**Noble Gas Partitioning in Two-Phase Flow**

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**Summary**
- Noble gas isoconcentrations are used as tracers and indicators of subsurface fluid flow and origin.
- Motivated by the case of the Bravo Dome magmatic CO₂ field in New Mexico, we study the enrichment of 36Ne and 4He in a natural CO₂ injection process.
- We observe qualitative agreement between theory, experiments, and field observations of noble gas enrichment during gas injection processes.
- Volumes of radiogenic noble gases can be used to infer thermal and tectonic history of regional crust.

**Experimental Results: 4 Component Drainage**
- Column initially filled with H₂O saturated with CH₄.
- Injection gas: 80% CO₂ and 20% Ar.
- Dissolved CH₄ swept and enriched into first arrival bank.
- Argon is 20X less soluble in water than CO₂.
- Enriched Ar bank reaches the end of the column before CO₂ enrichment.
- Experimental results match theory for both initial dissolved gas (CH₄) and injected noble gas (Argon).
- Gas composition measured away from source can be very different due to fractionation during migration.
- After arrival of trace gas banks, gas returns to input mixture.

**Theoretical Composition Profiles:**
- Solution to equation (4) with boundary conditions for magmatic gas injection into subsurface aquifer.
- Injected gas: 1% He and 99% CO₂ (Mantle input).
- Initial Brine: 99.5% H₂O + 0.5% 36Ne (Meteoric).
- Volatile noble gases enriched at the front.
- 36Ne completely swept from CO₂ plume.
- Mathematically describes two-stage gas enrichment model proposed by Gillfillan et al., 2008.

**Noble Gas Sourcing**
- He produced as decay product of U and Th in Zircon, Apatite, Monazite, and Titanite - accumulates in minerals below T₂.
- Ar produced by 4K decay in mica, K-spar.
- Ar/He Ratio = 3400 ± 11Ratio -> large crustal component.
- Noble-gas values not indicative of ASW volume contacted.
- Indicates volume of gas interaction with air saturated water (ASW).
- AsWS can currently contain over 92% residual H₂O.
- All ASW derived gases indicate ASW equilibration volumes of <0.2 residual water volumes - evidence of noble gas sweep.
- Noble-gas volumes not indicative of ASW volume contacted.

**Noble Gas Volumes: Air-Saturated Water Contribution**
- Indicates volume of gas interaction with air saturated water (ASW).
- AsWS can currently contain over 92% residual H₂O.
- All ASW derived gases indicate ASW equilibration volumes of <0.2 residual water volumes - evidence of noble gas sweep.
- Noble-gas volumes not indicative of ASW volume contacted.

**Observations: Bravo Dome Natural CO₂ Field**
- The Bravo Dome field contains 1.3Gt CO₂ (22 tcf), with a magmatic noble gas isotope signature.
- Noble gases have been used to determine location of gas source and interaction with initial brine.
- We used Apatite (U-Th)/4He thermochronology to identify a gas emplacement age between 1.2Ma and 1.5Ma.

**Gas Injection Theory: Two Phases, N Components**
- Total Volume Fraction of i: \( C_i = n_{i,\text{gas}}/n_{i,\text{gas}} + n_{i,\text{brine}} \) (1)
- Fractional flow of gas phase: \( f_{i,\text{gas}} = n_{i,\text{gas}}/(n_{i,\text{gas}} + n_{i,\text{brine}}) \) (2)
- Total Fractional Flow of i: \( K_i = \sum f_{i,\text{gas}} \) (3)
- 1D Equation for Gas Injection: \( \partial C_i/\partial t = D_i \frac{\partial^2 C_i}{\partial x^2} + K_i (C_i - \bar{C}_i) \) (4)
- \( K_i \) independent variables: \( C_i = 1 - \sum C_j \) (5)

**Noble Gas Volumetrics: Radiogenic Contribution**
- He produced as decay product of U and Th in Zircon, Apatite, Monazite, and Titanite - accumulates in minerals below T₂.
- 36Ar/3He Ar Ratio = 3400 ± 11Ratio -> large crustal component.
- Non-mantle 4He/3He Production Ratio = 5.
- Significant excess 40Ar in Bravo Dome gas.

**References**