Origin of Carbon Dioxide, Nitrogen, and Hydrocarbons in Upper Cretaceous Pab Sandstone Tight-Gas Reservoirs, Middle Indus Basin, Pakistan: Noble Gas and Stable Isotopic Evidence for Crustal and Magmatic Components

Christopher Laughrey[1], Michal Makos[2], Mateusz Gorniak[2], Ihtesham ul Wahab[2], Muhammad Shifaat Alum[3], Ishtiaq Noor[1], Rabeya Naeem Kahn[1]
[1]Stratum Reservoir; [2]PGNiG; [3]Pakistan Petroleum Limited

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Abstract

Hydrocarbon production in the Indus basin of Pakistan is dominated by natural gas. Tight-gas reservoirs in the Upper Cretaceous Pab Sandstone are the second largest gas-producing formations in the region. Recoverable resource estimates for the Pab Sandstone are optimistic, but co-produced CO_2 and N_2 present major problems by reducing the BTU value of the gases. Identification of the sources of CO_2 and N_2 is essential for developing geologic models that can help predict non-hydrocarbon occurrences in the reservoirs and mitigate risk during field development. The hydrocarbons produced from the Pab Sandstone are post mature thermogenic gases originally derived from mixed marine and terrestrial organic matter in the Lower Cretaceous Sembar and Goru Formations. The hydrocarbons were generated at vitrinite reflectance equivalents of 1.5 to 1.95%, based on $\delta^{13}C$ of methane, ethane, and propane. Secondary oil cracking was the principal source of the hydrocarbons. Secondary alteration effects include mixing of different thermogenic gases. Respective CO_2 and N_2 concentrations in the Pab Sandstone reservoirs are 2.57 to 4.52 and 6.19 to 15.69 mole %. The $\delta^{13}C$ of CO2 is between -4.88 and -10.22‰. The $\delta^{15}N$ of N_2 is between -1.7 and -3.1‰. Helium concentrations are between 0.0348 and 0.0769

mole %. 3He/4He ratios range between 0.017 and 0.028 Ra indicating that helium is predominately crustal in origin. However, the CO2/3He ratios of the Pab Sandstone gases range from 9.31 x 108 to 3.66 x 109, values that are within or below the MORB range of 1 x 109 to 1 x 1010. CO2 produced from the Pab Sandstone reservoirs is derived from a mantle source. The N2 produced from the Pab Sandstone is crustal in origin. Potential N2 sources include devolitization of Neoproterozoic metasediments in basement rocks and late catagenetic to metagenetic organic nitrogen released from post mature source rocks. The $\delta^{15}N$ of the nitrogen and its association with post mature hydrocarbons favor the late catagenetic to metagenetic organic nitrogen interpretation. Ne, Ar, Kr, and Xe isotope systematics indicate mixing between air-saturated water (ASW) and crustal radiogenic sources in the reservoirs, but there does not appear to be any link between the ASW components and the processes controlling the input of crustal-derived gases. This observation provides further support for a late catagenetic to metagenetic organic origin for the produced N_2.