1998; Ozima and Podosek, 2002).

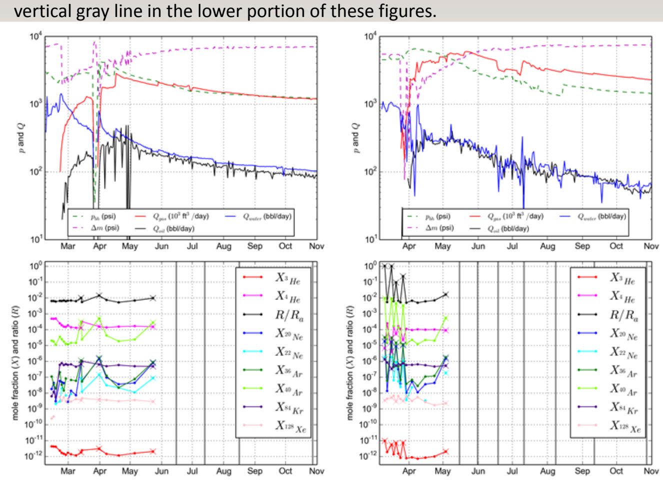
Use of noble gases as diagnostic tools is promising due to sensitivity of transport to: pore structure and sizes; phase partitioning between groundwater and liquid and gaseous hydrocarbons; and deformation from hydraulic fracturing and creation of surface area. A time-series of over thirty wellhead fluid samples were collected from two hydraulically-fractured wells with different oil-to-gas ratios, along with production data (i.e., flowrate and pressure). Tracer and production data sets can be combined to infer production flow regimes, to estimate reservoir transport parameters, and to improve forecasts of production decline.



The two figures below show production data (gas, water, and oil production rates, bottomhole pressure, and gas pseudo-pressure in the top panels.

The bottom panels show some select data from preliminary sampling results (early data only) for the same wells and time scales as the production data.

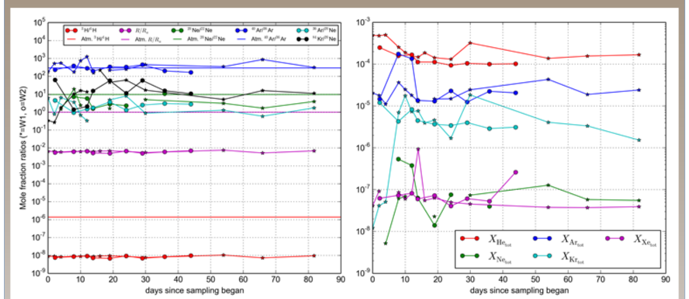
Likely contaminated samples (high O_2 and other atmospheric gases) are overprinted with an "X". Collected, but un-analyzed samples are marked with a vertical gray line in the lower portion of these figures.



Production (top) and Noble gas compositional (bottom) data for two shale gas wells

The figure below on the right shows mole fractions for the noble gases tested as part of this sampling (isotopes of He, Ar, Ne, Kr, and Xe), at two separate horizontal hydraulically fractured shale gas wells

The figure on the left shows several key ratios of noble gases, and horizontal lines indicating typical values of the ratios associated with atmospheric air

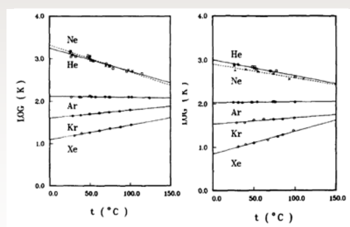


Noble gas isotopic ratios (left) and totals (right) for both wells (Well 1 stars, Well 2 circles)

These data show that the $^{3}H/^{4}H$ ratio (red data) for the remaining uncontaminated samples is quite different from atmospheric data (red line), but the $^{40}Ar/^{36}Ar$ ratio (blue data) is quite similar to atmospheric data (blue line). Most of the ratios are relatively stable in time, but the $^{84}Kr/^{20}Ne$ ratio changes several orders of magnitude during early production.

The mole fraction totals show the X_{Kr} increases dramatically during early sampling in well 1. The production data show the well was mostly producing water during this early period (i.e., hydraulic fracture flowback water), and once significant gas production began, the mole fraction of Kr increased several orders of magnitude.

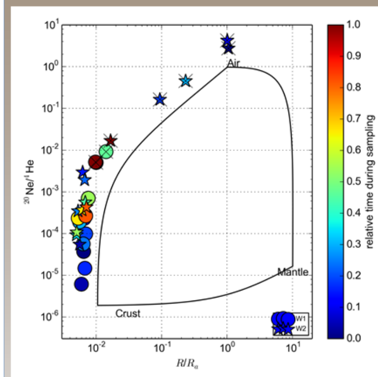
These two figures show the large variation of solubility of noble gases in light (right) and heavy (left) oil. Solubility is strongly a function of species and temperature, with increased solubility at lower temperatures.



Noble gas solubility in heavy (L) & light (R) oil Kharaka & Specht (1988)

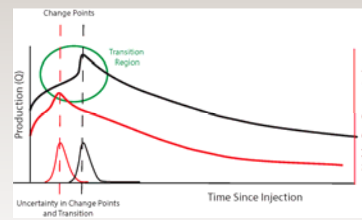
Diffusion coefficients and sorption properties of the noble gases also vary significantly across the range of pressures and temperatures occurring in hydrocarbon reservoirs (Prinzhofer, 2013). Using noble gas isotope compositional data, we hope to dramatically increase the information collected at the wellhead from oil and gas wells.

The figure below on the left plots the $^{20}Ne/^{4}He$ ratio and the $^{3}He/^{4}He$ ratio compared to atmospheric air (1.4×10^{-6}), expressed as the ratio R/R_a. This plot clearly shows the samples with high R/Ra values (close to 1) indicated with overprinted "X" (same as those shown in production data at bottom of leftmost column) are likely air contaminated. All the data clearly plot very different from typical mantle-influenced samples (end-member in lower right of figure).



The R/R_a for these samples is quite low (~5.0×10^{-3}), when typical crustal R/R_a is approximately 0.02 (Ballentine et al, 2001; Prinzhofer, 2013). This indicates the samples have very high levels of ^{4}He, which is likely due to radiogenic generation from high levels of natural uranium and thorium in the shale deposits.

As additional production and noble gas compositional data are collected, we will be combining these data in a Bayesian framework (right). This will exploit additional information possibly contained in the new data to quantify and reduce uncertainty, while possibly allowing earlier predictions of relevant reservoir parameters, compared to typical production data alone.



Noble gases may indicate characteristic change points sooner than production data alone.

References

Ballentine, C.J., R. Burgess and B. Marty (2001). Tracing fluid origin, transport and interaction in the crust, *Reviews in Mineralogy and Geochemistry*, 47(1):539-614.

Farley, K. A., and Neroda, E. (1998). Noble gases in the earth's mantle. Annual Review of Earth and Planetary Sciences, 26(1), 189-218.

Kharaka, Y.K. and D.J. Specht (1988) The solubility of noble gases in crude oil at 25-100 C. *Applied Geochemistry* 3:137—144.

Ozima, M. and F.A. Podosek (2002). *Noble Gas Geochemistry*, Second edition, Cambridge.

Prinzhofer A. (2013). "Noble Gases in Oil and Gas Accumulations" in *The Noble Gases as Geochemical Tracers*, 225—247, Springer.

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