Integrating hydrocarbon and noble gas geochemistry to determine source and timing of natural gas formation in coalbed methane reservoirs

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Despite expanding natural gas production from coalbed methane (CBM) reservoirs in recent decades, there are still many unknowns concerning the source and timing of natural gas accumulations within coal seams. Some of these uncertainites comprise of deciphering if biogenic or thermogenic processes, or a mixture of both are responsible for natural gas accumulations, the methanogenic pathways of methane formation and the associated timing of meteoric water recharge that stimulates biogenic methane production. Conventionally, the proportions of biogenic and thermogenic natural gas are determined using hydrocarbon molecular composition (e.g., C_1/C_2+) and the stable isotopic composition of gases (e.g., $\delta^{13}C$-CH_4, δ^2H-CH_4, $\delta^{13}C$-CO_2,), water (δ^2H-H_2O; $\delta^{18}O$-H_2O), and dissolved inorganic carbon ($\delta^{13}C$-DIC). However, these techniques used alone can be complicated by uncertainties in the importance and/or contributions of mixing, transport/migration, methanogenesis, and aerobic or anaerobic oxidation in the subsurface. Herein, we integrate major gas (e.g., CO_2, N_2), hydrocarbon gases (C_1 to C_5), hydrocarbon stable isotopic composition ($\delta^{13}C$-CH_4, δ^2H-CH_4 $\delta^{13}C$-C_2H_6), and noble gas data from 20 CBM wells from the Illinois Basin, USA. Our integrated data suggest that produced gases from Sellyville and Springfield coal seams are predominantly biogenic in origin but that a quantifiable exogenous thermogenic endmember is denoted by a positive relationship between CH_4, C_2H_6, ^4He, elevated $^{20}Ne/^{36}Ar$, and relatively enriched $\delta^{13}C$-CH_4 in samples with comparatively low abundances of atmospherically derived gases. We hypothesize that an exogenous source migrated to the coal seam stratigraphic traps, later stages of meteoric water recharge, oxidation, and biogenic methane formation diluted the geochemical signature of the thermogenic methane, most likely following the recharge of interglacial meltwaters.