The Stable Isotope and Noble Gas Geochemistry of a High-Nitrogen Natural Gas Reservoir, Northwestern Denver-Julesburg Basin

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Natural gas produced from the Permian Hartville sandstone in the Samson Oil and Gas Bluff #1-11 well in Goshen County, Wyoming is composed of 97.6% nitrogen, 2.05% methane, 0.17% carbon dioxide, and 0.15% helium. Argon and ethane through hexane+ hydrocarbons are present in trace amounts. The N$_2$/Ar ratio is 7,933.3, a value that eliminates air contamination as a possible source of the nitrogen. The $\delta^{15}$N of the produced nitrogen gas is +20.4‰, a value compatible with a crustal or magmatic source. The $^3$He/$^4$He ratio of the gas is $4.5 \times 10^{-8}$ ($R/R_a = 0.032$), a value which eliminates a magmatic source from consideration and indicates a crustal origin for the nitrogen.

There are three possible sources for the nitrogen:

1) $N_2$ fixed as NH$_4^+$ in potassium-rich sediment,
2) $N_2$ fixed in biotite and K-feldspar in crystalline rocks, and
3) Denitrification of organic matter in hydrocarbon source rocks.

The $N_2$ concentration, the $\delta^{15}$N of the gas, and both the $^4$He/$N_2$ and $N_2$/$^{20}$Ne ratios support an interpretation that the nitrogen produced from the Bluff #1-11 well was generated by denitrification of post mature organic matter.

The methane $\delta^{13}$C of the Bluff #1-11 gas is -32.87‰ and the $\delta^2$H of the methane is -173.7‰. These isotopic values, in combination with the chemical composition of the gas, indicate that the methane is thermogenic and post-mature in origin. Ethane and propane $\delta^{13}$C are -27.9 and -32.3‰, respectively. The hydrocarbon gases exhibit a partial isotope reversal with respect to carbon number, i.e., $\delta^{13}$C$_1 < \delta^{13}$C$_2 > \delta^{13}$C$_3$, which suggests mixing of wet and dry thermogenic gases in the Hartville reservoir, or in its petroleum source rock (Pennsylvanian-age Desmoinesian black shale and marlstone). Methane and ethane in the gas were generated through moderate to extensive cracking of oil. Propane was generated from oil-prone kerogen within the late oil window.

The $\delta^{13}$C of the carbon dioxide in the gas is -1.6‰. The relative magnitude of isotopic offset between the carbon dioxide and methane is consistent with thermogenic CO$_2$. Thermal degradation of carbonate minerals in the source rocks is the likely source of carbon dioxide in the gas.

The $^{20}$Ne/$^{22}$Ne ratio of 9.461 in the Bluff #1-11 gas approximates the air ratio of 9.80. The $^{38}$Ar/$^{36}$Ar and $^{21}$Ne/$^{22}$Ne ratios further constrain an atmospheric source for $^{20}$Ne and $^{36}$Ar components in the gas. $R/R_a$ and $^{20}$Ne/$^{4}$He suggest mixing of radiogenic crustal-produced He and Ne with groundwater-transported radiogenic He and atmospheric Ne components.
Regional groundwater degassing of $^{20}\text{Ne}$, $^{36}\text{Ar}$, and $^{84}\text{Kr}$ is the source of the atmospheric noble gas components in the produced gas. High $^{20}\text{Ne}/^{36}\text{Ar}$ and relatively low $^{132}\text{Xe}/^{36}\text{Ar}$ ratios reflect gas-water equilibrium in the Hartville sandstone reservoir. This interpretation has significant implications for seismic interpretation and operational decisions pertaining to field data. The geochemical data also reveal new complexities in our understanding of the tectonic setting and burial history of petroleum source rocks near the northern edge of the D-J basin.