Noble Gas Partitioning in Two-Phase Flow

Kiran Sathaye, Toti Larson, Marc A. Hesse, Esben Pederson
University of Texas at Austin Department of Geological Sciences
Email: kiransathaye@utexas.edu

THE UNIVERSITY OF TEXAS AT AUSTIN JACKSON SCHOOL OF GEOSCIENCES

Summary

- Noble gas isotope concentrations are used as tracers and indicators of subsurface fluid flow and origin
- Motivated by the case of the Bravo Dome magmatic CO_2 field in New Mexico, we study the enrichment of ^{20}Ne and ^{3}He in a natural CO_2 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 inform thermal and tectonic history of regional crust

Gas Injection Theory: Two Phases, N Components

Total Volume Fraction of i : $C_i = c_{i,gas}S_{gas} + K_i c_{i,gas}(1 - S_{gas})$ (1)

Fractional flow of gas phase: $f_{gas} = \dfrac{k_{gas}/\mu_{gas}}{k_{gas}/\mu_{gas} + k_{liq}/\mu_{liq}}$ (2)

Total Fractional Flow of i : $F_i = c_{i,gas}f_{gas} + K_i c_{i,gas}(1 - f_{gas})$ (3)

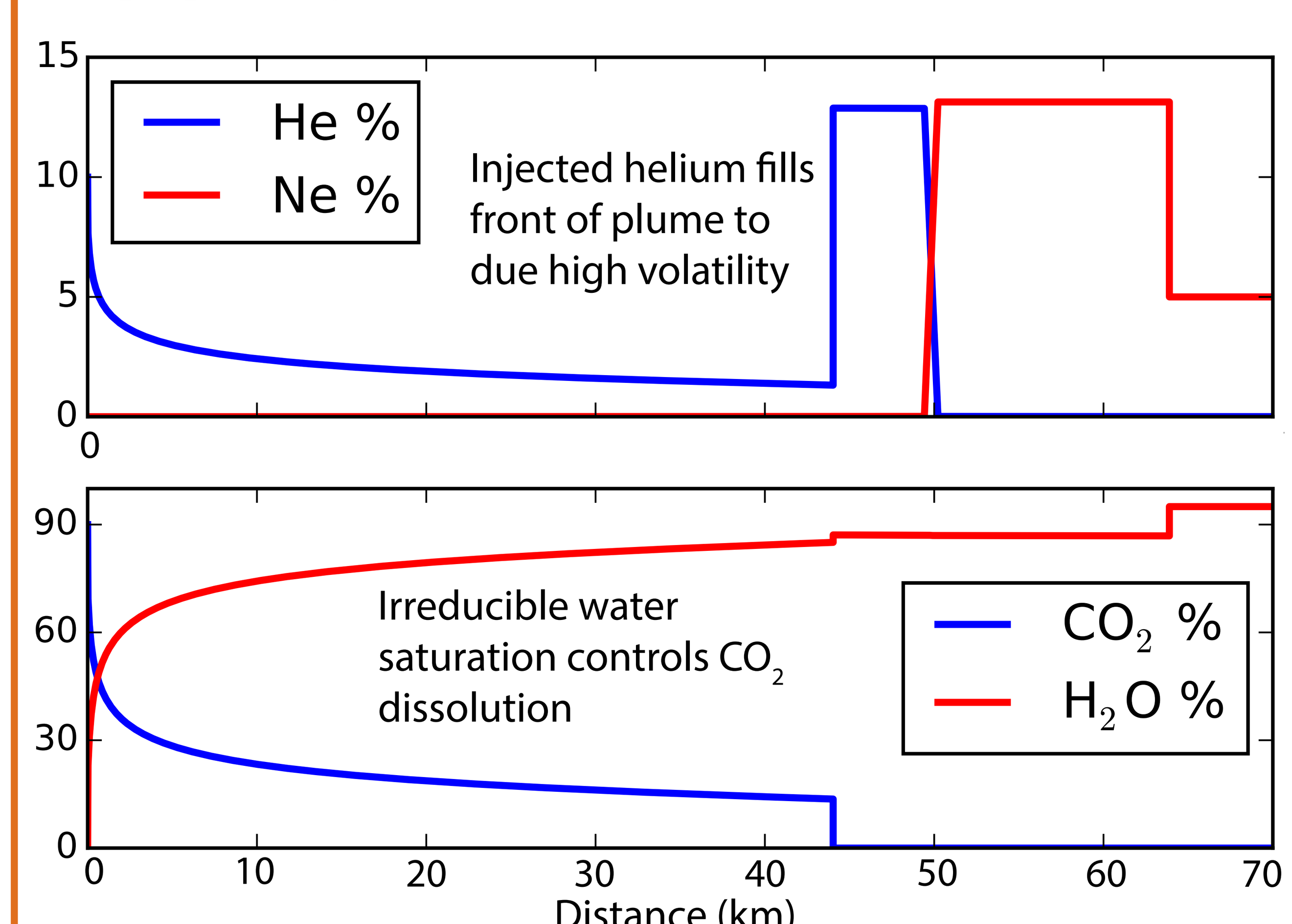
1D Equation for Gas Injection: $\dfrac{\partial C_i}{\partial t} + \dfrac{\partial F_i}{\partial x} = 0 \quad i = 1 \ldots N-1$ (4)

(N-1) Independent variables: $C_N = 1 - \sum_{1}^{N-1} C_i$ (5)

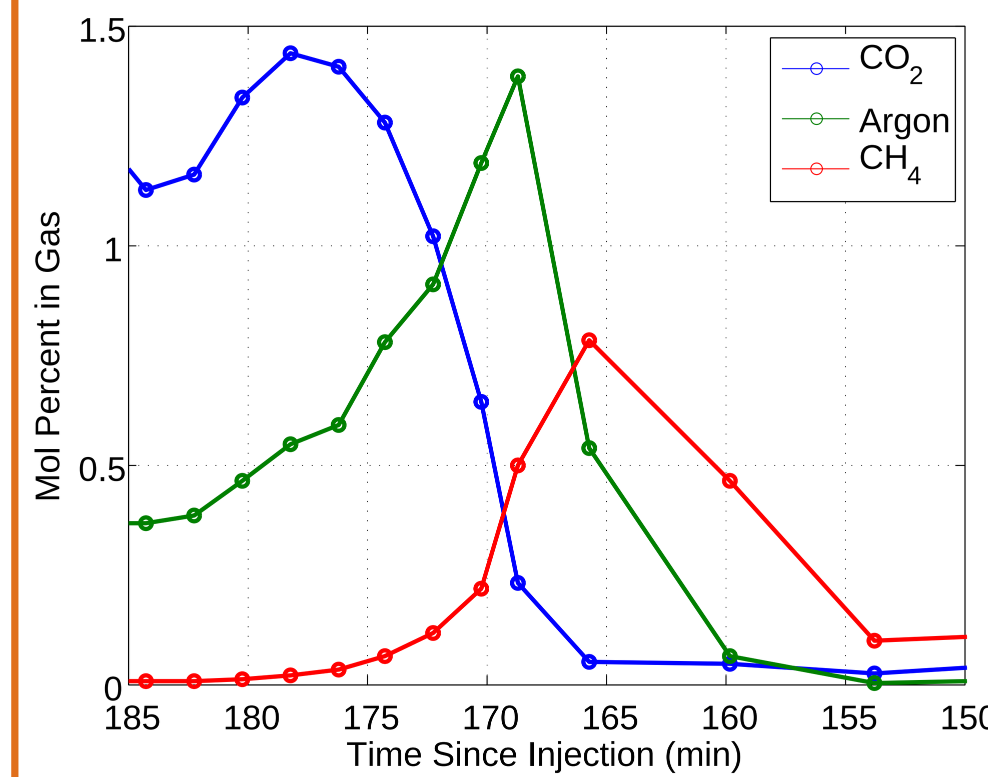
- K_i: dimensionless Henry's law partitioning coefficient
- $c_{i,gas}$: volume fraction of component i in the gas phase

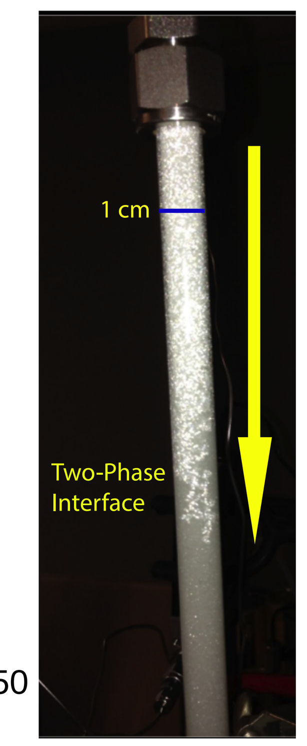
Theoretical Composition Profiles: (Equation 4)

- Solution to equation (4) with boundary conditions for magmatic gas injection into subsurface aquifer
- Injected gas: 1% ^{3}He + 99% CO_2 (Mantle input)
- Initial Brine: 99.5% H_2O + 0.5% ^{20}Ne (Meteoric)
- Volatile noble gases enriched at the front
- ^{20}Ne completely swept from CO_2 plume
- Mathematically describes two-stage gas enrichment model proposed by Gilfillan et al., 2008



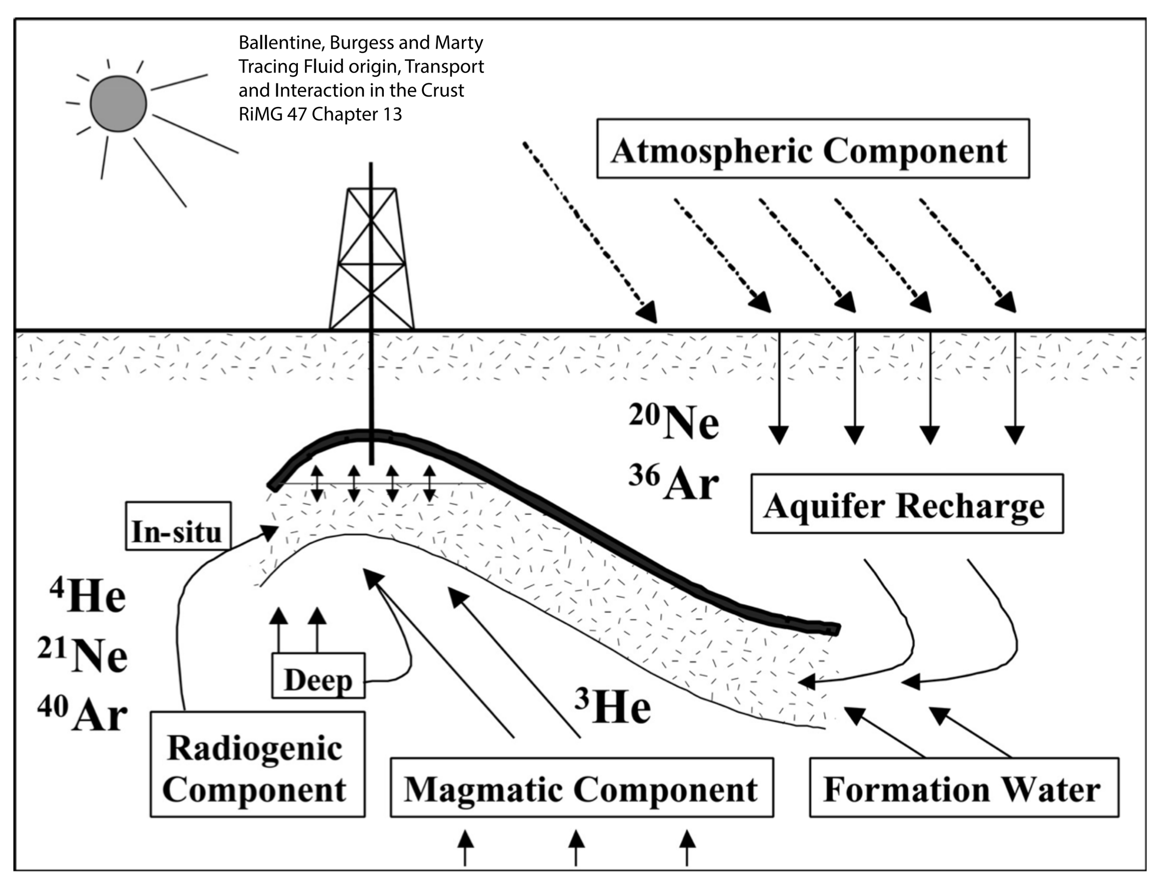
Experimental Results: 4 Component Drainage





- Column initially filled with H_2O saturated with CH_4
- Injection gas: 80% CO_2 and 20% Ar
- Dissolved CH_4 swept and enriched into first arrival bank
- Argon is 20X less soluble in water than CO_2
- Enriched Ar bank reaches the end of the column before CO_2
- Experimental results match theory for both initial dissolved gas (CH_4) 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

Noble Gas Sourcing



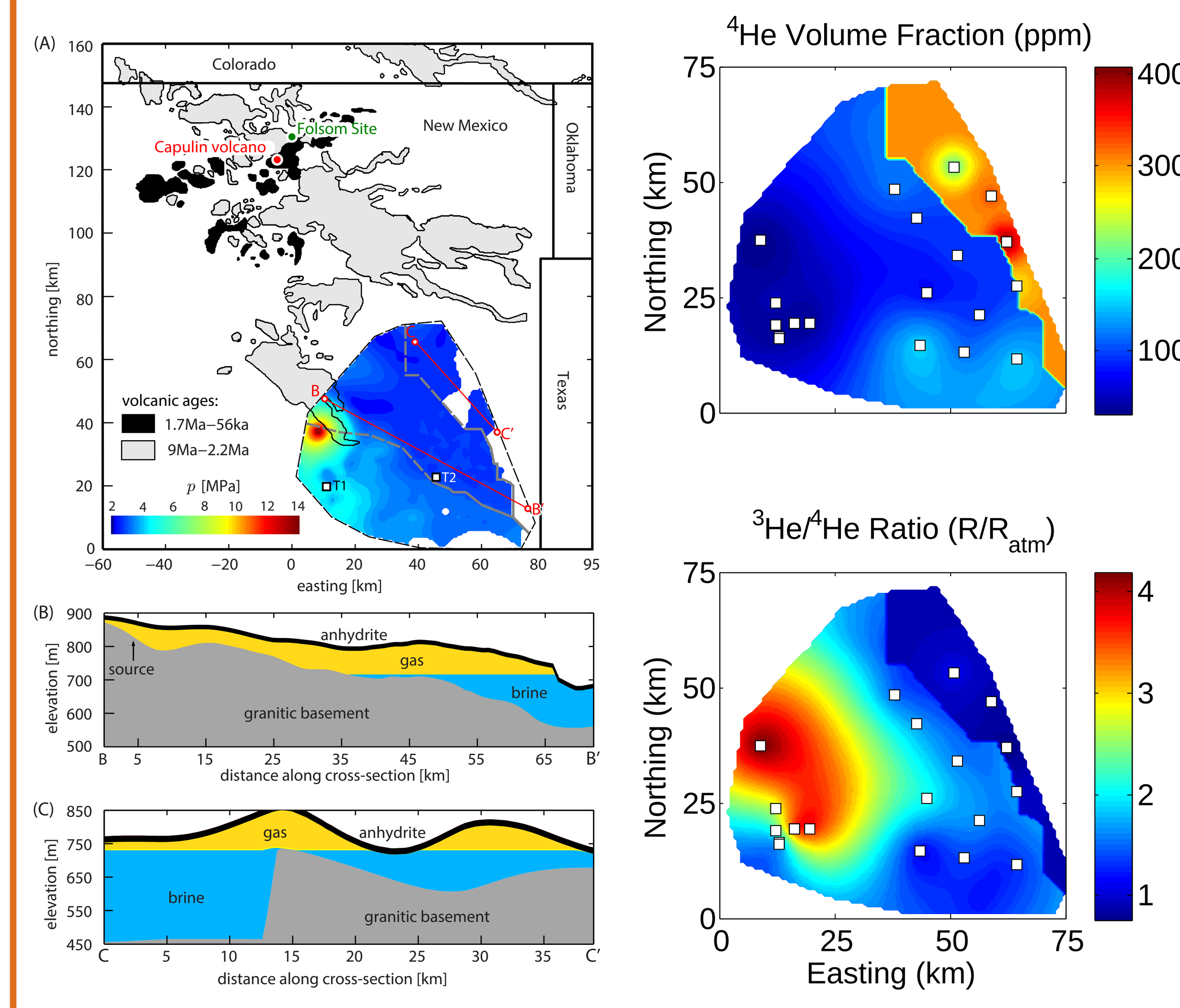
Noble Gas Volumes: Air-Saturated Water Contribution

- Indicates volume of gas interaction with air saturated water (ASW): Gas cap currently contains roughly 9km^3 residual H_2O
- 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

Isotope	Total Mols	Non-Mantle Mols	ASW Required	S_{rw} Volumes
^{20}Ne	6500	3100	0.4 km^3	0.05
^{36}Ar	1.1 (10^5)	7.7(10^4)	1.7 km^3	0.2
^{84}Kr	410	250	0.16km^3	0.02

Observations: Bravo Dome Natural CO_2 Field

- The Bravo Dome field contains 1.3GtCO_2 (22 tcf), with a magmatic noble gas isotope signature
- Noble gas isotopes have been used to determine location of gas source and interaction with initial brine
- We used Apatite (U-Th)/He thermochronology to identify a gas emplacement age between **1.2Ma** and **1.5Ma**

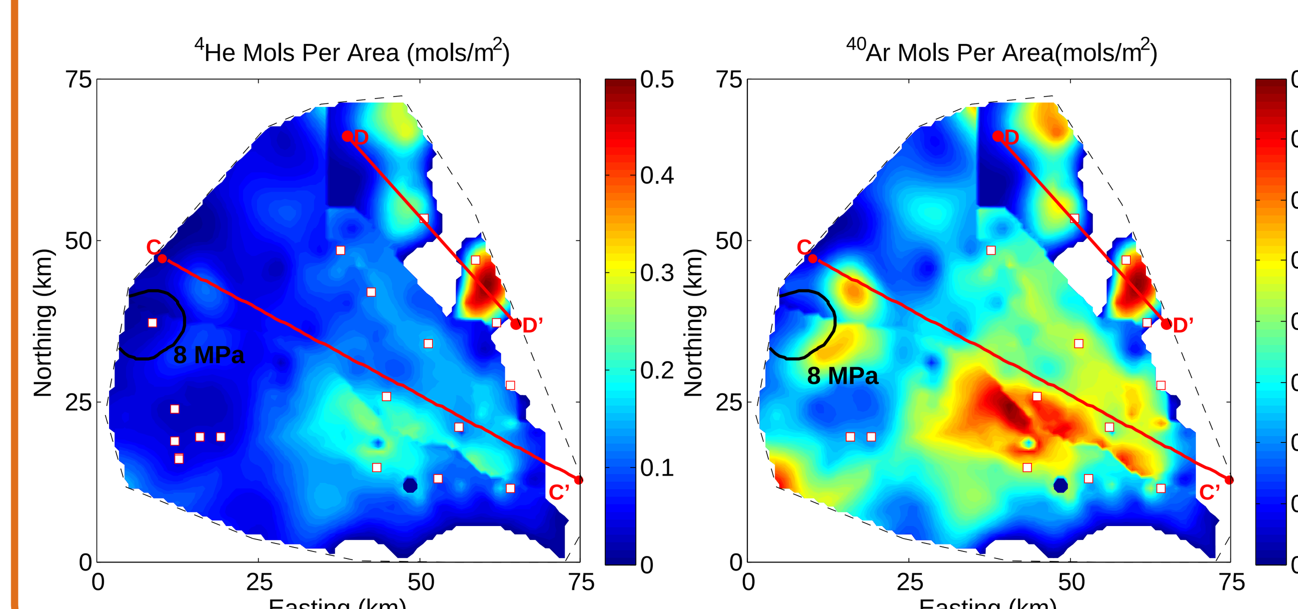


- CO_2/^{3}He ratio is used to infer the amount of local CO_2 dissolution into brine: in total, **22% ± 7% has dissolved**
- 40% of the dissolution took place above the gas-water contact in the residual brine: analog to gas injection process

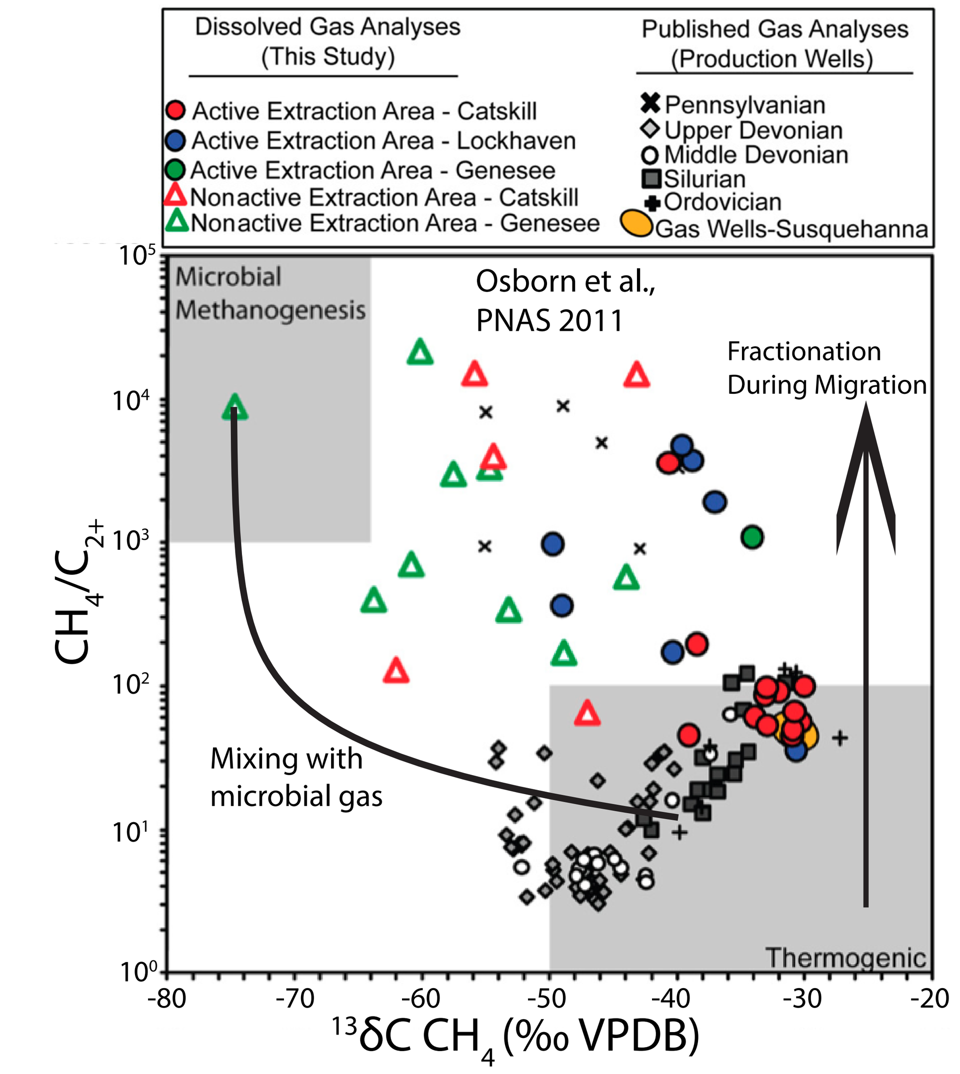
Noble Gas Volumetrics: Radiogenic Contribution

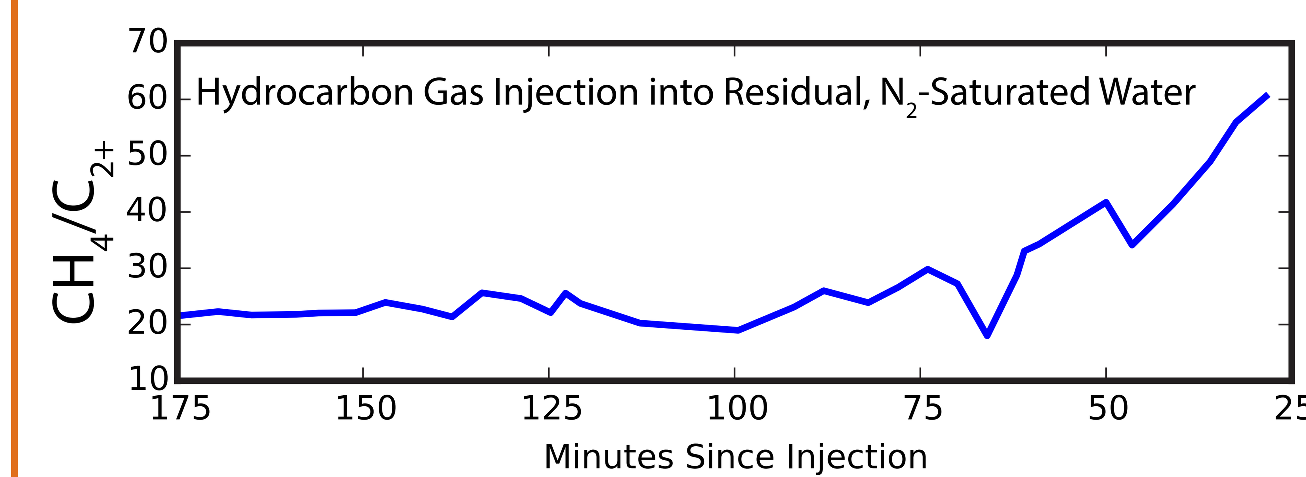
- ^{4}He produced as decay product of U and Th in Zircon, Apatite, Monazite, and Titanite - accumulates in minerals below T_C
- ^{40}Ar produced by ^{40}K decay in mica, K-spar
- ^{40}Ar/^{36}Ar Ratio ≈ 3400 = 11R_{atm} → large crustal component
- Non-mantle ^{4}He/^{40}Ar = 0.9, ^{4}He/^{40}Ar Production Ratio = 5
- Significant excess ^{40}Ar in Bravo Dome gas

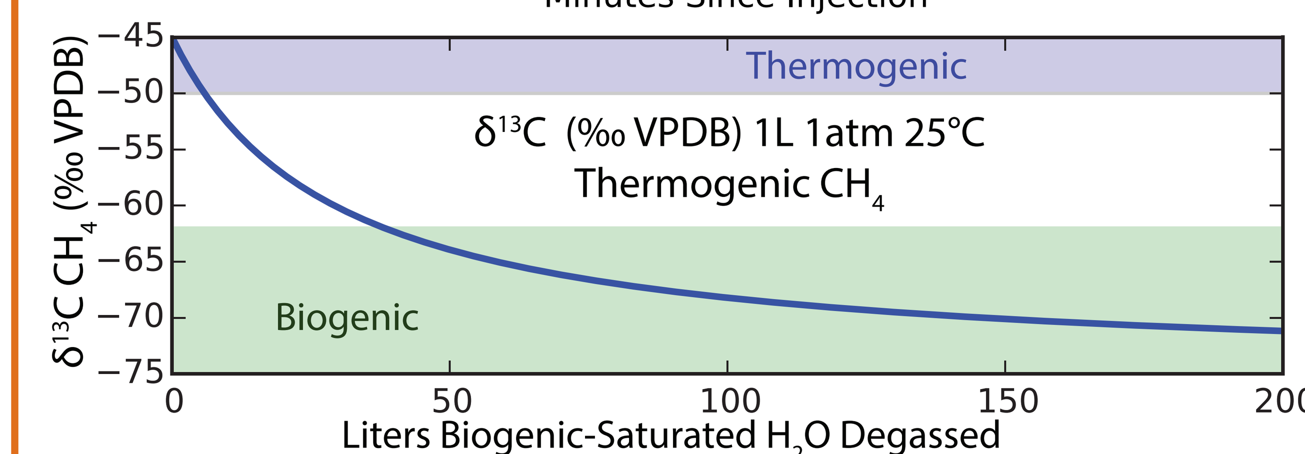
Isotope	Total Mols	Non-Mantle Mols	ASW Required	S_{rw} Volumes
^{4}He	3.3 (10^8)	2.3 (10^8)	1.2(10^5) km^3	1.3(10^4)
^{40}Ar	1.1(10^9)	2.6(10^8)	20 km^3	2.2



Hydrocarbon Fractionation and Groundwater







- Hydrocarbon composition and isotopes are used to distinguish between bacterial and thermogenic gas
- Experiment shows composition change during gas injection
- Degassing of bacterial methane form groundwater into migrating gas plume can change C isotope value of methane gas

References

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