ABANDONED WELLS AS POTENTIAL LEAKAGE PATHWAYS: LESSONS LEARNED FROM CO_2 GEOLOGICAL STORAGE

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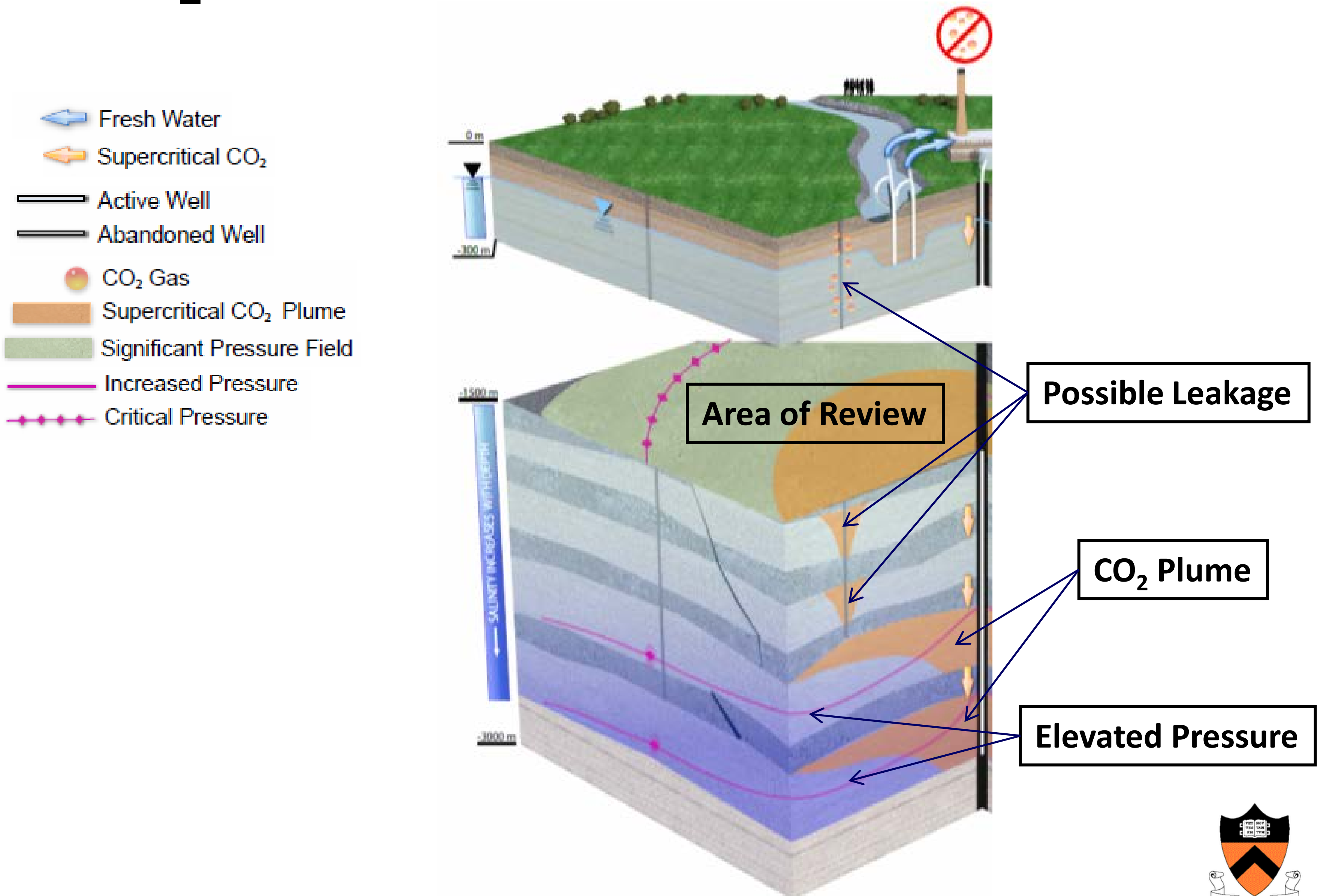
CO_2 Plume Size and Critical Pressure



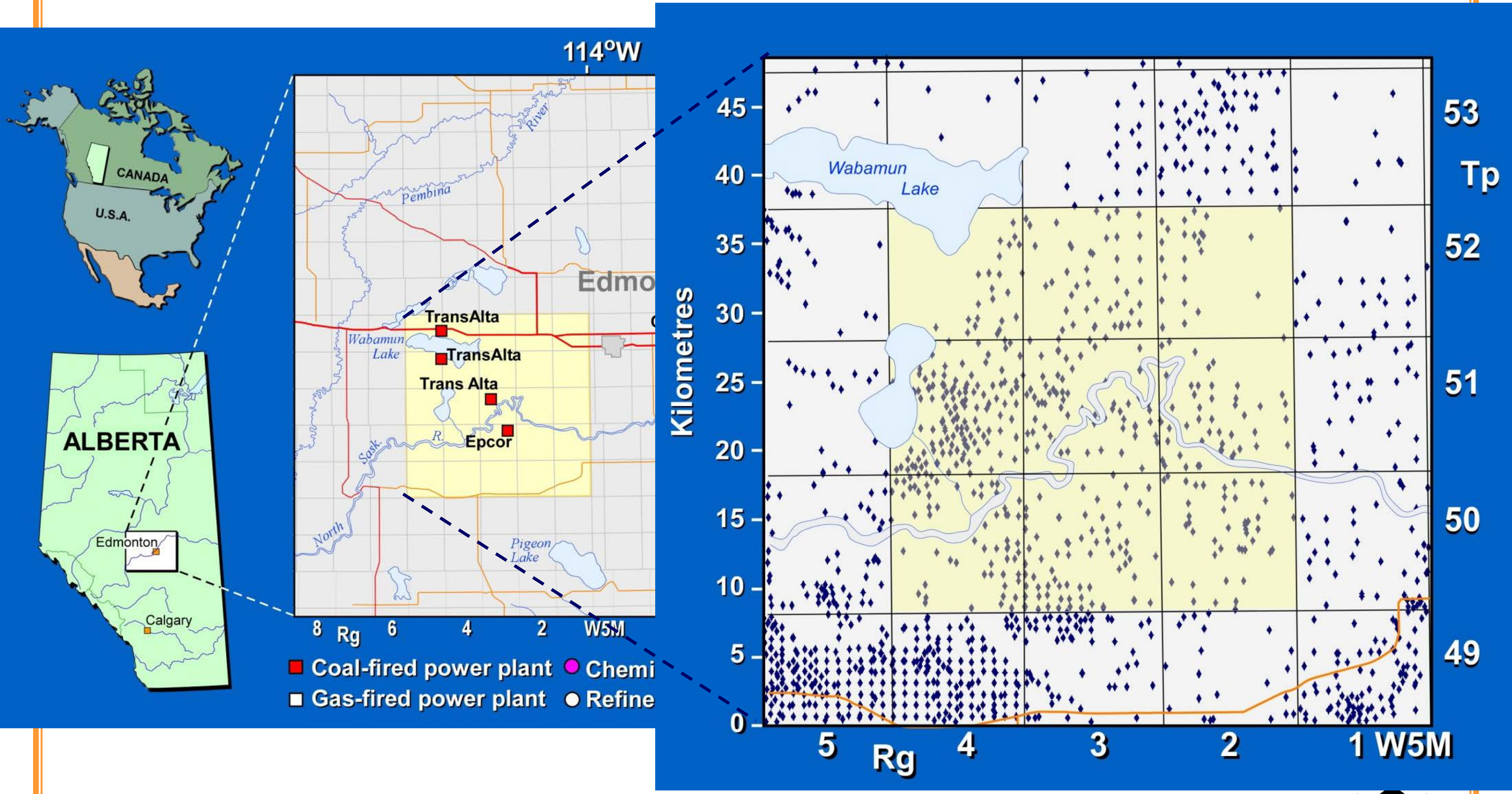
LEAKAGE ISSUES

1. Leakage involves vertical migration of CO_2 or other fluids (brines).

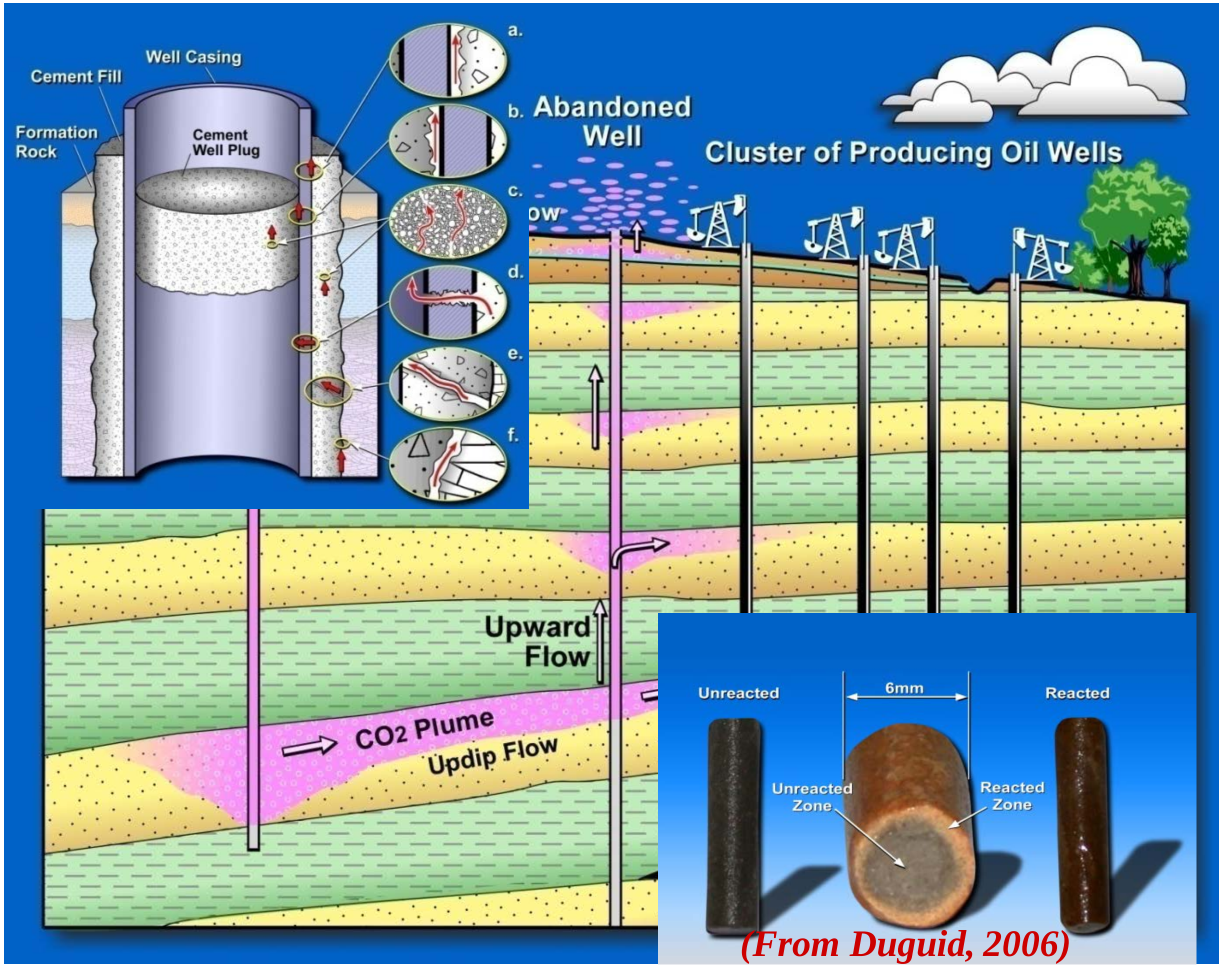
2. Leakage is most likely to occur along concentrated pathways: faults, fractures, wells.

3. In North America, old wells are considered to be the most likely pathways.

Existing Wells



INJECTION AND LEAKAGE

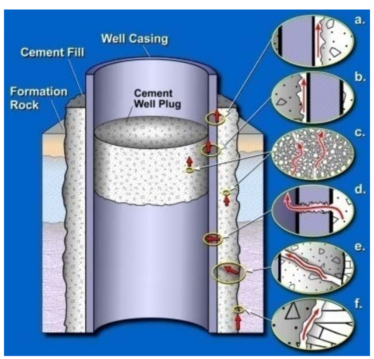


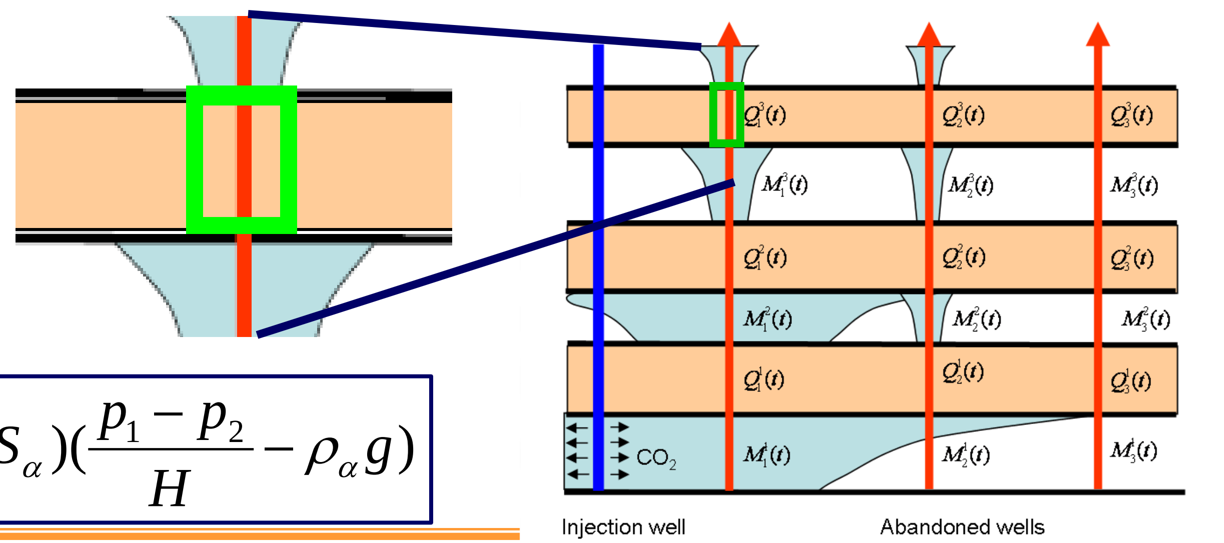
(From Duguid, 2006)

- How to model this system?
- Domain Size: $>1{,}000\ km^2$
- Leakage Pathways: $0.001\ m^2$.
- Flow Properties along wells highly uncertain.
- Possible Material Degradation.

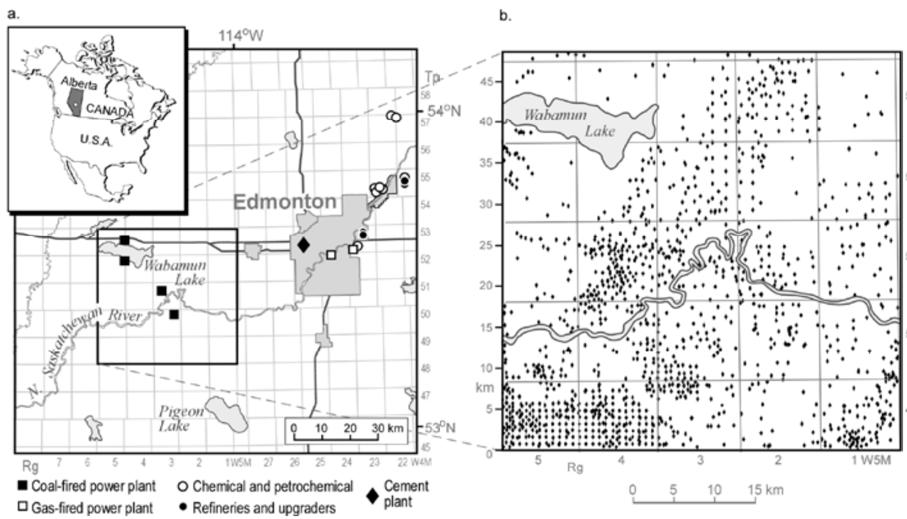
A Semi-analytical Model

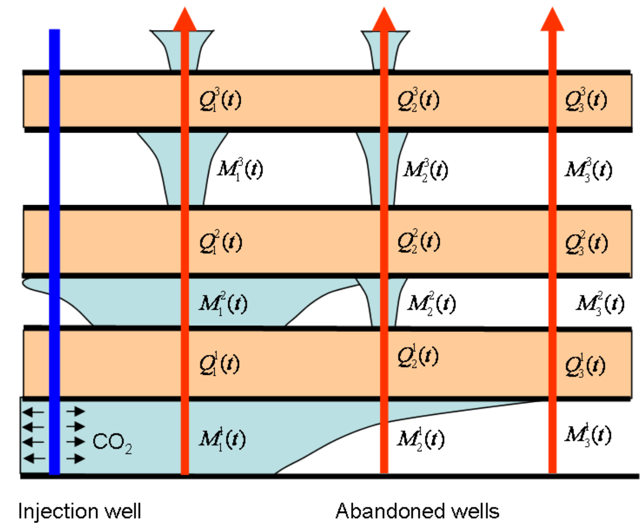
1. **Injection Plume, Secondary Plumes and Pressure Fields: Similarity Solution (*Nordbotten and Celia, 2006, 2012; Celia et al., 2011*)**
2. **Leakage Dynamics: Multi-phase Darcy Flow along Leaky Well Segments (*Nordbotten et al., ES&T, 2005, 2008*)**
3. **Upconing around Leaky Wells (*Nordbotten and Celia, WRR, 2006*)**
4. **Grid-free solutions: We can now solve 50 years of injection over 2,500 km^2, 12 layers, and 1,200 wells in about 2 minutes.**

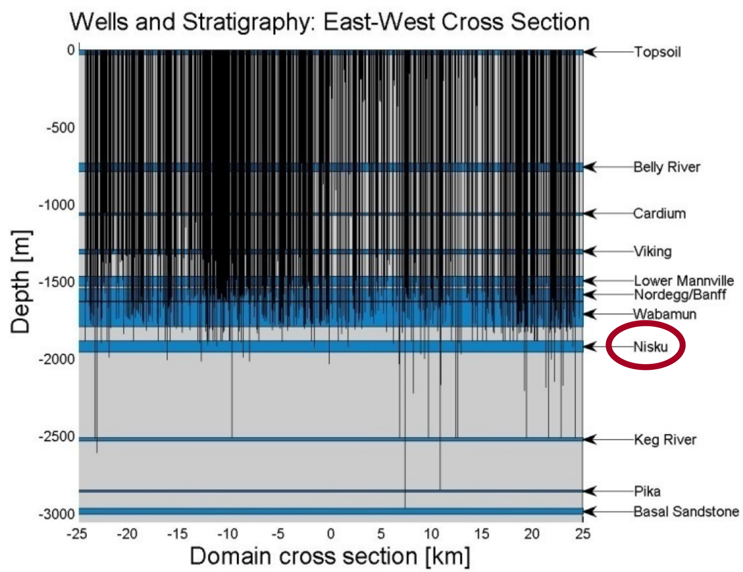


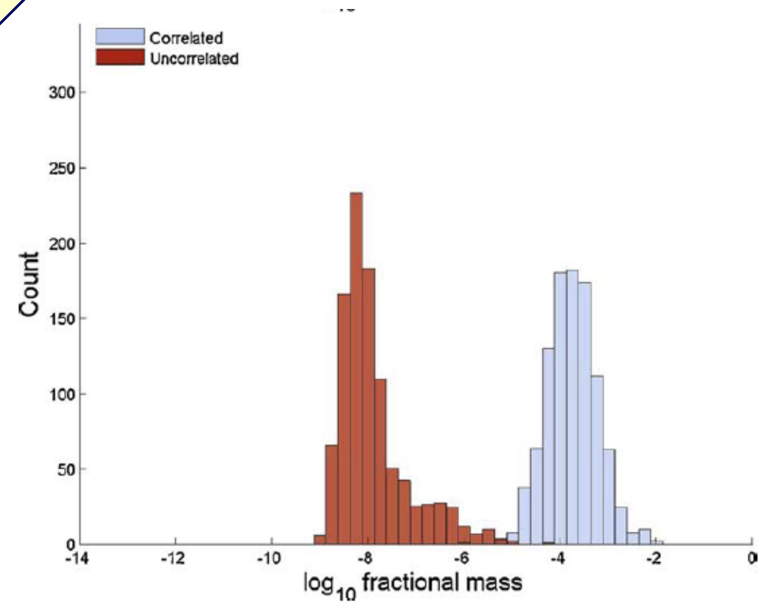


$$Q_{well} \propto K_{well} k(S_\alpha)\left(\frac{p_1 - p_2}{H} - \rho_\alpha g\right)$$



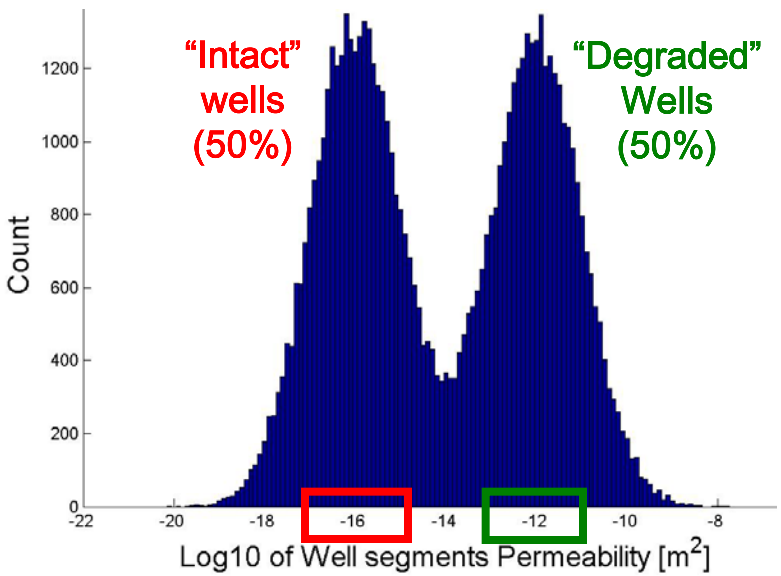


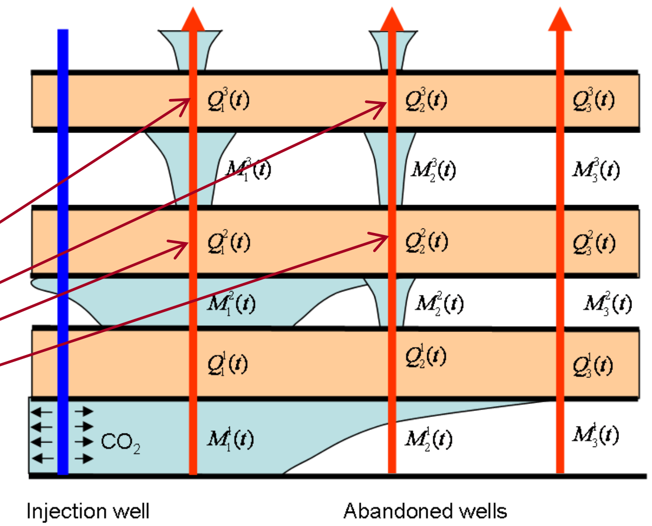




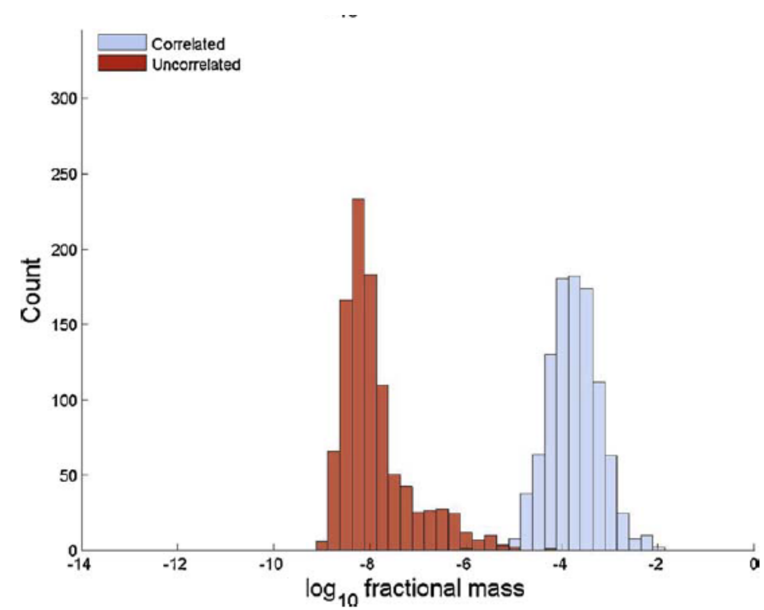
(See: Celia et al., 2011; Court et al., 2012)

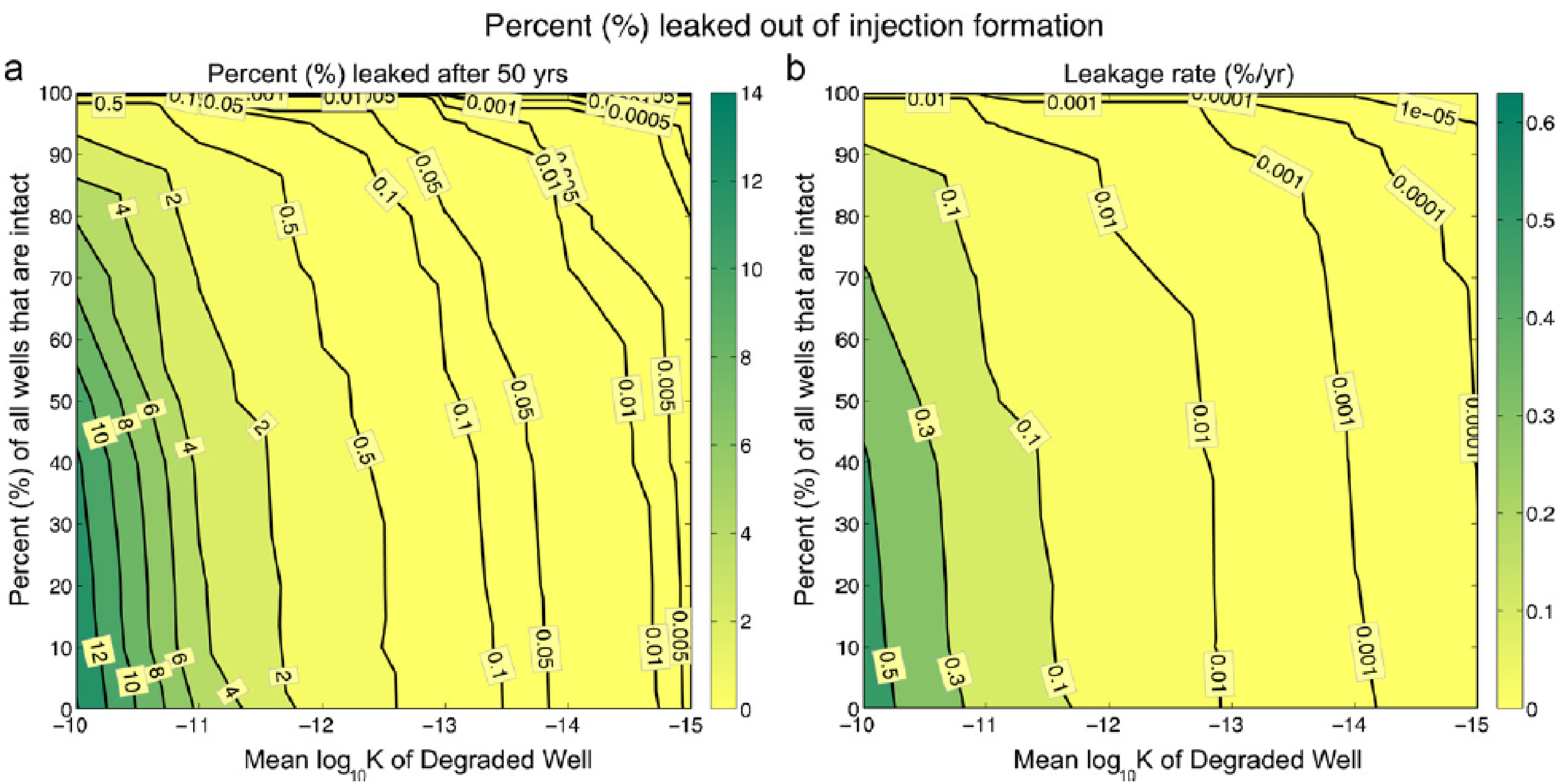
Random Well Permeability





Bi-modal Lognormal Distribution for Well Permeability





(See: Nogues et al., 2012)

Field Measurements in Old Wells

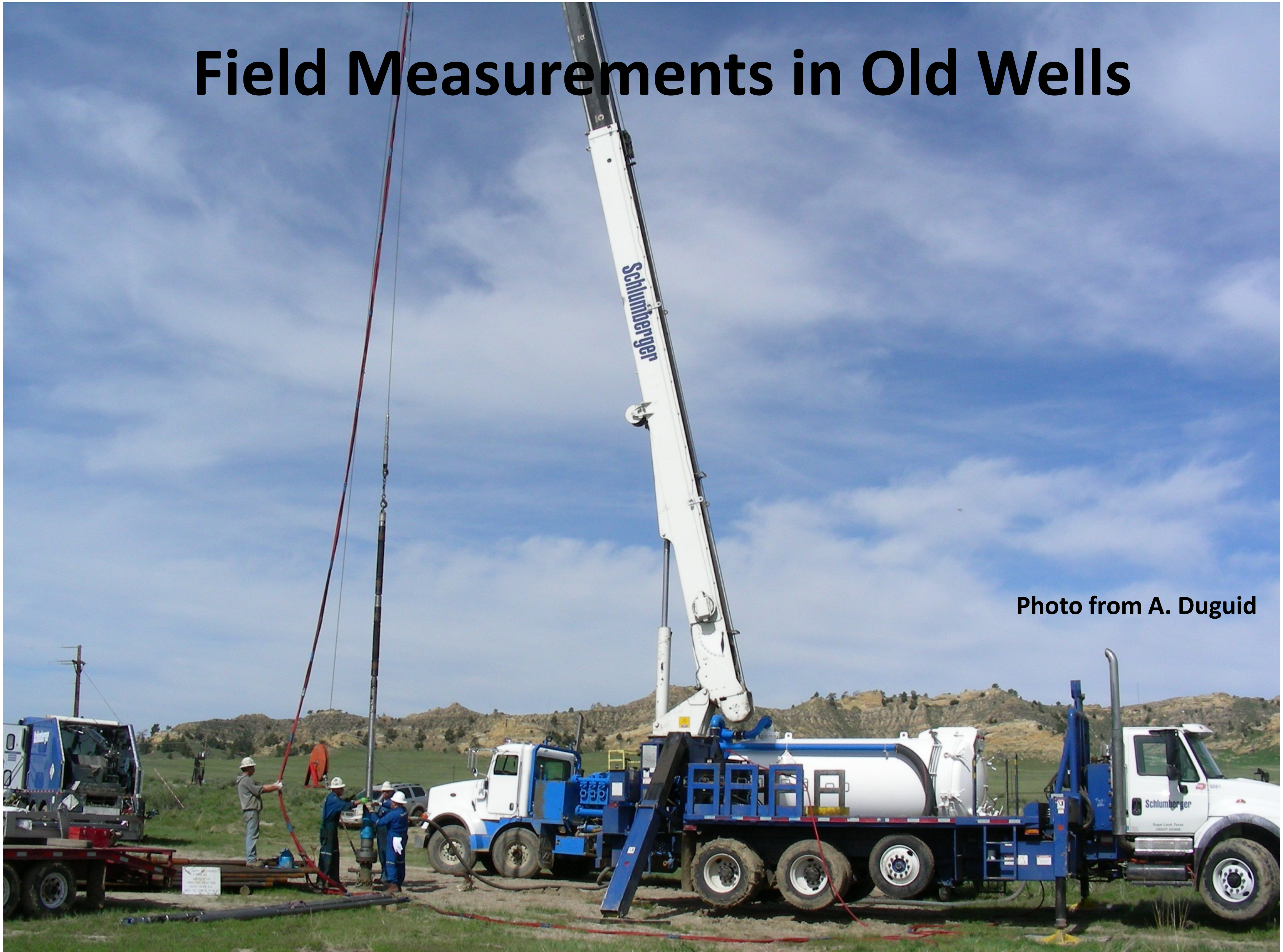
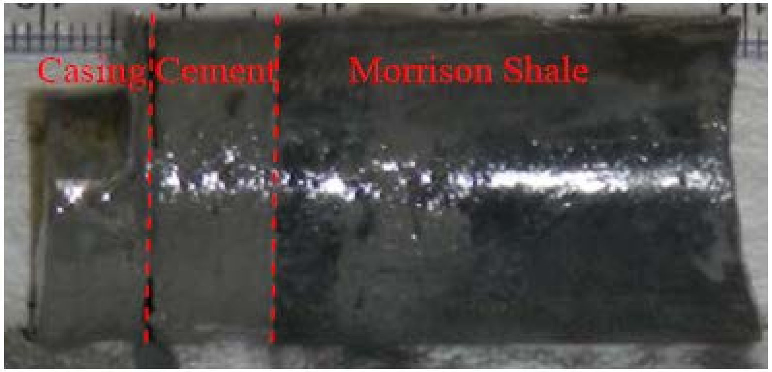
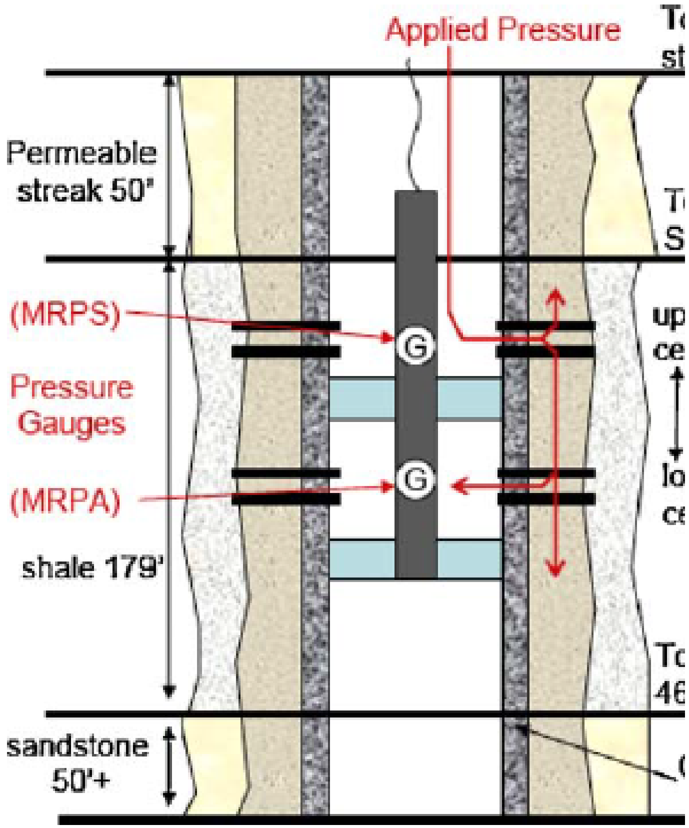
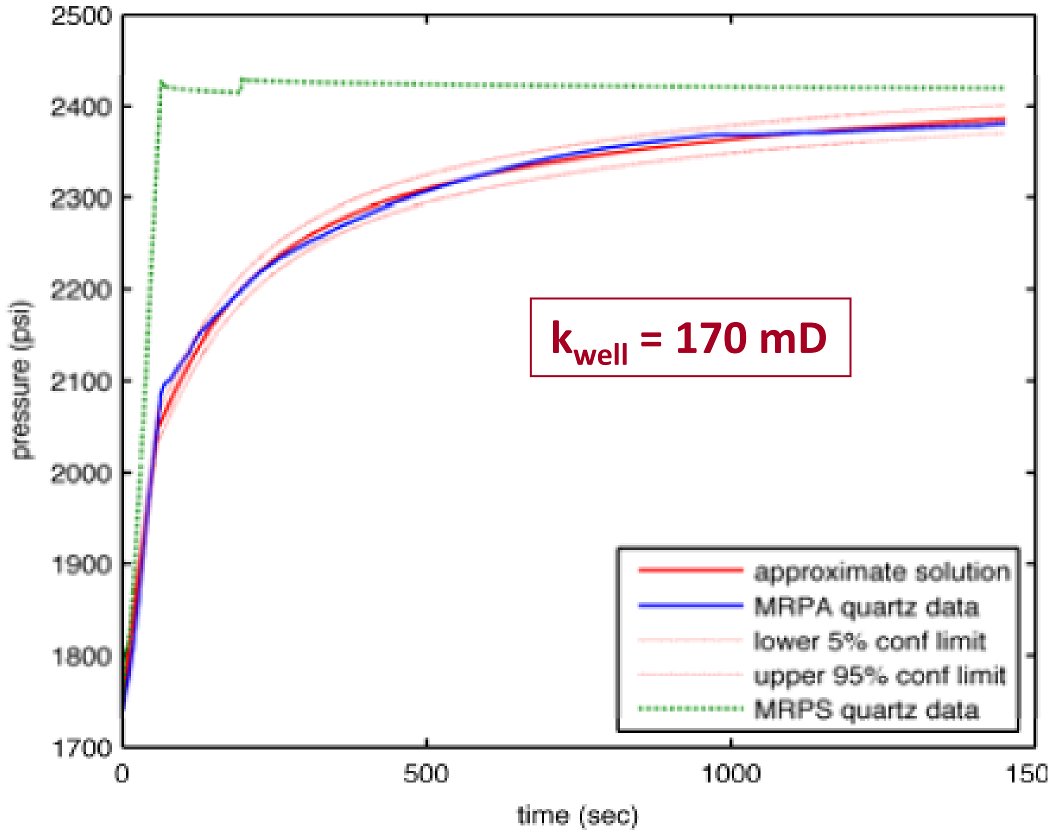
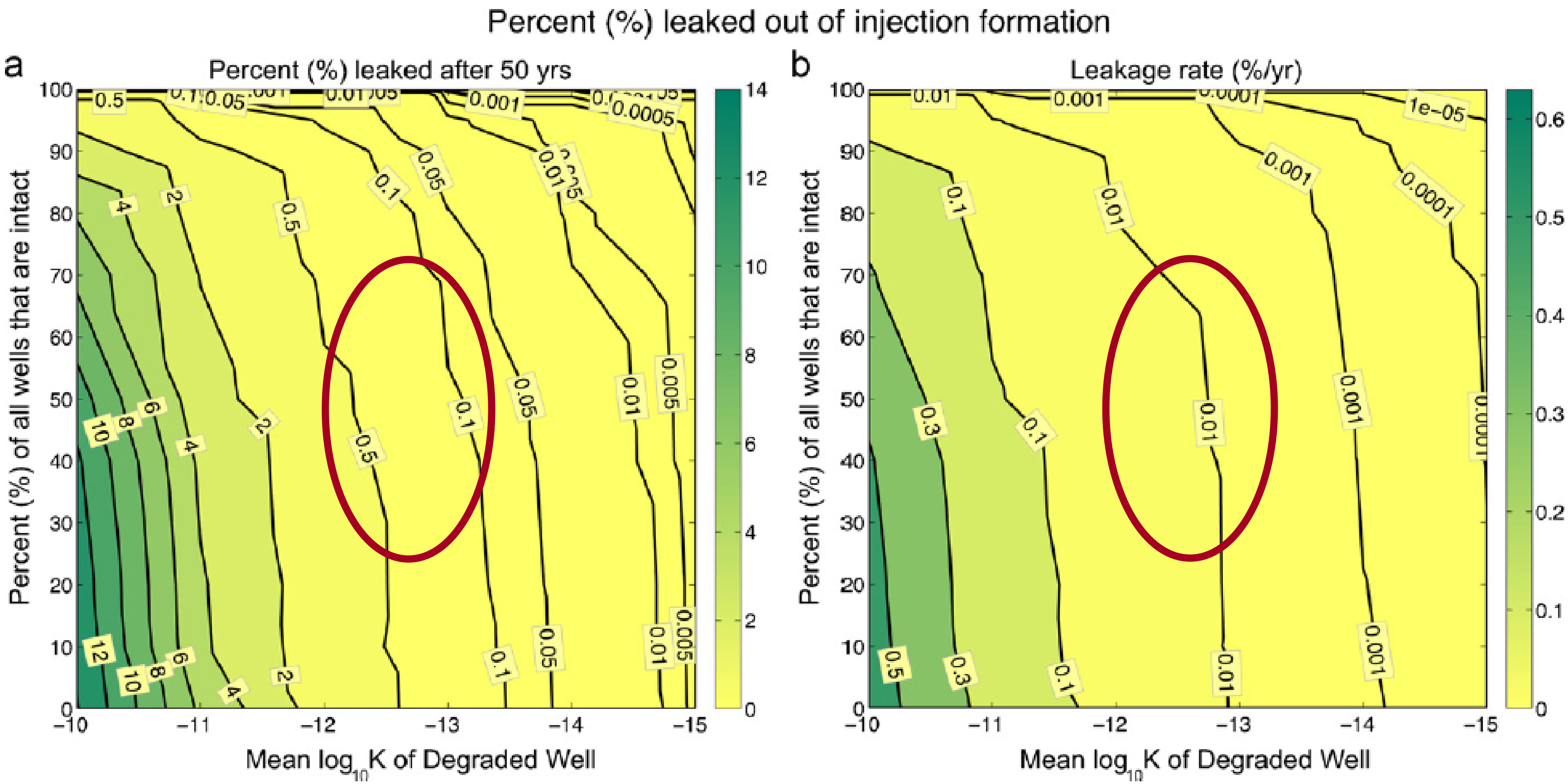


Photo from A. Duguid


Casing
Cement
Morrison Shale


Applied Pressure
Permeable streak 50'
(MRPS)
Pressure Gauges
(MRPA)
shale 179'
sandstone 50'+


pressure (psi)
time (sec)
k_{well} = 170 mD
approximate solution
MRPA quartz data
lower 5% conf limit
upper 95% conf limit
MRPS quartz data


Percent (%) leaked out of injection formation
a
Percent (%) leaked after 50 yrs
Percent (%) of all wells that are intact
Mean log10K of Degraded Well
b
Leakage rate (%/yr)
Percent (%) of all wells that are intact
Mean log10K of Degraded Well

COMMENTS

- Estimate of maximum CO_2 leakage appears to be acceptably low.
- Brine leakage into drinking water zone is much less than CO_2 leakage.
- These kinds of models can be used to assess risk in many different formations in North America.
- Some components of these models may be useful for fracking risk assessment studies.

FRACKING AND WELL LEAKAGE

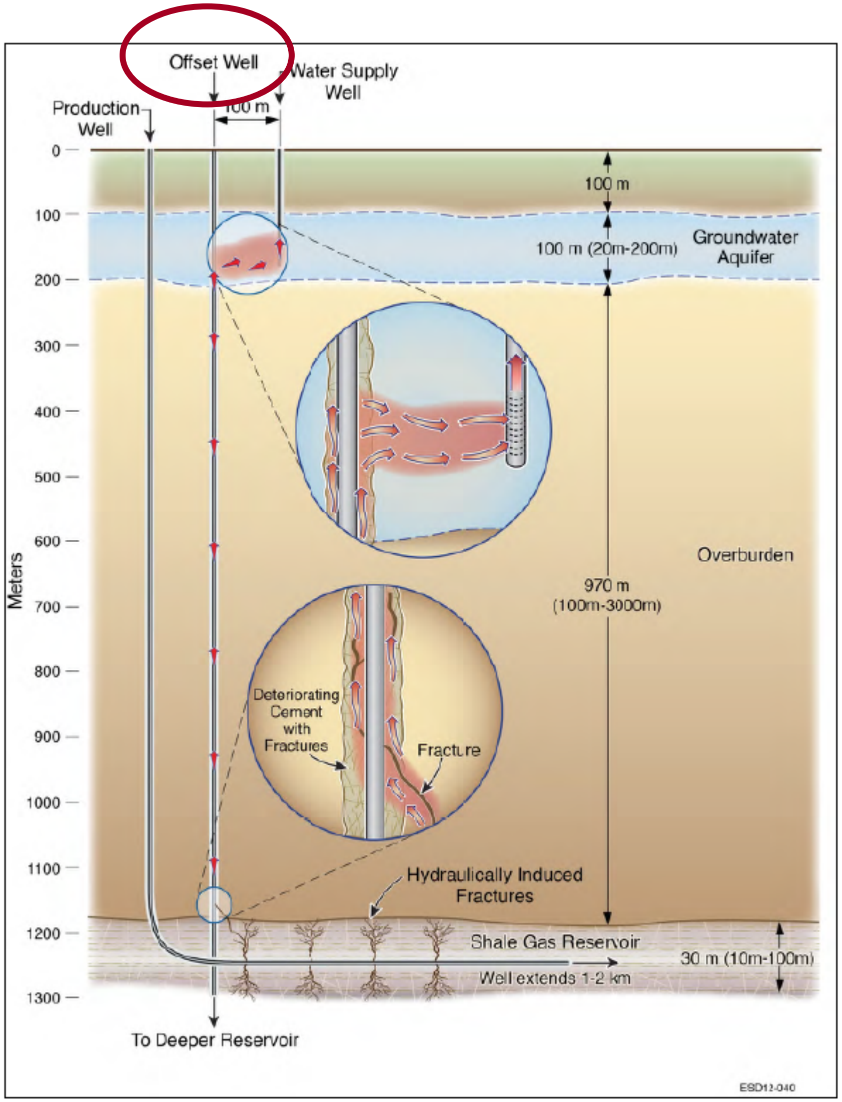


Figure 18. Scenario D1 of the subsurface migration modeling project. This hypothetical scenario simulates movement of hydrocarbons and other contaminants into offset wells in conventional oil/gas reservoirs with deteriorating cement due to fracturing of the overburden. The offset wells may intersect and communicate with aquifers, and inadequate or failing completions/cement can create pathways for contaminants to reach ground water aquifers.

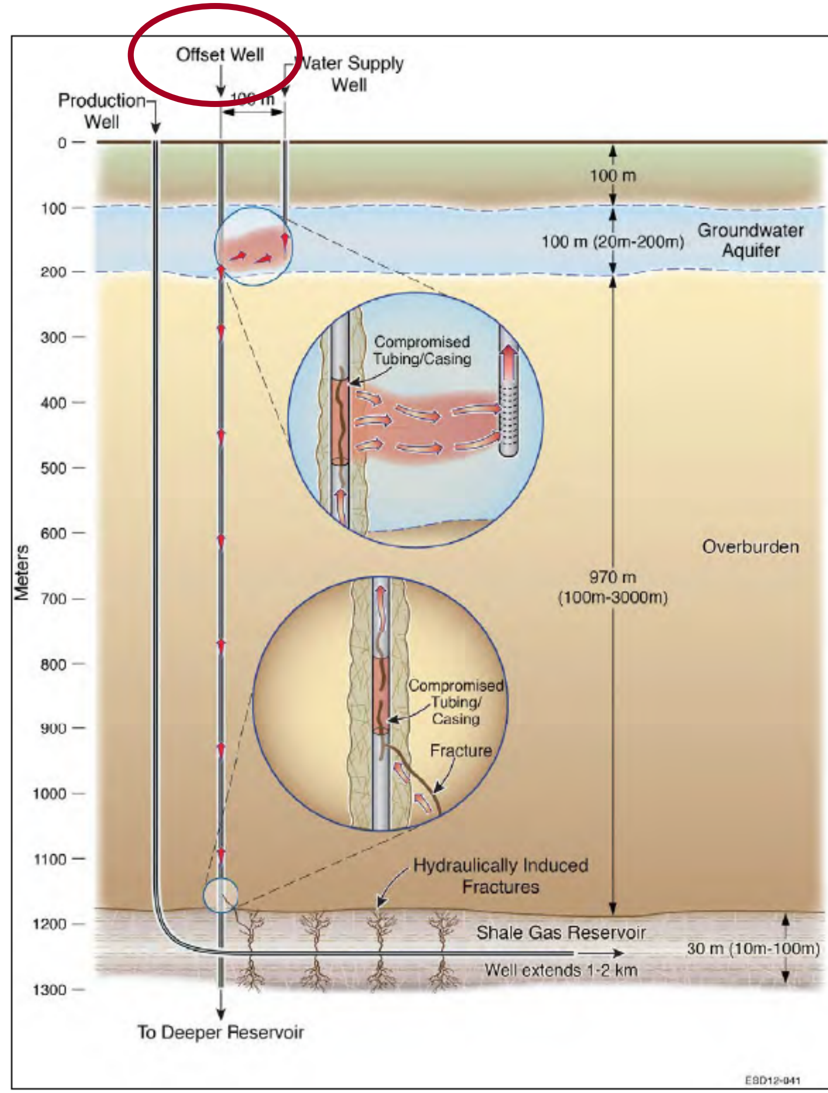


Figure 19. Scenario D2 of the subsurface migration modeling project. Similar to Scenario D1, this hypothetical scenario simulates movement of hydrocarbons and other contaminants into offset wells in conventional oil/gas reservoirs due to fracturing of the overburden. The offset wells in Scenario D2 are improperly closed with compromised casing, which provides a low-resistance pathway connecting the shale gas reservoir with the ground water aquifer.