Effects of In-situ Conditions on Relative Permeability Characteristics of CO_2-Brine Systems

Dr. Stefan Bachu
Alberta Energy and Utilities Board

Dr. Brant Bennion
Hycal Energy Research Laboratories

EUB Alberta Energy and Utilities Board
Alberta Geological Survey
AGS

HYCAL ENERGY RESEARCH LABORATORIES LTD.

Stefan.Bachu@gov.ab.ca

CO_2 Storage in Geological Media

- In oil and gas reservoirs
- In coal beds
- In deep saline aquifers:
  - Static trapping in stratigraphic and structural enclosures
  - Hydrodynamic trapping in deep long-range flow systems
  - Residual-gas trapping in the pore space

➡ Need to know the relative-permeability displacement characteristics of CO_2-brine systems for storage capacity and for CO_2 injectivity and migration

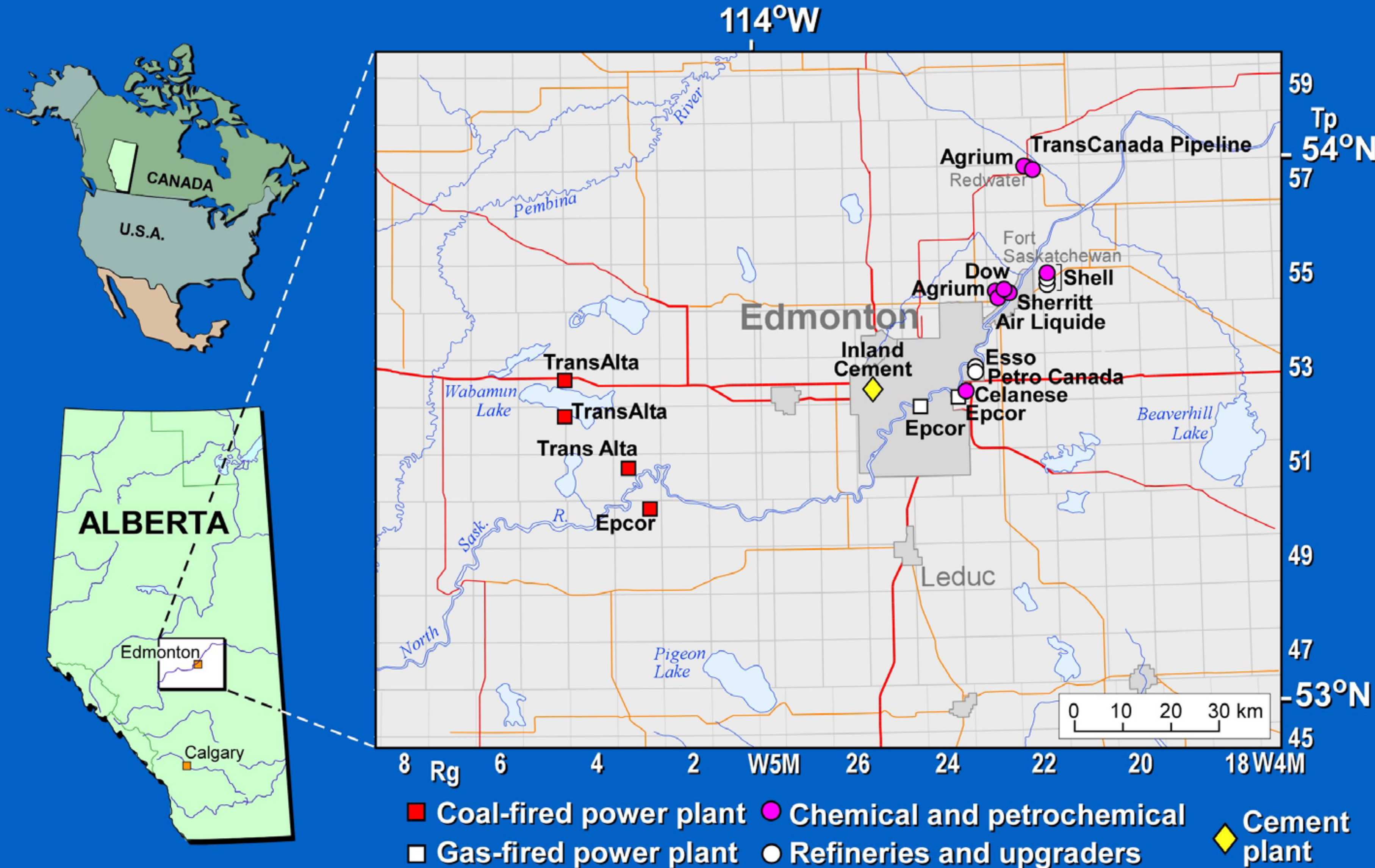
Laboratory Work and Detailed Results

Details in a series of SPE papers by Bennion and Bachu:

- SPE 95547 – presented at the SPE Annual Technical Conference and Exhibition, Dallas, TX, October 9-12, 2005
- SPE 99325 – to be presented at the SPE/DOE 15th Symposium on Improved Oil Recovery, Tulsa, OK, April 22-26, 2006
- SPE 99326 – to be presented at the SPE Europec/EAGE Annual Conference and Exhibition, Vienna, Austria, June 12-15, 2006
- SPE 102138 – to be presented at the SPE Annual Technical Conference and Exhibition, San Antonio, TX, September 24-27, 2006

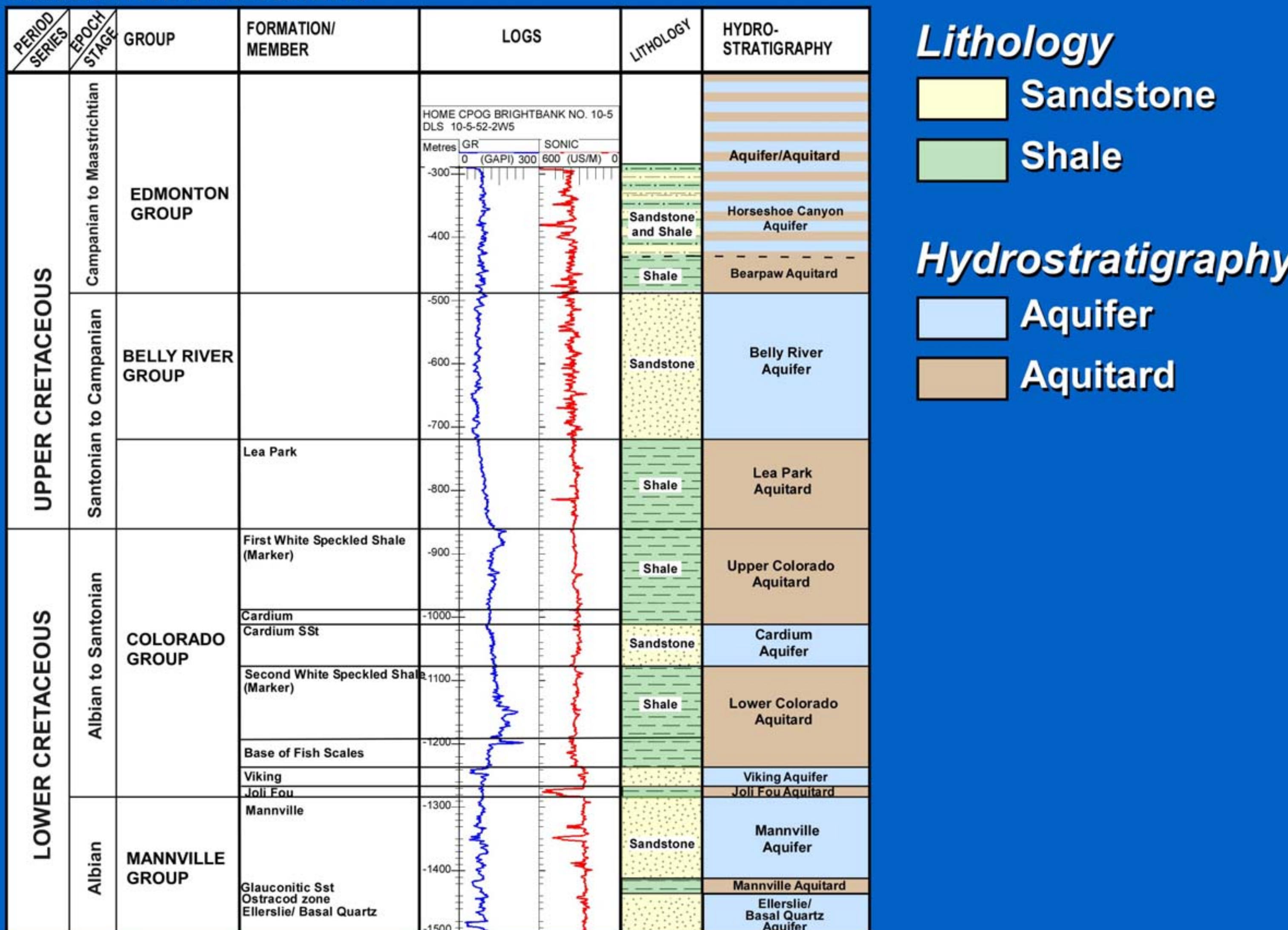
Work in progress; new and synthesis results presented here; Synthesis data in tables in the written abstract.

Location of Major CO_2 Sources in the Edmonton – Wabamun Lake Area

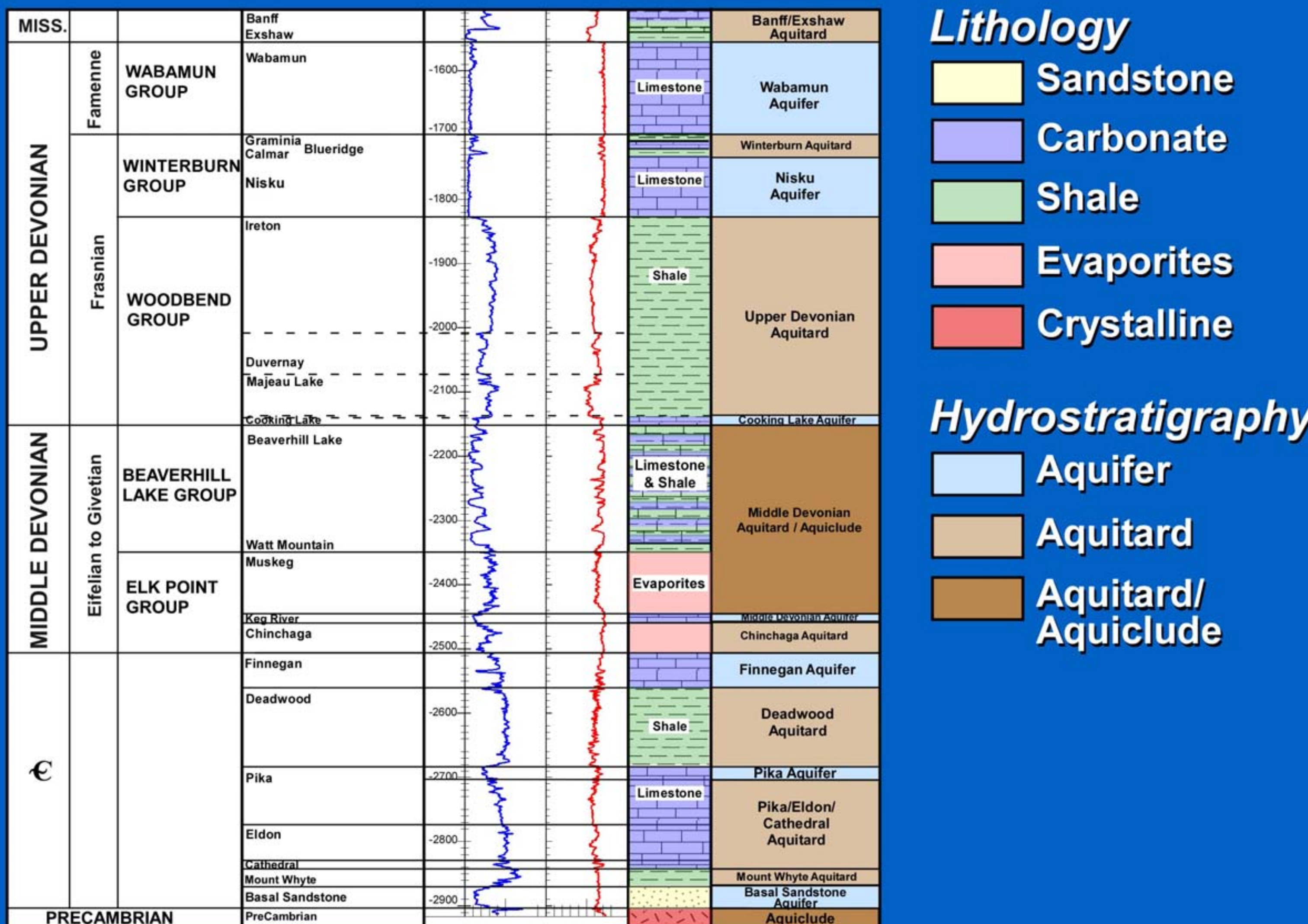


Down-Hole Stratigraphic Model for the Lake Wabamun Area, Alberta, Canada – Pre-Cretaceous Unconformity to Surface

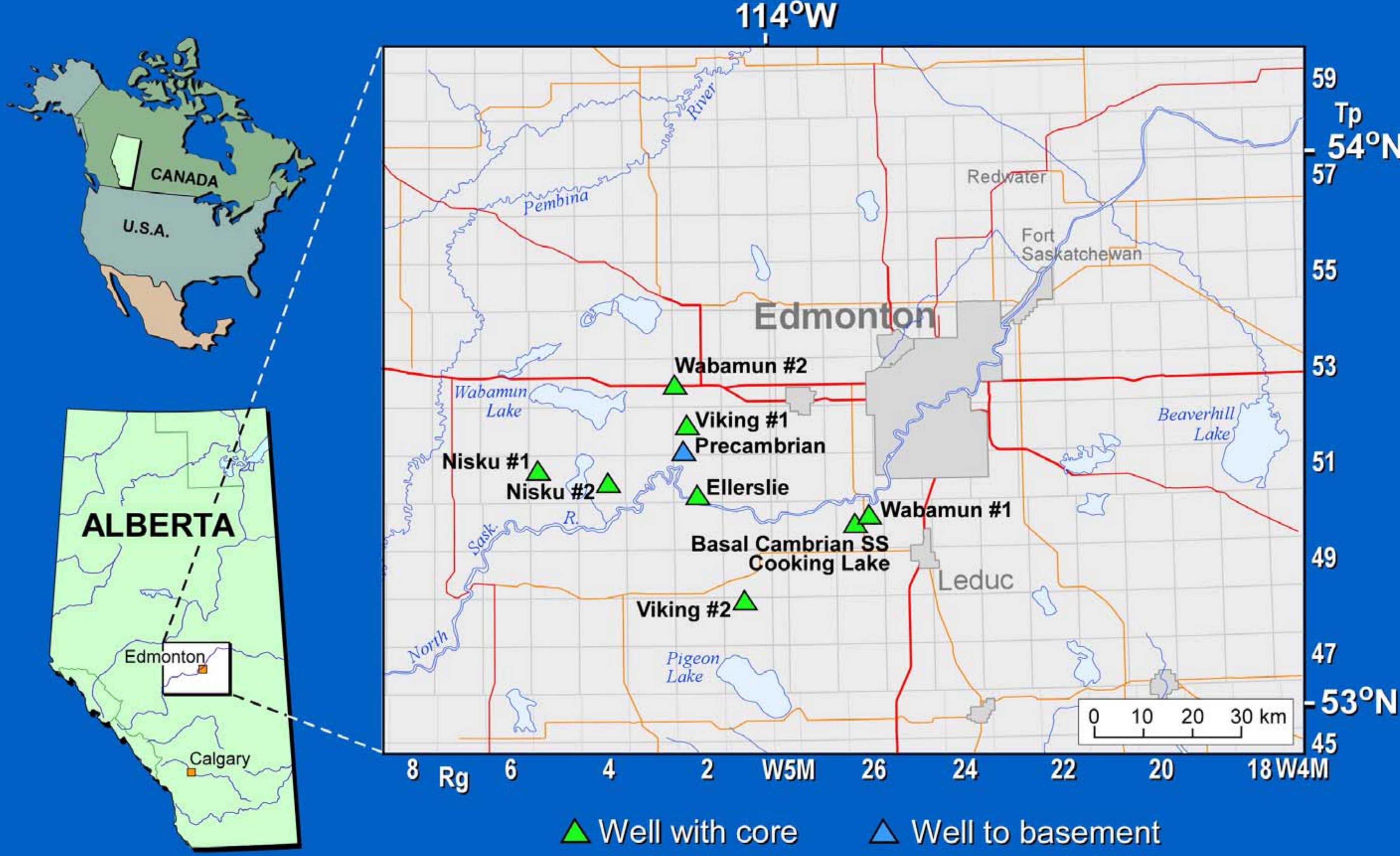
Location:00/10-05-052-2W5



Down-Hole Stratigraphic Model for the Lake Wabamun Area, Alberta, Canada – Precambrian to Pre-Cretaceous Unconformity



Location of Wells with Core Tested for Relative Permeability of Brine-CO_2 Systems



Capillary Pressure and Relative Permeability

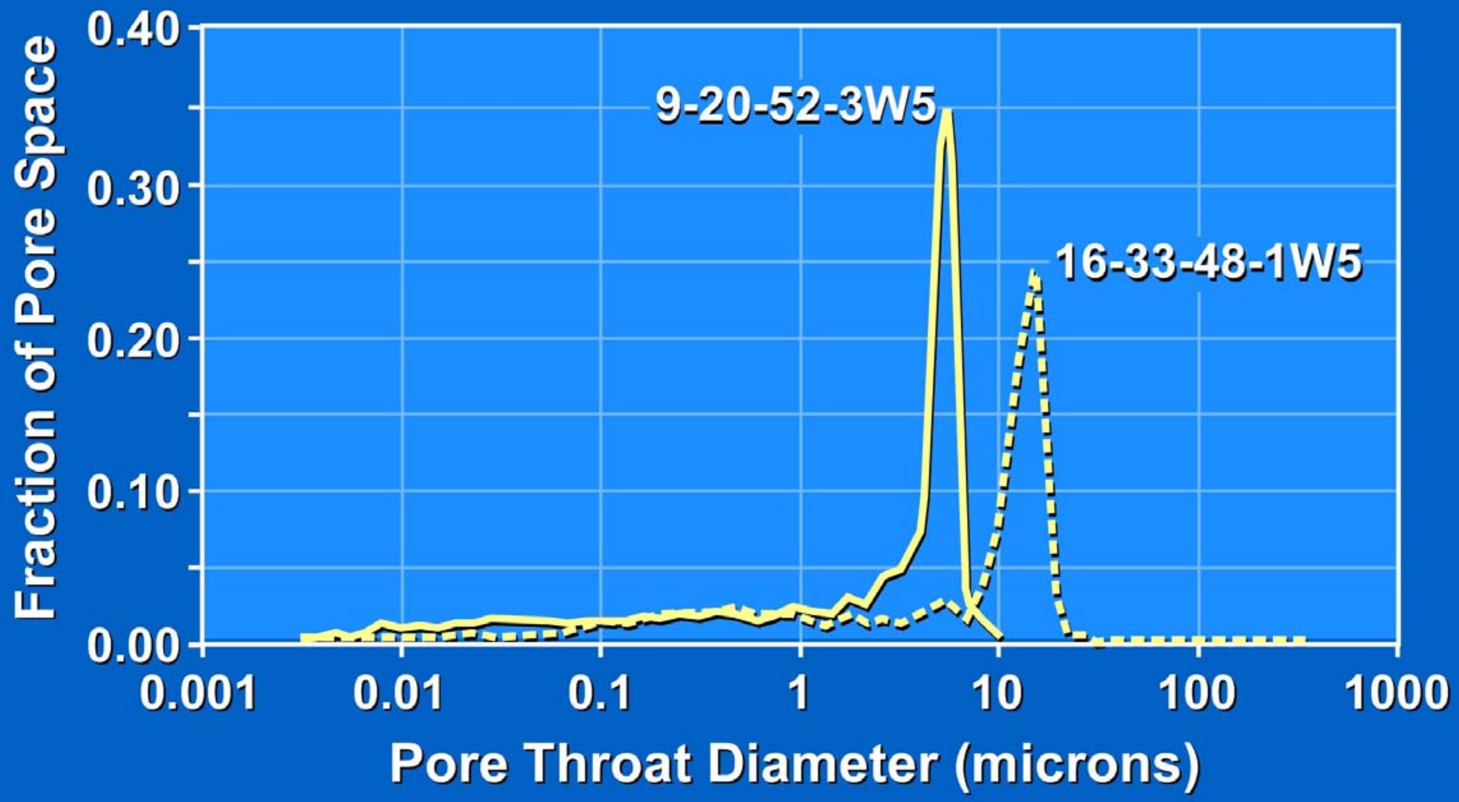
$$P_c = 2 \times IFT \times \cos\theta / r = 4 \times IFT \times \cos\theta / d$$

If displacement characteristics depend on the capillary pressure P_c, and the interfacial tension IFT depends on in-situ conditions, then:

➡ The relative permeability of brine-CO_2 systems depends on in-situ conditions!

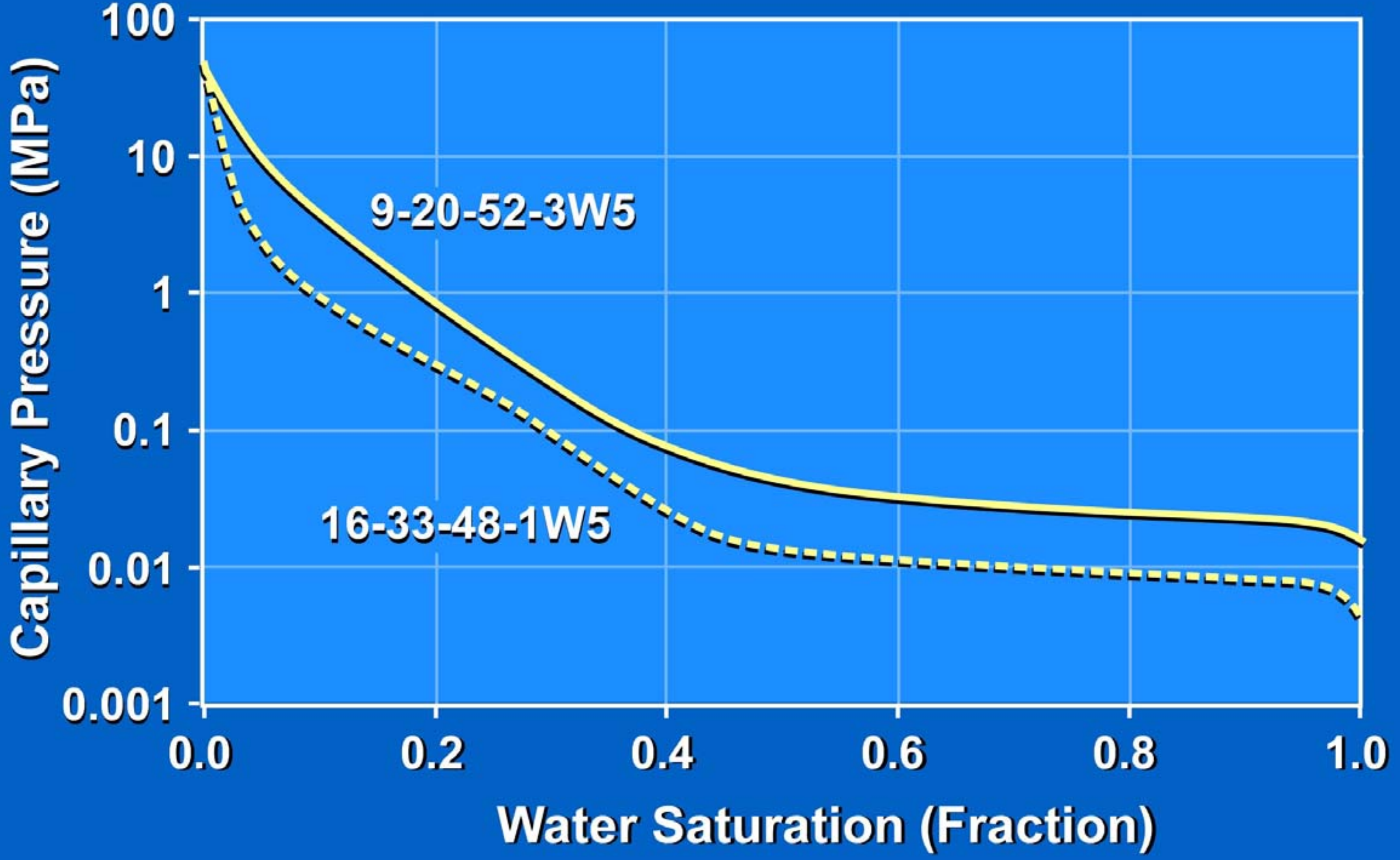
Pore Size Distribution for Viking Fm. Sandstone

Wabamun Lake Area, Alberta Basin, Canada

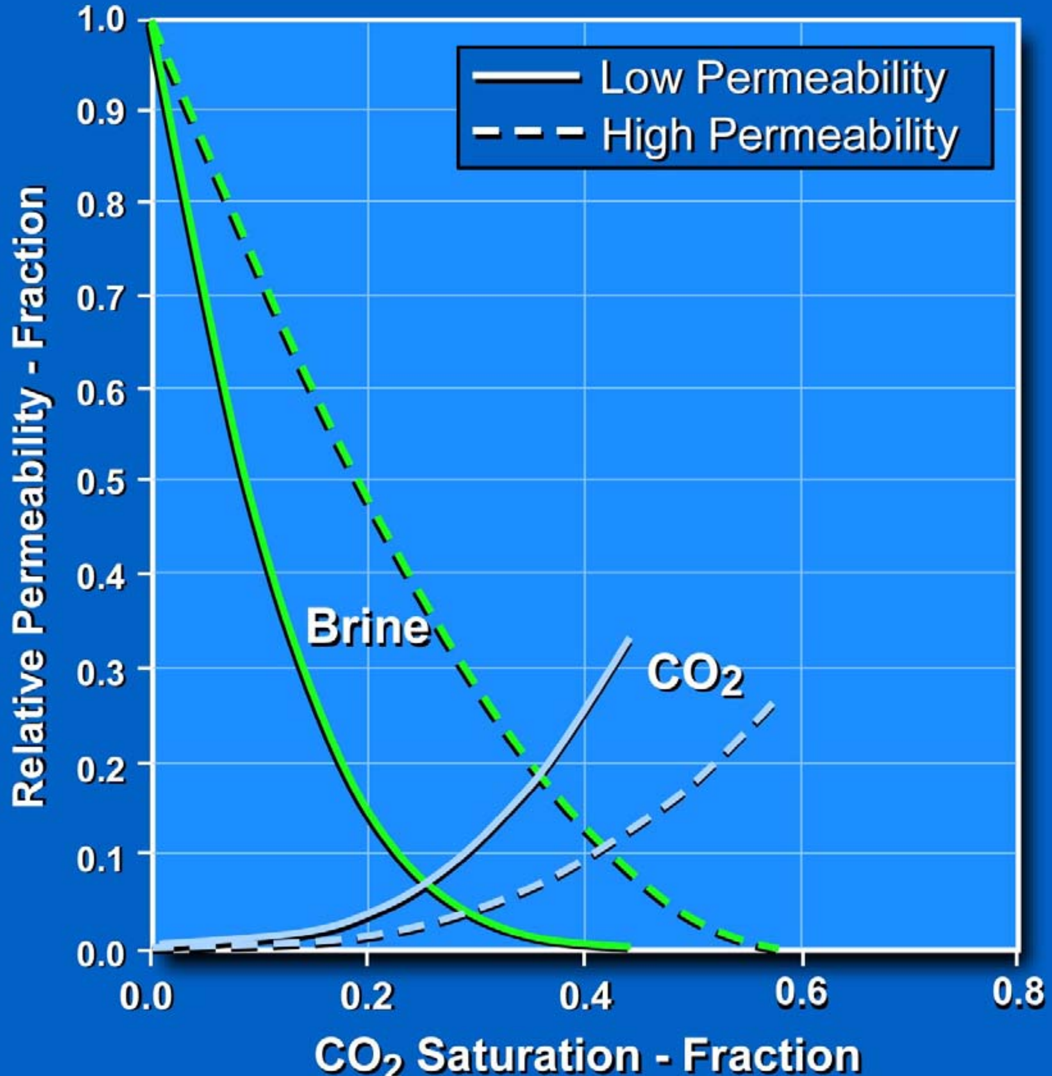


CO_2-Brine Capillary Pressure for Viking Fm. Sandstone

Wabamun Lake Area, Alberta Basin, Canada



Relative Permeability of Brine and CO_2 in Viking Fm. Sandstone

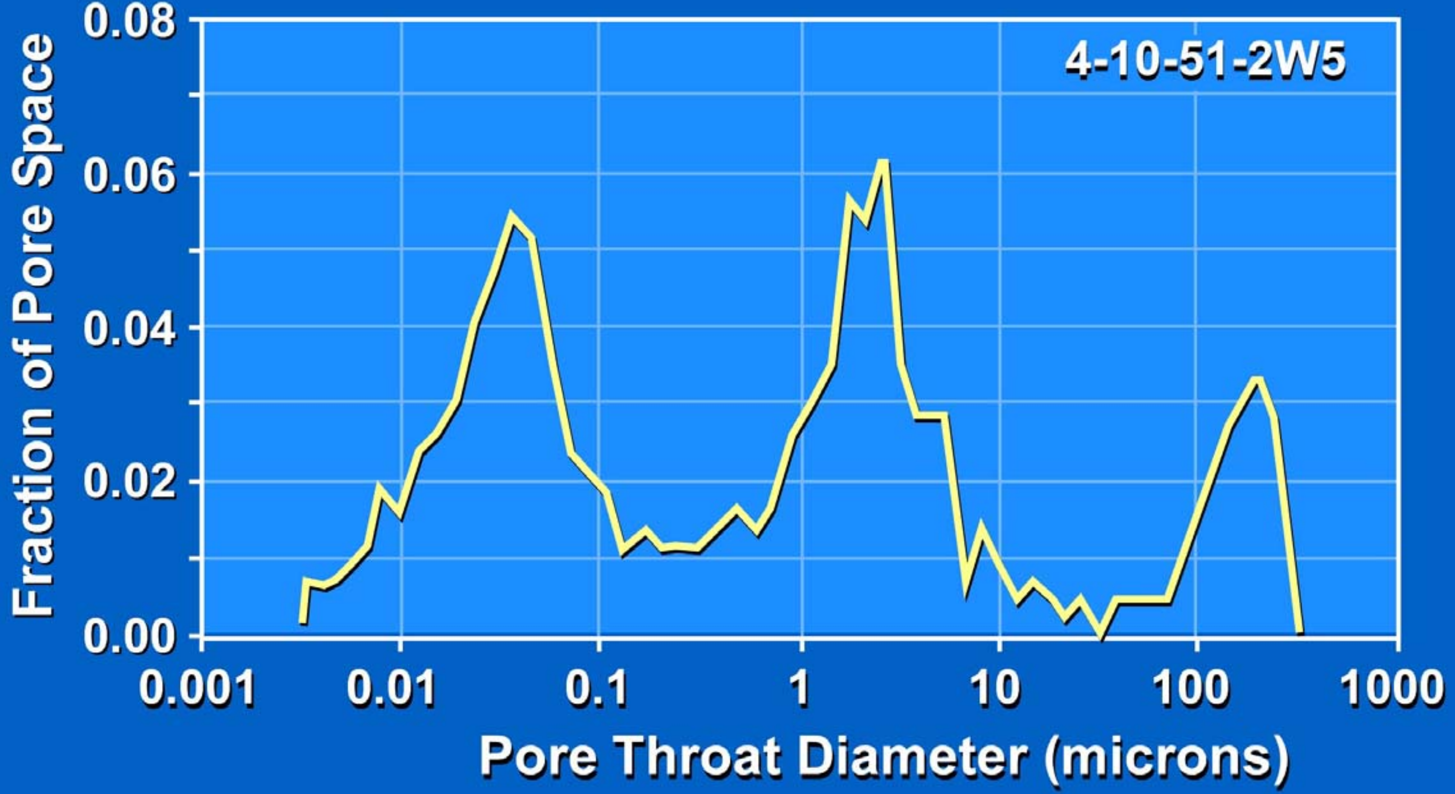


Low Permeability
Well 09-20-52-03W5M
Depth 1240.35 m

High Permeability
Well 16-33-48-01W5M
Depth 1342.46 m

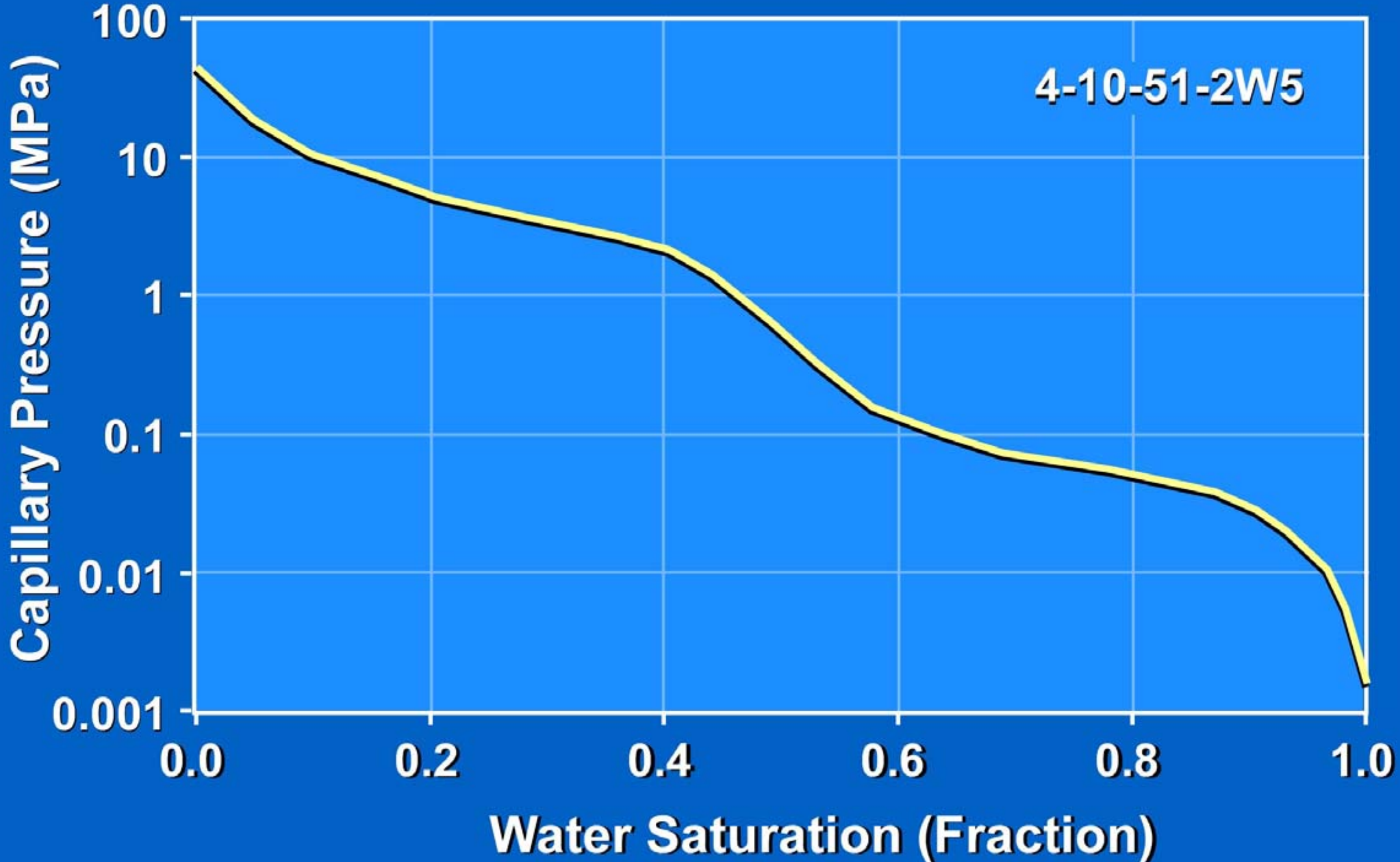
Pore Size Distribution for Ellerslie Fm. Sandstone

Wabamun Lake Area, Alberta Basin, Canada



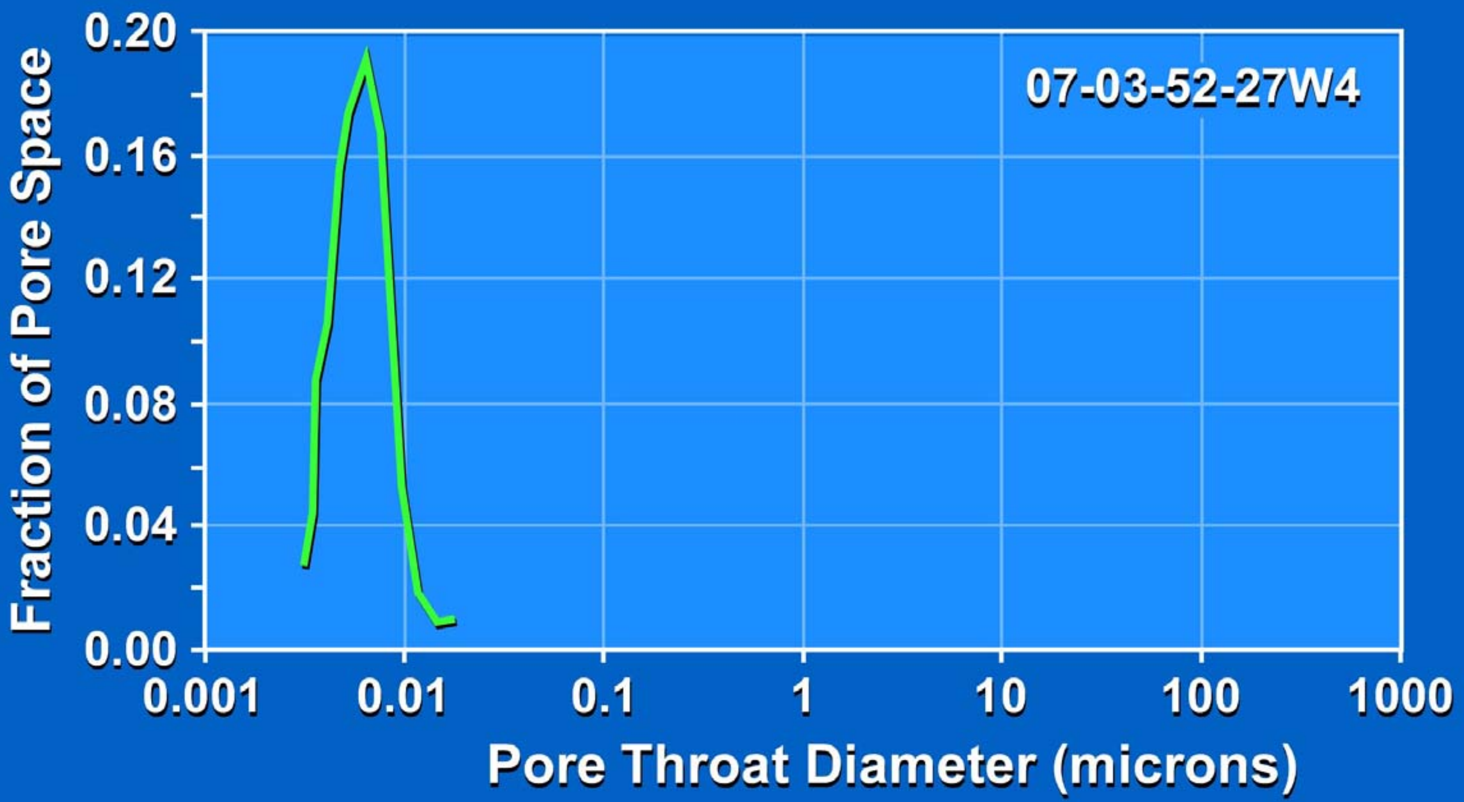
CO_2-Brine Capillary Pressure for Ellerslie Fm. Sandstone

Wabamun Lake Area, Alberta Basin, Canada



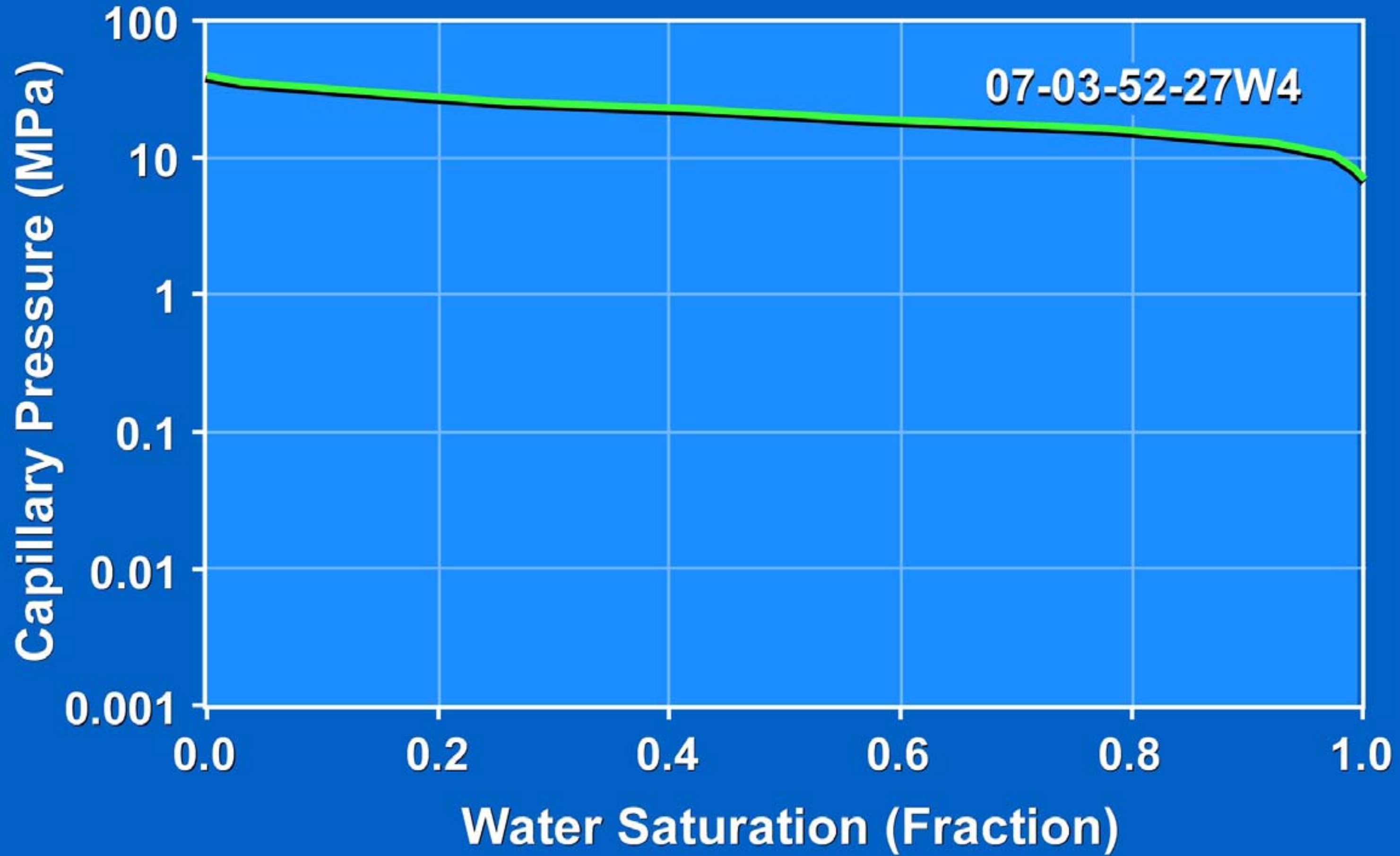
Pore Size Distribution for Calmar Fm. Shale

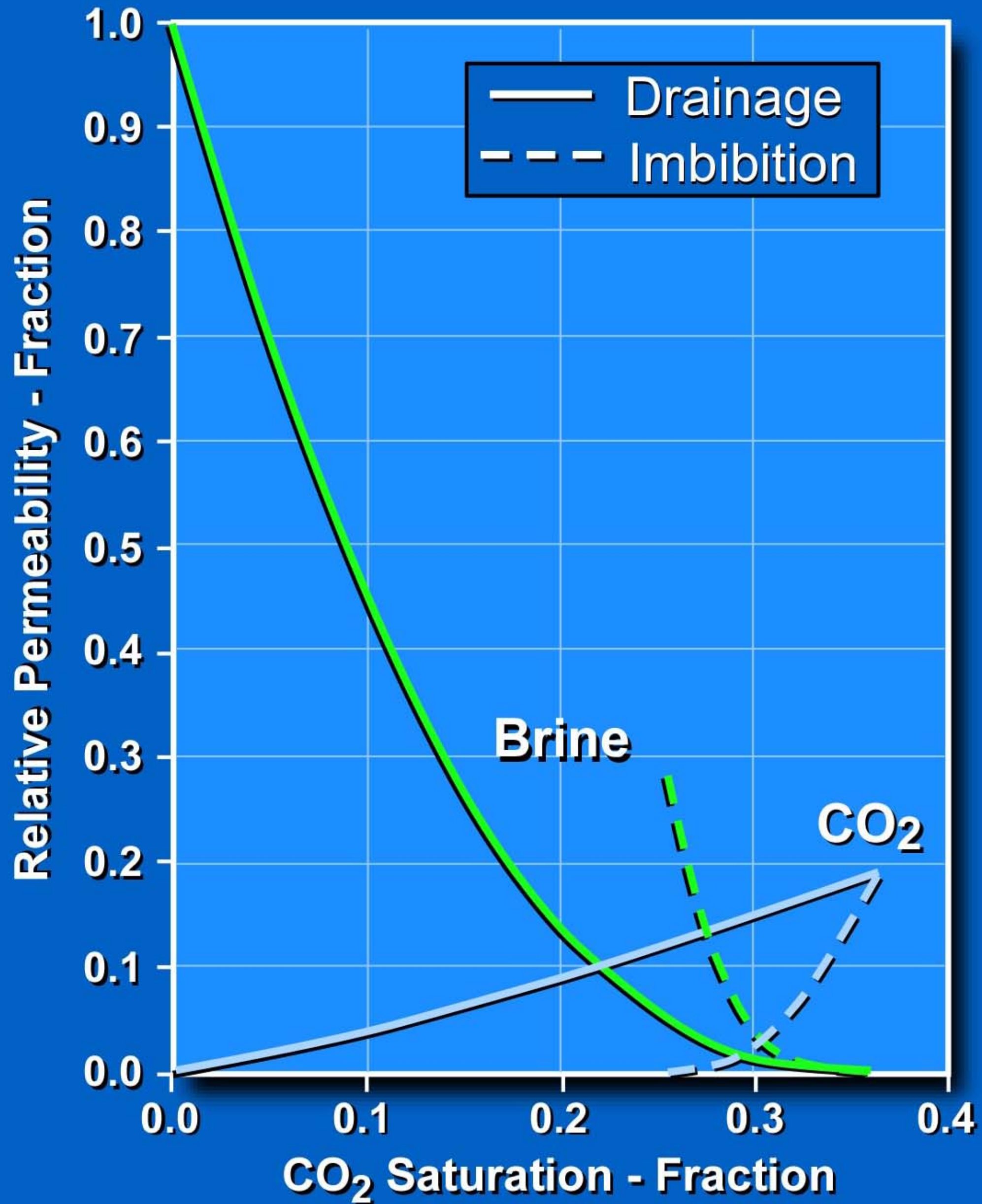
Wabamun Lake Area, Alberta Basin, Canada



CO_2-Brine Capillary Pressure for Calmar Fm. Shale

Wabamun Lake Area, Alberta Basin, Canada

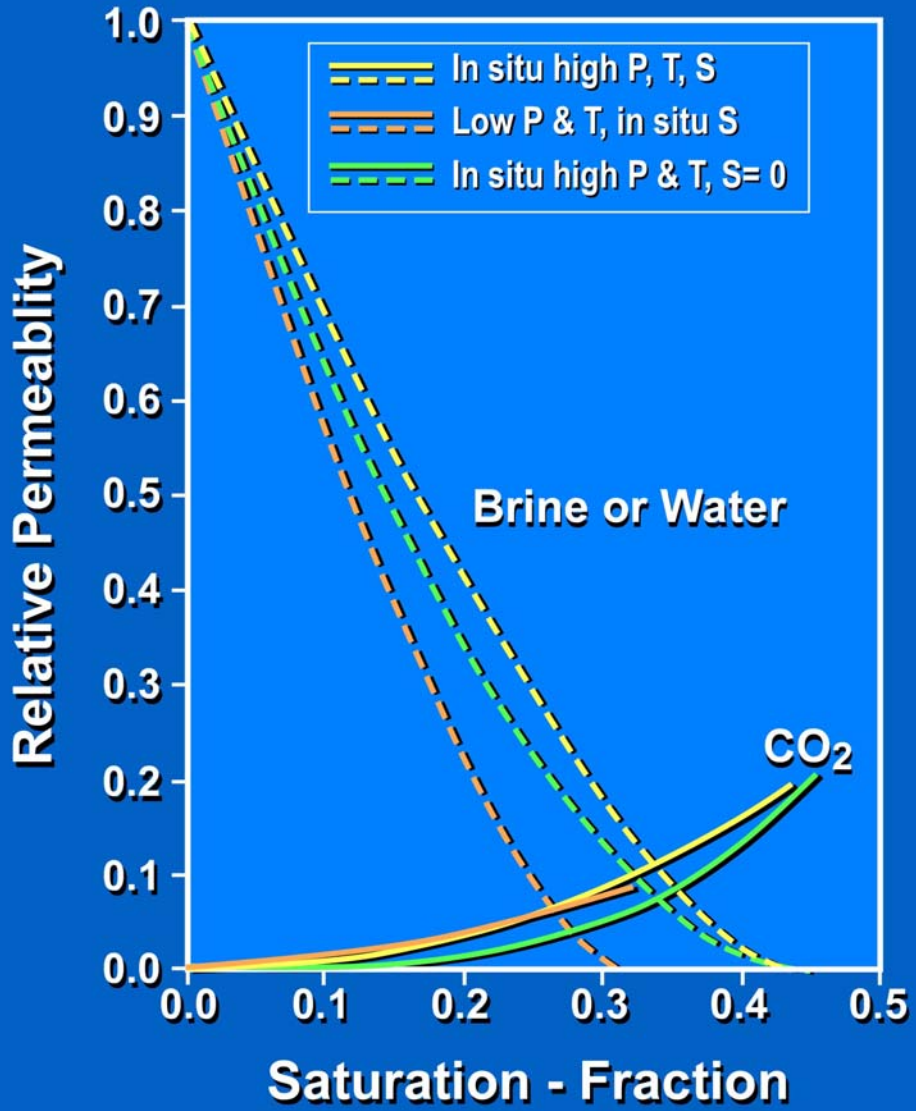




Relative Permeability of Brine and CO_2 in Calmar Fm. Shale

Well 07-03-52-27W5M;
Depth 1566.05 m

Relative Permeability of CO_2-Brine in Wabamun Group Carbonate

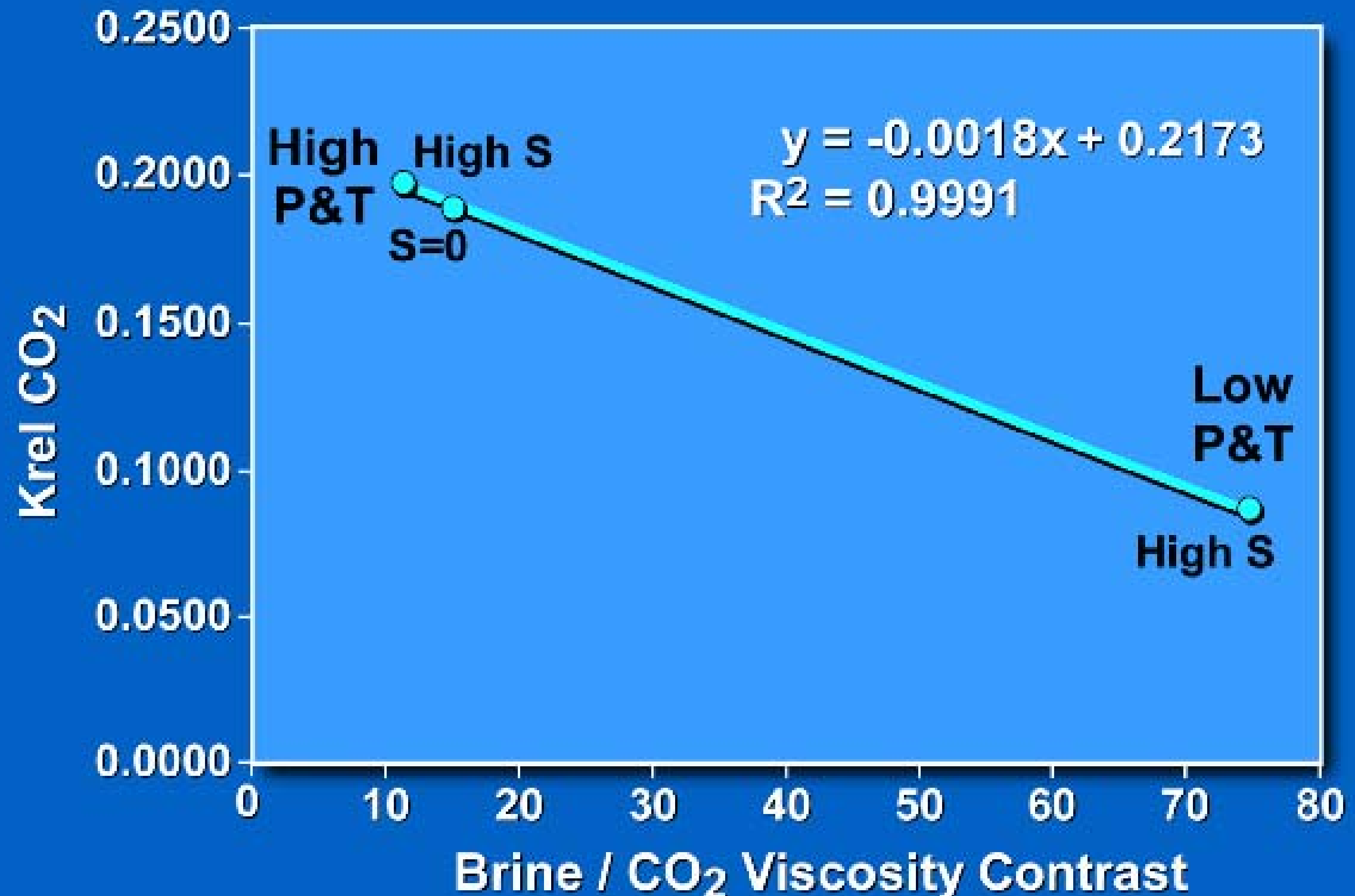


Well 04-20-53-02W5M;
Depth 1602.64 m

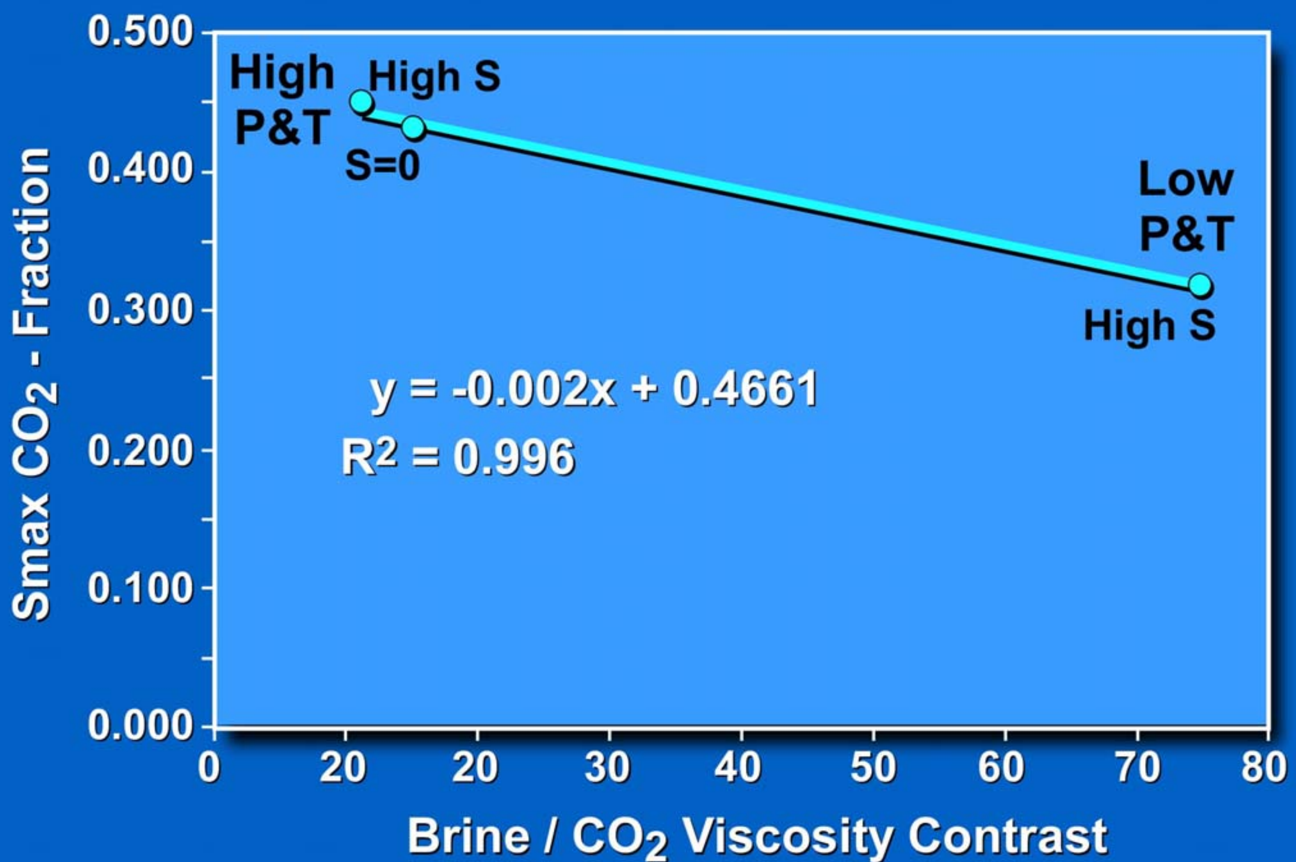
T = 41ºC
P = 11,920 kPa
S = 144,304 mg/l

Low P & T
T = 20ºC
P = 3,445 kPa

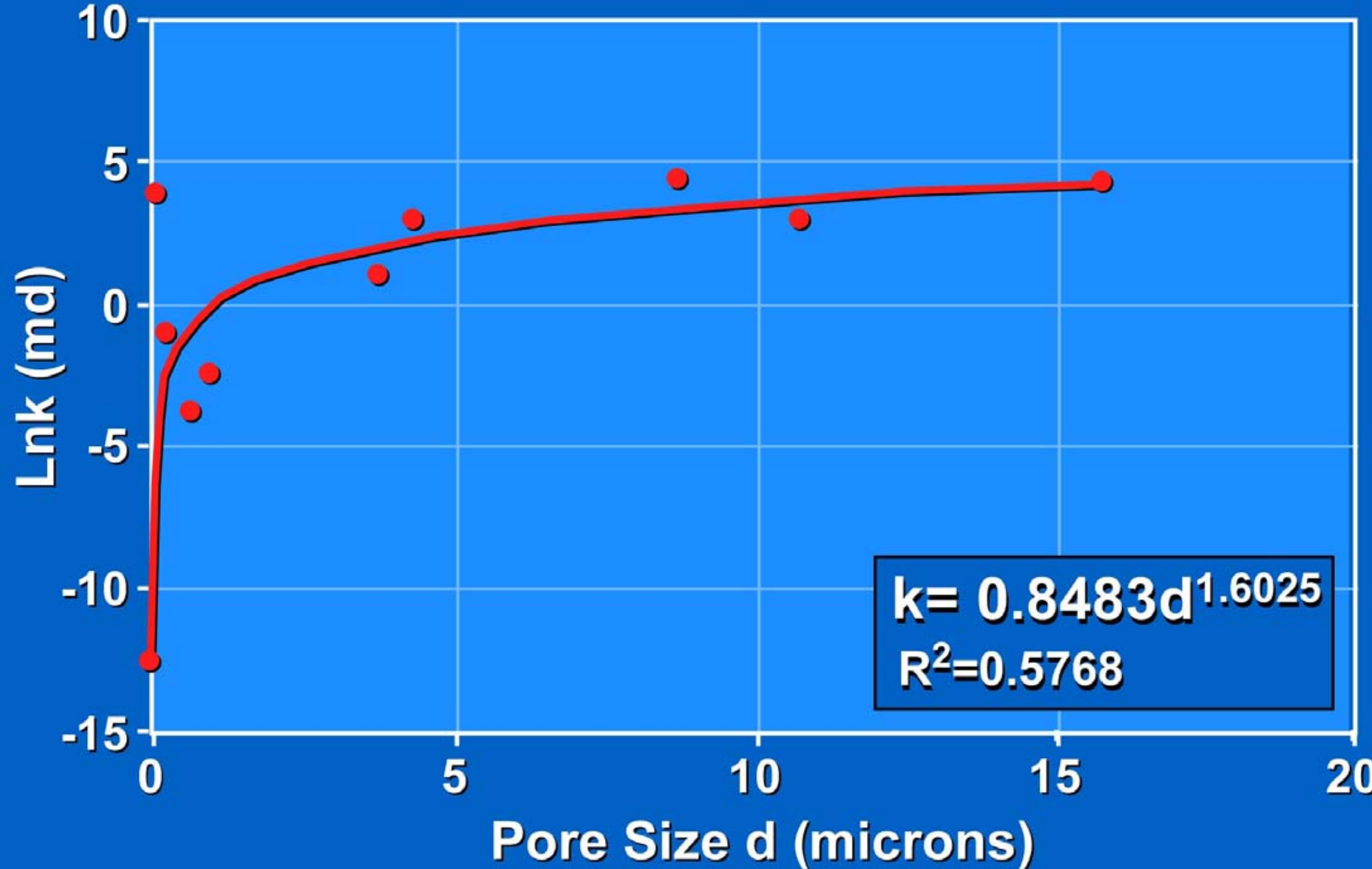
Effect of Viscosity Contrast on Endpoint CO_2 Relative Permeability for Wabamun Gp. Core Sample, Wabamun Lake Area, Alberta, Canada



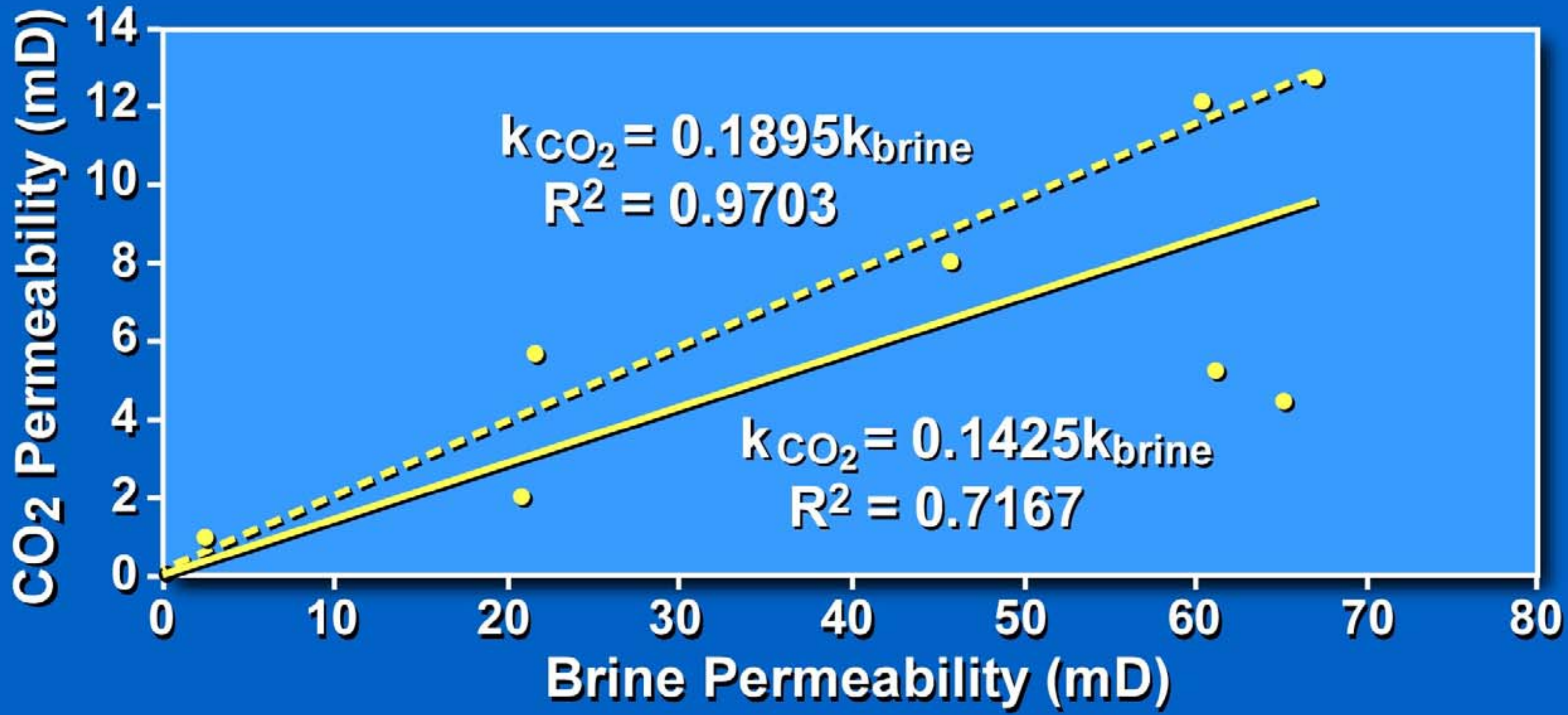
Effect of Viscosity Contrast on Maximum CO_2 Saturation for Wabamun Gp. Core Sample, Wabamun Lake Area, Alberta, Canada



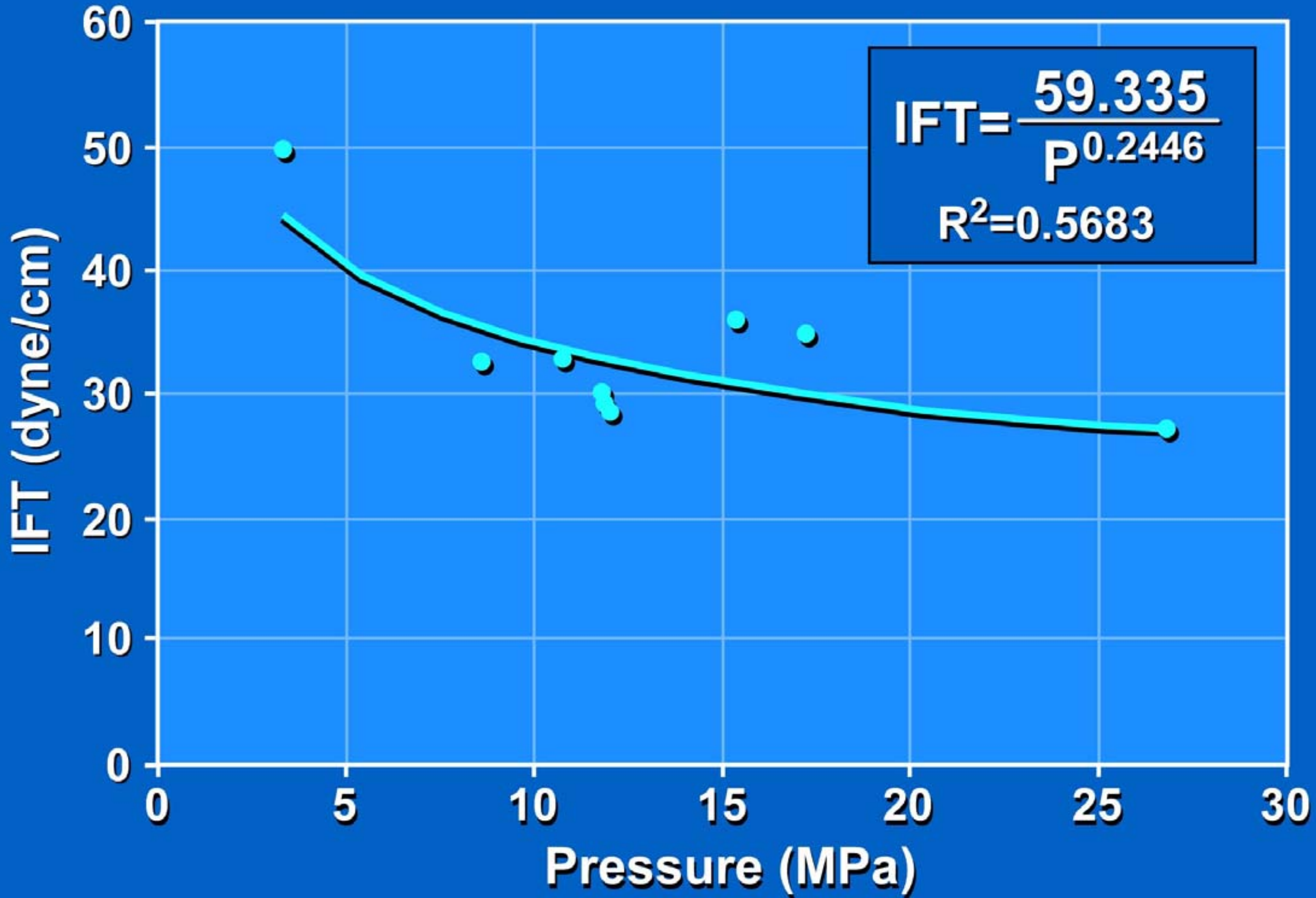
Variation of Permeability to Brine at In-situ Conditions With Rock Pore Size



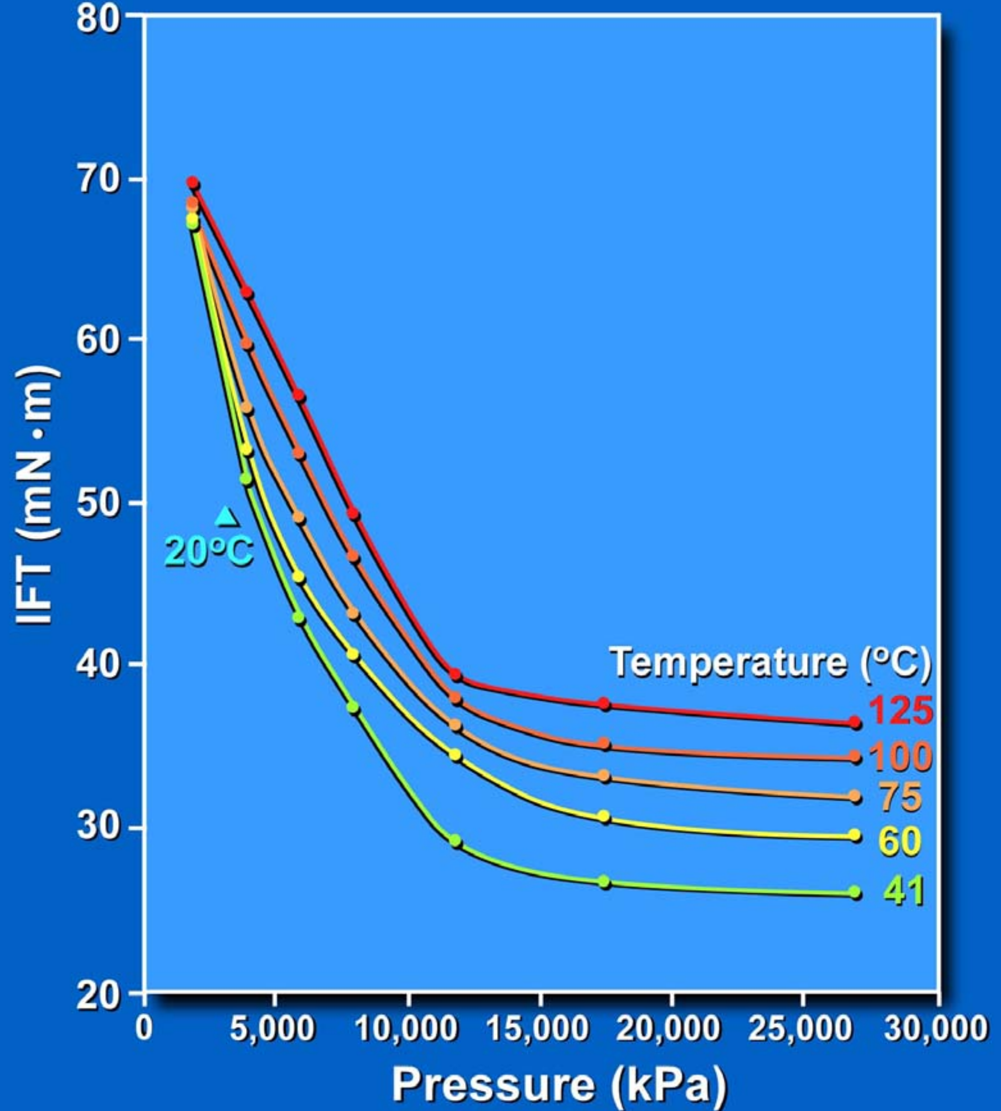
Relative Permeability of CO_2 at Irreducible Brine Saturation versus Permeability to Brine



Variation of Interfacial Tension of CO_2-Brine Systems with Pressure

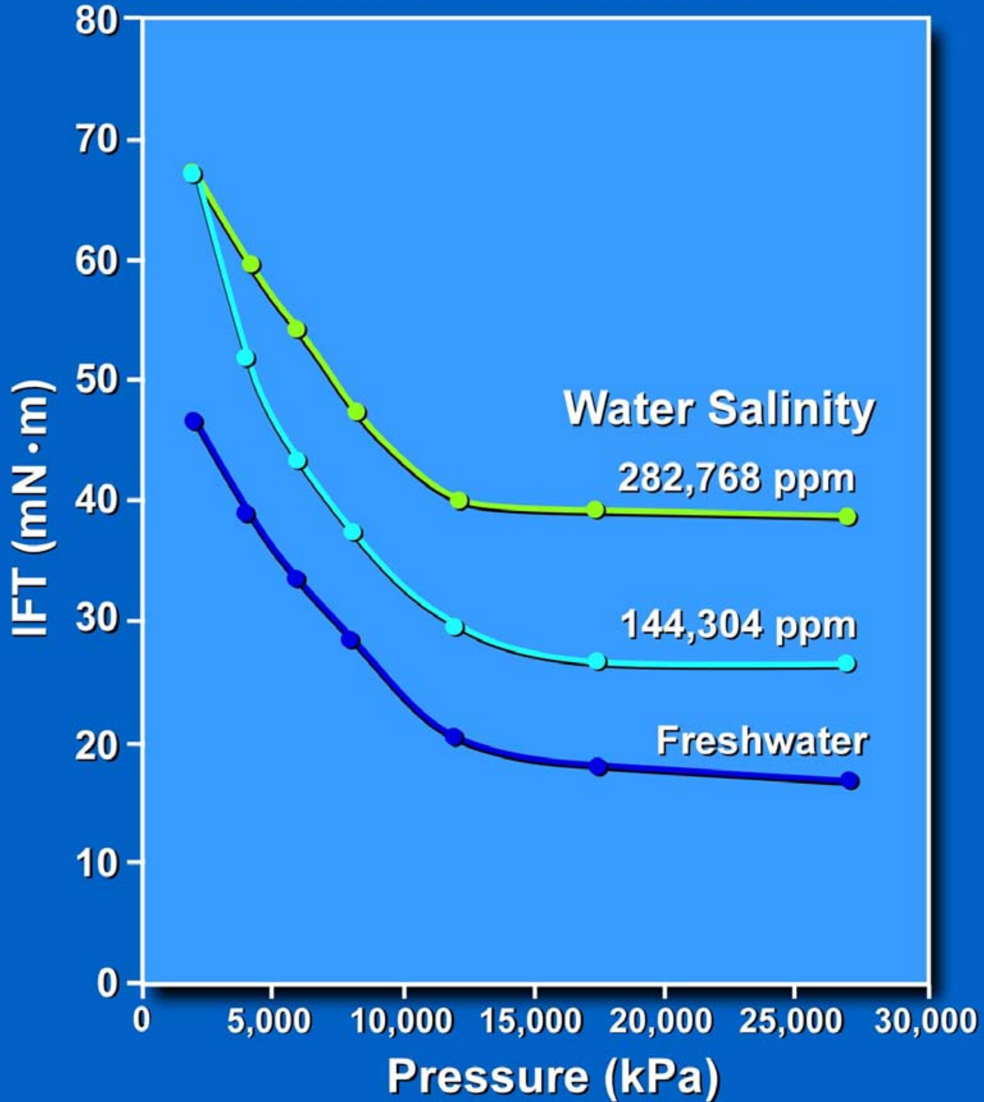


Variation of CO_2-Brine Interfacial Tension with Pressure and Temperature



Salinity 144,304 mg/l

Variation of CO_2-Brine Interfacial Tension with Pressure and Water Salinity



Temperature 41°C

Conclusions - I

Laboratory determinations for the relative permeability of CO_2 displacing brine at in situ conditions for sandstone and carbonate formations in western Canada show that:

- Pore distribution and size affect the absolute permeability to brine, CO_2 capillary pressure, and the shape and characteristics of relative permeability curves
- The relative permeability to supercritical CO_2 at irreducible brine saturation is ~ 1/7th to 1/5th of that of brine at 100% brine saturation
- The relative-permeability displacement characteristics of CO_2-brine systems, i.e. the endpoint relative permeability and maximum saturation for CO_2, both decrease with increasing contrast between brine and CO_2 viscosity

Continued….

Conclusions - II

…Continuation

- The interfacial tension (IFT) for CO_2-brine systems decreases with increasing pressure, and increases with increasing temperature and salinity
- The IFT dependence on pressure, temperature and salinity are likely due to phase and solubility effects
- It is expected that, for the same rock and pore system, the relative-permeability characteristics of CO_2-brine systems depend on IFT (*work in progress*), hence on in-situ pressure, temperature and water salinity

Implications

- Assuming constant relative-permeability displacement characteristics for supercritical CO_2 and formation water may result in significant errors in estimates of CO_2 storage capacity at irreducible saturation, and in rates of CO_2 injection (injectivity) and migration