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Using Advanced Geochemical Techniques to Determine the "Line of Death" Productive Limits of the Marcellus in NE Pennsylvania

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Abstract

The Marcellus Formation in northeast Pennsylvania produces gas from post mature marine mudrocks. Organic matter reached the metagenetic stage of thermal evolution. Mean vitrinite reflectance increases from 2.0 percent in Bradford County to ~4.5 percent in Sullivan and Wyoming counties, before decreasing to ~3 percent adjacent to the Jack's Mountain Anticlinorium in Luzerne County. In the most mature Marcellus samples (prehnite-pumpellyte facies), measured kerogen H/C and O/C ratios are 0.4 and 0.06, respectively. Mean illite crystallite thickness is 211^{o} and the Kübler Index is 0.428.

The isotope composition of production and mud gases collected from 24 wells in the highest maturity area implies high thermal stress. Production $\delta^{13}C_1$ ranges from -28.69 to -24‰. Mud gas $\delta^{13}C_1$ ranges from -27.3 to -21.5‰. All gases exhibit carbon isotope reversals with respect to carbon number. $\delta^{13}C_1$ approaches, or is heavier than, $\delta^{13}C_{KEROGEN}$. Production gases exhibit hydrogen isotope reversals (methane δ^2H > ethane δ^2H). $\delta^{13}CO_2$ ranges from -19.7 to -10.2‰.

The $\delta^{13}C$ and δ^2H isotope reversals may be interpreted in one of five ways: (1) carbon isotope fractionation during gas migration by diffusion at elevated temperatures and pressures, (2) mixing of gases generated from primary kerogen cracking and secondary cracking of residual oil and condensate, (3) a combination of mixing, Rayleigh fractionation of C_2 and C_3, and exchange of methane hydrogen with formation water, (4) water-reforming followed by Fischer-Tropsch synthesis, and (5) destruction of C_{2+} alkanes followed by reforming via gas-phase radical recombination reactions.

Post mature Marcellus prospects are limited by thermal maturity, geologic structure, hydrocarbon residence time, and loss of organic porosity. Gas isotopes help to predict well performance. Productive wells have $\delta^{13}C_1 \geq \delta^{13}C_{KEROGEN}$, $\delta^{13}C_{2-3} < \delta^{13}C_{KEROGEN}$, and high $\delta^{13}C_{1-3}$ correlation. Marginal wells have $\delta^{13}C_1 \geq \delta^{13}C_{KEROGEN}$, $\delta^{13}C_{2-3} < \delta^{13}C_{KEROGEN}$, and variable $\delta^{13}C_{1-3}$ correlation. Unproductive wells have $\delta^{13}C_1 > \delta^{13}C_{KEROGEN}$, $\delta^{13}C_2 \geq \delta^{13}C_{KEROGEN}$, trace C_{3+}, and poor $\delta^{13}C_{1-3}$correlation.