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Noble gas applications in energy extraction and environmental monitoring

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The successful development of unconventional hydrocarbon resources is of preeminent importance to the US energy portfolio. For example, unconventional petroleum resources now account for 74% and 69% of US gas and liquid hydrocarbon production, respectively. Nonetheless, critical gaps in our understanding of fundamental properties of hydrocarbon fluid flow and storage in nanopore structures with unconventional reservoirs such as black shales remain, as do uncertainties regarding the optimal processes for petroleum well completion and stimulation in unconventional reservoirs. For example, despite the successes of the "shale revolution", the average recovery percentage of hydrocarbon fluids-in-place from a given well remains surprisingly low (~20% and 10% for gas and liquids, respectively). The poor characterization of these complex formations and the lack of suitable geochemical tracers to interrogate these processes, as compared to conventional hydrocarbon reservoirs, has led to the low per-well recovery factors and large variations both between formations and even for different wells within the same formation. To compensate for this low efficiency, the UOG industry has begun to drill more and longer horizontal wells and to incorporate more hydraulic fracturing stages; each factor increases the associated environmental risks of petroleum recovery.

One of the most commonly raised environmental concerns about shale gas development still centers around drinking-water contamination and other potential environmental risks associated stray gas migration. Specifically, the presence and environmental implications of elevated methane and aliphatic hydrocarbons (ethane, propane, etc.) in drinking-water remain highly controversial and require a distinction between naturally occurring and anthropogenic sources. Previous efforts to resolve these questions have generally focused on identification of the genetic fingerprint of natural gas using the molecular (e.g., C_2H_6/CH_4) and stable isotopic (e.g., $\delta^{13}C\text{-}CH_4$, $\delta^{2}H\text{-}CH_4$, or $\Delta^{13}C = (\delta^{13}C\text{-}CH_4 - \delta^{13}C\text{-}C_2H_6)$) compositions of hydrocarbon gases. In many cases, these techniques can resolve thermogenic and biogenic contributions of natural gas and further differentiate between multiple thermogenic sources (e.g., Marcellus production gases vs. intermediate Upper Devonian gas pockets). However, these parameters are subject to alteration by microbial activity and oxidation and may not always uniquely identify the source or mechanism of fluid migration. Moreover, they do not necessarily identify the transport mechanisms by which material would migrate into shallow aquifers. In contrast to hydrocarbon gases, noble gases provide a suite of elemental and isotopic tracers that are unaffected by chemical reactions or microbial activity.

Here I will present two case studies that examine the start-of-the-art applications that integrate noble gas and hydrocarbon geochemistry to 1) evaluate economic recovery of hydrocarbons from unconventional reservoirs by using these geochemical proxies to determine the initial recoverable fluid-in-place, the mechanisms of fluid flow during hydraulic fracturing and production from nano-scale pores to large-scale fractures, and the spatial heterogeneity of hydrocarbon gas storage in shales and 2) a subset of potential environmental impacts by determining if elevated levels of natural gas in drinking-water aquifers near gas wells are derived from natural or anthropogenic sources and to determine the mechanism by which stray gas contamination occurs.