STANFORD UNIVERSITY

A Strategy for Enhanced Recovery and CO_2 Sequestration in Gas Shales

Mark D. Zoback

Stanford University

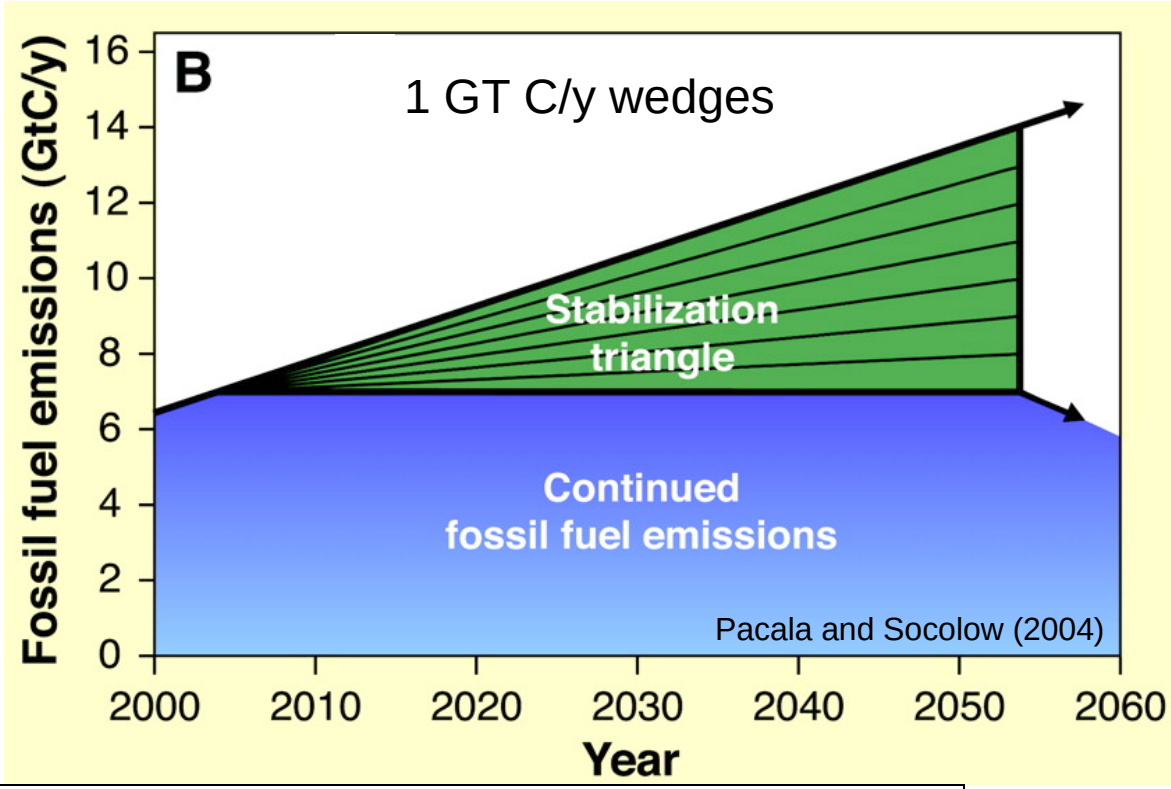
Emerging Abundance of Unconventional Natural Gas from Shales – Strategic and Policy Implications for Producers

Colorado Oil and Gas Association - July 7, 2009

GCEP Global Climate & Energy Project

Switching from Coal to Gas Reduces Emissions by 1 GT C/y

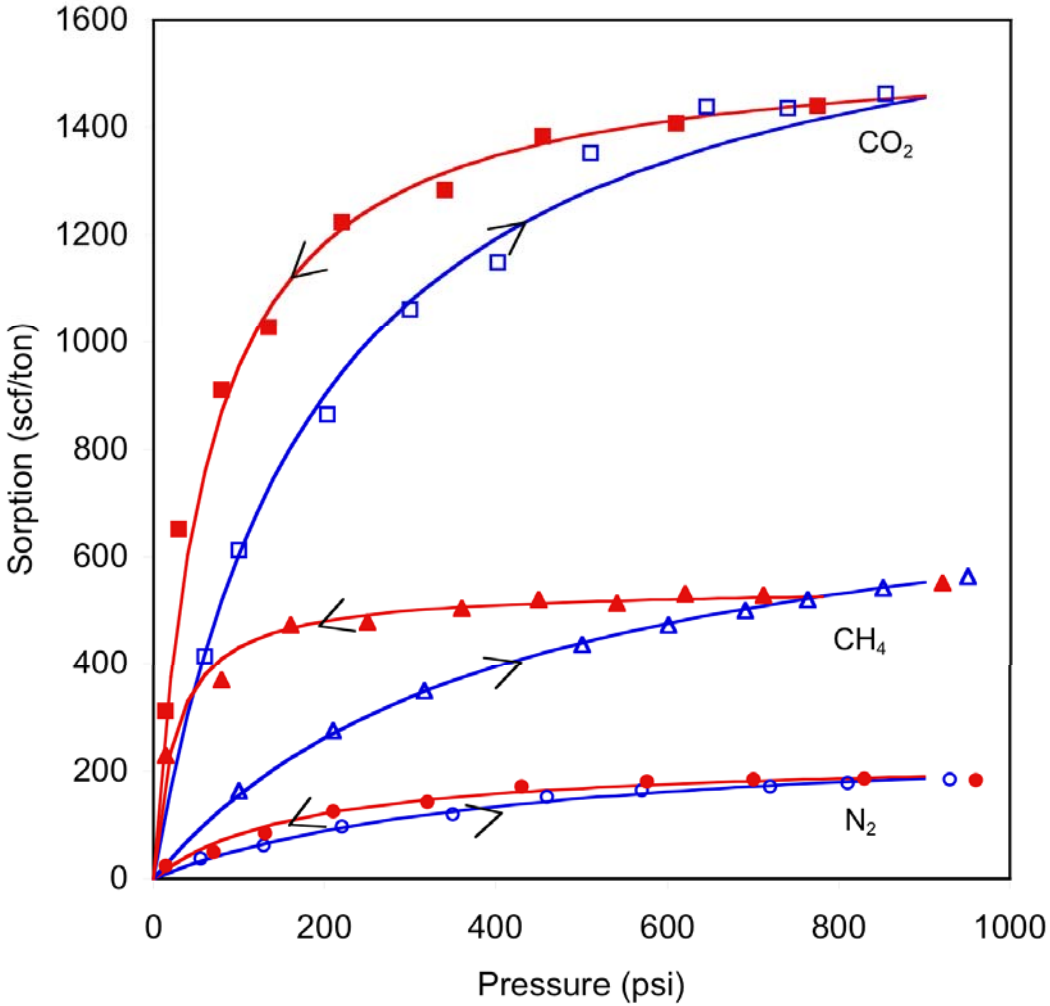
Pacala and Socolow's Potential Wedge #5 - Using Gas Baseload Power to Replace Coal Baseload Power - Provides one, 1 GT C/y wedge

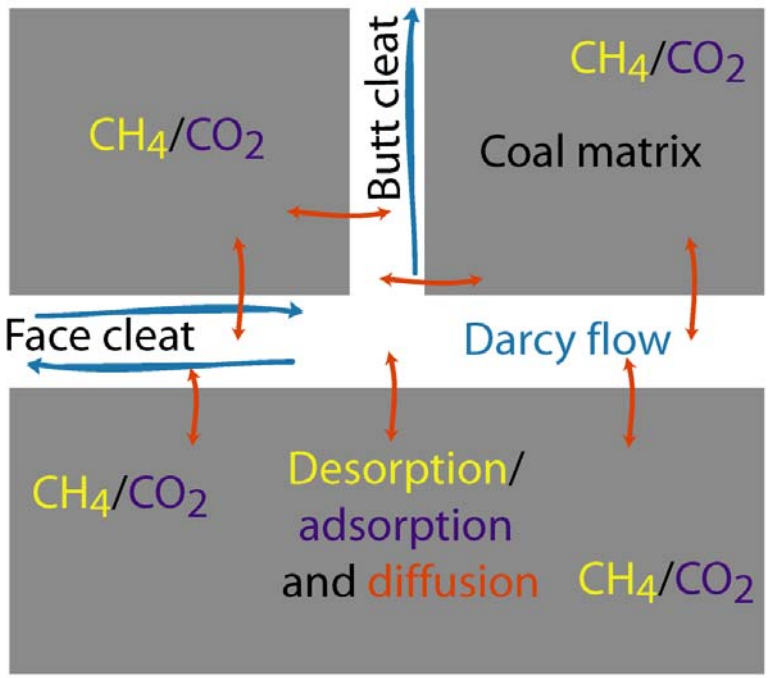


Switching from Coal to Gas With CCS – 2 wedges!

Shale Gas Recoverable Reserves 650 – 2000 TCF (1 TCF ~ QUAD)
Replacing Coal by 2030 Requires Increasing Production to 27 TCF/y

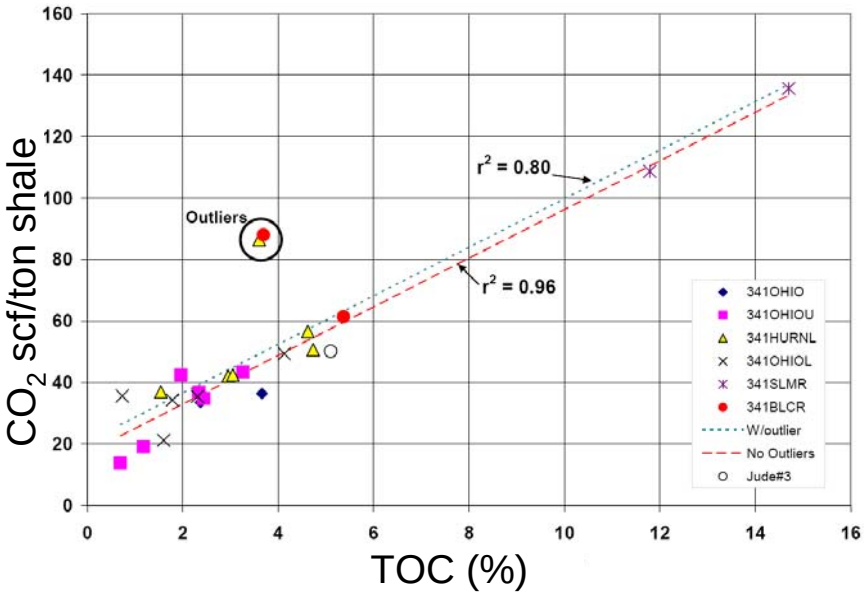
Utilization of CO_2 for Enhanced CBM Production and CCS

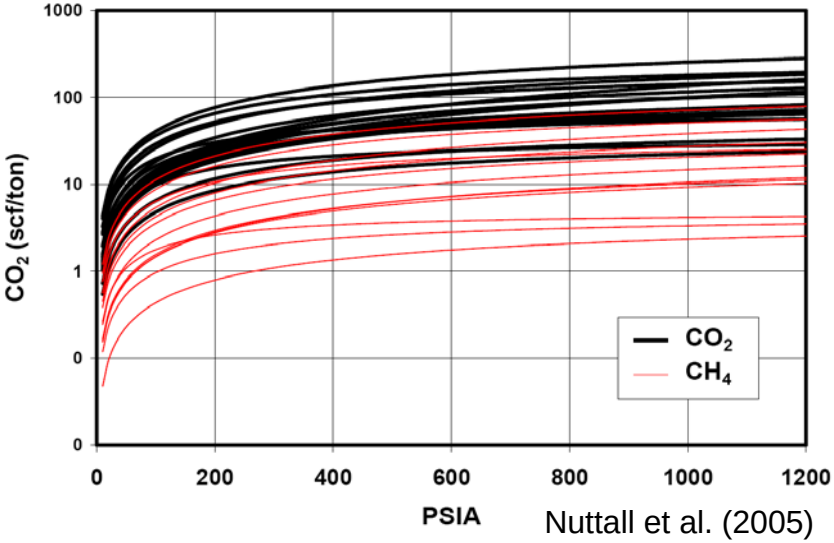




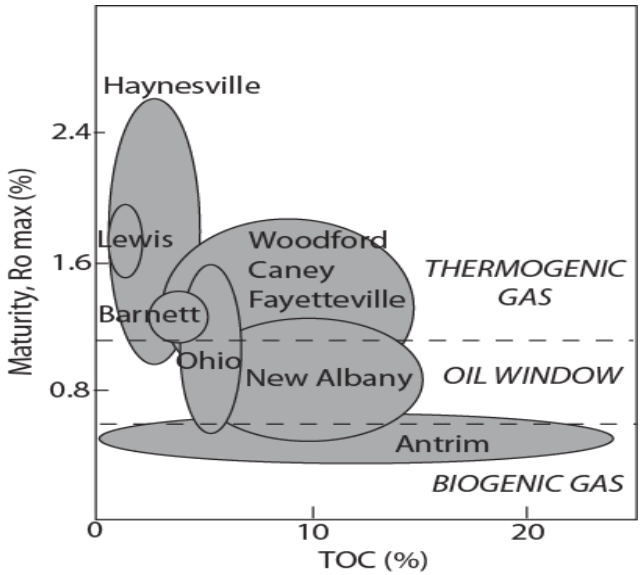
CO_2/CH_4 Adsorption in Appalachian Devonian Shales

- Only one study on shale adsorption for both CO_2 and CH_4
- ~5x greater adsorption of CO_2
- Linear relation between TOC and adsorption capacity

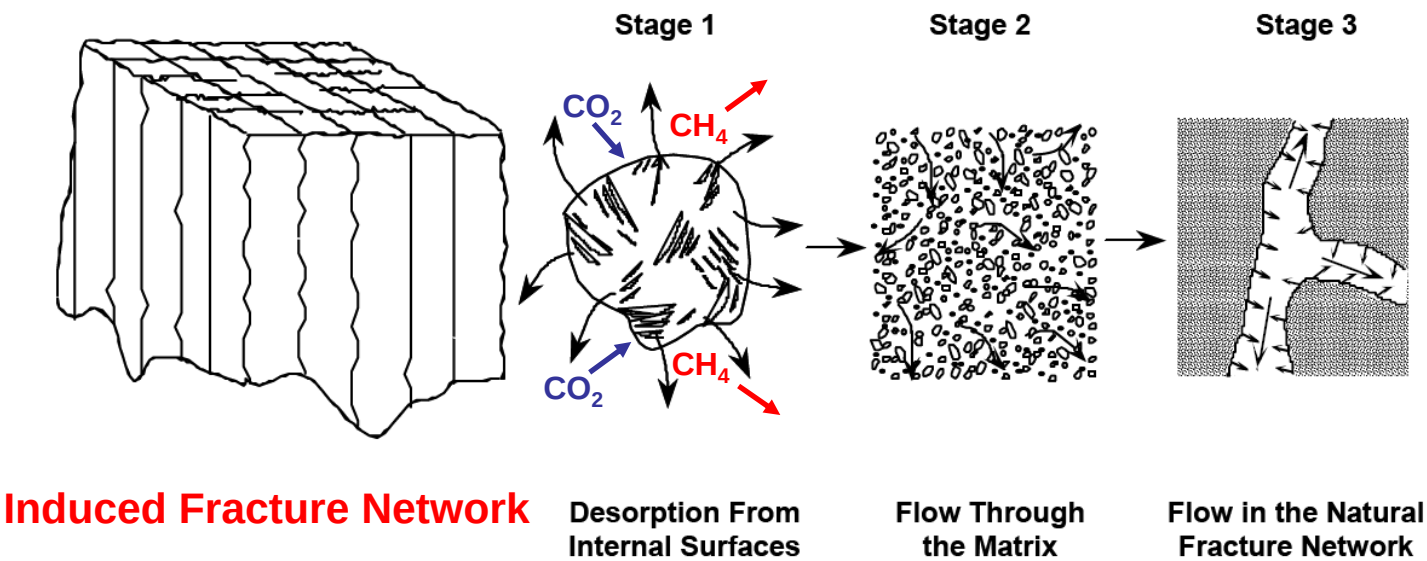




Nuttall et al. (2005)



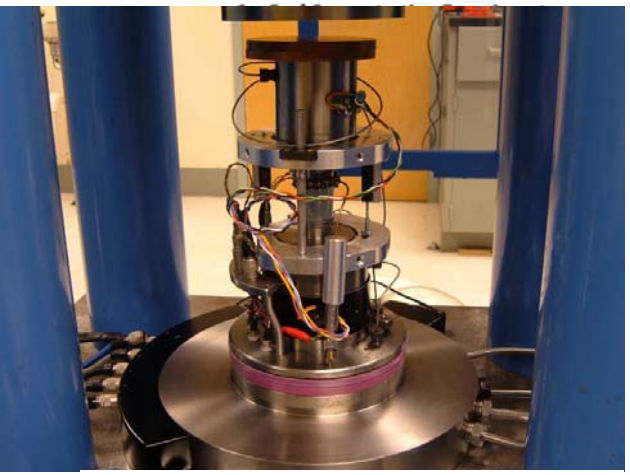
Fundamental Question About Gas Shale Reservoirs

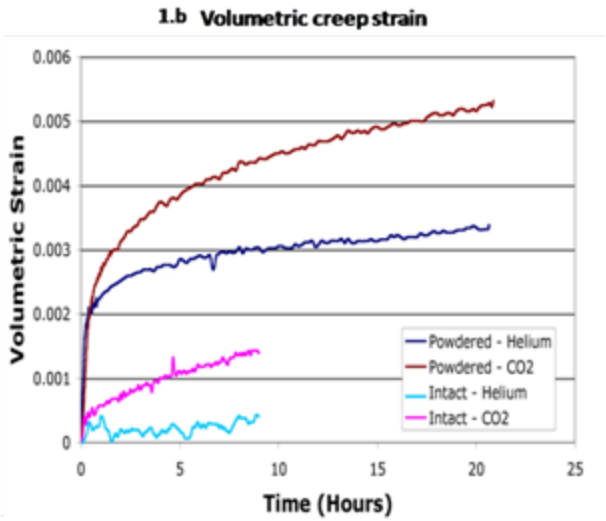


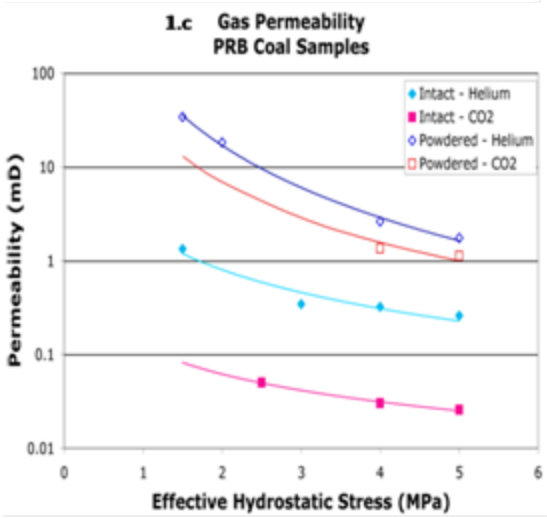
Enhanced Recovery and Carbon Sequestration

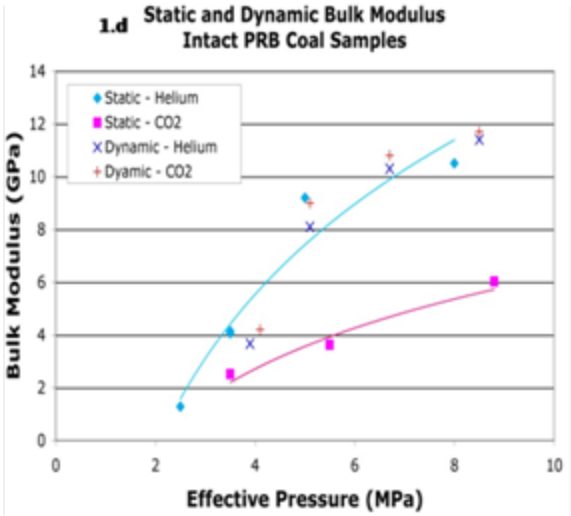
- Is there the potential for significant adsorption of CO_2 and desorption of CH_4 at the pore scale?

CO_2 and Physical Properties









Sample:
Intact & Powdered
Powder River Basin

Adsorption Gas:
CO_2 & Helium

Changing factor
Effective Stress

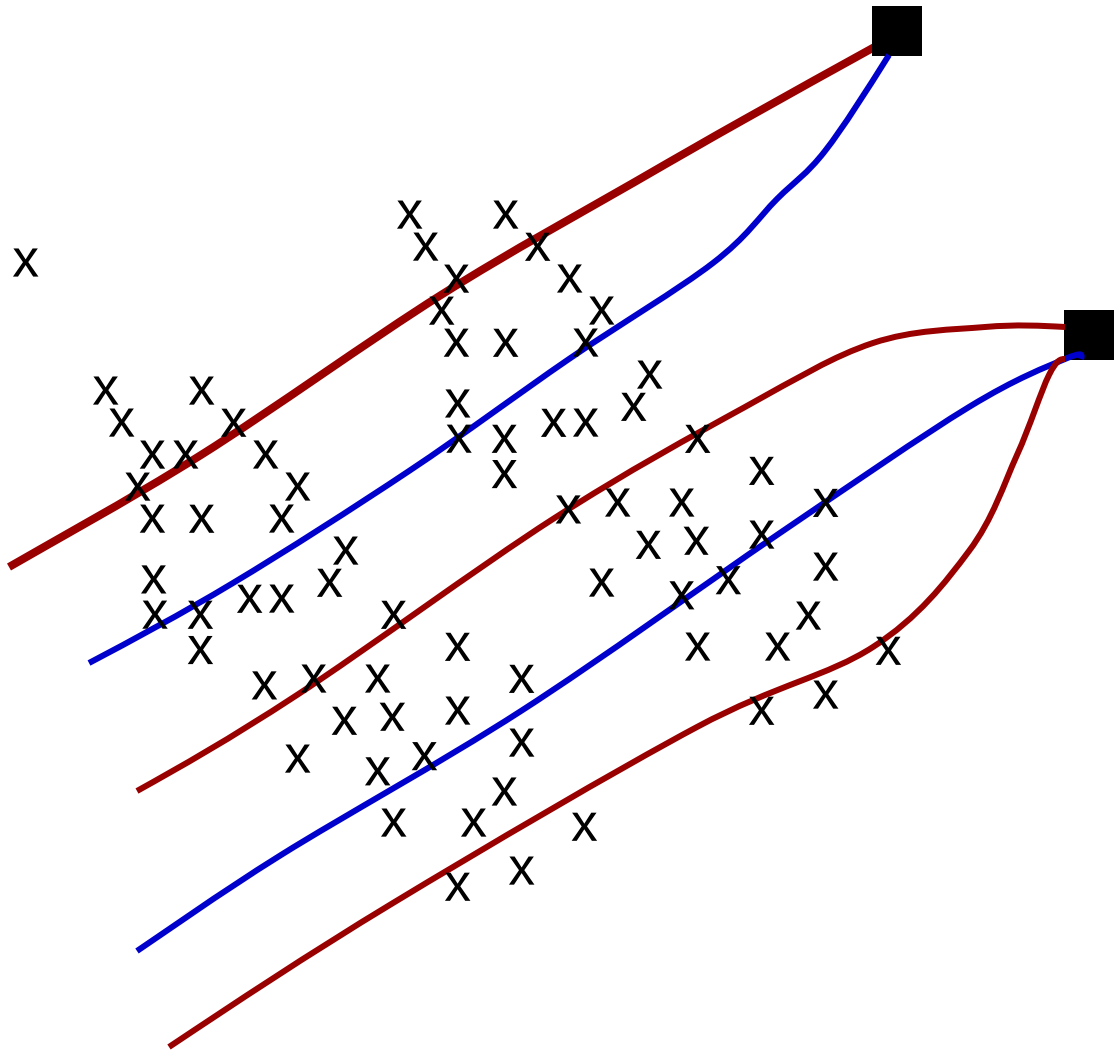
Physical Property:
Permeability
Static & Dynamic bulk Moduli
Volumetric strain

Hagin and Zoback (2009)

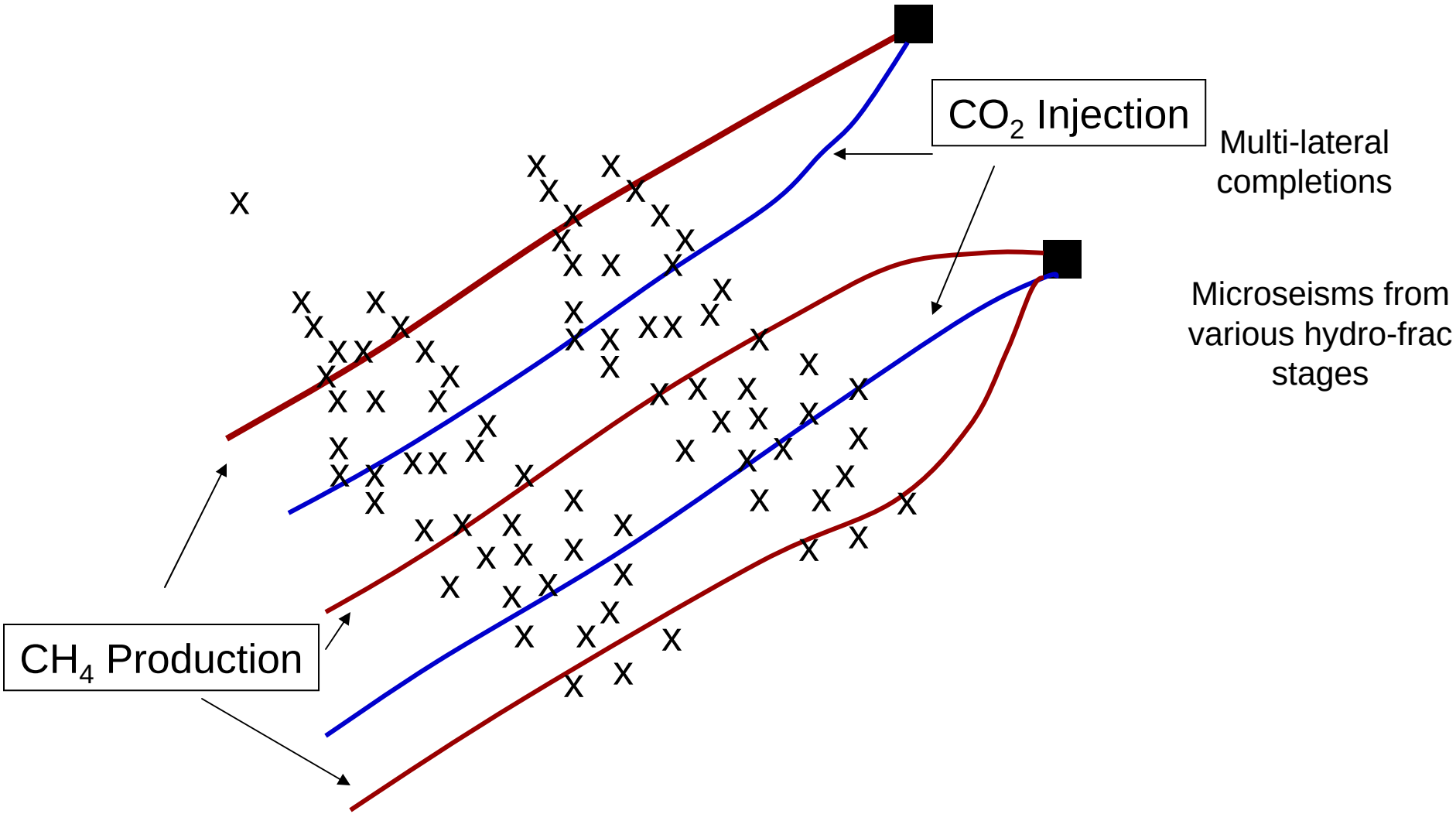
Complications…

- Clay content and type
- Kerogen maturity and type
- Shale fabric and microstructure
- Adsorbed and free gas content
- Water saturation
- Depth and temperature effects
- CO_2 phase
- Geochemistry
- Permeability and diffusion times
- Stress- and adsorption-dependent permeability
- Natural and enhanced fracture networks
- Stress state
- Constitutive models
- Injection rate
- Production design

Current Drilling and Stimulation Schemes



Multi-lateral completions

Microseisms from various hydro-frac stages

So if It's Going to Happen, Let's Do It Right