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Characterization of Hydraulic Fractures and Reservoir Properties of Shale Using Natural Tracers

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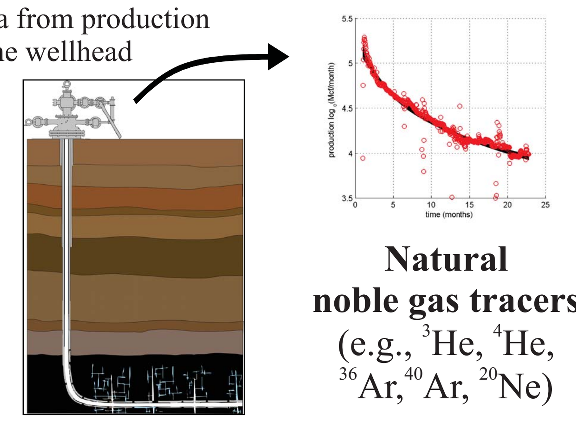
Jason Heath, W. Payton Gardner, Kristopher Kuhlman, Stephen Bauer, Bwalya Malama

Sandia National Laboratories, Albuquerque, New Mexico; jeheath@sandia.gov

I. Introduction

Hydraulic fracturing plays a major role in the economic production of hydrocarbons from shale. Current fracture characterization techniques have limited ability to diagnose transport properties of fractures from the near-wellbore scale to that of the entire stimulated reservoir volume. Microseismic reveals information on fracture geometries, but not transport properties. Production analysis (e.g., rate transient analysis using produced fluids) estimates fracture and reservoir flow characteristics, but often relies on simplified models in terms of fracture geometries and fluid storage and transport. We investigate incorporating natural tracers with production data analysis for fracture and reservoir characterization. Hydraulic fracturing releases omnipresent natural tracers that have accumulated in low permeability rocks over geologic time. Key reservoir characteristics govern the tracer release. We explore natural tracer systematics using numerical and experimental techniques under relevant shale-reservoir conditions and evaluate the impact on reservoir characterization.

Data from production at the wellhead



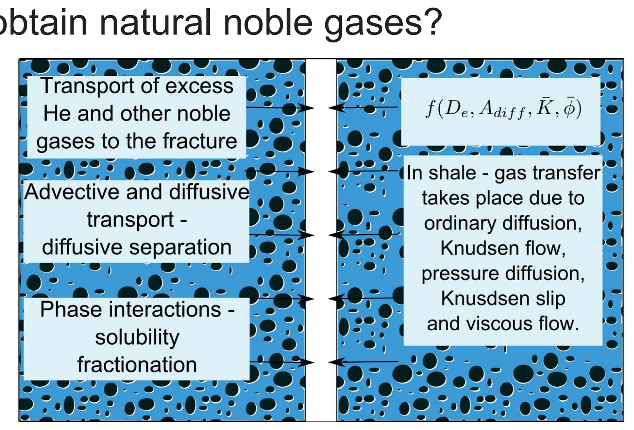
Natural noble gas tracers (e.g., ^{3}He, ^{4}He, ^{36}Ar, ^{40}Ar, ^{20}Ne)

Summary and goals: We develop methods to combine production analysis w/ natural tracers to:

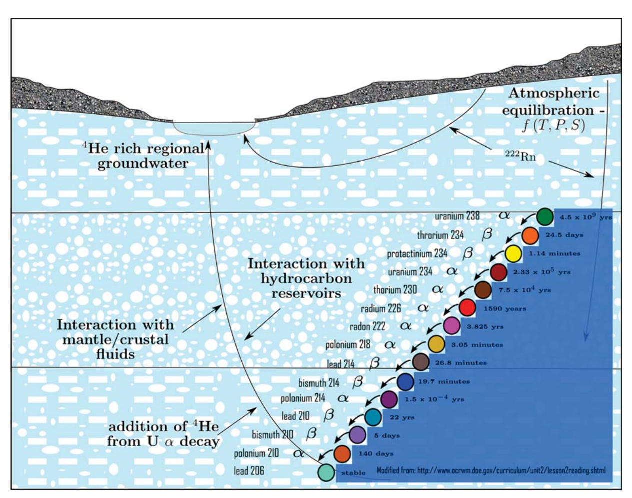
- obtain hydrocarbon decline and recovery information more quickly
- better understand fluid transport mechanisms in shale
- lower uncertainty during reservoir parameter estimation

II. Motivation and Background on Natural Tracers in Fractured Shale Reservoirs

Why obtain natural noble gases?

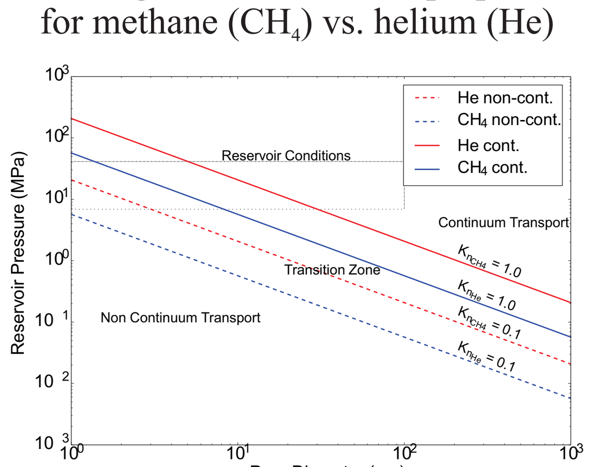


Transport of natural noble gases to newly created fractures reflects fracture and reservoir flow characteristics through several processes

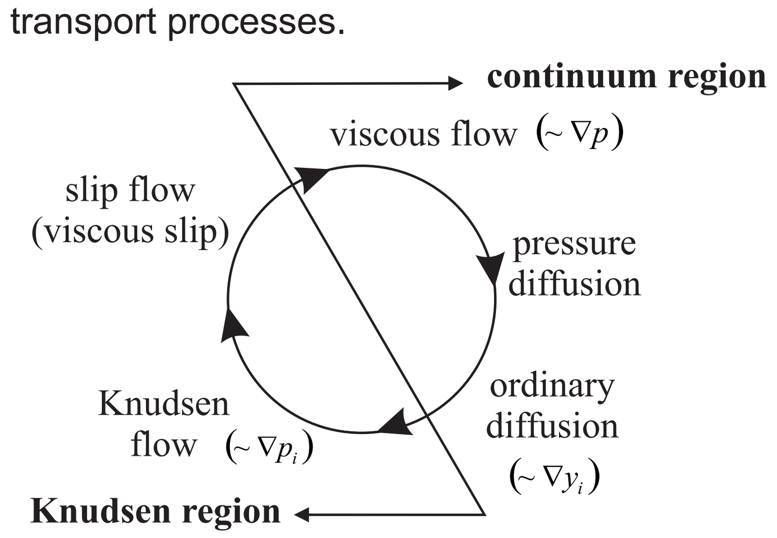


Helium-4 in particular is abundant in the subsurface and has potentially 2 to 4 times higher transport coefficients than methane depending on the Knudsen number (ratio of mean free path to pore diameter) and transport processes.

Flow regions and reservoir properties for methane (CH_4) vs. helium (He)



Does non-continuum transport mean helium will deliver production decline information more quickly?



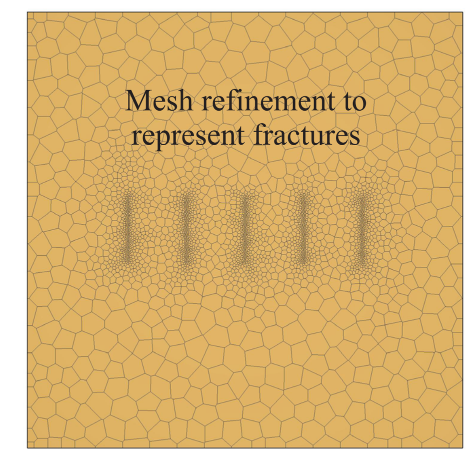
(modified from Kast Hohenthanner, 2000)

III. Flow and Transport: Numerical Modeling

Numerical modeling of species-dependent transport

We investigate whether helium can deliver production flow regime information more quickly than methane. We run simulations with varying permeability to reflect that non-continuum/transition region transport rates may be proportional to the square root of molecular masses of the two species (Graham's law) or just the masses (ordinary diffusion; see Kast and Hohenthanner, 2000).

Simulations with TOUGH2-EOS7C: For methane and brine



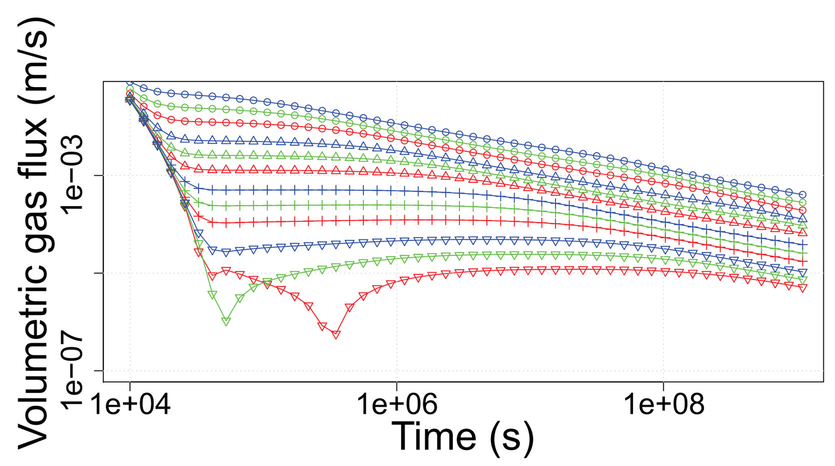
1138 m on a side
No flow on boundaries

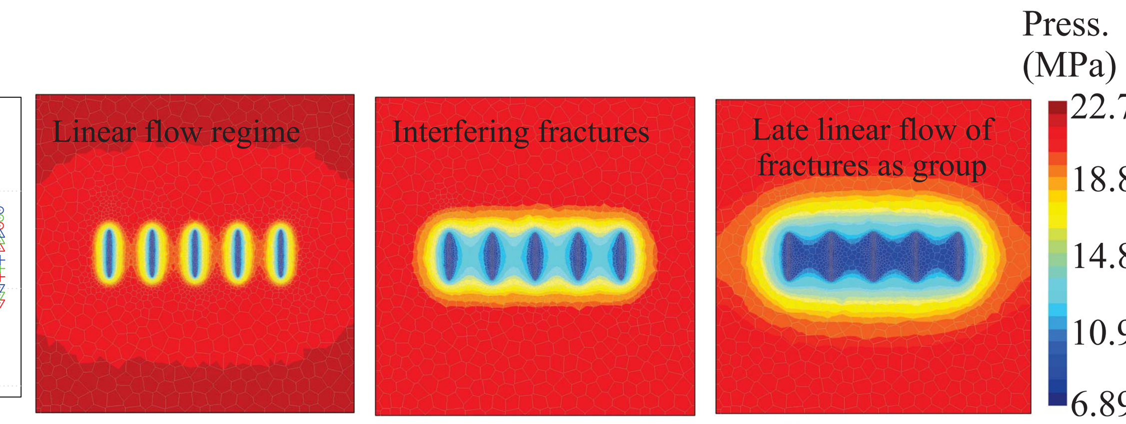
Input Parameters	Values
Thickness (m)	23
Porosity (%)	8
Initial water saturation (%)	30
Initial reservoir pressure (MPa)	22.8
Flowing bottomhole pressure (Mpa)	6.89
Fracture half-length (m)	84
Rel. perm. Slr (Corey's curves)	0.2
Rel. perm. Sgr (Corey's curves)	0.02
Cap. press. lambda (van Gen.)	0.45
Cap. press. Slr (van Gen.)	0.2
Cap. press. Pmax (Pa) (van Gen.)	5.00E+06
Temperature (degrees C)	60

Similar parameters to Clarkson and Beierle (2011)

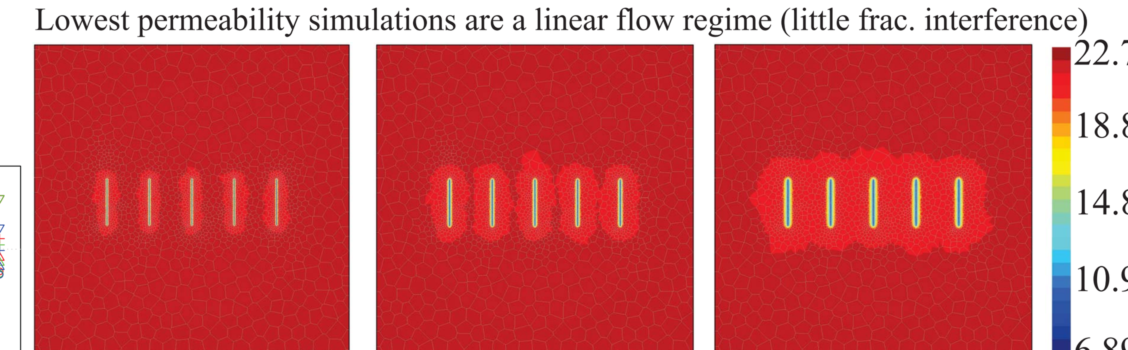
Gas flux data are a function of permeability (m^2):
circles: 1×10^{-19}(red), 2×10^{-18},(green), 4×10^{-18} (blue)
upward triangles: 1×10^{-19}(red), 2×10^{-19},(green), 4×10^{-19} (blue)
crosses: 1×10^{-20}(red), 2×10^{-20},(green), 4×10^{-20} (blue)
downward triangles: 1×10^{-21}(red), 2×10^{-21},(green), 4×10^{-21} (blue)

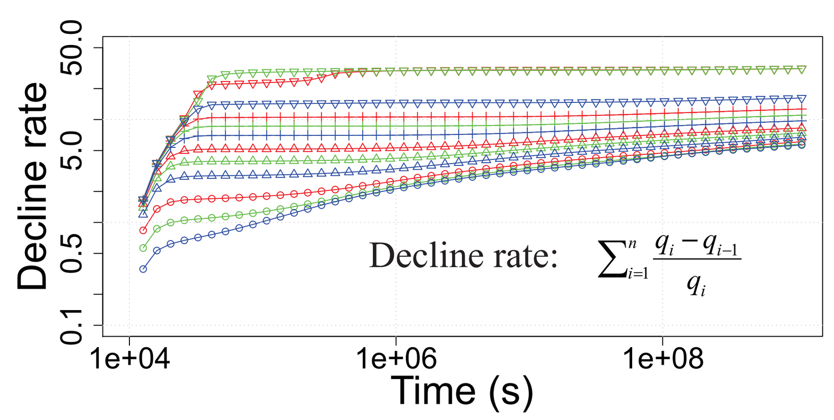
Simulations include constant pressure at the center of each "fracture", which represents the producing well.





Lowest permeability simulations are a linear flow regime (little frac. interference)





Pressure distribution:
upper row: early, middle, and late flow regimes for plots with circles (1×10^{-18}, 2×10^{-18}, and 4×10^{-18} m^2)

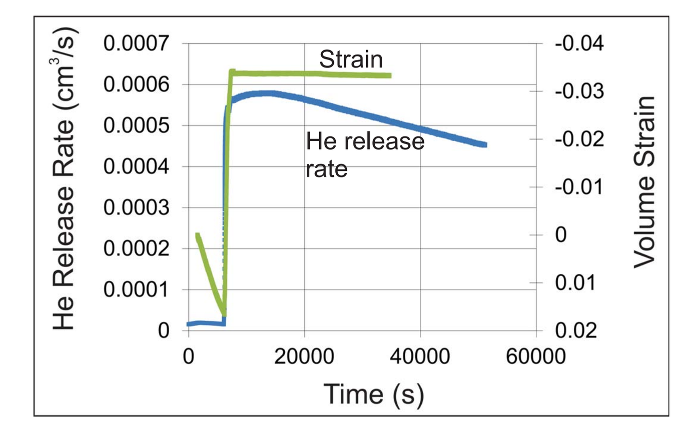
lower row: same output times as above for downward triangles, but flow regime progression is very limited

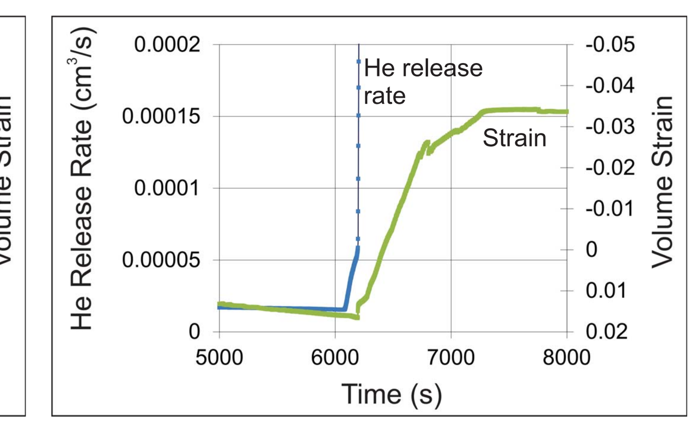
Decline rate is used to assist in identifying changes in flow regimes. Flow regimes in turn are used to estimate reservoir parameters and reserves in place (especially using the boundary-dominated flow regime).

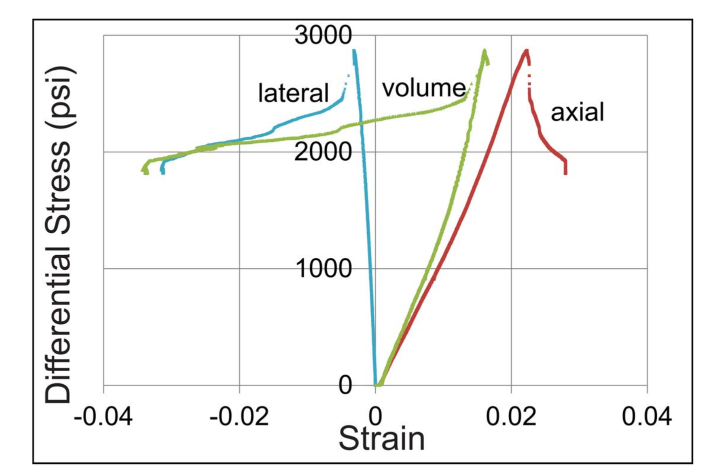
Onset of flow regimes vary greatly for the simulations results. For a given permeability set (1, 2, 4×), onset of flow regimes vary most for the higher permeabilities. The lower permeability simulations show long-term persistence (even over 35 years) of low production rates.

IV. Laboratory Experiments: Release of Helium During Shale Deformation

- 1" x 2" core, parallel and perpendicular to bedding
- Instrumented for axial and radial displacement
- Confining pressure = 3,000 psi
- Saturated with He 48 hours
- Triaxial compression, strain rate = 5×10^{-6}
- Record: force, displacement, and He release rate
- Flow induced by vacuum through the pore pressure port and flow rate monitored with a mass spectrometer
- Acoustic emission detection attempted to quantify microfracturing, but there is need to increase sensitivity with larger transducers







- He release rate and volume strain are plotted versus time
- Fairly typical "brittle" stress strain response of this shale
- During all of the tests– prior to axial loading, a vacuum pump was attached to the sample and He was sucked from the sample and through the mass spectrometer
- Key correlation/relationship of He release phenomena relating compaction/dilation and He flow
- Perhaps precursive He release in advance of dilatancy observed

V. Summary and ongoing work

- Natural helium release may yield information on flow regimes more quickly than methane, which may be important for reserves estimation. Methane flow regimes may take decades to develop.
- Deformation experiments record helium release prior to onset of dilatancy. Helium release may reflect changes in pore structure, reflecting an increase in matrix permeability prior to macroscopic fracturing.
- Ongoing work includes obtaining time-series noble gas data from wellheads at a new hydraulically-fractured well. A well will be sampled immediately following hydraulic fracturing in early 2014.
- Representation of fractures is being developed using the multi-rate model (see post H53A-1405 on Friday by Kristopher Kuhlman and others.)

References

Clarkson, C.R., Beierle, 2011, Integration of microseismic and other post-fracture surveillance with production analysis: A tight gas study. Journal of Natural Gas Science and Engineering 3, 382-401,

Kast, W., Hohenthanner, C.R, 2000, Mass transfer within the gas-phase of porous media. International Journal of Heat and Mass Transfer 43, 807-823.

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