Noble gas fractionation during subsurface gas migration

Talk outline

1) Bravo Dome observations motivate column experiments to understand noble gas banks.

2) 1-D Column experiments to demonstrate development of noble gas banks

3) Apply analytical solutions (Theory of gas injection processes, F.M. Orr. 2007) to experimental results
Noble gases as traces for geological carbon storage

Scientific Achievement
Developed a physical basis for the interpretation of noble gas signatures during subsurface gas migration.

Significance and Impact
Quantification of CO₂ mass transfer in subsurface for the monitoring of geological carbon storage.

Research Details
– Experiments demonstrate the changes in noble gas concentrations due to CO₂ dissolution and migration:
  • Accumulation of co-injected noble gases tracks CO₂ dissolution
  • Accumulation of dissolved noble gases track migration distance
– Gas injection theory explains observed patterns.
– Identification of predicted noble gas fractionations in analyses of natural gas and CO₂ at three field sites:
  • Noble gas patterns at Bravo Dome consistent with CO₂ emplacement direction inferred from pressure trends
  • Co-enrichment of atmospheric and epigenetic noble gases in methane-rich groundwater above shale plays indicative of natural methane migration.

Variation of effluent gas composition in two-phase column displacement experiment. Demonstrates the simultaneous enrichment of both initially dissolved (neon) and co-injected (argon) noble gases at front of the migrating gas front.

Sathaye, Larson, Hesse (2016b)
Noble gas fractionation during subsurface gas migration,

Work was performed at The University of Texas at Austin
Noble gas fractionation during subsurface gas migration

Kiran Sathaye, Toti Larson, Marc Hesse and Esben Pedersen (Theme 2)

Hypothesis

Gas composition can constrain the magnitude and rate of CO₂ dissolution, and pore volume interrogated during CO₂ “injection”.

Background

Noble gas ‘banks’ observed in Bravo Dome provide field evidence of transport-related compositional changes. Coupled column experiments and analytical modeling validate this hypothesis.

Impact on Specific Challenges

Challenge 2: Using pore space with unprecedented efficiency

Challenge 3: Controlling undesired or unexpected behavior

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CO$_2$ sequestration: How much CO$_2$ has dissolved into the brine?

Bravo Dome

23km$^3$ total pore volume, 9km$^3$ residual brine

1.3Gt CO2 stored. 22% dissolved into brine.

The difference between the highest CO$_2$/$^3$He ratio and lower values can provide a minimum estimate of this CO$_2$ loss.
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- Distribution of noble gases in Bravo Dome

Observation: Enrichment of atmospheric ($^{36}$Ar and $^{20}$Ne) and crustal ($^{40}$Ar and $^{4}$He) to the west, establishing flow direction.

Hypothesis: Noble gas compositions be used to quantify 1) the amount of brine that CO$_2$ has exchanged with and therefore can 2) estimate the volume of pore space occupied by CO$_2$.
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Column experiments to investigate mechanisms of dissolved gas enrichment

Hypothesis: Gas composition can constrain the magnitude and rate of CO₂ dissolution, and pore volume interrogated during CO₂ injection.

Experiment

- 1-dimensional four-component two-phase column displacement experiments.
- 1cm diameter glass column packed with glass beads initially saturated with water.
- Water initially saturated with Neon or CH₄.
- Water displaced with CO₂-Argon mixture at constant rate.
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Mass balance interpretation of experimental results

\[ V_p = \text{pore volume} \]
\[ L = \text{column length} \]
\[ Q = \text{volumetric flow rate} \]
\[ P_g = \text{gas injection pressure} \]

Pore Volume = \( \frac{nRT}{P_g} \)

Break through time < \( \frac{V_p}{Q} \)
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Mass balance interpretation of experimental results

\[ S_{wr} = \text{residual water saturation} \]
\[ V_g = V_p (1 - S_{wr}) \]

Because of dissolution:
\[ t_{mb} < \frac{V_p}{Q} \]

Mass balance requires:
\[ t_{mb} = \frac{V_g}{Q} \]

Moles of gas at breakthrough:
\[ n_b = \frac{p_g \cdot V_g}{RT} \]
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Conclusions

1) Insoluble gas banks define the front of gas injection plumes.

2) Gas chemistry at the plume front can be used to estimate residual saturation and pore volume of occupied gas phase.

3) The amount of CO2 dissolved in a brine can be calculated using Theory of Gas Injection processes and measured insoluble gas banks.