

Noble Gas Tracing of Deformation and Transport in Shale Reservoirs

Jason Heath,
Stephen Bauer, and
Kristopher Kuhlman

February 21, 2017



Sandia National Laboratories is a multi-mission laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

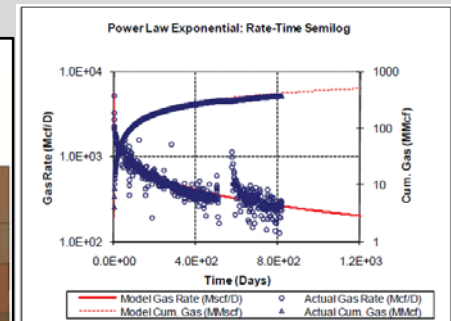
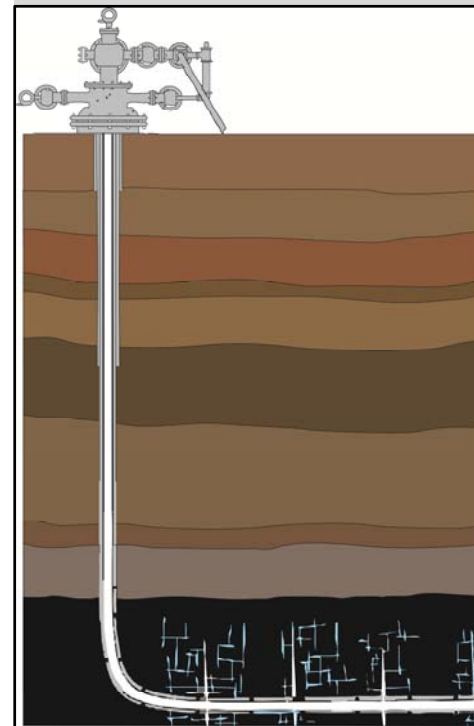
SAND2017-1851PE

*Exceptional service
in the national interest*



Sandia
National
Laboratories

Production data



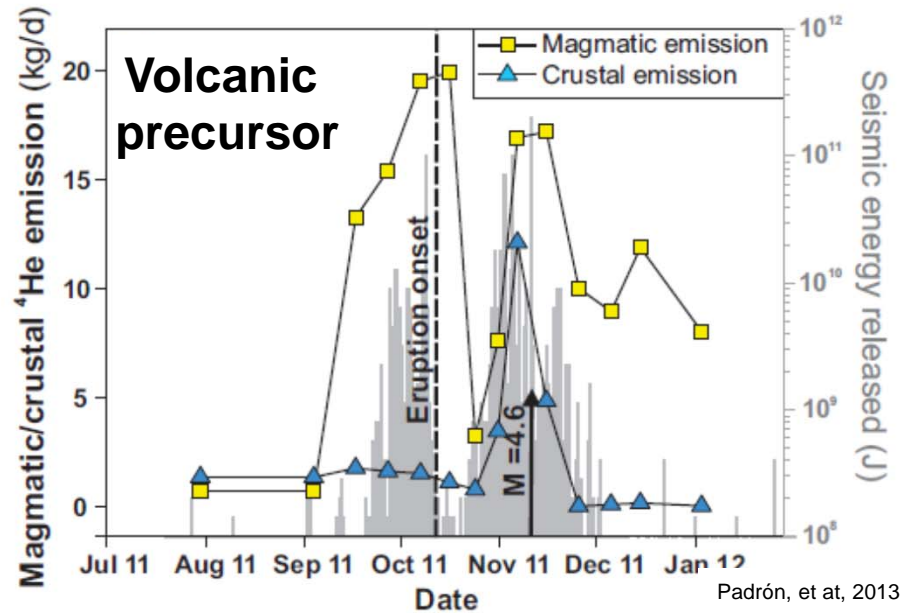
+

Natural tracers
(e.g., ^3He , ^4He ,
 ^{36}Ar , ^{40}Ar , ^{20}Ne ,
 ^{22}Ne , Kr, Xn)

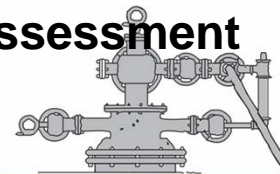
Noble Gas Release as a Deformation Signal



D. Garisto, 2016, 2010 Chile Earthquake, C. Núñez



Resource Assessment



^3He , ^4He , ^{36}Ar , ^{40}Ar ,
 ^{20}Ne , ^{22}Ne , ^{78}Kr , ^{84}Kr ,
 ^{86}Kr , ^{126}Xe , ^{129}Xe , ^{131}Xe ,
 ^{132}Xe , ^{134}Xe , ^{136}Xe , ^{222}Rn

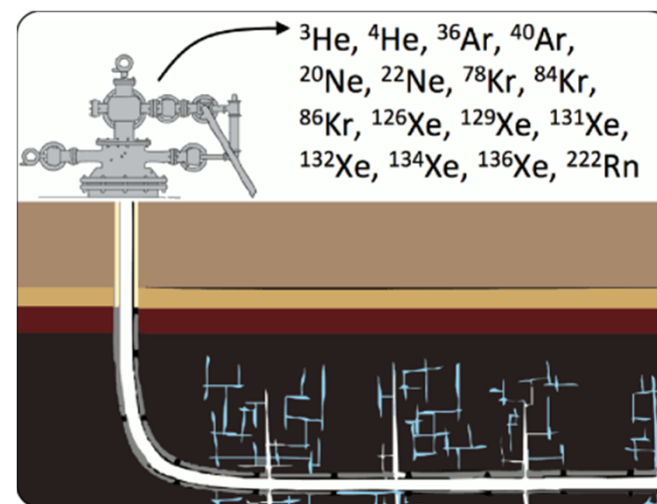


(modified from King, 2010)

Purpose and Approach

Develop fracture and reservoir diagnostics using natural tracers collected from the well head, focusing on:

1. *Production decline and early delivery of information* – Deformation releases helium, which is more mobile than other gases and may forecast production.
2. *Transport Mechanisms* – Noble gases may indicate transport process (diffusive vs advective flow), phase behavior, and mixing of fluids.

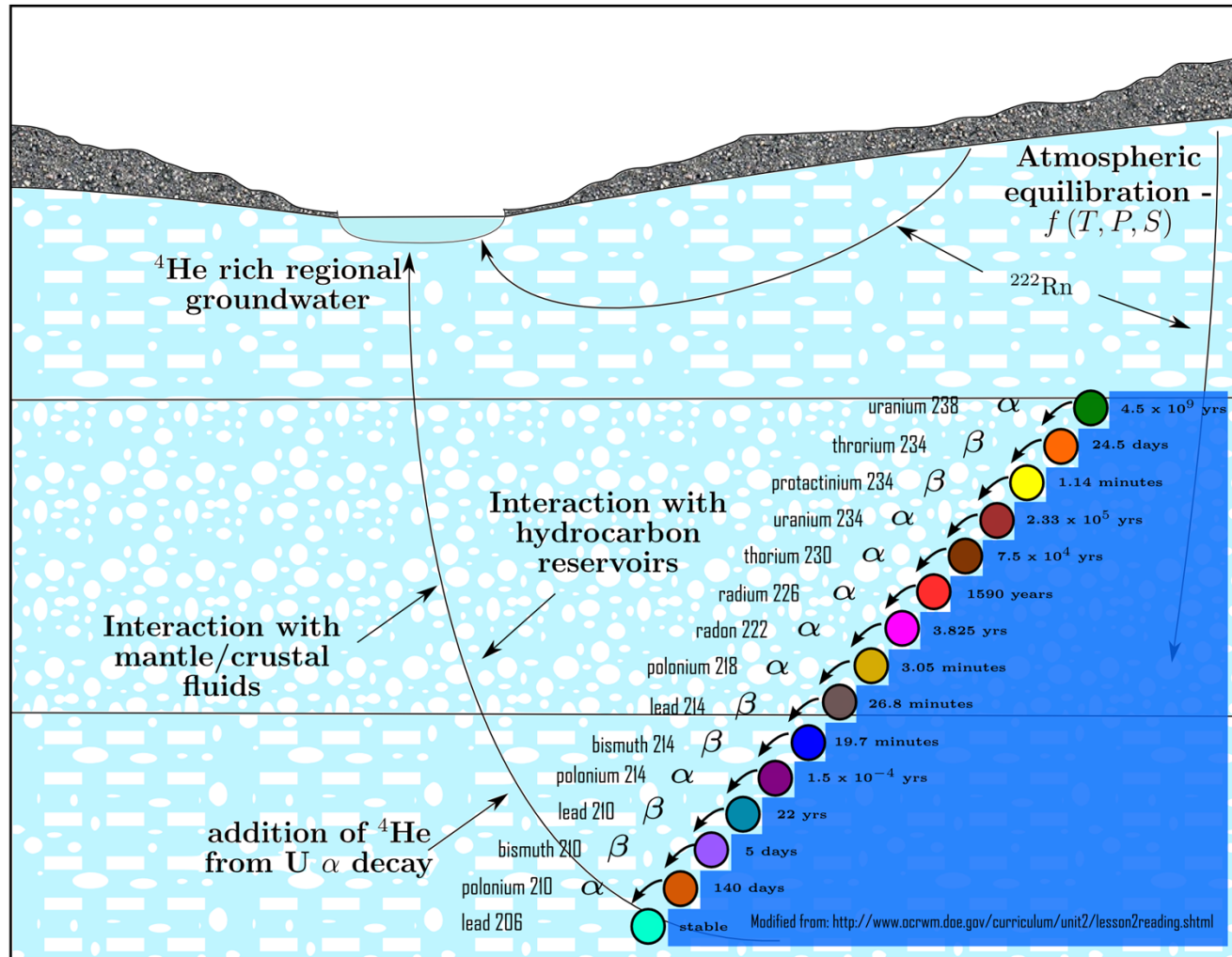


Technical accomplishments:

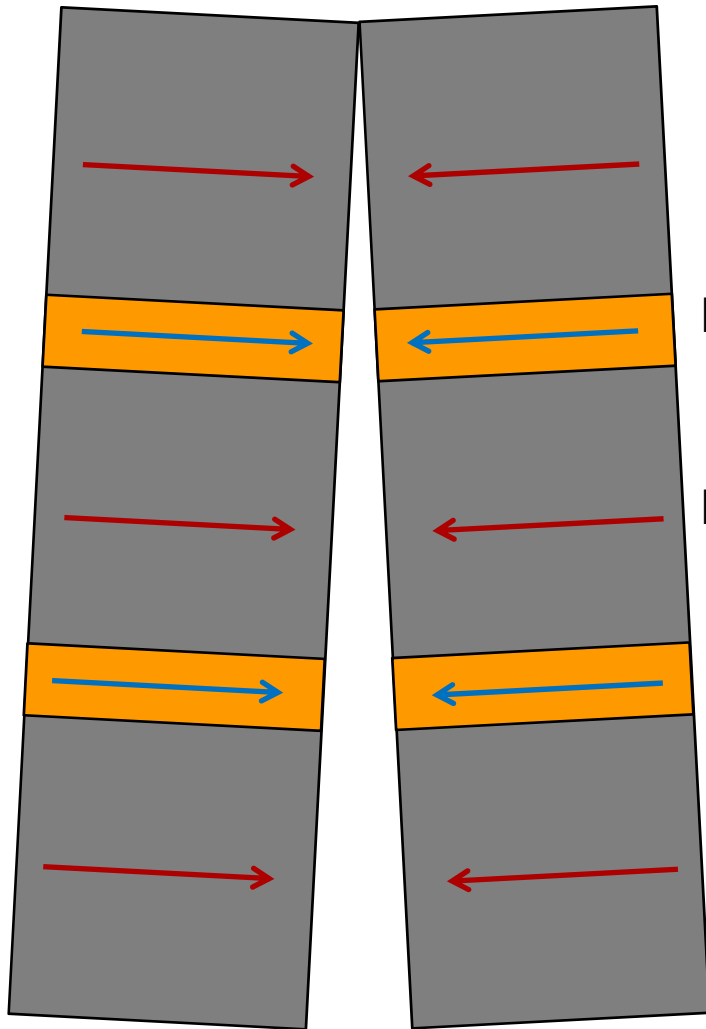
- Obtained 1.5-yr time series of natural tracers from two hydraulically-fractured wells
- Performed novel deformation and helium release lab tests
- Developed statistical methods for reducing production forecast uncertainty with less (time-series) data

See Heath et al., 2015; ongoing work on gas release from granites by S Bauer

Intro to Noble Gas Geochemistry



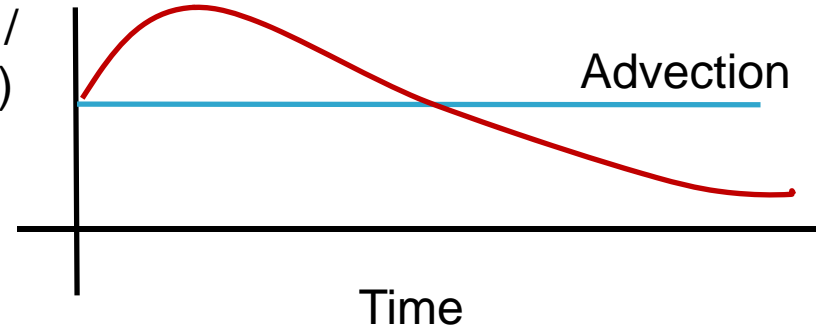
Noble Gas Fractionation Conceptual Model



Transport to fracture

Light-heavy noble gas plot vs time

Light(He) /
heavy(Xn)



High perm

Low perm

High perm transport

Advective transport, no mass dependence

Low perm transport

Mass dependent transport

E.g., Diffusion fluxes can follow:

Fick's law

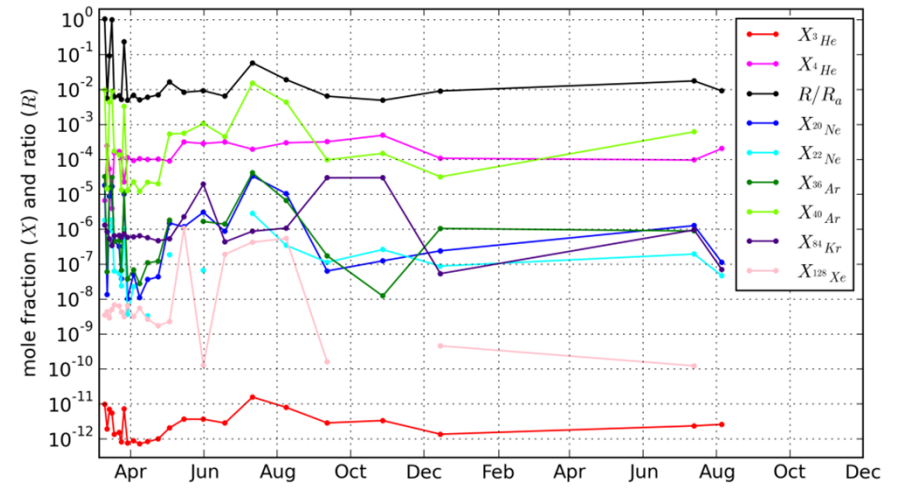
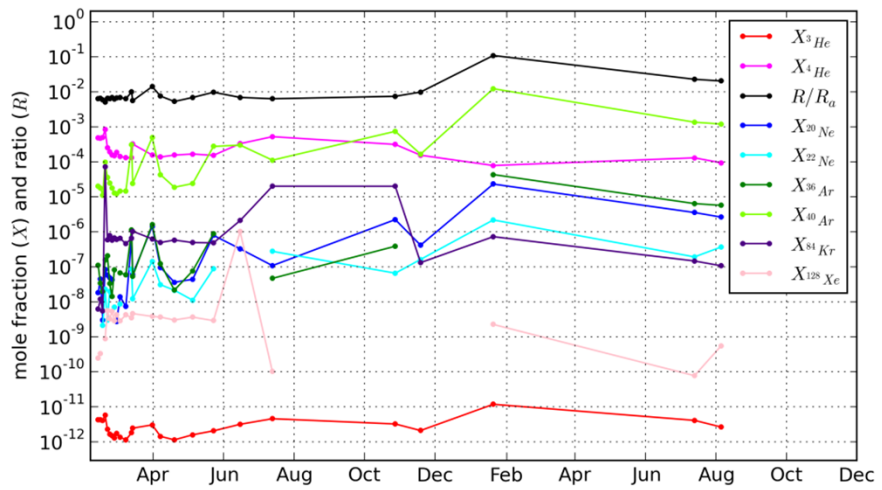
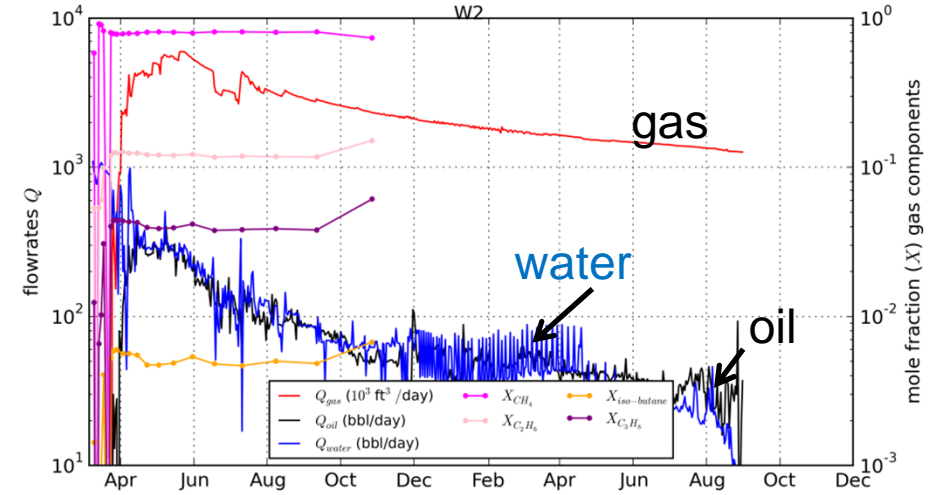
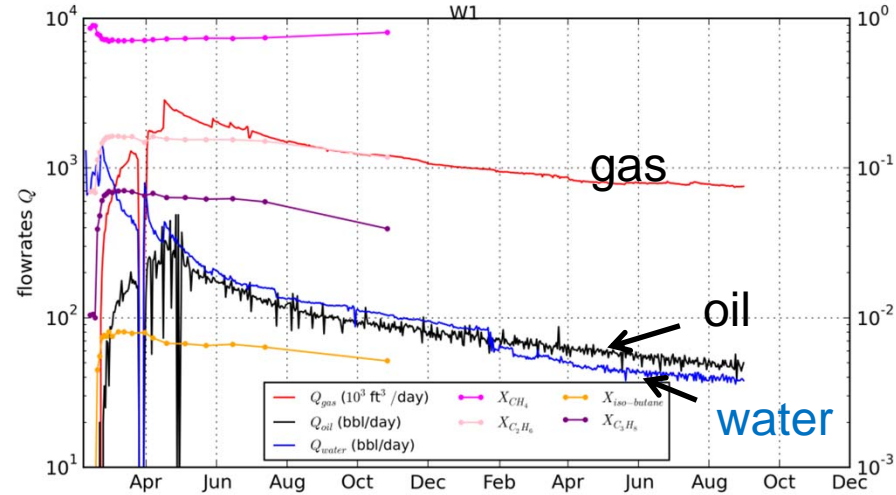
or

Graham's law

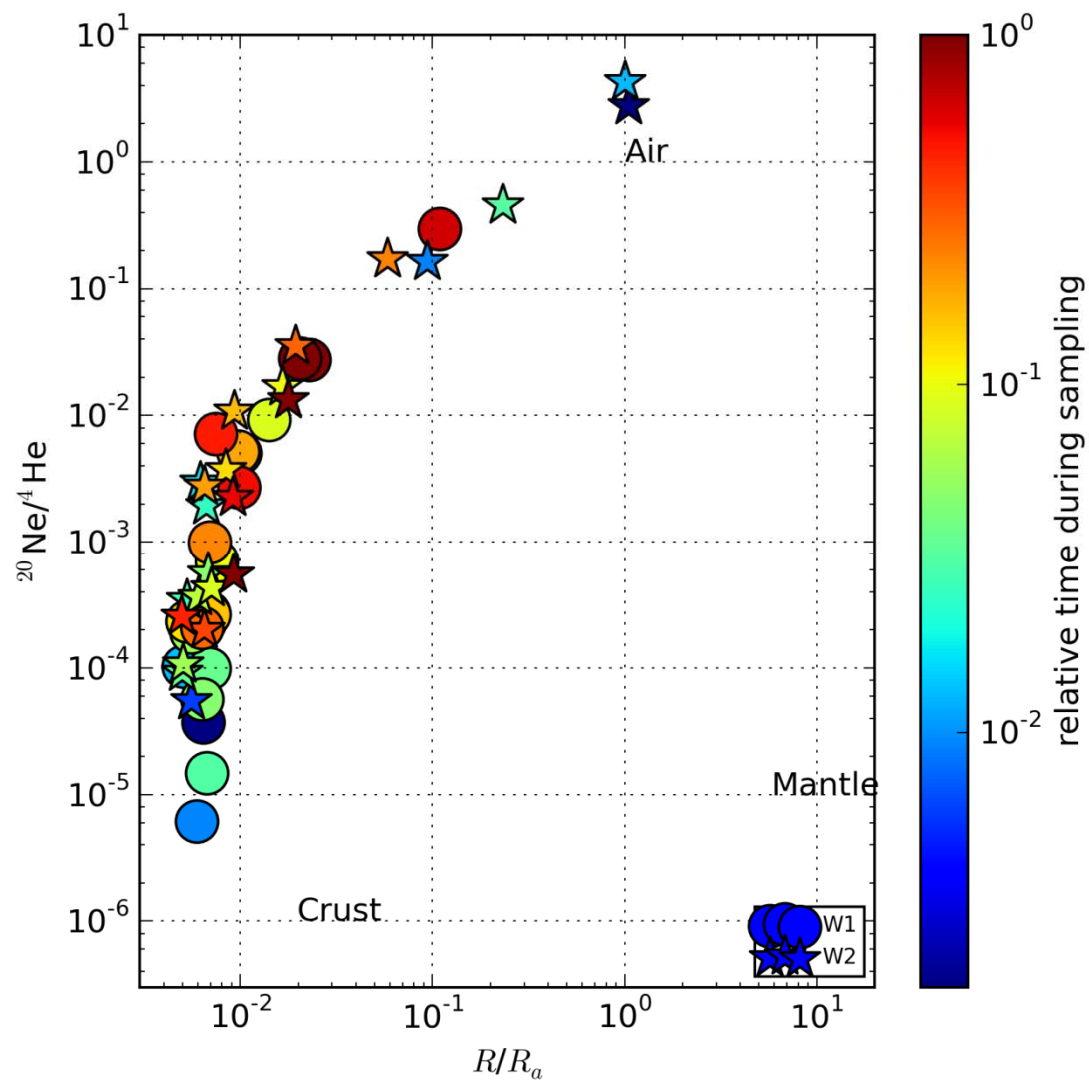
$$\frac{D_1}{D_2} = \frac{M_1}{M_2}$$

$$\frac{D_1}{D_2} = \sqrt{\frac{M_1}{M_2}}$$

Field: Noble gases and transport processes



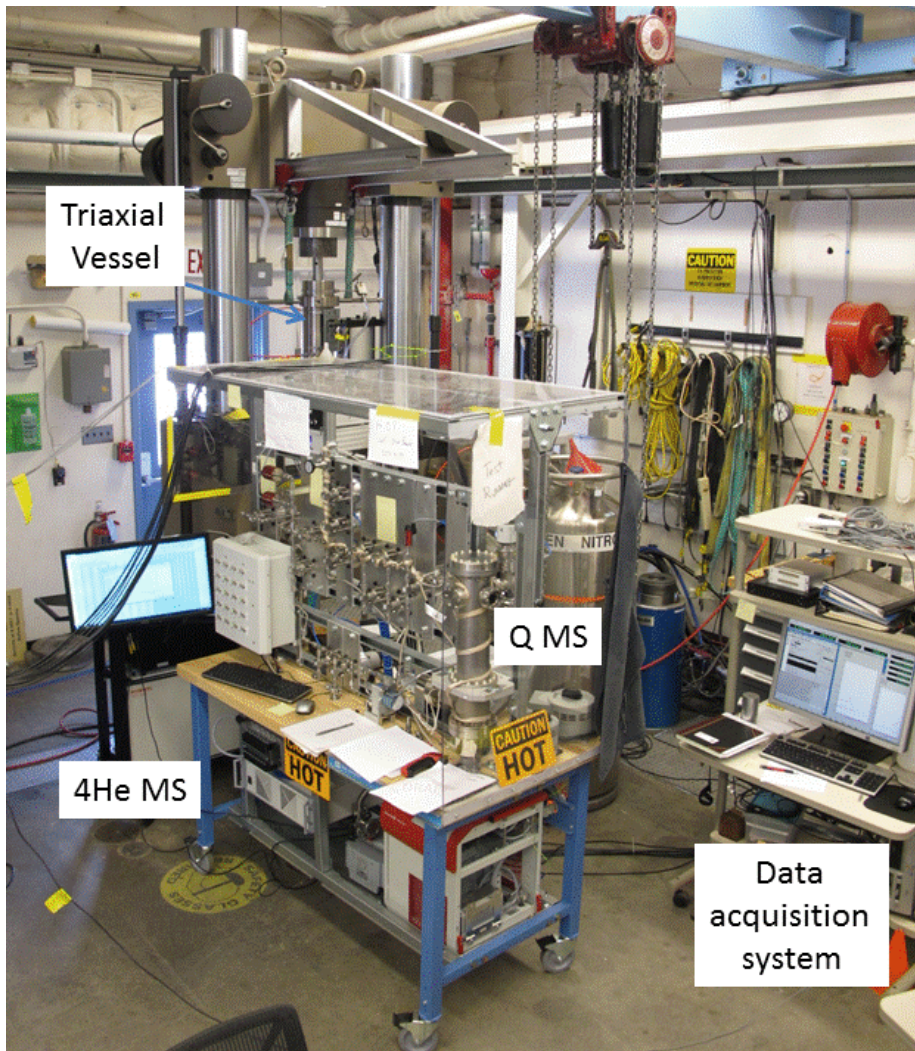
- Crustal signature: higher ^4He or lower R/R_a ($^3\text{He}/^4\text{He}$ normalized to atmosphere; higher ^{40}Ar)
- Atmospheric fluids (e.g., fracturing fluid): higher ^{20}Ne , ^{36}Ar , ^{84}Kr , and N_2
- Crustal vs atm. Input oscillates with time, especially for Well # 2 (on right)



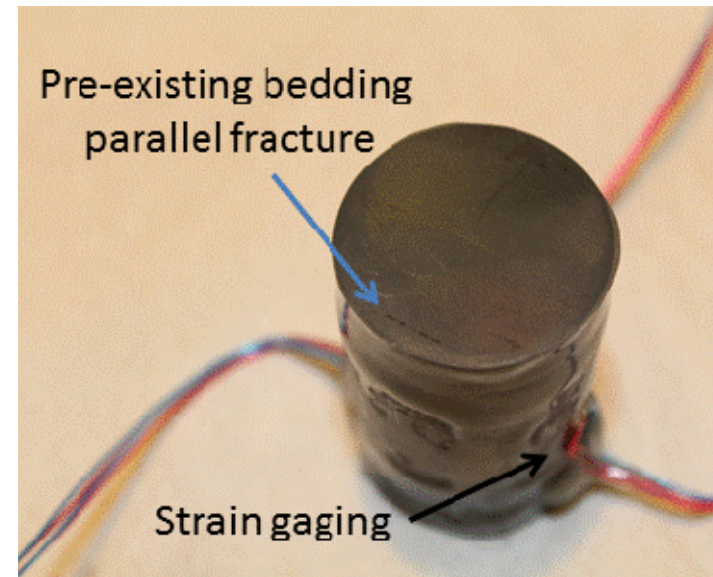
**Crustal vs atm. input
oscillates with time,
especially for W2**

Blue = early samples
Red = late samples

Gas release and flow measurements at elevated pressure and differential stress



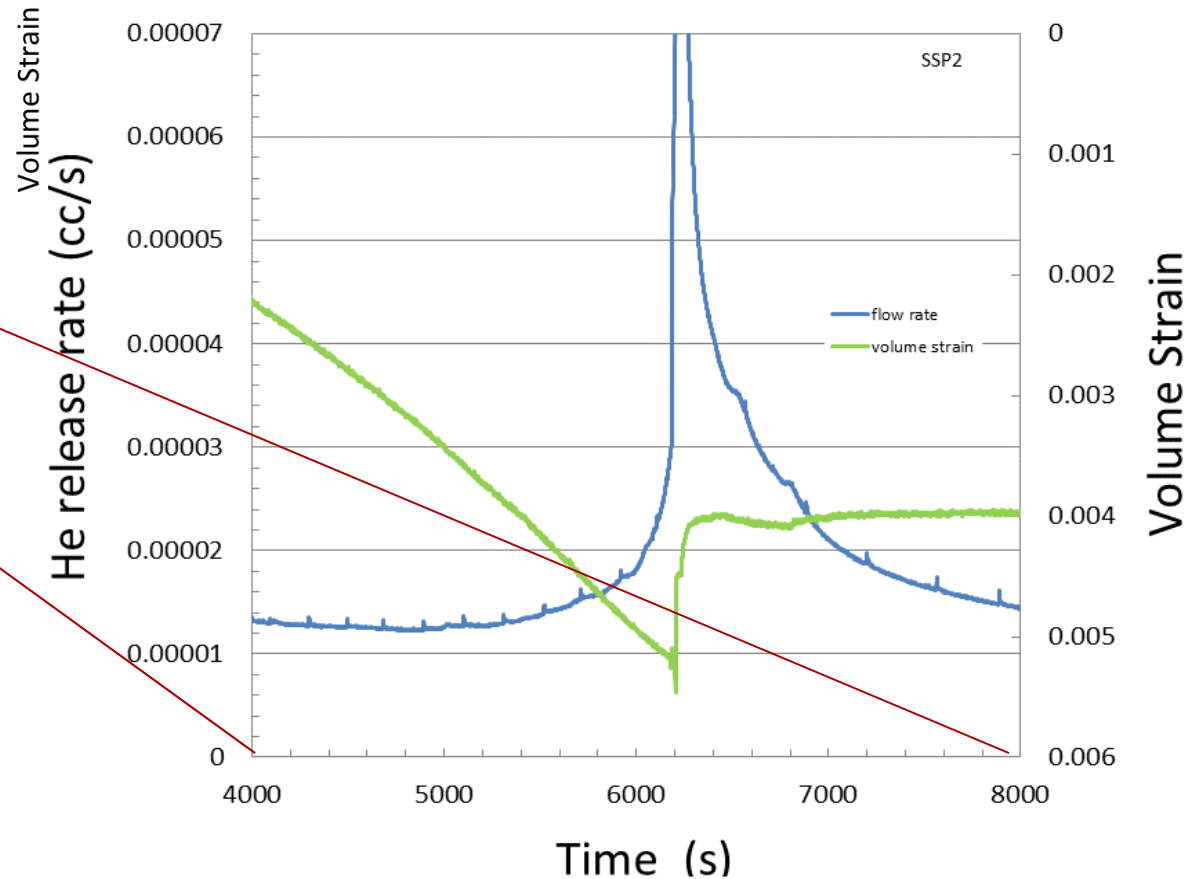
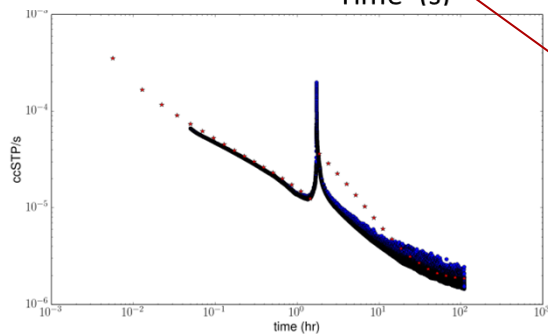
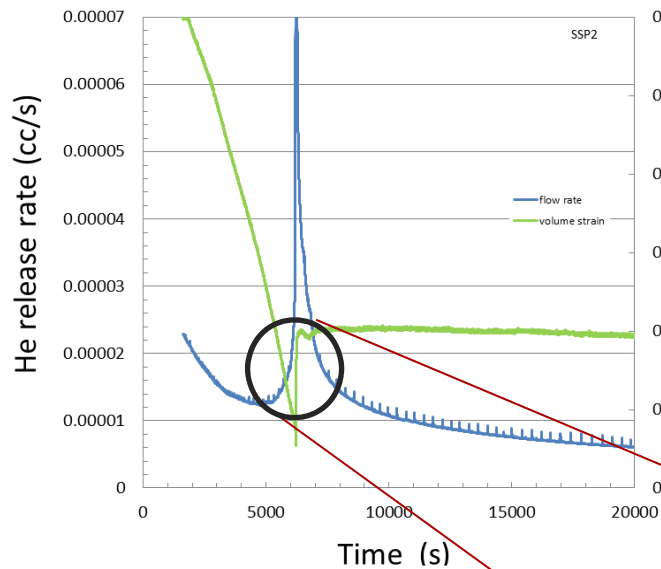
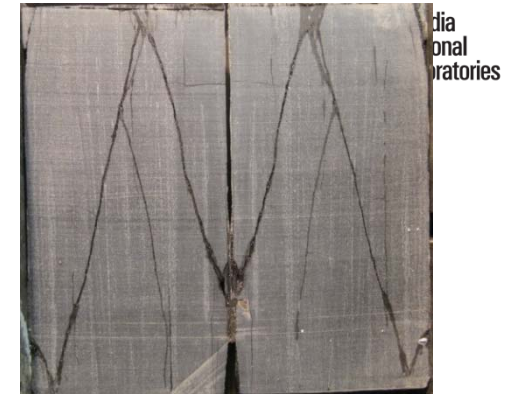
Helium mass spectrometer and quadrupole mass spectrometer used to measure gas release and flow through shale at simulated downhole conditions



Test duration ~1 week

Experimental Effort: Helium Release

- Helium tracing of fracture and pore structure evolution
- Sensitive signal precursive to macrofracture formation
- Helium release/volume strain inform model development
 - Helium release during deformation due to draining fractures and matrix contribution

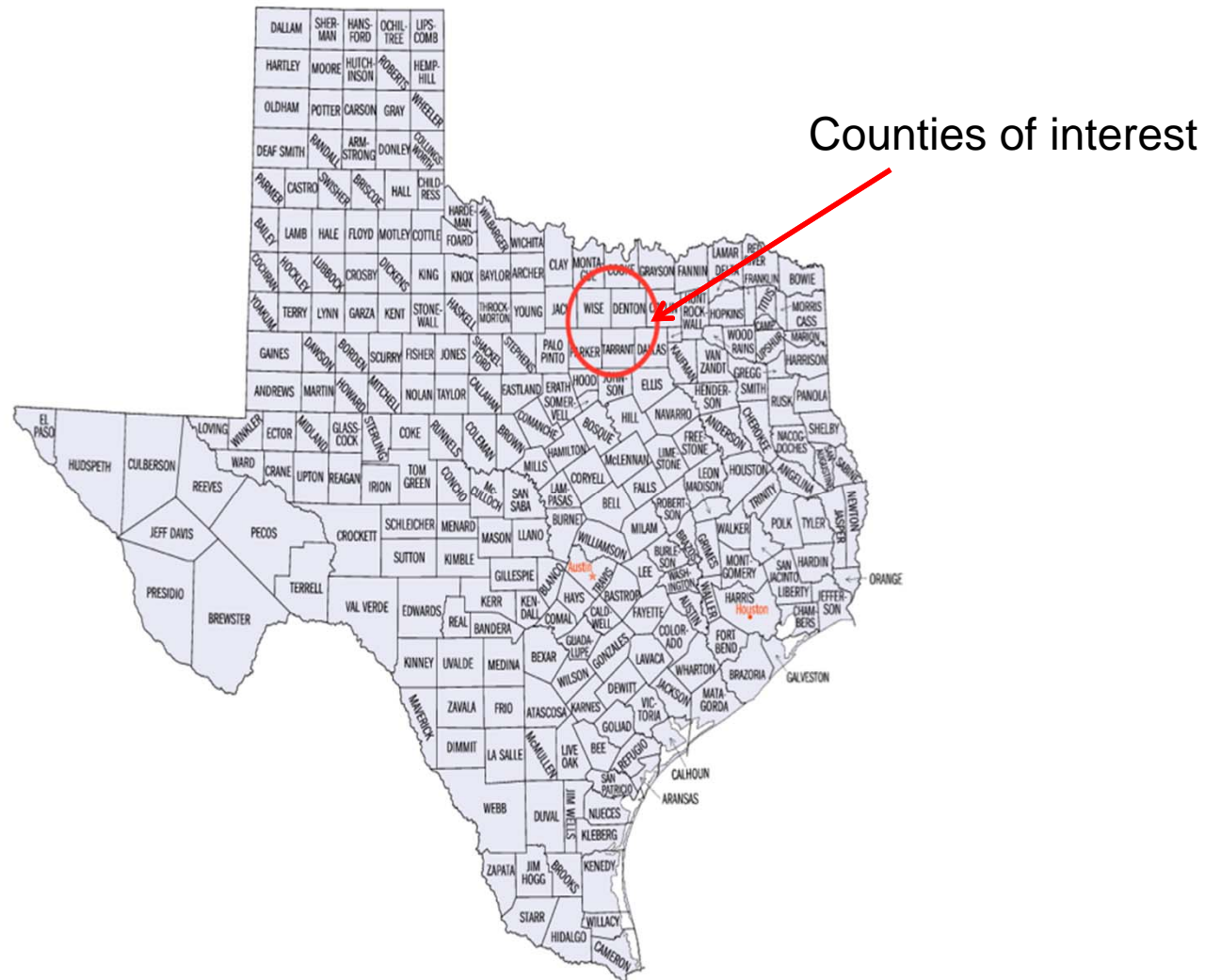


$$\frac{\partial}{\partial t} \left(\frac{V_f \phi_f P_f}{z(P_f)} \right) = \nabla \cdot \left(\frac{k(P_f) P_f}{\mu(P_f) z(P_f)} \cdot \nabla P_f \right) + q^*$$

$$\frac{\partial}{\partial t} \left(\frac{V_m \phi_m P_m}{z(P_m)} \right) = \nabla \cdot \left(\frac{k_m(P_m) P_m}{\mu(P_m) z(P_m)} \cdot \nabla P_m \right) + q^*$$

$$q^* = \frac{\alpha k_m(P_m)}{\mu(P_m)} (P_m - P_f)$$

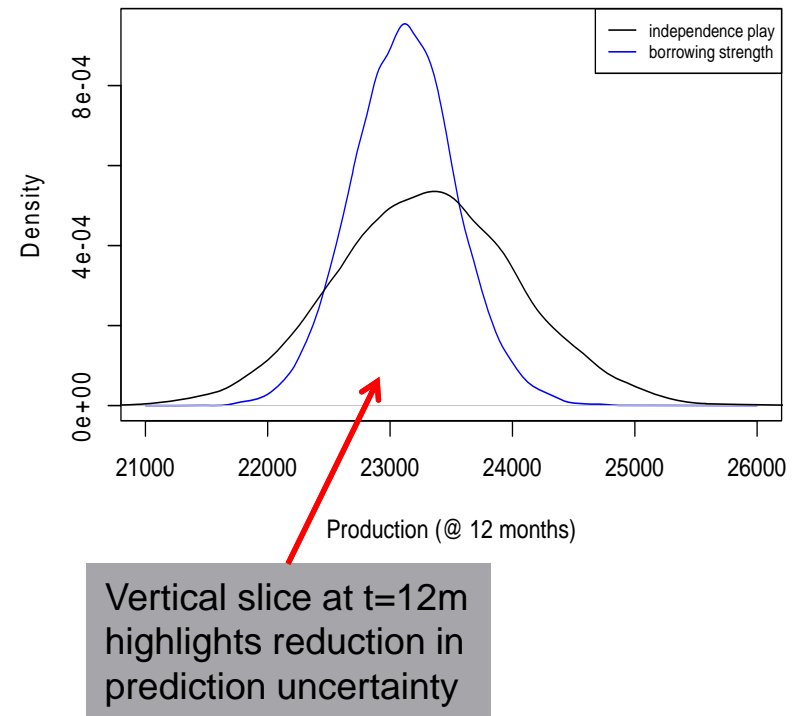
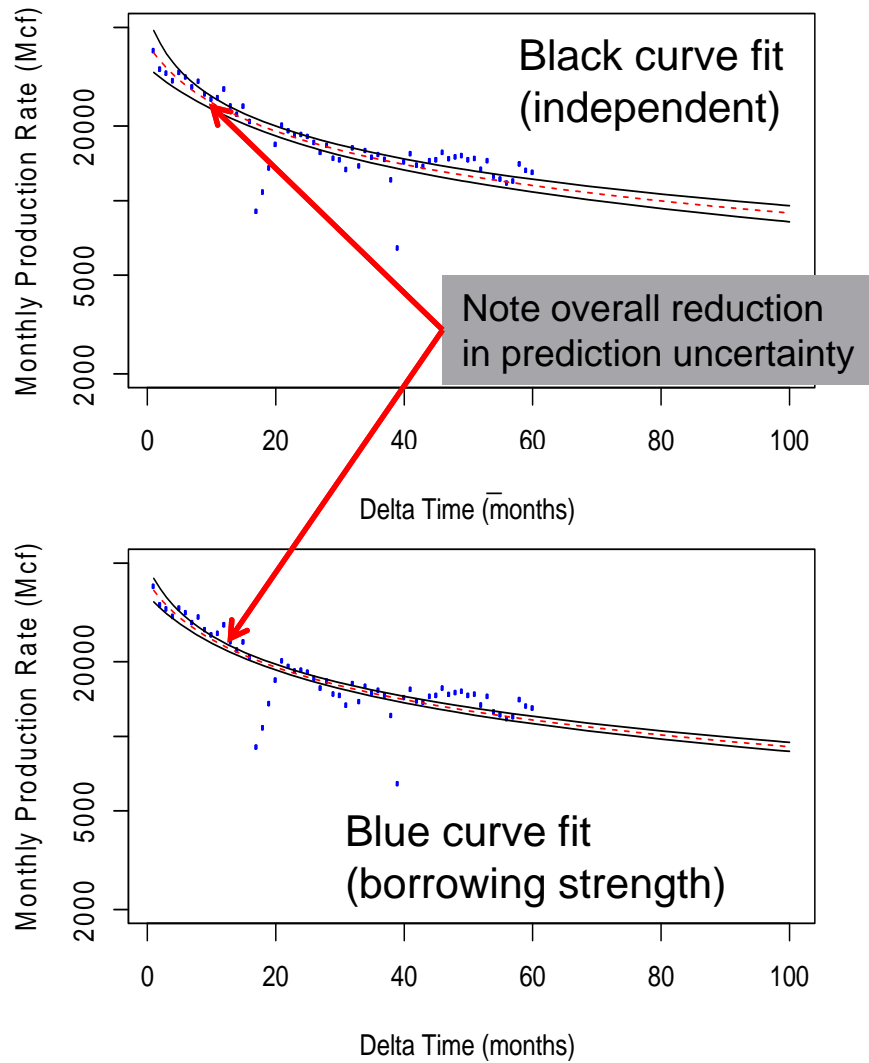
Bayesian Data Analysis: 197 TX wells



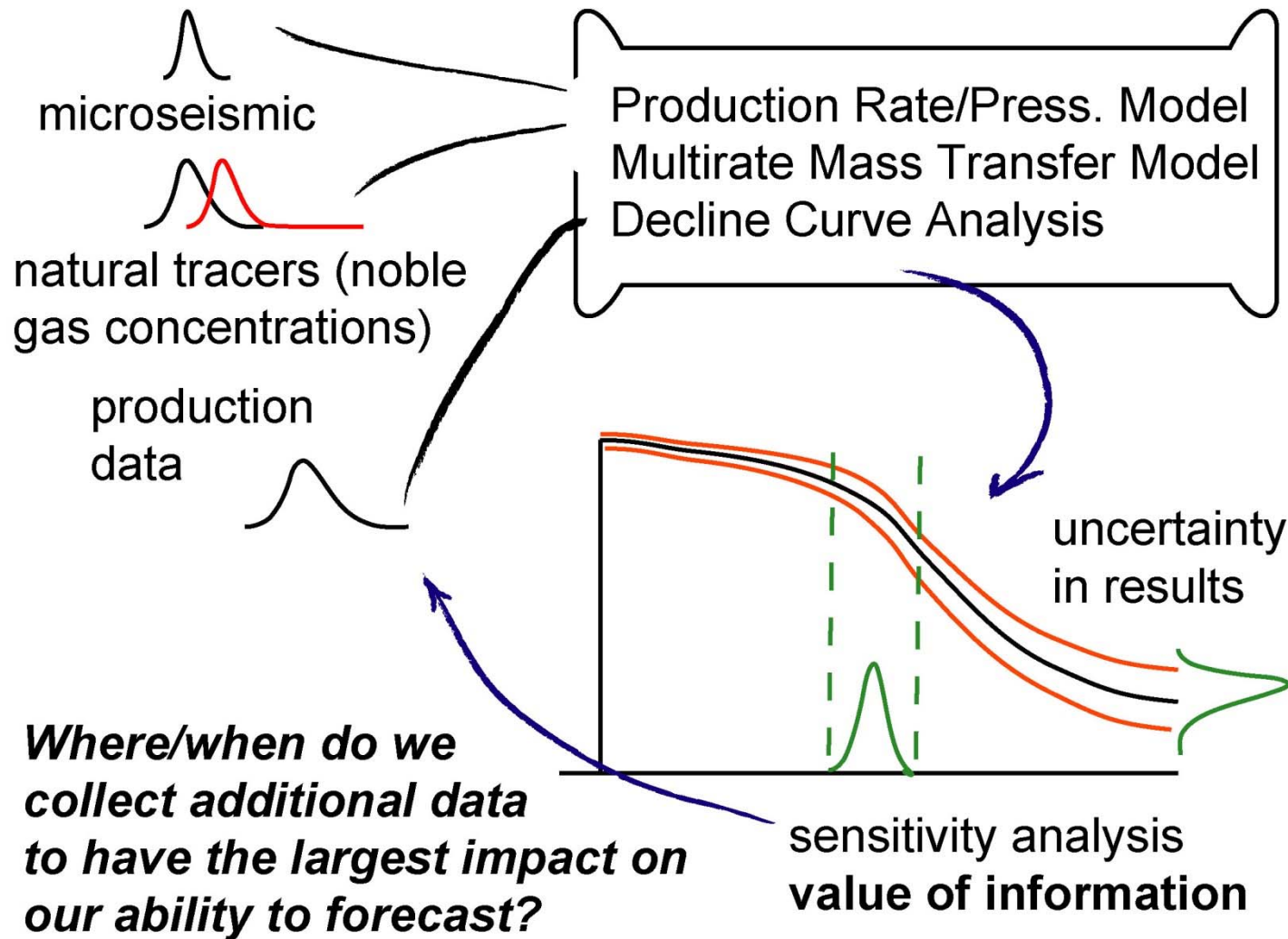
Bayesian Data Analysis

- By their nature hierarchical Bayesian methods have reduced forecast uncertainty due to ‘borrowing statistical strength’
 - Borrowing statistical strength in our application involves the assumption that wells of similar location (and therefore geology), depth, fracking technology, etc. have similar production *model* uncertainty
 - The ability to borrow statistical strength reduces the number of samples needed to achieve the same statistical credibility.
 - ‘Strength’ may also arise from considering additional sources of information, e.g. complimentary computer model results (e.g., multiporosity model) – data fusion.

Borrowing Statistical Strength

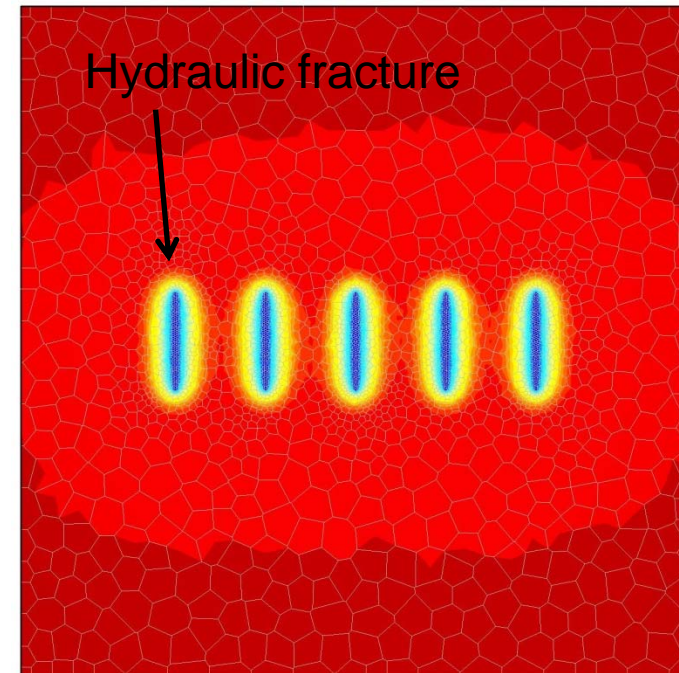
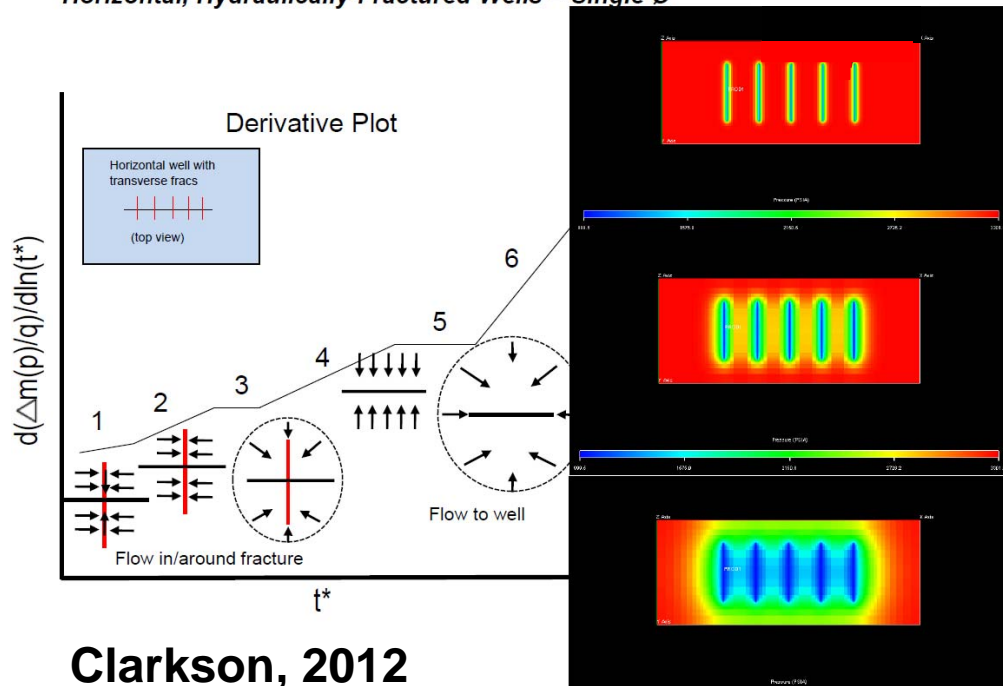


Future Work: Reduction of uncertainty



Future Work: Reservoir Simulator

Horizontal, Hydraulically-Fractured Wells – Single \emptyset



Workflow to assess “early delivery of info” question

- TOUGH2 (EOS7C) simulator reproduces flow regimes
- Evaluation of onset of flow regimes for different tracer species