North American Power Group, Ltd.

Two Elk Energy Park Carbon Site Characterization Study

DOE NETL Meeting October 5-7, 2010

October 7, 2010

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Purpose of Study

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- To conduct a characterization study of the south central Powder River Basin for CO_2 sequestration
- Improve understanding of injectivity, seal integrity, capacity, rate of dissolution and chemical reaction, pressure buildup, potential vulnerability and on-going management
- Promote commercialization of carbon sequestration projects for local industrial, power and other carbon sources

Characterization and Studies

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- Site characterization studies will be carried out with Stanford and BSCSP to refine and add detail to the CO_2 sequestration capacity in multiple partially depleted oil and gas reservoirs, coal seams, saline aquifers and other geologic formations for the area, as identified by DOE and BSCSP
- In addition, best practices and risk mitigation strategies will be established to demonstrate that these formations are safe and viable targets for sequestration and are capable of retaining CO_2 for millennia without adversely affecting human health, the environment or drinking water sources
- Study enlarged to include additional data gathering and three additional shallower wells
  - Geo phones will be inserted in these wells for vertical seismic profiles, continuing experiments and water sampling
  - Later use may include monitoring, prior to large scale CO_2 injection operations

Work Flow and Project Integration

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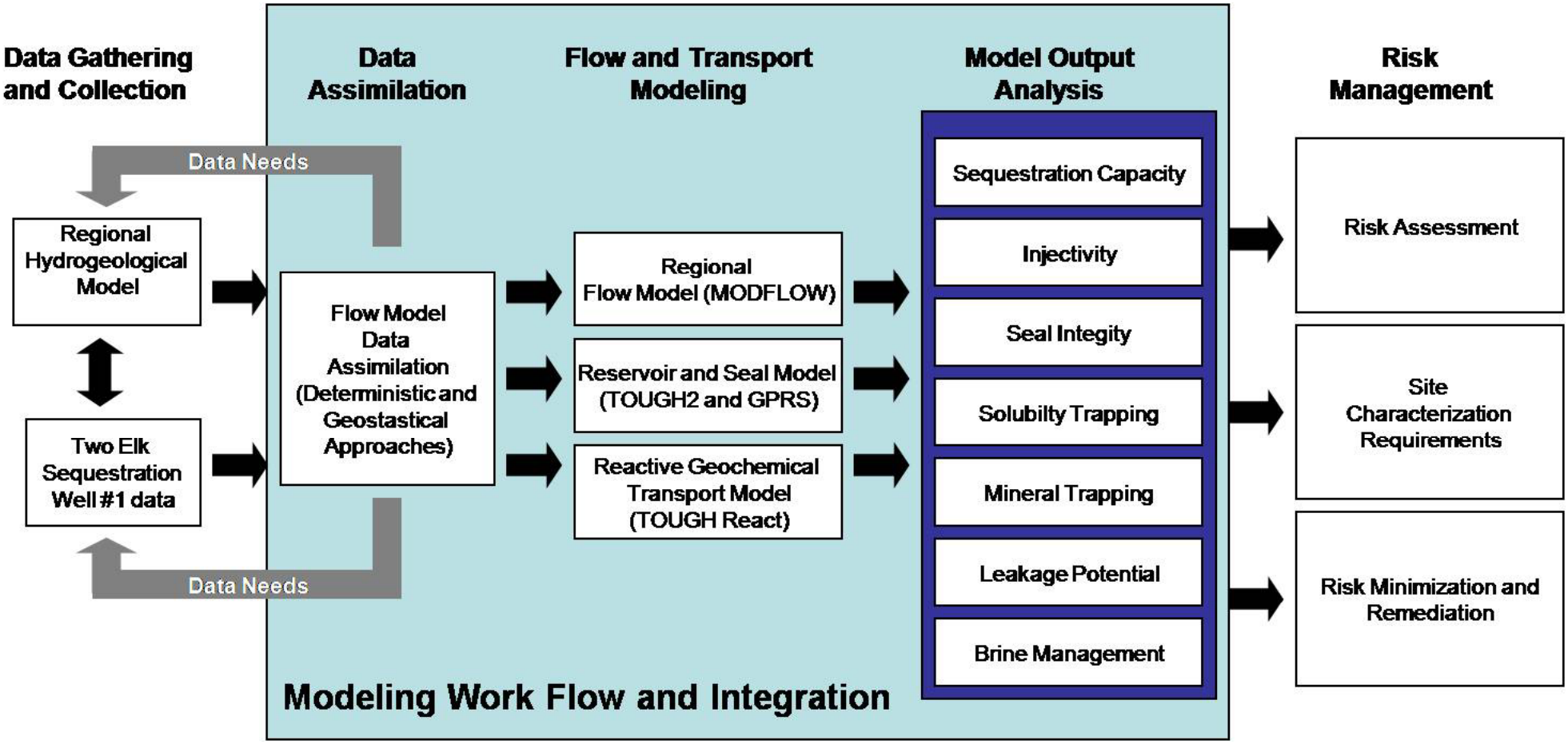

Two Elk Project Location

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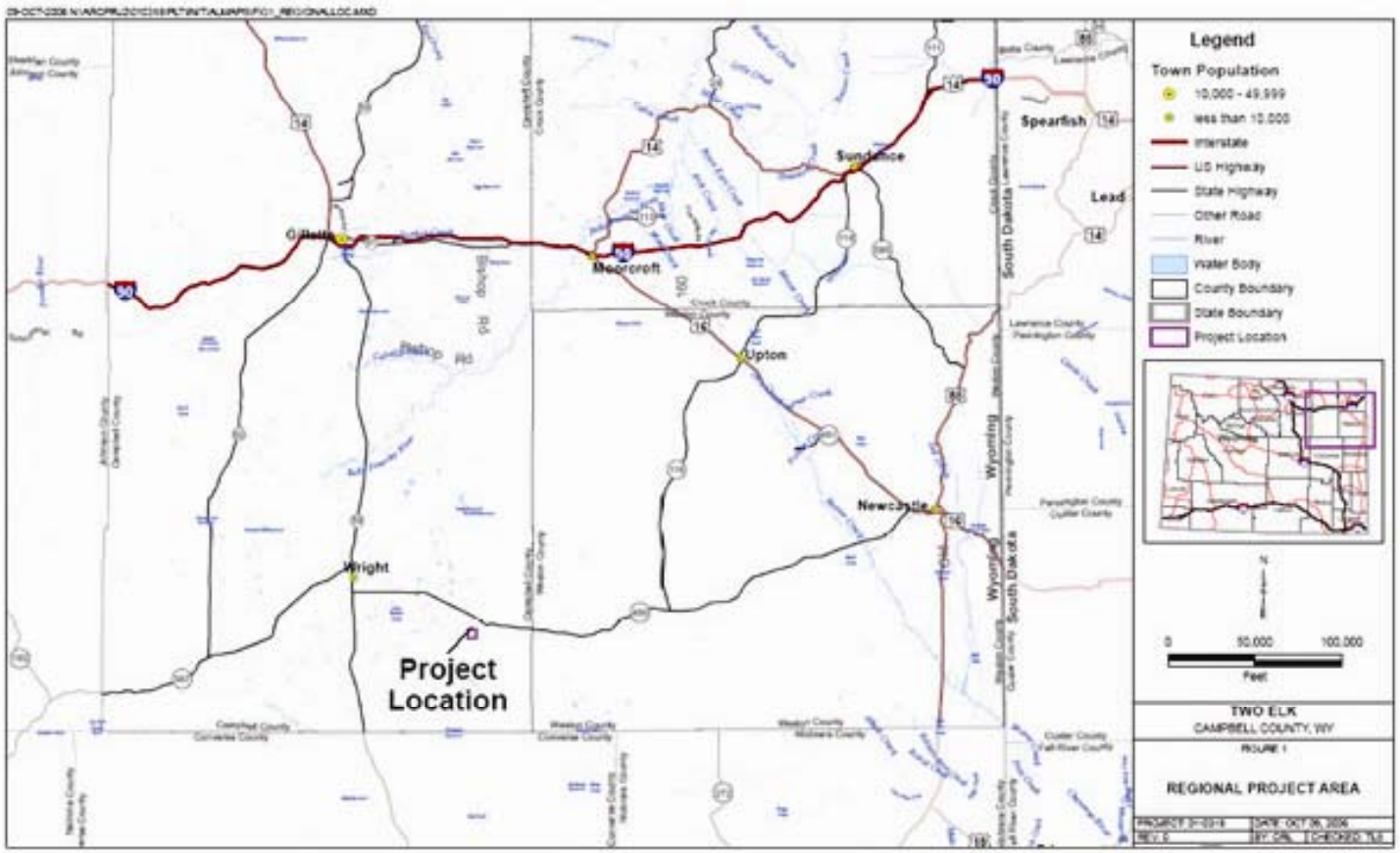

Existing Regional CO_2 Point Sources

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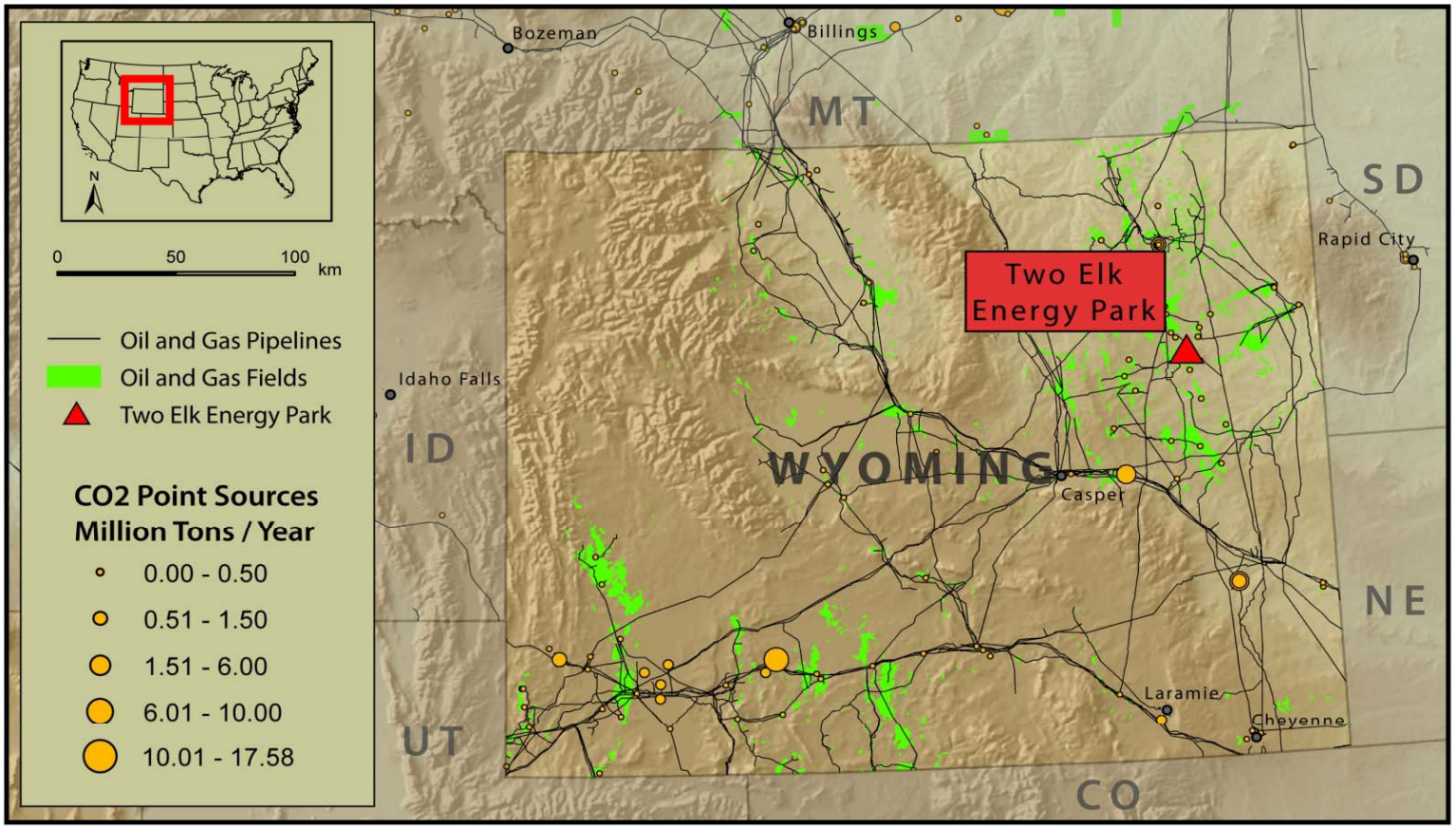

Powder River Basin Resources

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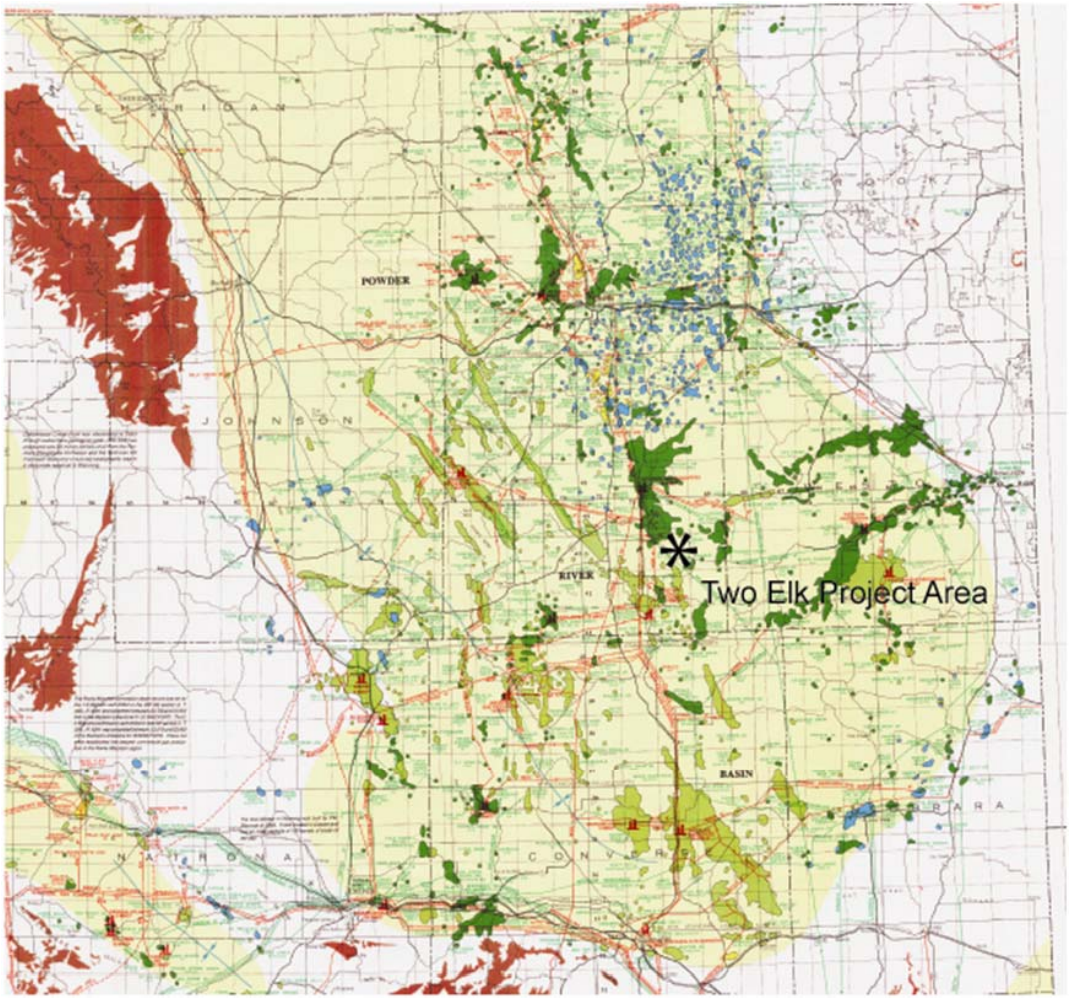

Map of oil and gas fields in the Powder River Basin with the location of Two Elk Project area.

Existing CO_2 Utilization Locations

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Top CO_2 Reservoirs Around Two Elk

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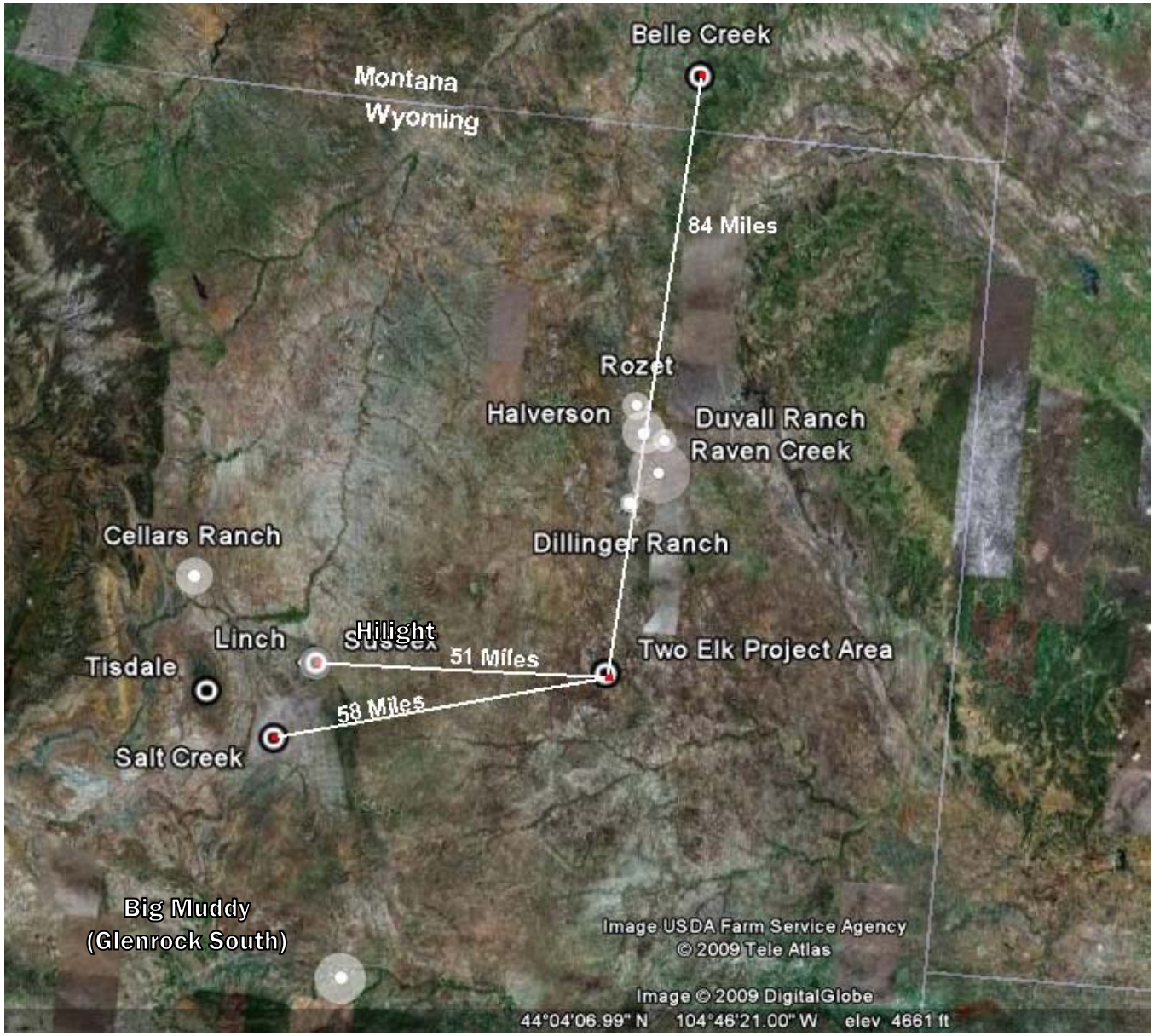

Major Structural Features of the Northern Rocky Mountain Region

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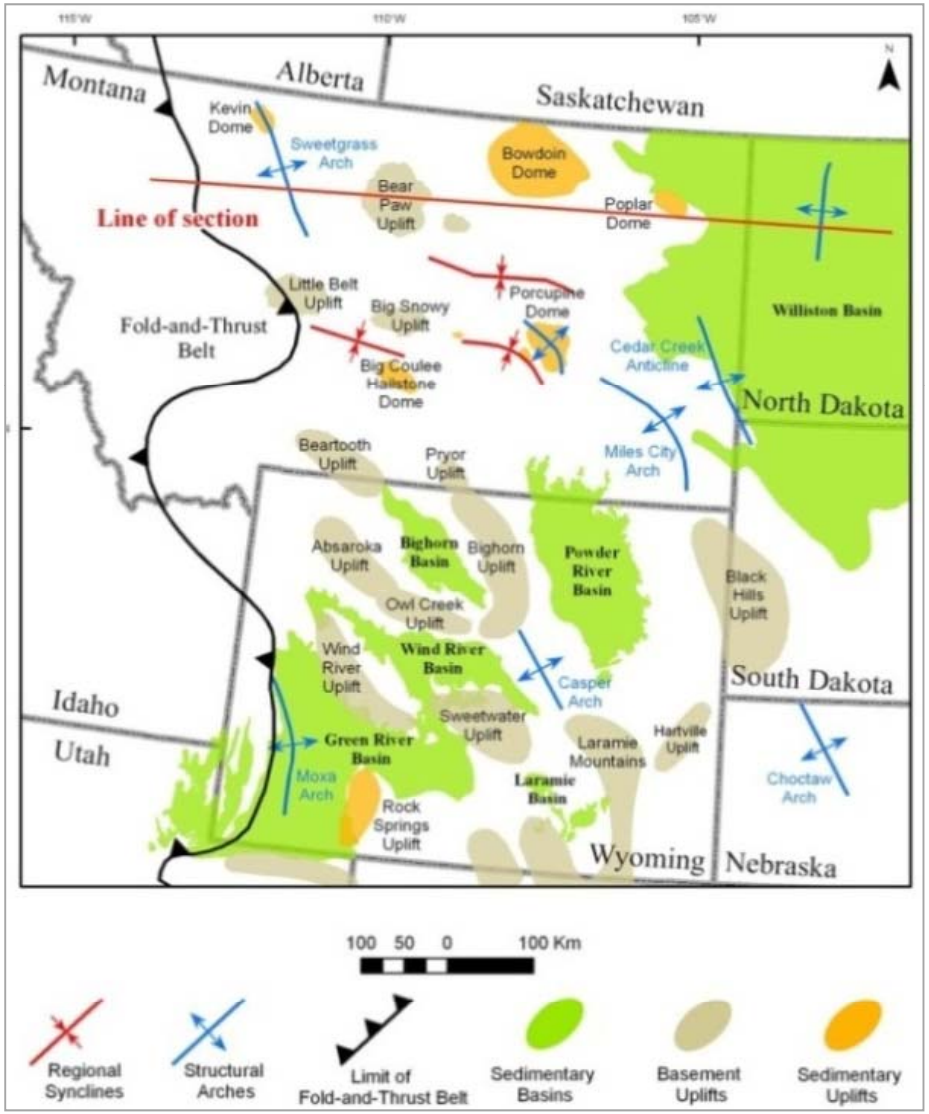
The Powder River Basin is a Laramide aged structural basin located in northeastern Wyoming. The basin is bounded by the Black Hills Uplift to the east, the Bighorn Mountains to the west , the Laramie Mountains and Hartville Uplift to the south, and the Miles City Arch to the north.



Hydrostratigraphic Units Northern Great Plains Aquifer System

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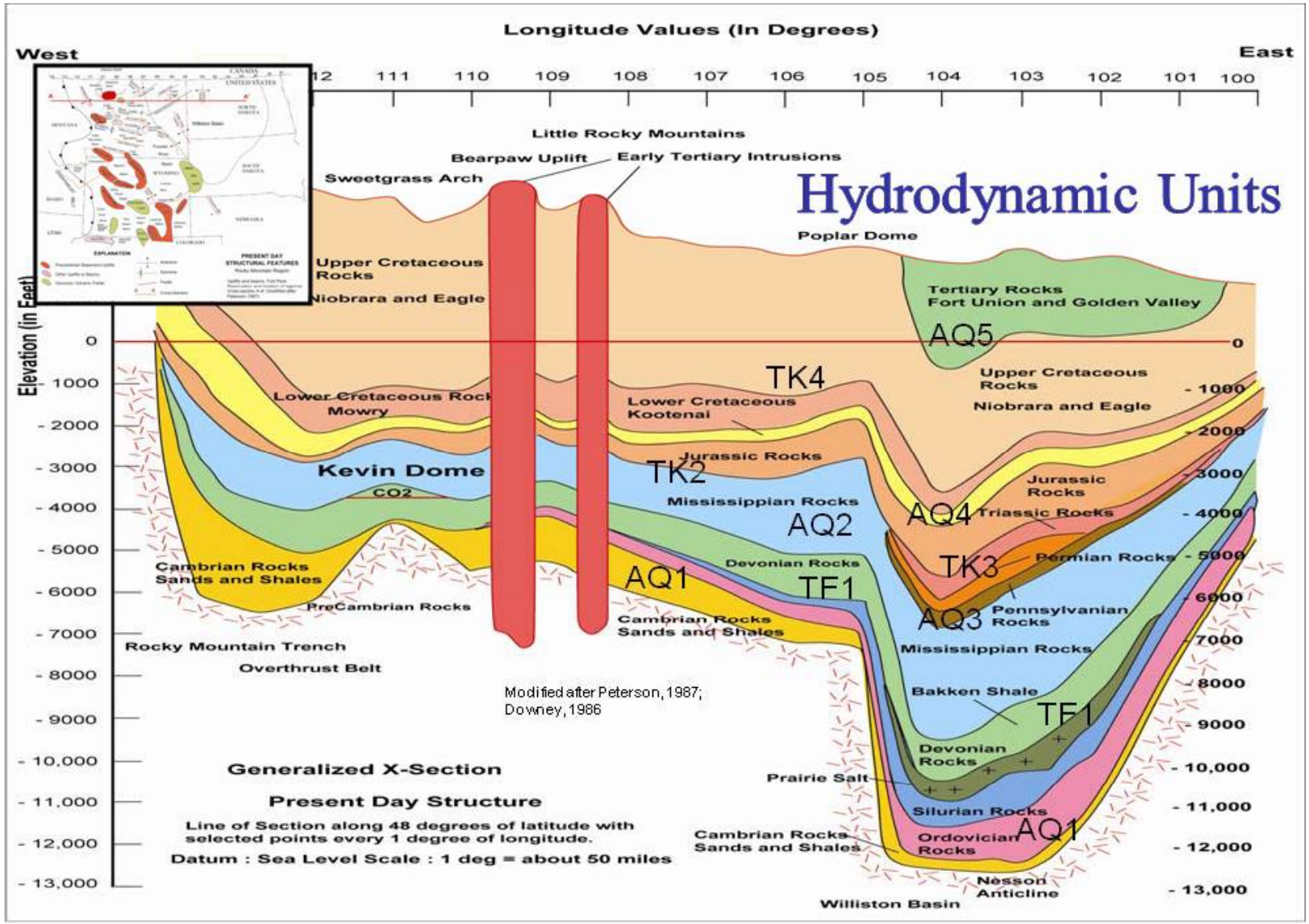

Generalized cross-section, present day structure.

Structure Contour Map of the Precambrian Surface NE Wyoming

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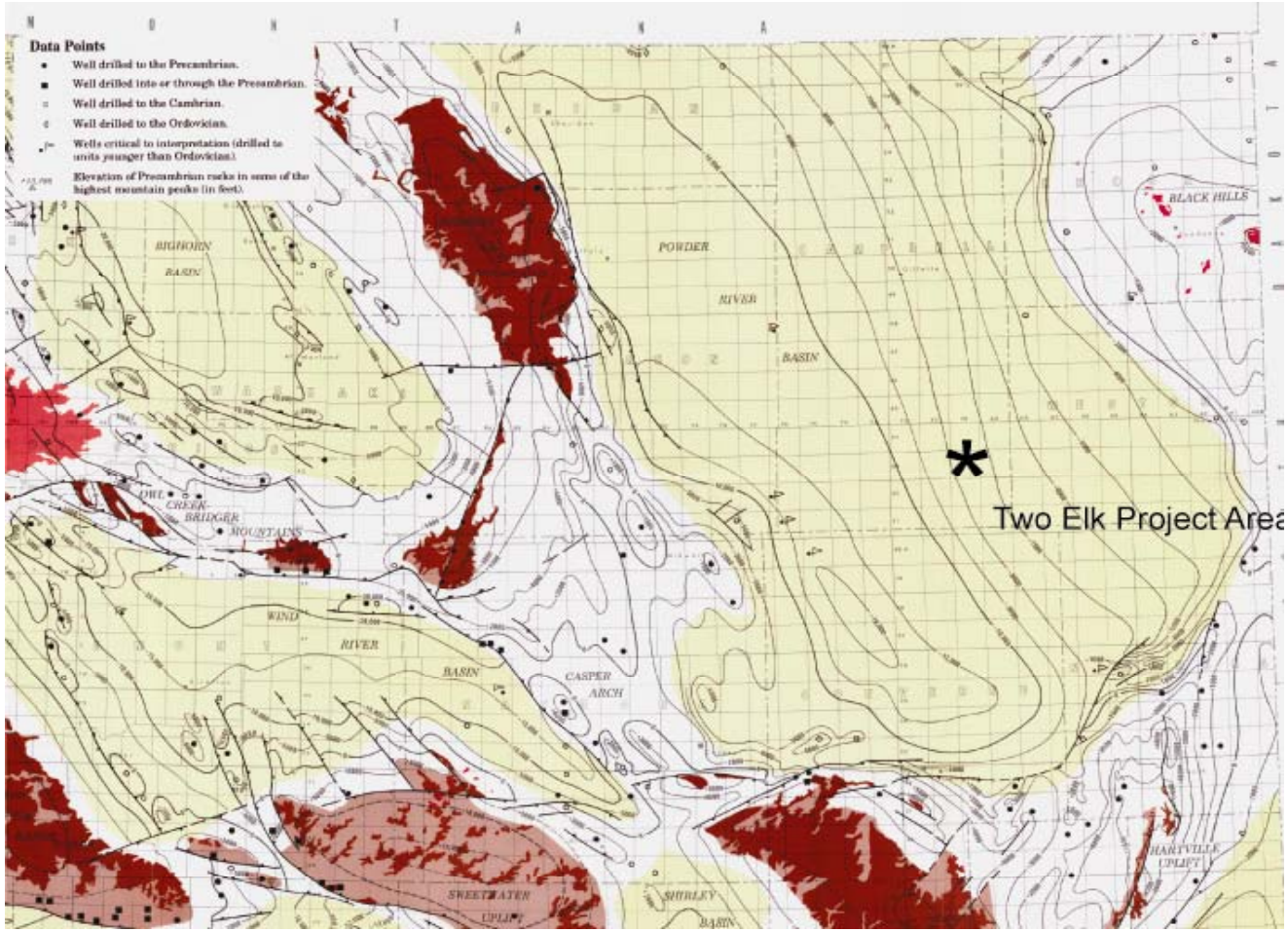

Stratigraphic Units in the Powder River Basin

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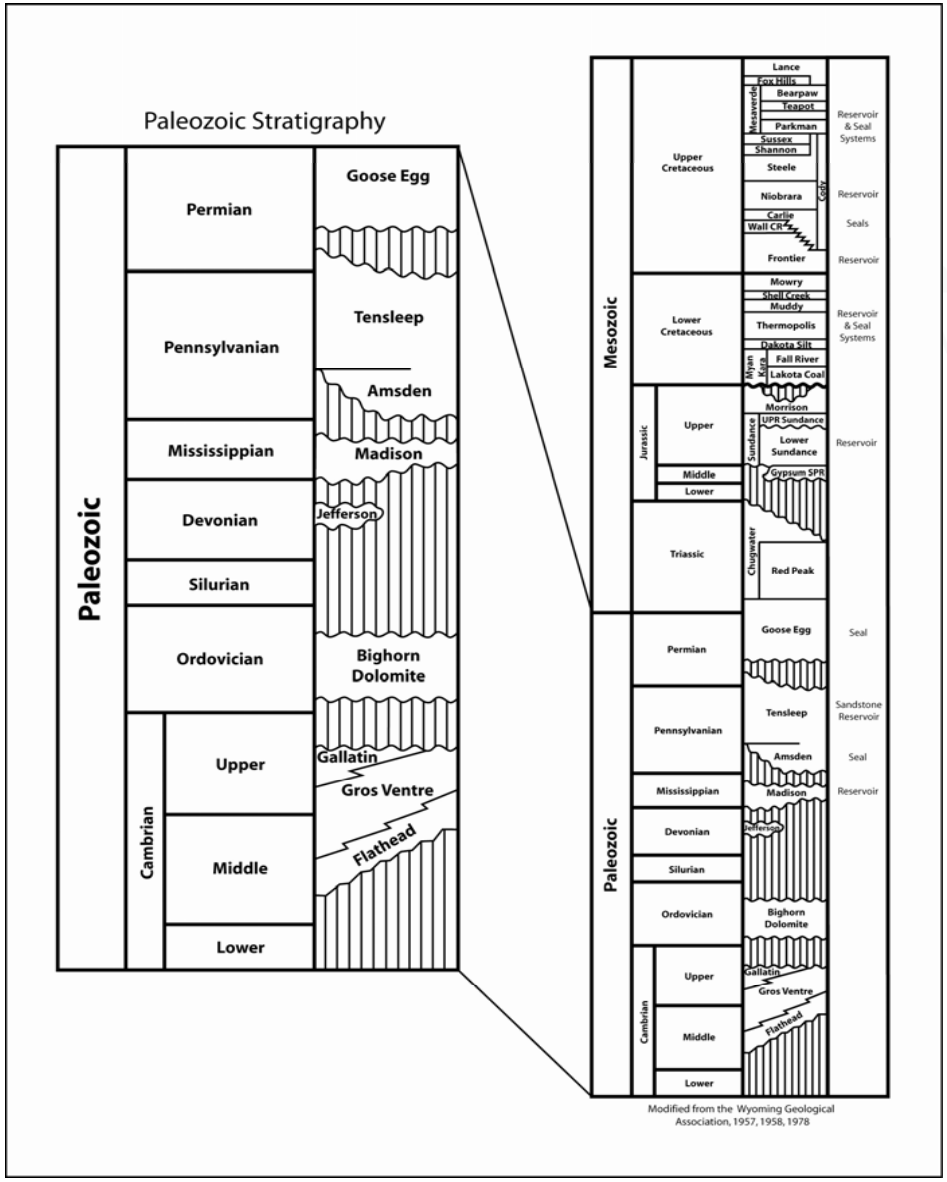

One Key Consideration

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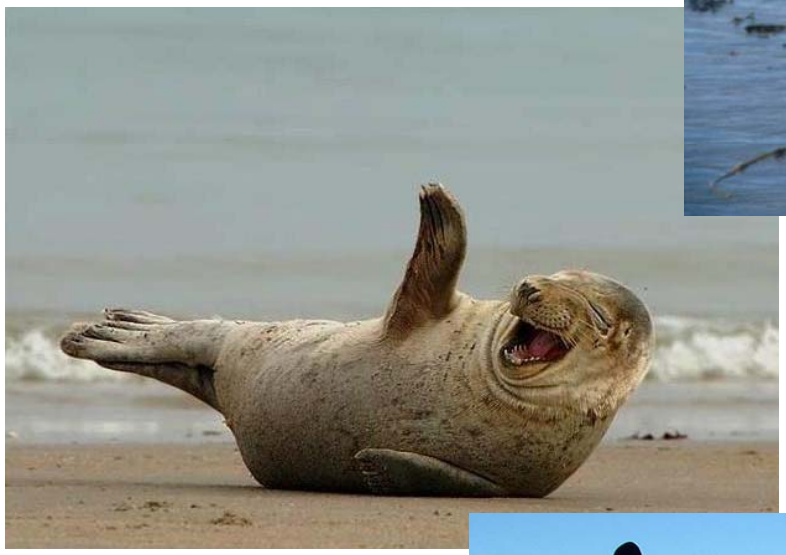
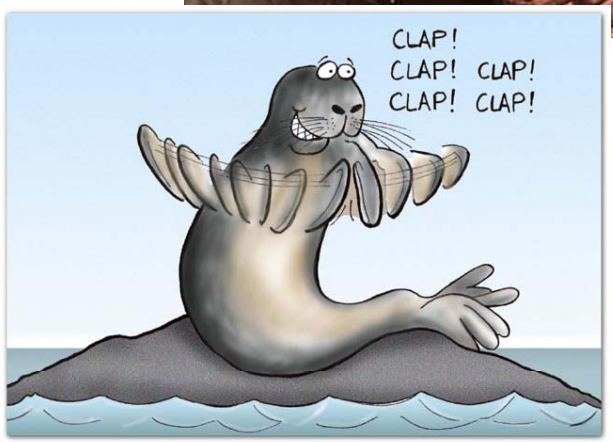
- What makes a good seal?





The Seal of Approval

What Makes a Good Seal for CO_2 Sequestration

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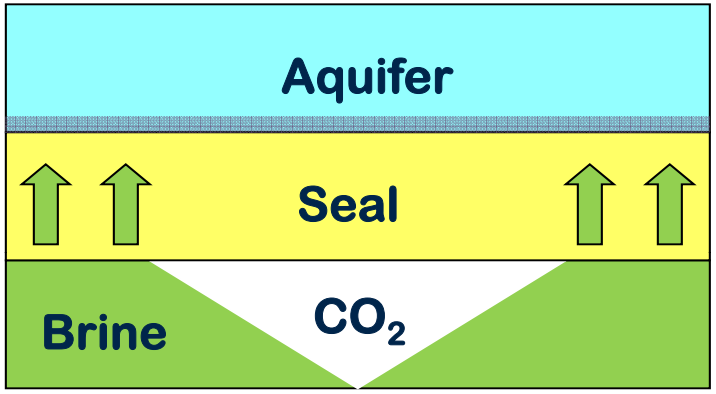
CO_2 Retention ✓

Brine Displacement ±



+ Brine displacement can reduce pressure buildup in the reservoir
- Brine displacement can jeopardize groundwater quality

Goal of This Study
- What properties control CO_2 retention and brine migration?
- What values of these properties are sufficient to retain CO_2?
- How do you prospect for a seal at a "green field" site?

CO_2 Trapping Mechanisms of Seals

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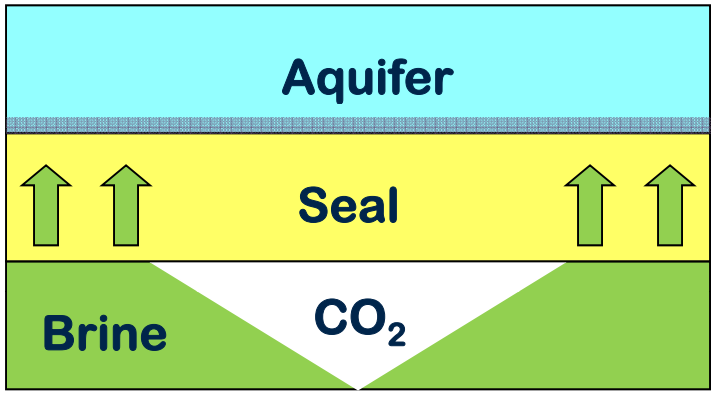
- Permeability Barrier

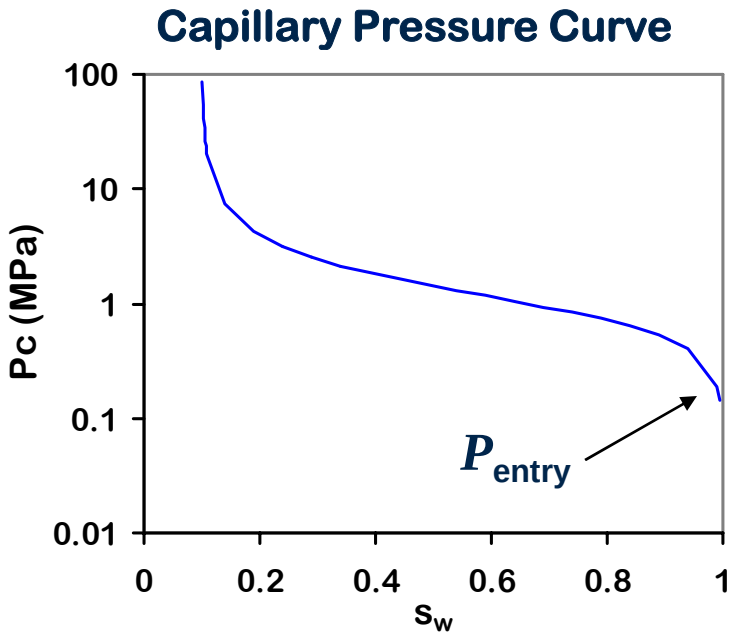
$$v = -\frac{kk_{r_{CO_2}}}{\mu_{CO_2}}\left(\frac{dp_{CO_2}}{dz} + \rho_{CO_2} g\right)$$



- Capillary Barrier

$$P_{entry} = P_{CO_2} - P_w > \frac{2\sigma\cos\theta}{r_{Max}}$$

$r_{Max} =$ ***Maximum pore throat radius***



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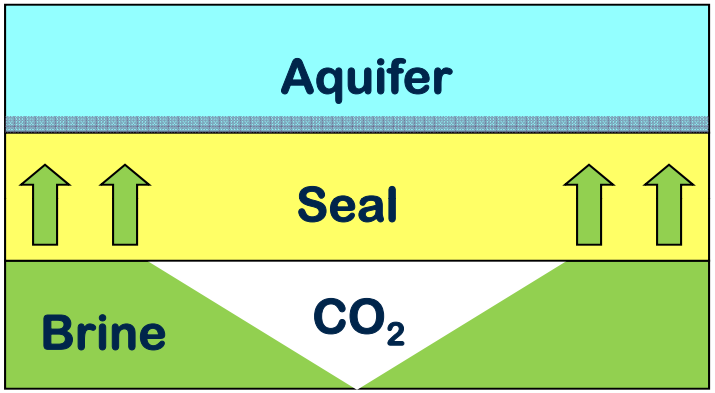
- Permeability Barrier

$$v_w = -\frac{k}{\mu_w}\left(\frac{dp_w}{dz} + \rho_w g\right)$$



This Study
- Systematically evaluate CO_2 retention and brine displacement for a range of rock properties

Approach of the Study

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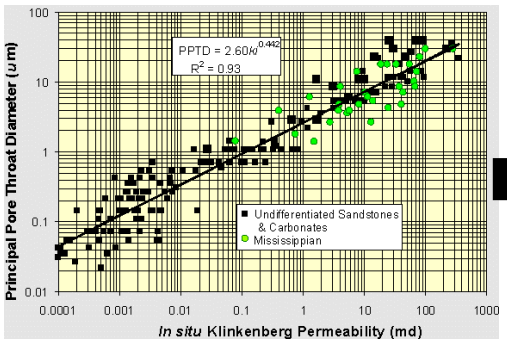
1. Establish a relationship between $P_{c\ entry}$, P_c and permeability
2. Systemically simulate CO_2 retention and brine displacement for a range of k and $P_{c\ entry}$ using TOUGH2

Literature

$$P_o \approx \frac{2\sigma\cos\theta}{r_{PPTR}}$$

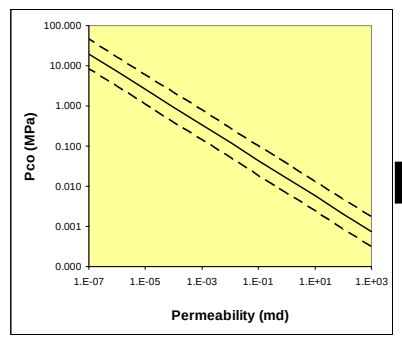
$$P_c = -P_o\left(\left[s^*\right]^{-1/\lambda} - 1\right)^{1-\lambda}$$

r_{PPTR}

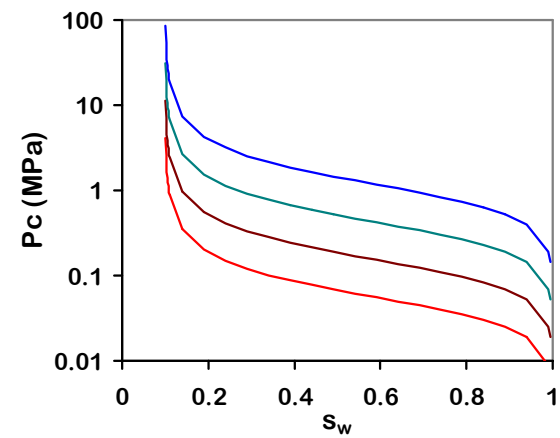


k

P_o



k



Simulation Geometry

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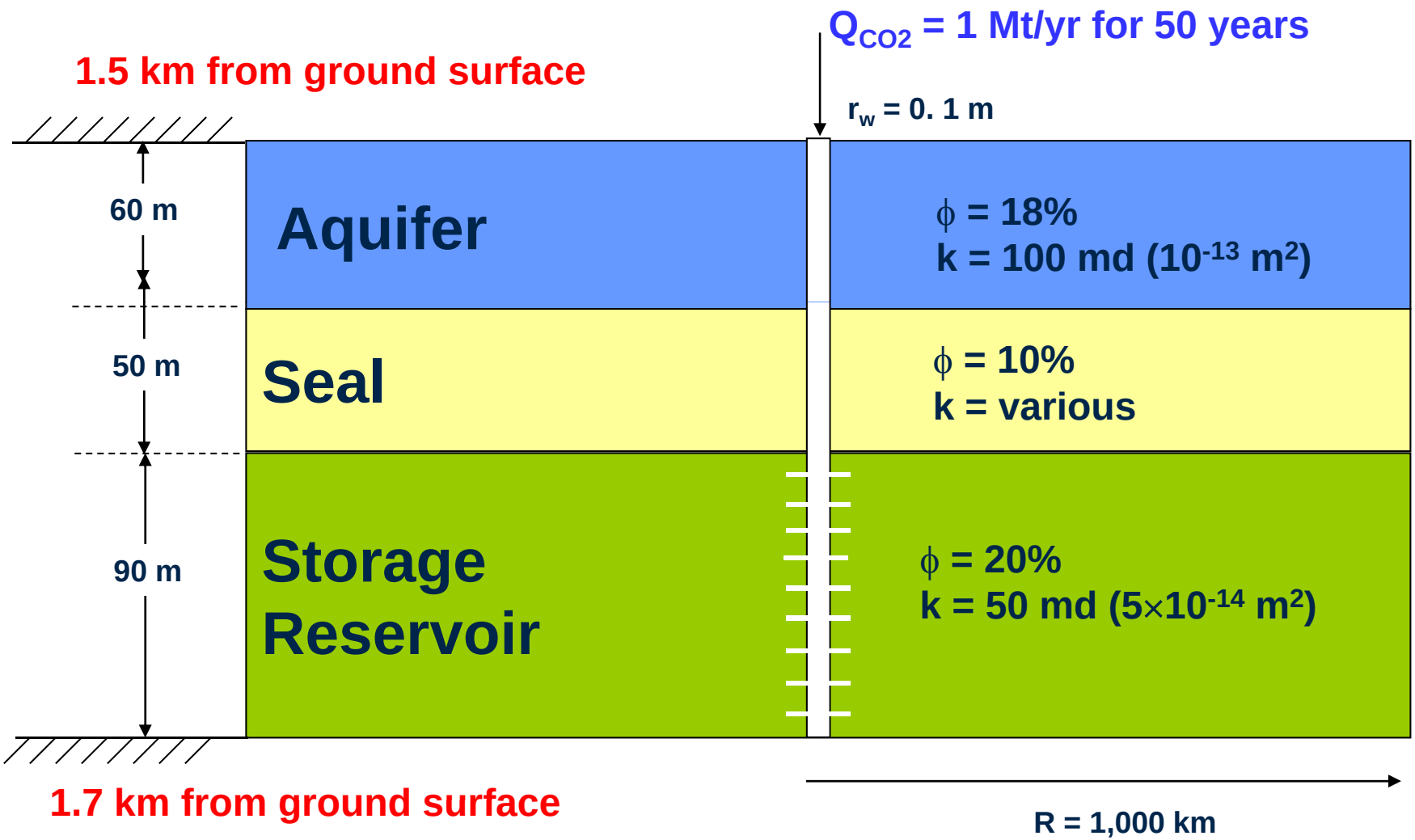

Material Properties

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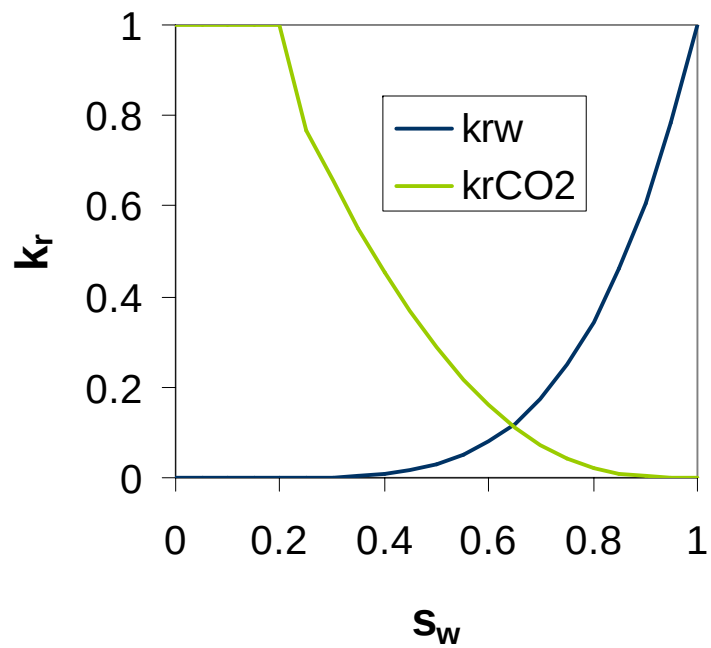
	k (md)	ϕ	s_{lr}	P_o (Mpa)	λ	h (m)
Reservoir	50	0.2	0.15	0.0015	0.4	90
Aquifer	100	0.18	0.17	0.0021	0.4	60
Seal A	0.1	0.1	0.2	0.0044	0.6	50
Seal B	0.01	0.1	0.2	0.1218	0.6	50
Seal C	0.001	0.1	0.2	0.3370	0.6	50
Seal D	0.0001	0.1	0.2	0.9326	0.6	50

Relative Permeability

$$k_{r_w} = s^{*4}$$

$$k_{r_{CO_2}} = (1 - s^*)^2 \cdot (1 - s^{*2})$$

$$s^* = \frac{s - s_{rw}}{1 - s_{rw}}$$



CO_2 Retention (50 Years)

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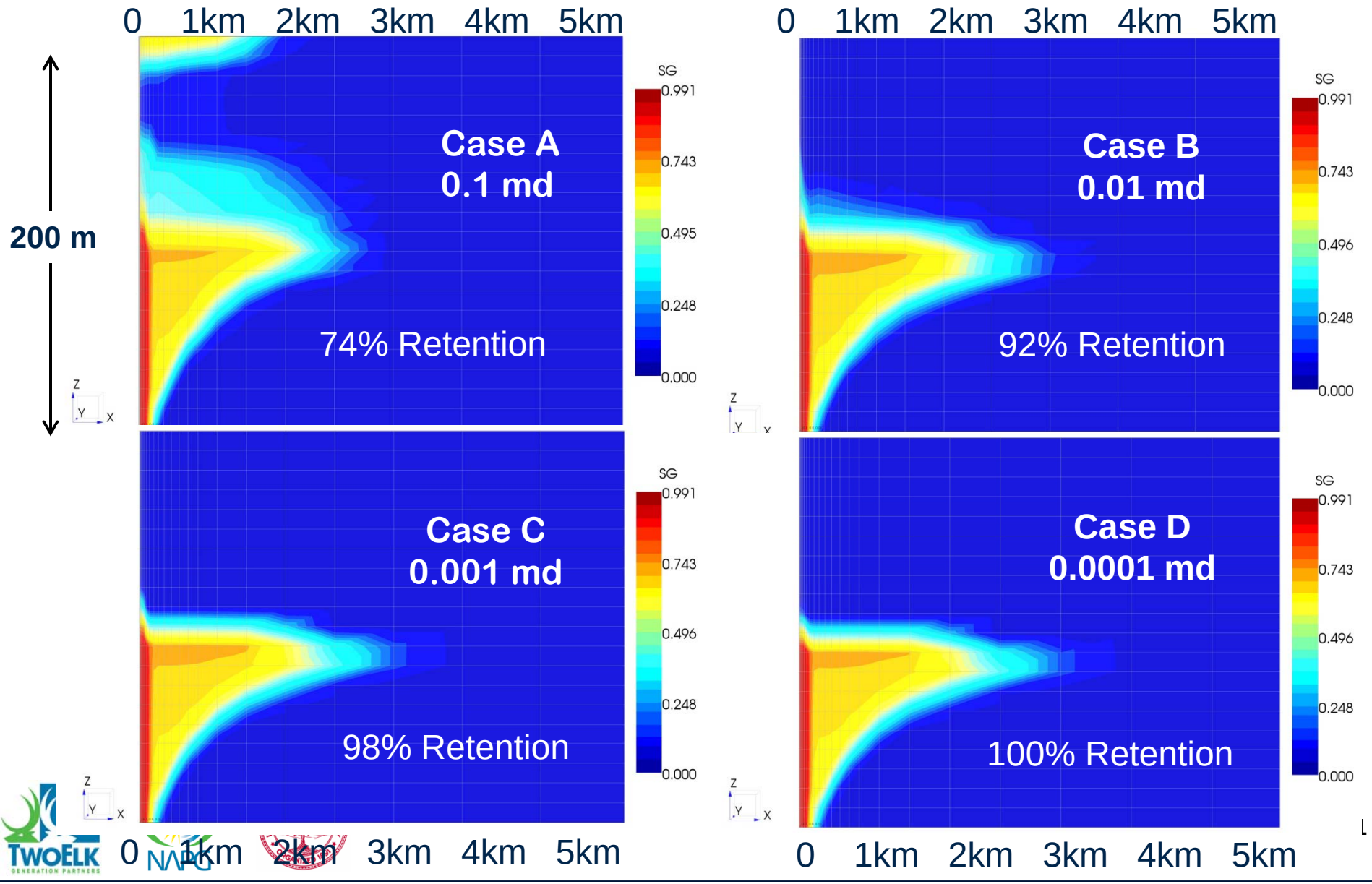

CO_2 Saturation Distribution (50 Years)

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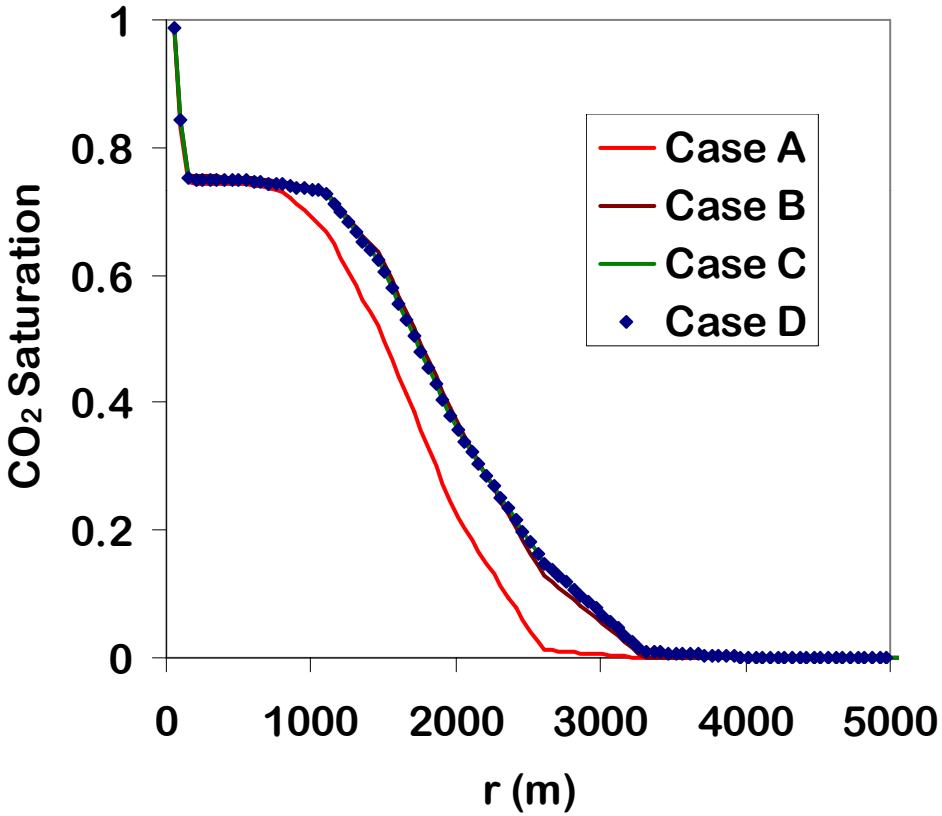
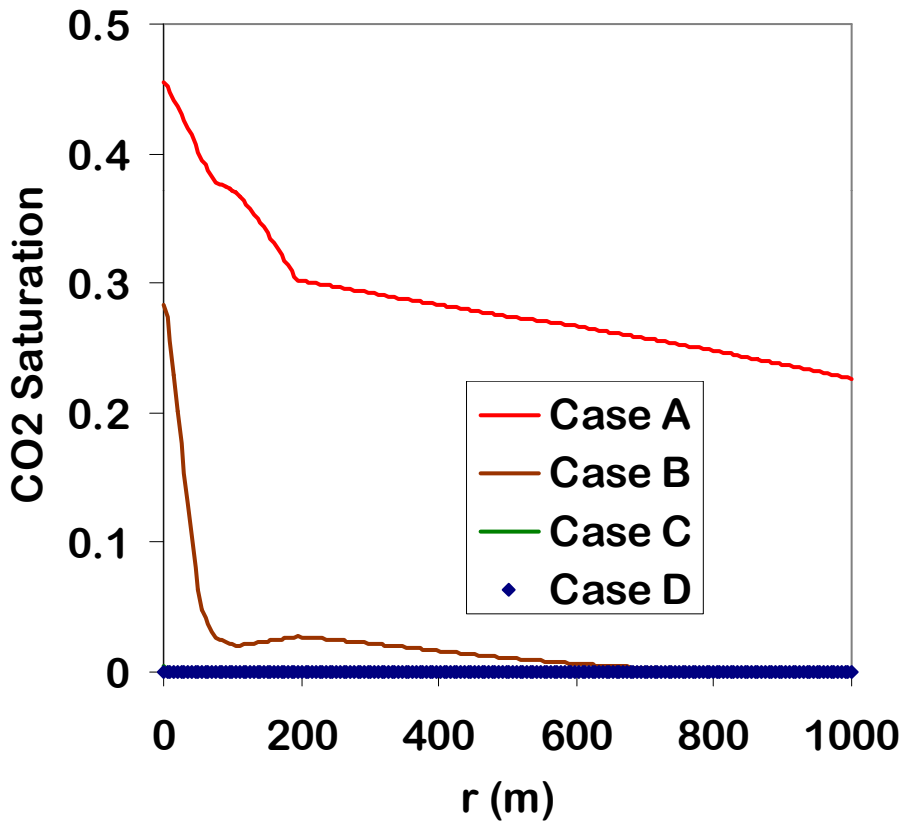
Top of the Reservoir



Base of the Aquifer



Pressure Buildup (50 Years)

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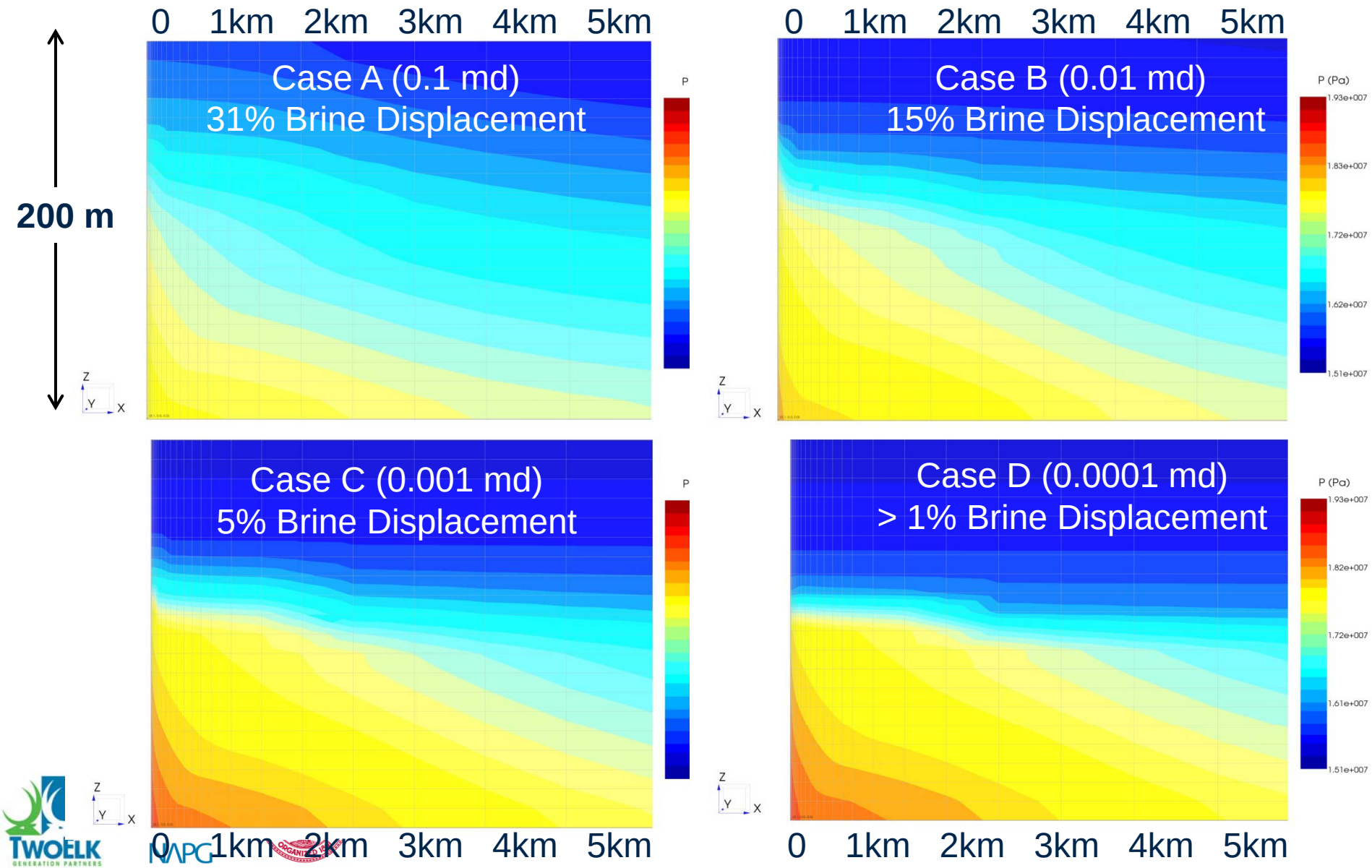

Pressure Distribution (50 Years)

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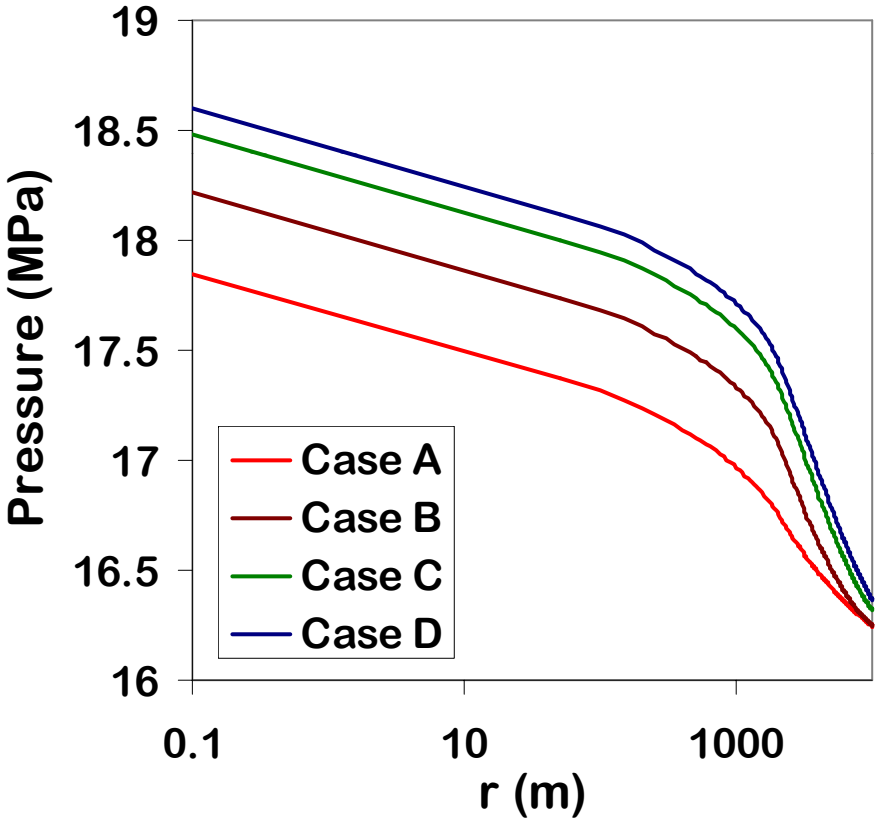
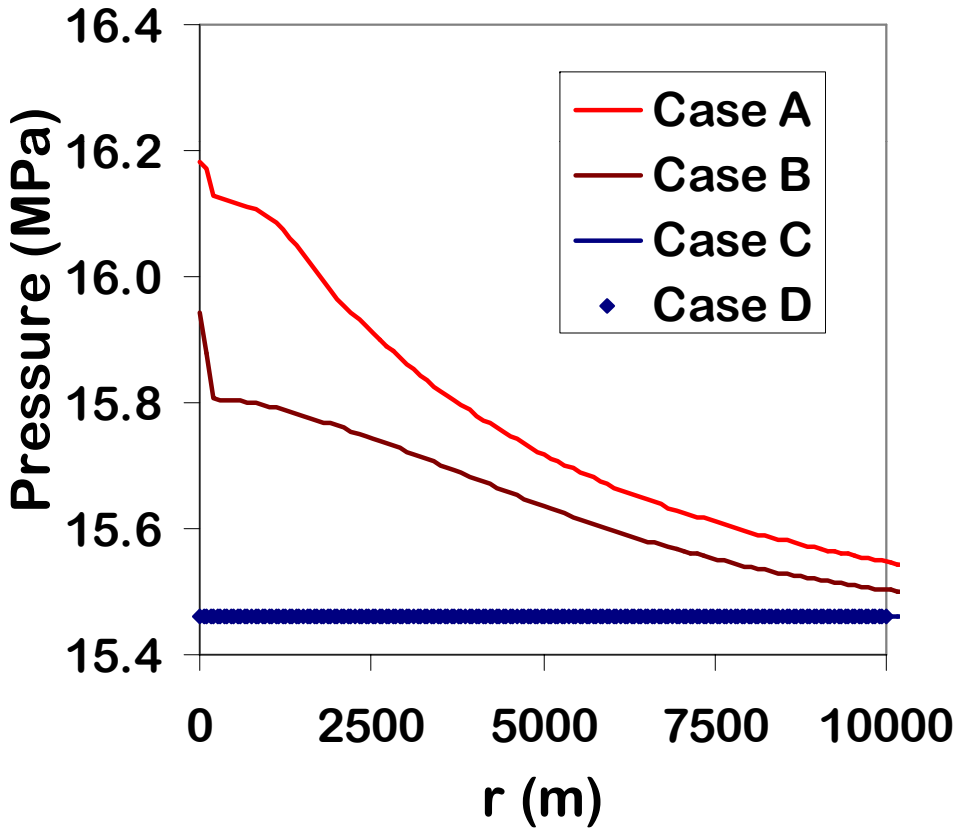
Reservoir Pressure



Aquifer Pressure



Effect of Dry -out on Seal Performance

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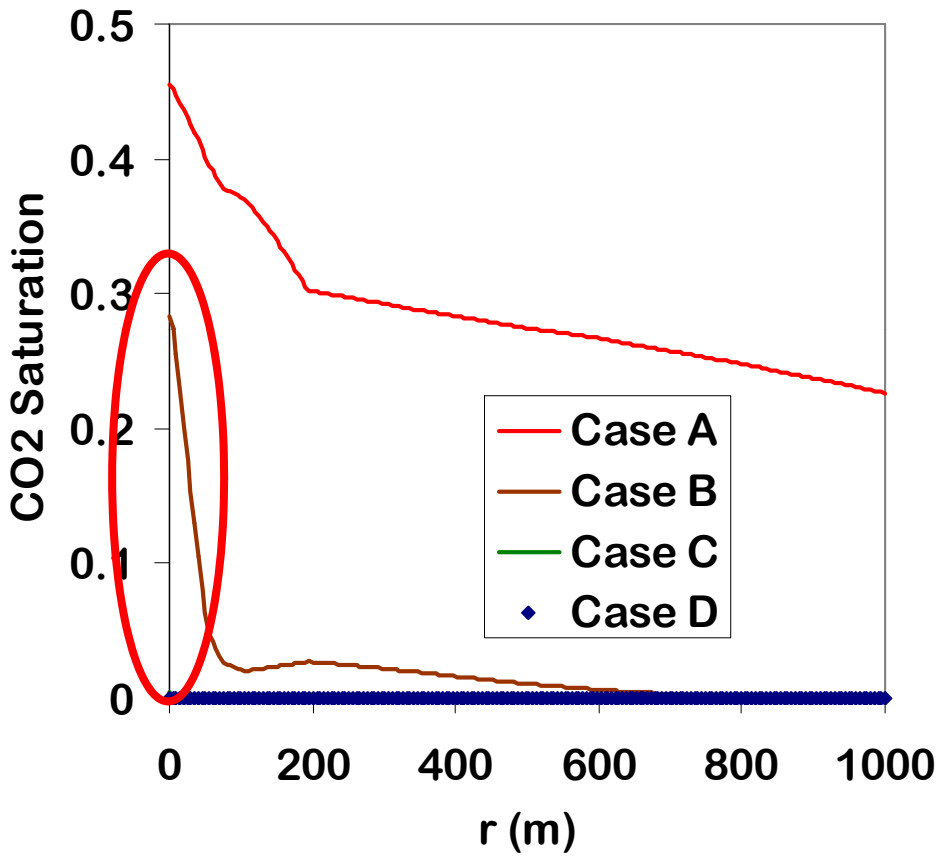

CO_2 Saturation at the Base of the Aquifer

Dryout can cause an otherwise competent seal to leak.

Preventing Dry-out at the Base of the Seal Increases Retention

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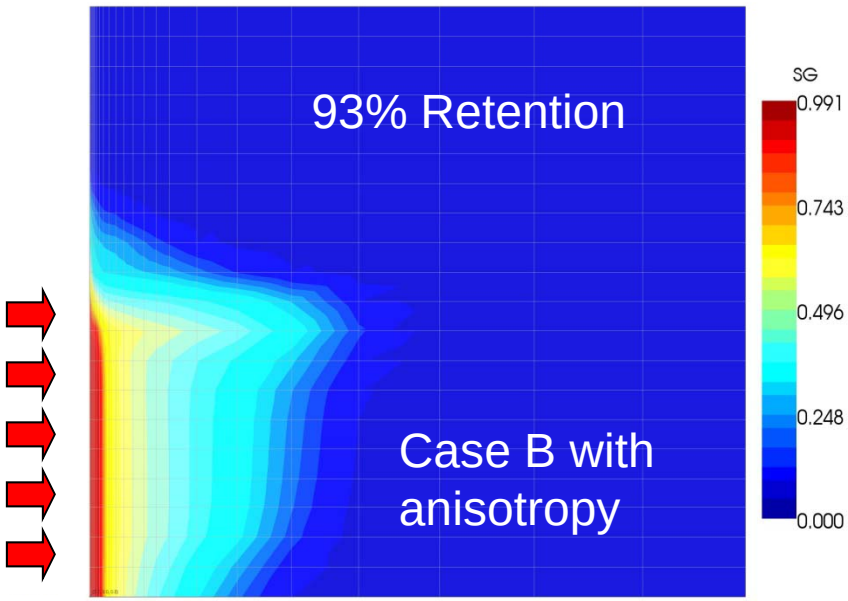

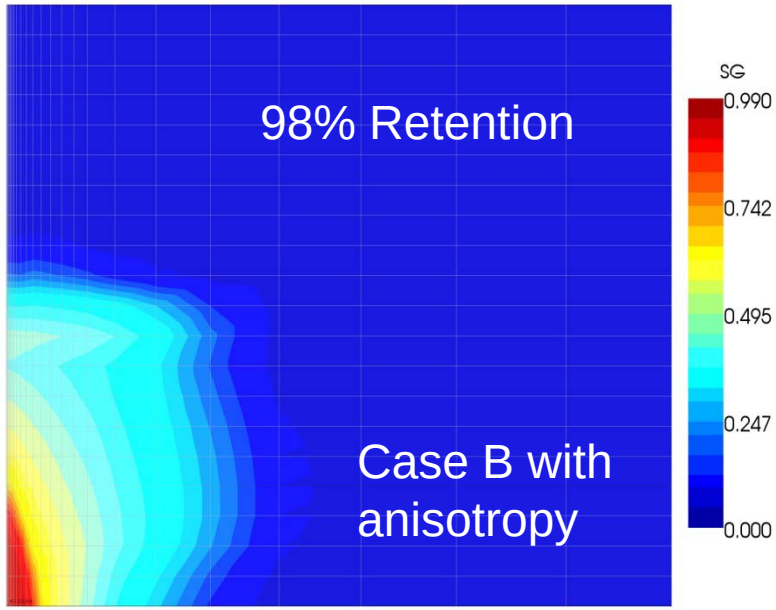

Injecting at the base of the formation can help prevent dry-out at the base of the seal—and increase retention.

Summary and Conclusions

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- Site specific assessments are needed to assess the performance of reservoir/seal pairs
- Rocks with permeability > 0. 01 μd (10 μd) are unlikely to be effective seals
- Brine displacement is negligible for intact seals with permeability of < 0.001 md (1 μd)
- Dry-out at the base of a seal—and resulting high capillary pressures can lead to leakage from an otherwise competent (thin) caprock
- Avoiding dry-out will decrease the risk of leakage