Noble gases in Jackson Dome gas deposits: identifying and quantifying natural CO₂ sequestration processes

Z. Zhou¹, C. J. Ballentine¹, M. Schoell² and S. Stevens³

¹ School of Earth, Atmospheric and Environmental Sciences, The University of Manchester, UK
² GasConsult International L.L.C., USA
³ Advanced Resources International, USA

Jackson Dome natural CO₂ gas deposit, one of the deepest commercial CO₂ gas fields in the world, is located in central Mississippi, USA. It provides an important analogue for studying natural CO₂ sequestration process. We show in this presentation how noble gases can be used, together with other gases, to identify and quantify the origin, migration and sequestration processes of CO₂ gas in the Jackson Dome reservoir. We collected 10 gas samples from producing wells from Jackson Dome reservoirs. The Jackson Dome gas is dominated by CO₂, which ranges from 98.75% to 99.38%. The trace amounts of CH₄ and N₂ are correlated, and both correlate negatively to CO₂, suggesting that they have a common source. The greatest admix of N₂ and CH₄ is found on the crest of the trapping structure, however, the purest CO₂ is found at the field margins. §He/³He ratios range between 4.27 Ra and 5.01 Ra (where Ra is the atmospheric value of 1.4 x 10⁶), indicating a strong mantle signature. CO₂/³He ratios vary between 1.07 x 10⁹ and 4.62 x 10⁹, they all fall in the range of the values found in pure magmatic samples (1-7 x 10⁹). ²⁰Ne concentrations correlate with resolved crustal radiogenic ³He concentrations, suggesting radiogenic noble gases also dissolved into groundwater before partitioning into the gas phase. The negative correlation between air-derived ²⁰Ne and CO₂/³He ratios shows that water plays a role in CO₂ sequestration, it can be responsible for more than 70% of CO₂ loss. The difference in mixing characteristics between the various gas reservoirs suggests that either the magmatic or crustal fluid end member varies from one system to another over relatively short distances. ⁴⁰Ar/³⁶Ar ratios are between 4071 and 6420, the resolved radiogenic ⁴⁰Ar* contributes more than 90% of the total ⁴⁰Ar. The relationship among major gases (CO₂, N₂, ⁴⁰Ar, ³He and Ne isotopes shows that the gases in Jackson Dome reservoir are a mixture of a fractionated air component, a magmatic end member and a radiogenic/crustal component. Elemental fractionation of ²⁰Ne/³⁶Ar in the gas phase increased the ratio from 0.156 to between 0.798 and 1.35. CO₂/³He ratios correlate with both ²⁰Ne/³⁶Ar and δ¹³C (CO₂) values. We explored a variety of models to explain this data including: oil-groundwater partitioning; gas-groundwater partitioning; excess air dissolution and noble gas redissolution. A solubility controlled Rayleigh fractionation of groundwater modified by oil interaction can account for the correlations. In this case all the gases are dissolved in the groundwater on reaching the trapping structure. The concentrations of air-derived noble gases and other gas species (e.g. CO₂, CH₄ and N₂) also tell us the migration history of CO₂ gas in the reservoir. Relatively high concentrations of ²⁰Ne, ³He, CH₄, N₂ and low concentrations of CO₂ in gas samples from the centre of reservoir are consistent with the solubility partition of gases between gas and groundwater phases at the first degassing stage. At the later stages of the partition, gases with relatively high CO₂ concentrations and low ²⁰Ne, ³He, CH₄ and N₂ concentration fill the margin of the trapping structure. We are exploring other models to identify whether or not this concept provides a unique solution.