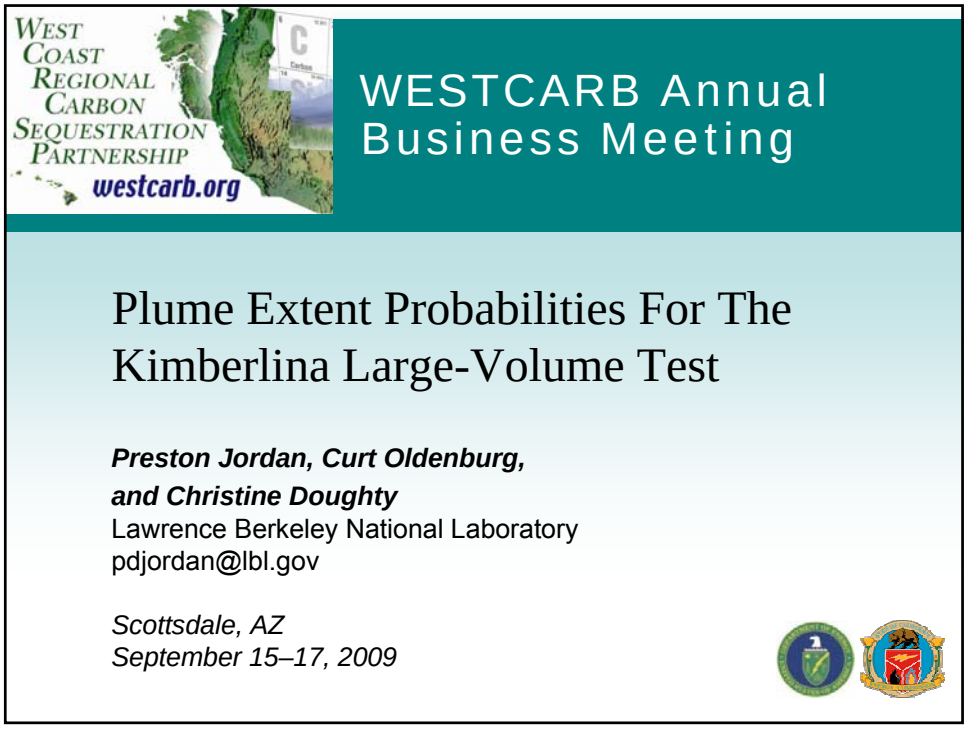
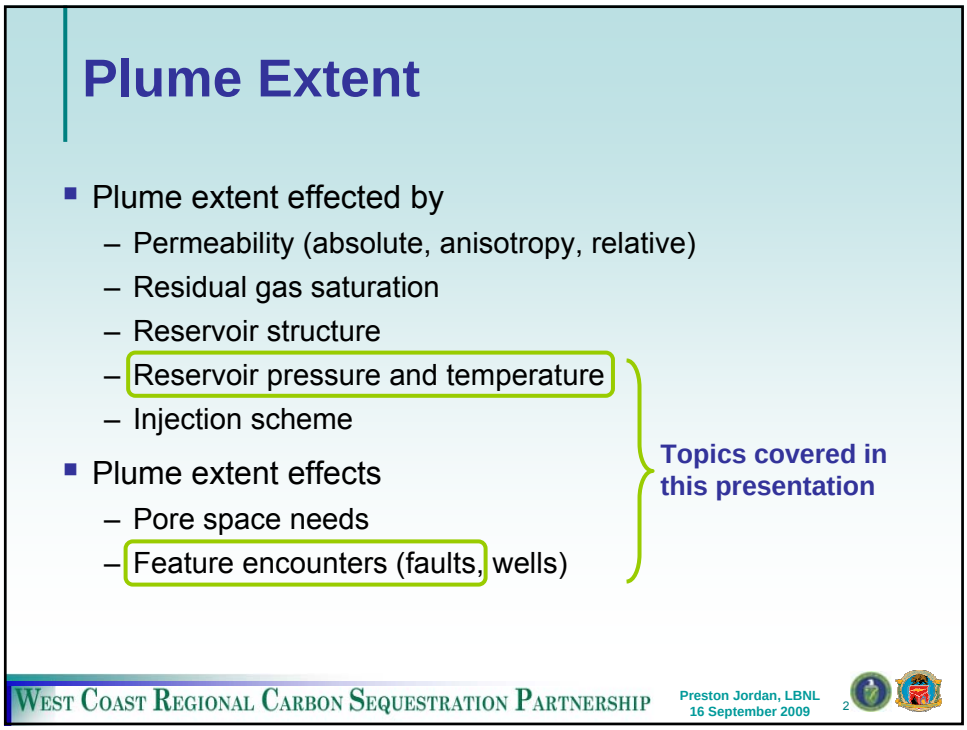
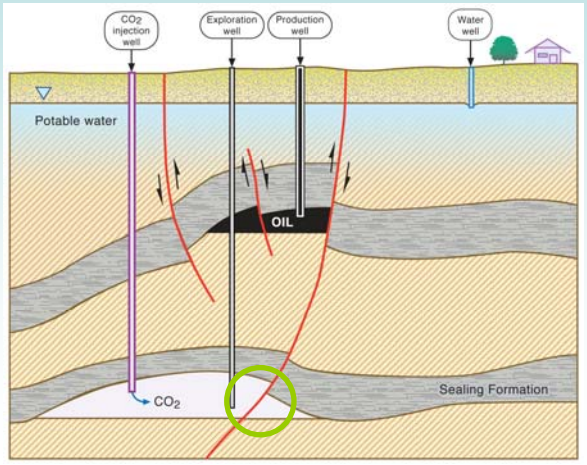

West Coast Regional Carbon Sequestration Partnership
westcarb.org
WESTCARB Annual Business Meeting
Plume Extent Probabilities For The Kimberlina Large-Volume Test
Preston Jordan, Curt Oldenburg, and Christine Doughty
Lawrence Berkeley National Laboratory
pdjordan@lbl.gov
Scottsdale, AZ
September 15–17, 2009


Plume Extent
Plume extent effected by
– Permeability (absolute, anisotropy, relative)
– Residual gas saturation
– Reservoir structure
– Reservoir pressure and temperature
– Injection scheme
Plume extent effects
– Pore space needs
– Feature encounters (faults, wells)
Topics covered in this presentation
West Coast Regional Carbon Sequestration Partnership
Preston Jordan, LBNL
16 September 2009
2

Example Site Section

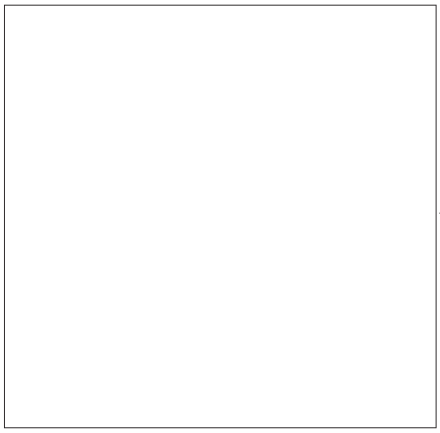


Probability of Fault Leakage

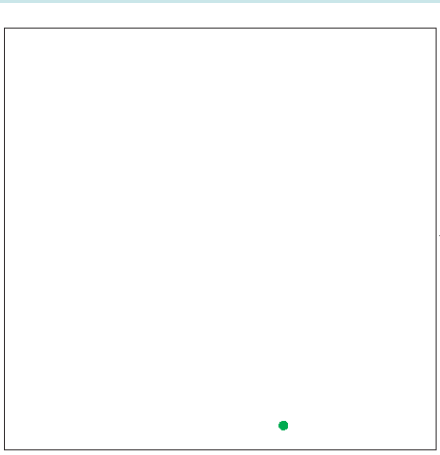
$$\Pr(l) = \Pr(g) \cdot \Pr(q)$$

The probability of **leakage via a fault (event *l*)**
is the probability of **encountering a fault (event *g*)** times
the probability of **flow along the fault (event *q*)**,
if *g* and *q* are independent
(no geomechanical effects for instance).

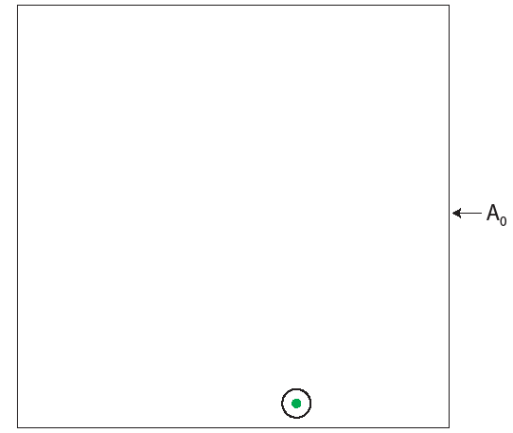
A Prospective Injection Region



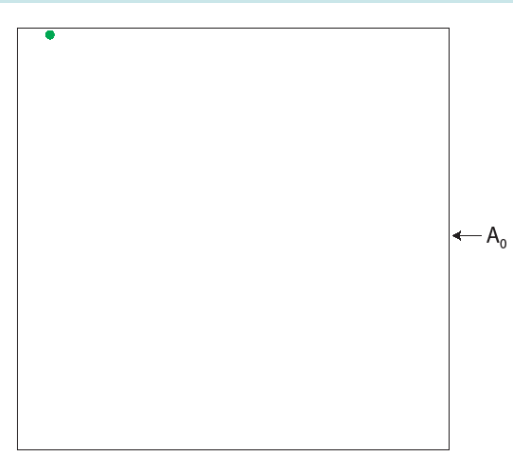
A Possible Injection Well



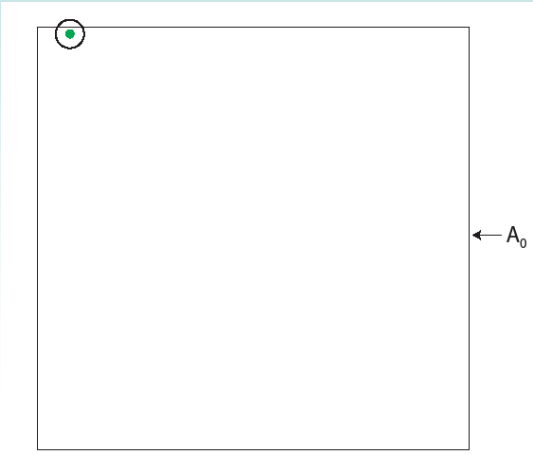
The Plume From That Well



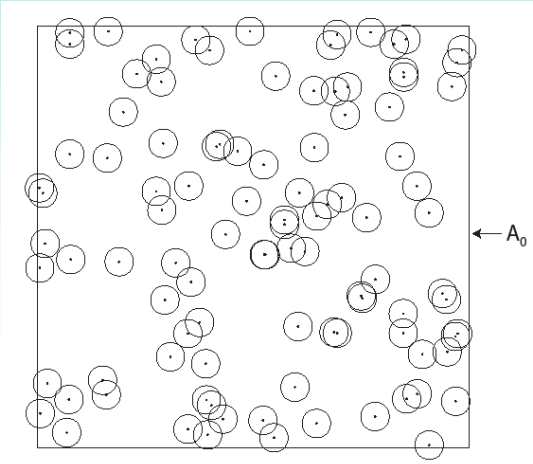
Another Possible Injection Well



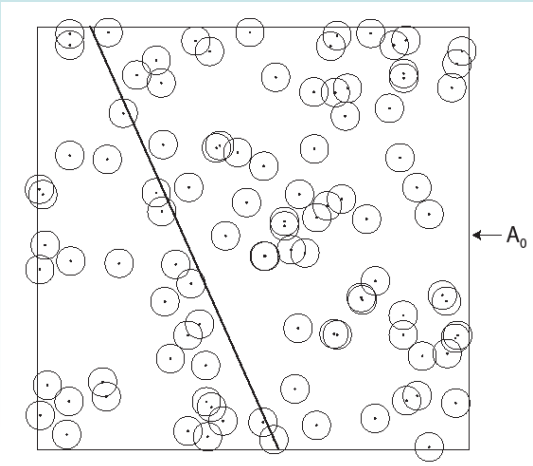
The Plume From That Well



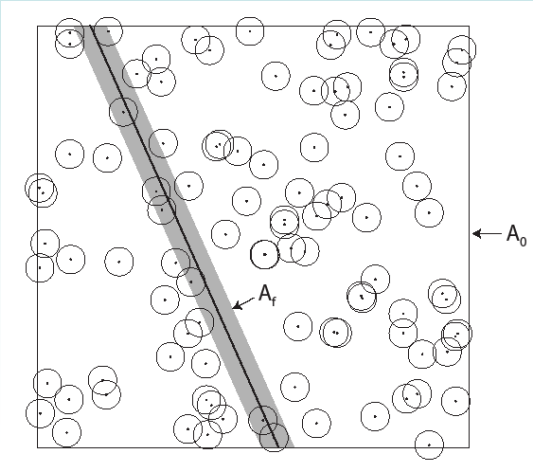
Plumes From A Hundred Different Possible Injection Wells



An Unknown Fault

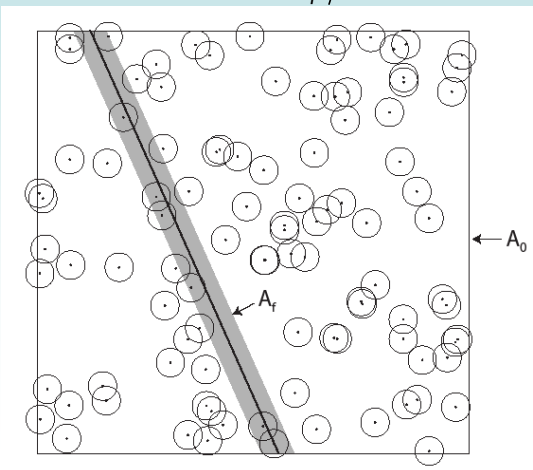


Area Where Injection Results In Fault Encounter



Fault Encounter Probability

$$\Pr(g) = A_f / A_o$$



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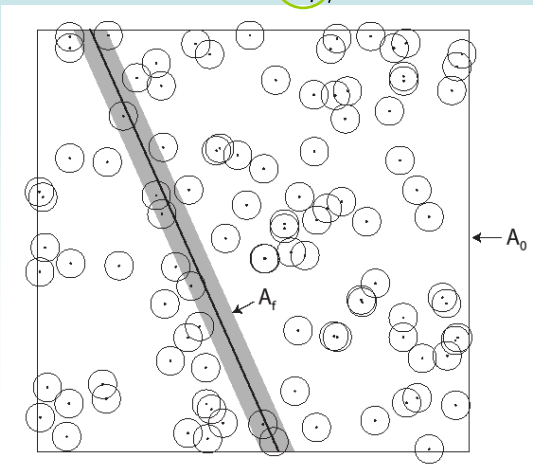
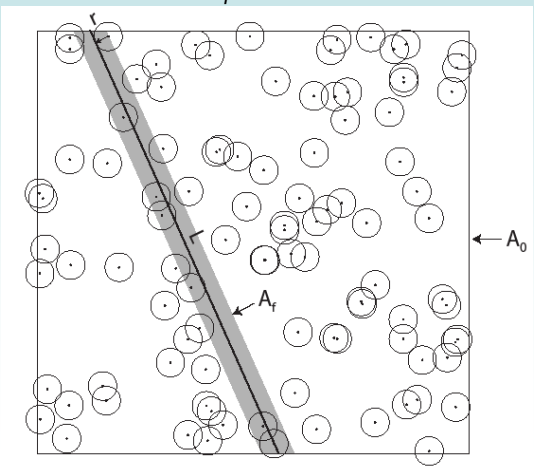


Fault Encounter Injection Area

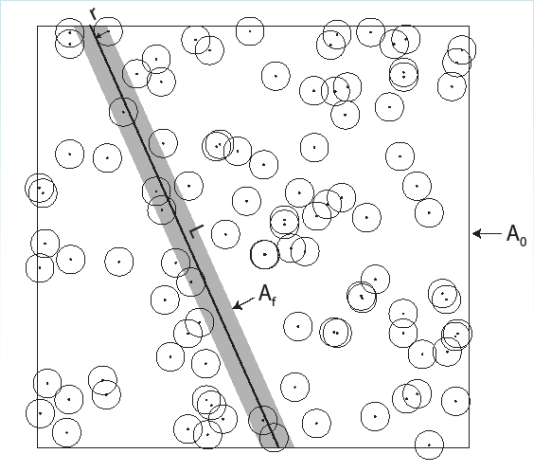
$$A_f = 2rL$$



Fault Encounter Injection Area

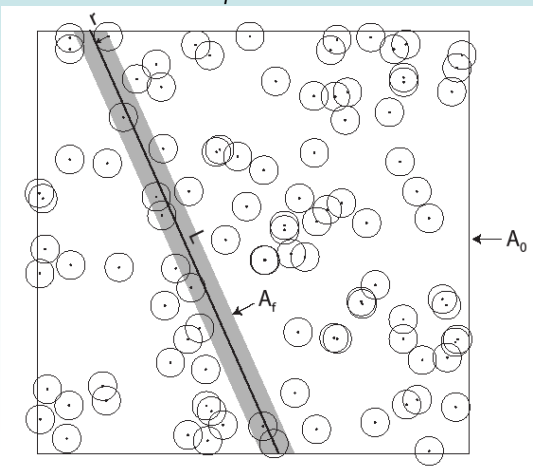
$$A_f = 2rL*$$

*if the spacing between and the length of the faults is large relative to the plume size.



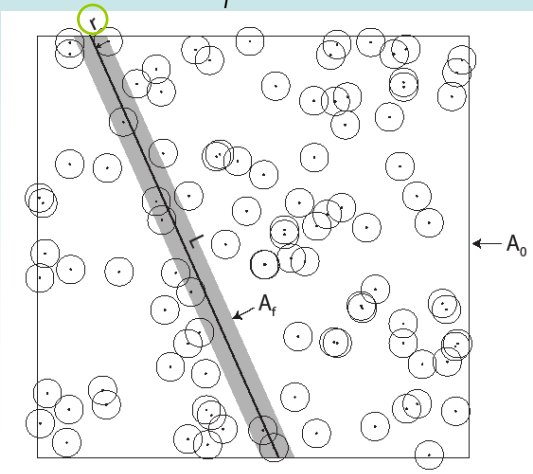
Fault Encounter Injection Area

$$A_f = 2rL$$



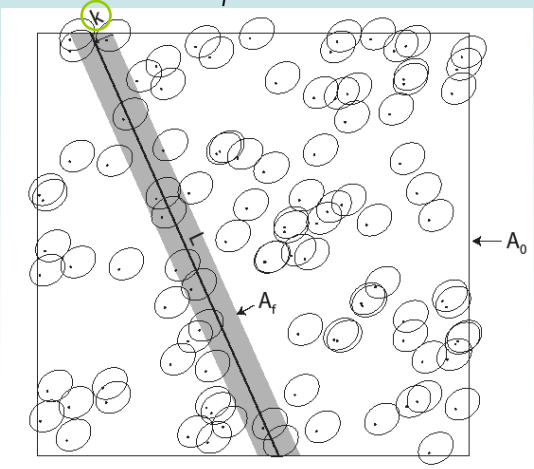
Fault Encounter Injection Area

$$A_f = 2rL$$



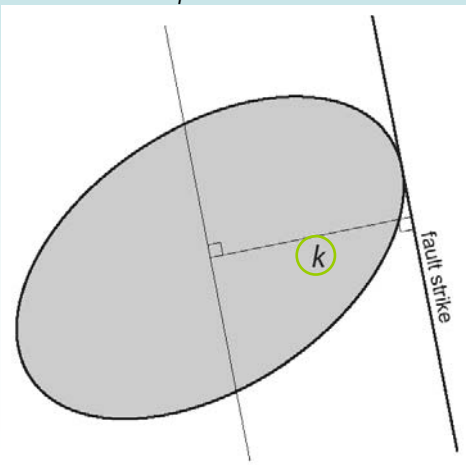
Fault Encounter Injection Area

$$A_f = 2kL$$



Fault Perpendicular Dimension

$$A_f = 2kL$$



Fault Perpendicular Dimension

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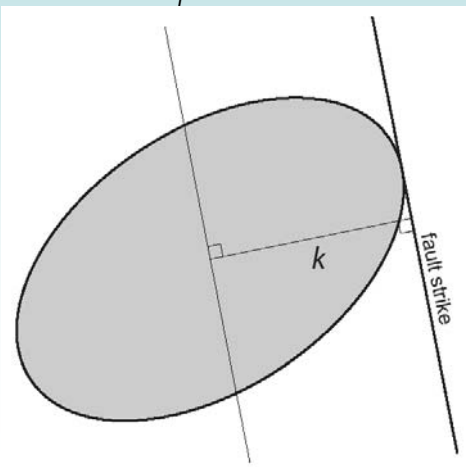
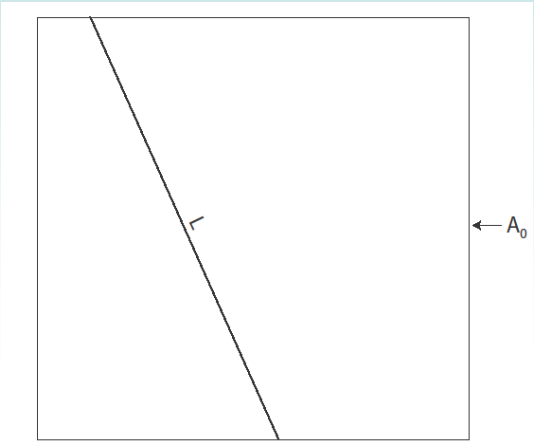


Fault Length

$$F = \frac{L}{A_0} \Rightarrow L = FA_0$$



Fault Encounter Probability

So if $L = FA_0$,

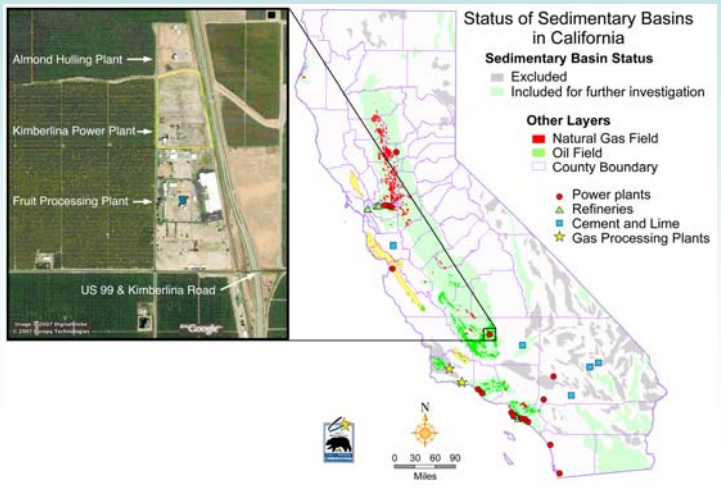
Substituting into the formula for fault encounter injection area yields

$$A_f = 2kFA_0.$$

Substituting into the formula for the fault encounter probability yields

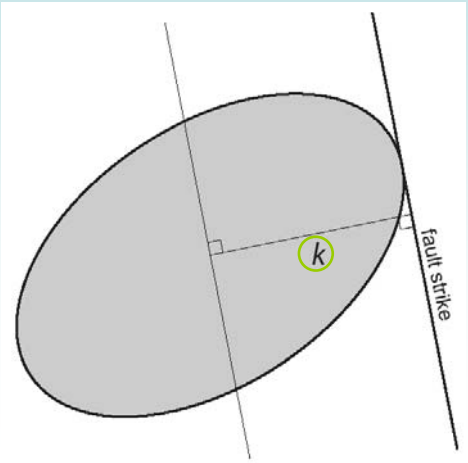
$$\Pr(g) = \frac{2kFA_0}{A_0}, \quad \text{which gives} \quad \Pr(g) = 2kF.$$

Kimberlina Phase III Pilot

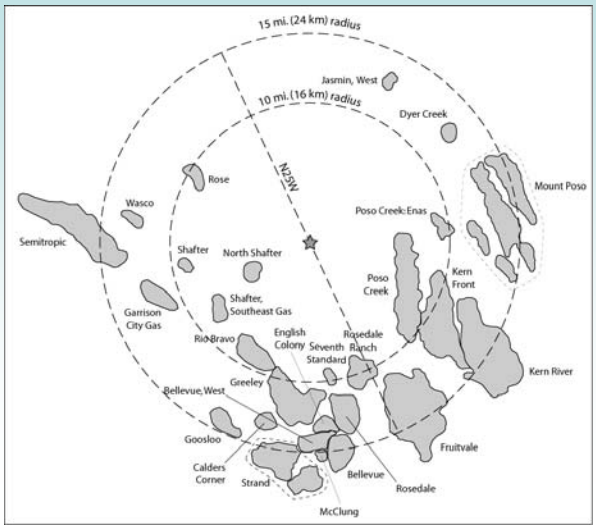


Probability for Elliptical Plumes

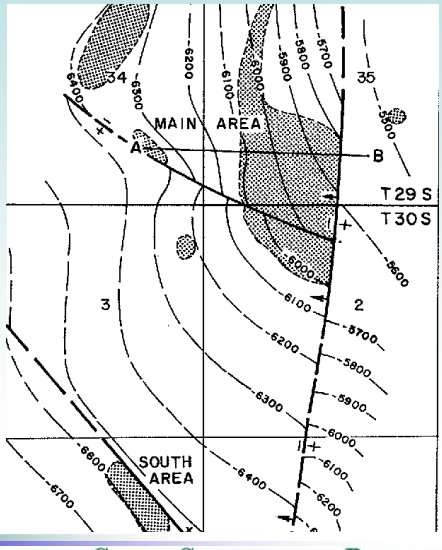
$$\Pr(g) = 2kF$$



Oil And Gas Fields Near Kimberlina

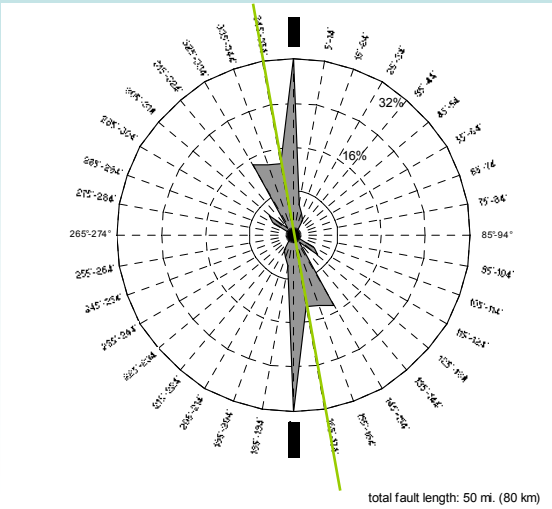


Oil Field Structure Map



Structure Maps in DOGGR, 1998, CA Oil and Gas Fields, V.1

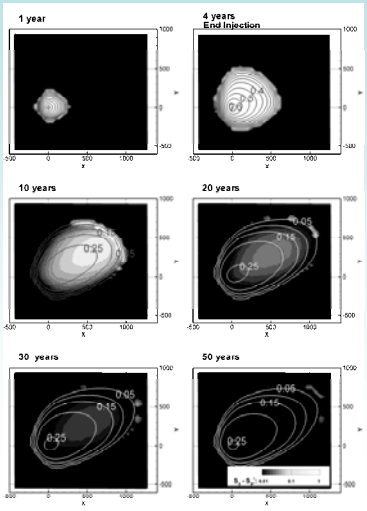
Fault Orientation Near Kimberlina



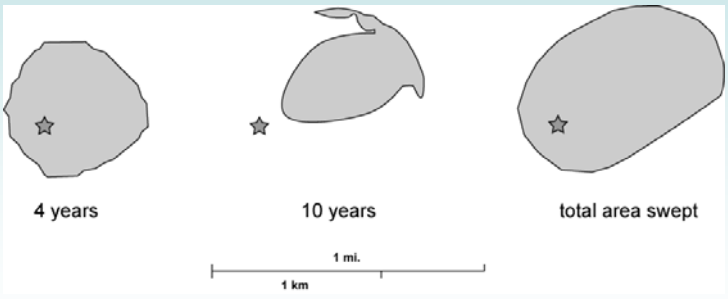
Simulated Kimberlina Plume

Kimberlina base case injection

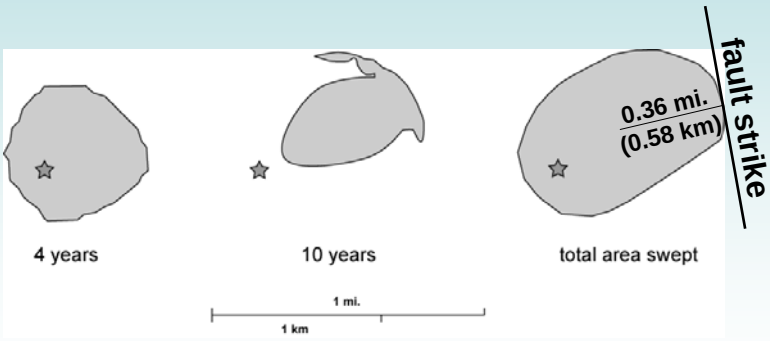
- **250,000 tonnes CO_2/year**
- **4 years**
- **Vedder Formation 2200-2360 m**
- **7° dip to the west/southwest**
- **interbedded sand/shale**
- **about half sand with 90 m net**
- **injection over the entire Vedder**



Mobile CO_2 And Area Swept



Value of *k*



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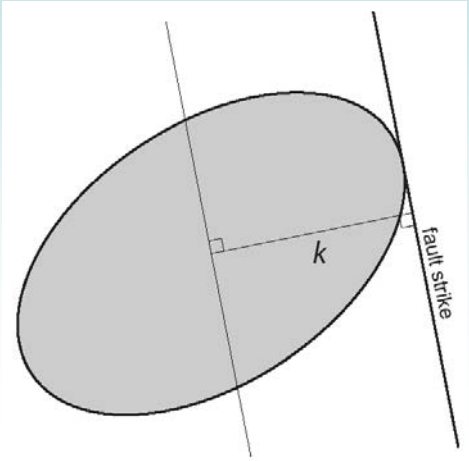
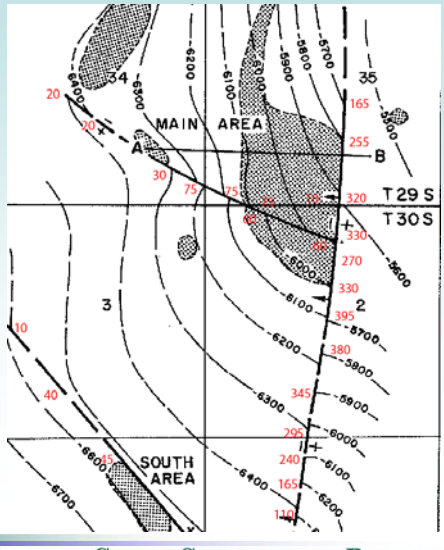
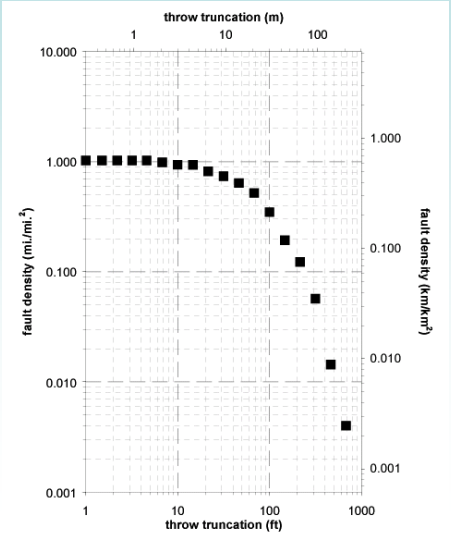


Fault Displacements



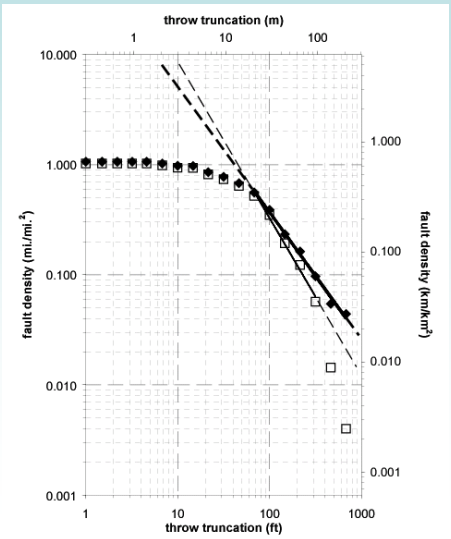
Structure Maps in DOGGR, 1998, CA Oil and Gas Fields, V.1

Near-Kimberlina Fault Density



fault density through section

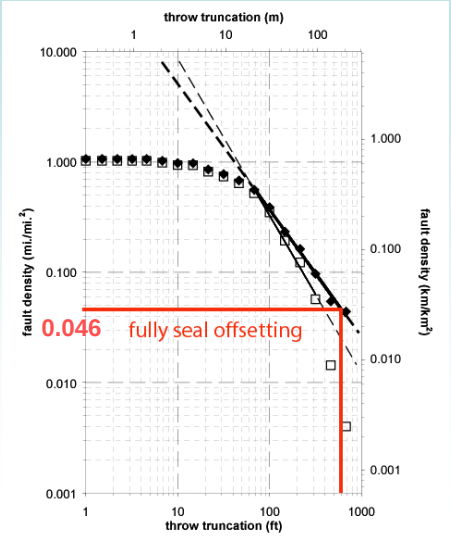
Modeled Fault Density: Power-Law



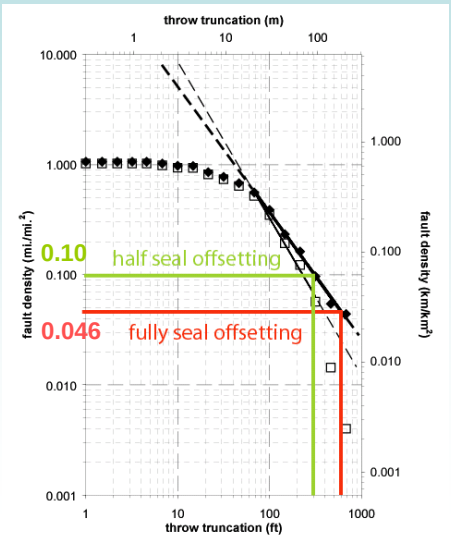
power-law fault population

K3 fault density model

Near-Kimberlina Fault Density



Near-Kimberlina Fault Density



Kimberlina Fault Encounter Probability

$$\Pr(g) = 2kF$$

Fully Containment Zone Offsetting Fault

$$\Pr(g) = 2 \bullet 0.36\text{mi.} \bullet 0.046 \frac{\text{mi.}}{\text{mi.}^2} = \mathbf{3.3\%}$$

Half Containment Zone Offsetting Fault

$$\Pr(g) = 2 \bullet 0.36\text{mi.} \bullet 0.10 \frac{\text{mi.}}{\text{mi.}^2} = \mathbf{7.2\%}$$

Pond Fault

Kimberlina geology report

probability versus plume variation

normal fault k

Plume Extent

- Plume extent effected by
  - Permeability (absolute, anisotropy, relative)
  - Residual gas saturation
  - Reservoir structure
  - Reservoir pressure and temperature
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  - Pore space needs
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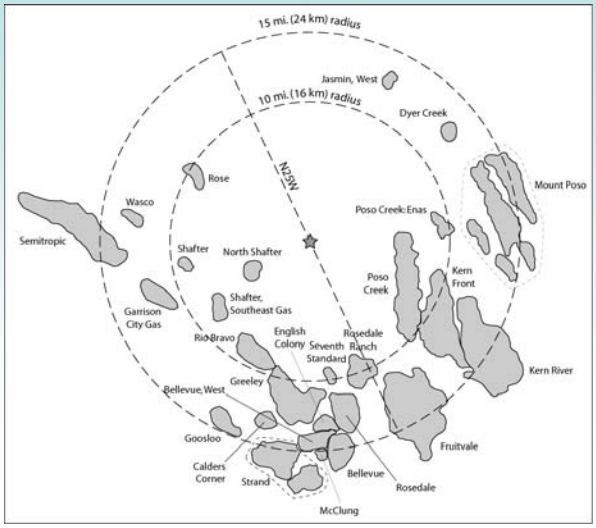
Oil And Gas Fields Near Kimberlina



Initial Pool Pressure and Temperature

COUNTY: KERN

POSO CREEK OIL FIELD
PREMIER AREA

DISCOVERY WELL AND DEEPEST WELL

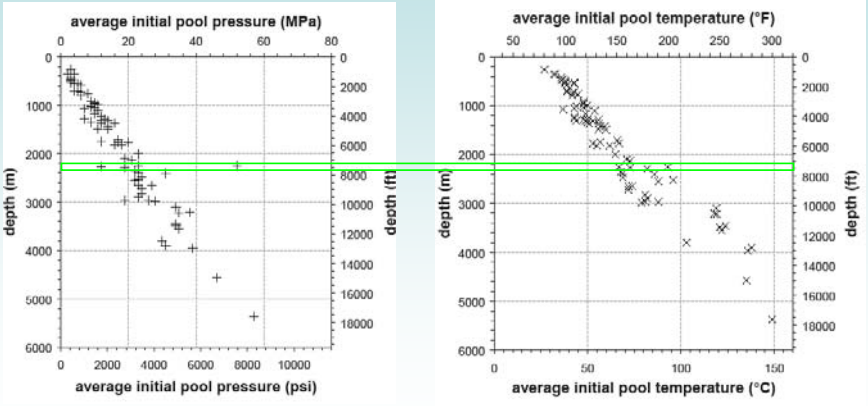
	Present operator and well designation	Original operator and well designation	Sec. T. & R.	B.&M.	Total depth (feet)	Pool (zone)	Strata & age at total depth
Discovery well	Chevron U.S.A. Inc. No. 2	Standard Oil Co. of Calif. No. 2	5 28S 27E	MD	2,822	Chanac	
Deepest well	Chevron U.S.A. Inc. No. 34	Standard Oil Co. of Calif. No. 34	5 28S 27E	MD	7,187		basement Lt. Jurassic(?)

POOL DATA

ITEM	MACOMA	BASAL ETCHEGOIN	CHANAC	KELLY 2		FIELD OR AREA DATA
Discovery date	November 1959	June 1944	December 1920	June 1946		
Initial production rates						
Oil (bbl/day)	-	125	90	130		
Gas (Mcf/day)	973	-	-	-		
Flow pressure (psi)	638	on pump	on pump	on pump		
Bean size (in.)	1/4	-	-	-		
Initial reservoir pressure (psi)	-	500–1,200	1,050–1,200	1,300		
Reservoir temperature (°F)	110	105–111	110–115	115		
Initial oil content (STB/ac.-ft.)	-	1,325–1,629	1,325–1,610	1,000**		
Initial gas content (MSCF/ac.-ft.)	-	360	360	-		
Formation	Etchegoin	Etchegoin	Chanac	Santa Margarita		
Geologic age	Pliocene	Pliocene	Miocene	Miocene		
Average depth (ft.)	9,360	2,400	2,500	3,460		
Average net thickness (ft.)	7	100	250	40		
Maximum productive area (acres)						3,610

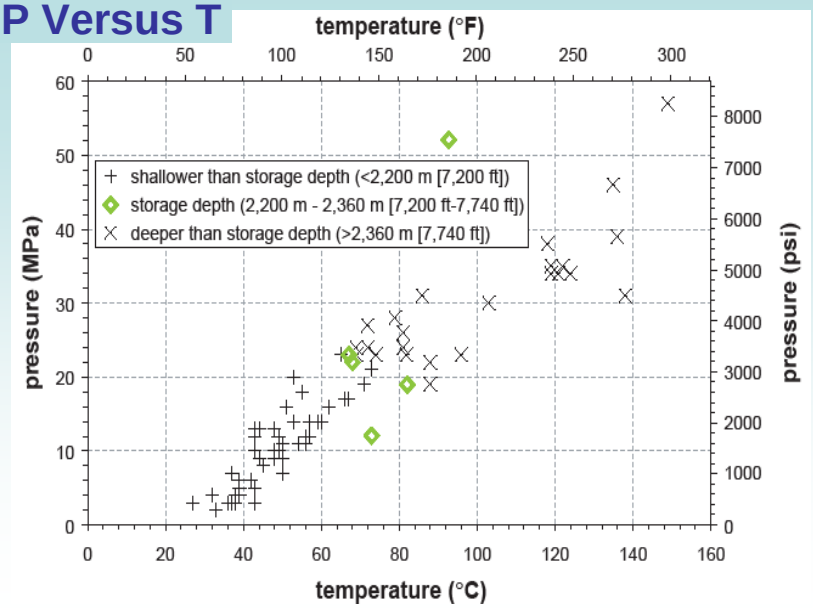
California Department of Conservation, Division of Oil, Gas, and Geothermal Resources, California oil and gas fields, Volume 1, Sacramento, California, 1998

Initial Pool Pressure and Temperature versus Depth



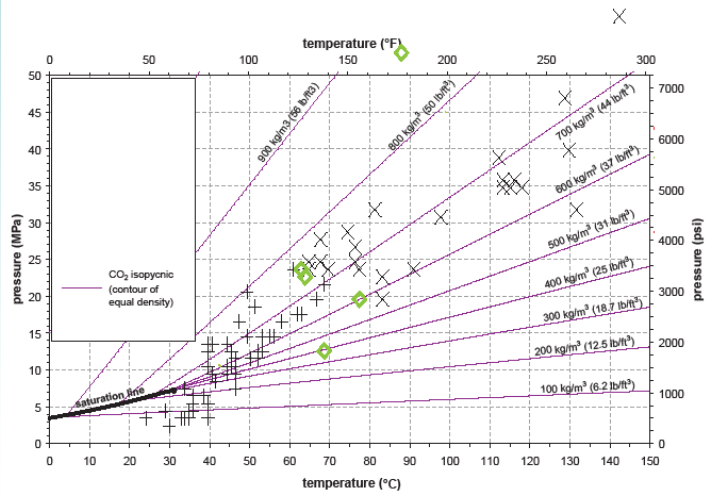
near-Kimberlina discovery PT

P Versus T

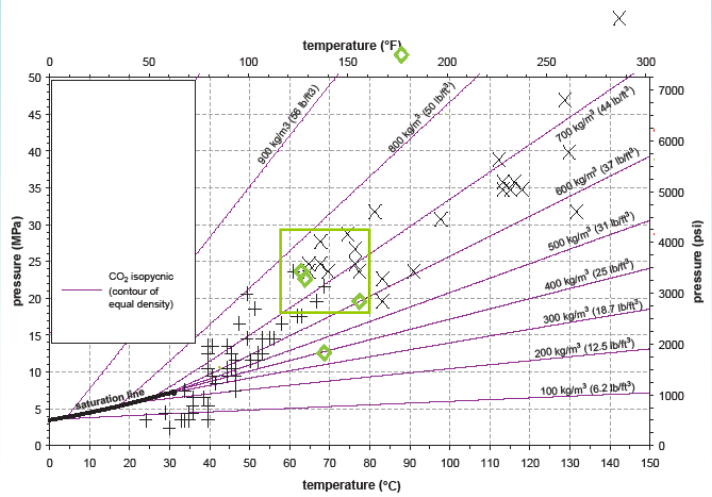


gradient statistics

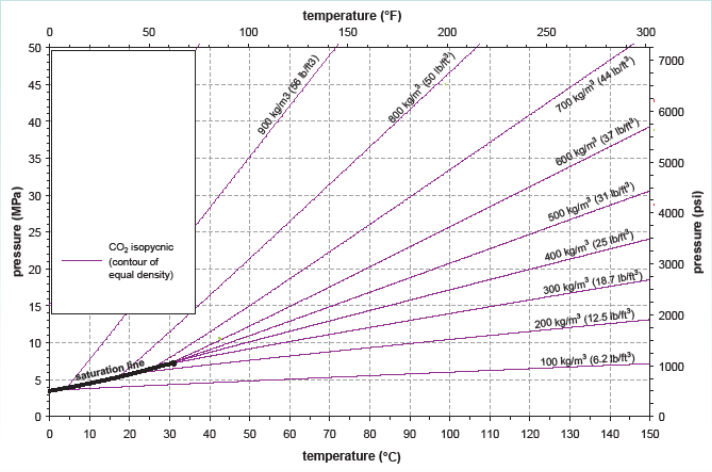
CO_2 Density Versus P And T



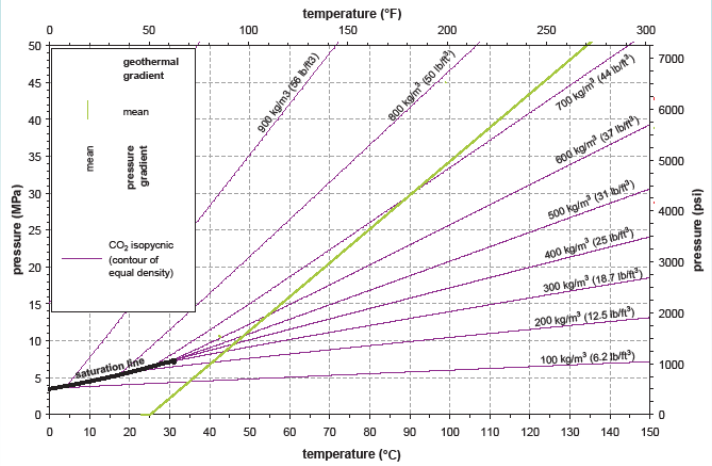
CO_2 Density Versus P And T



CO_2 Density Versus Pressure And Temperature

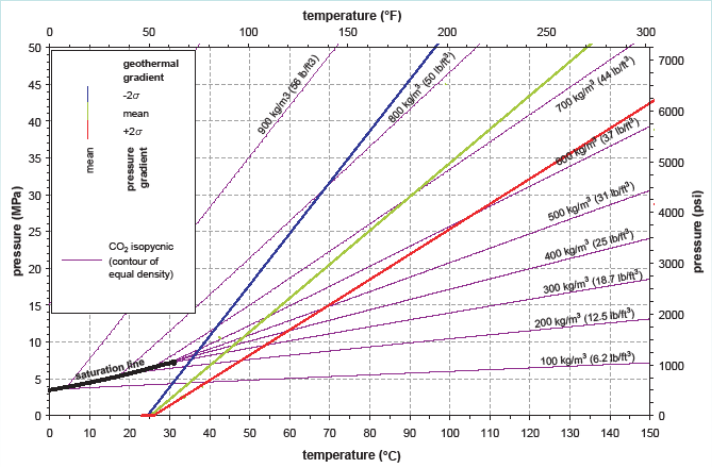


Pressure-Temperature Probability



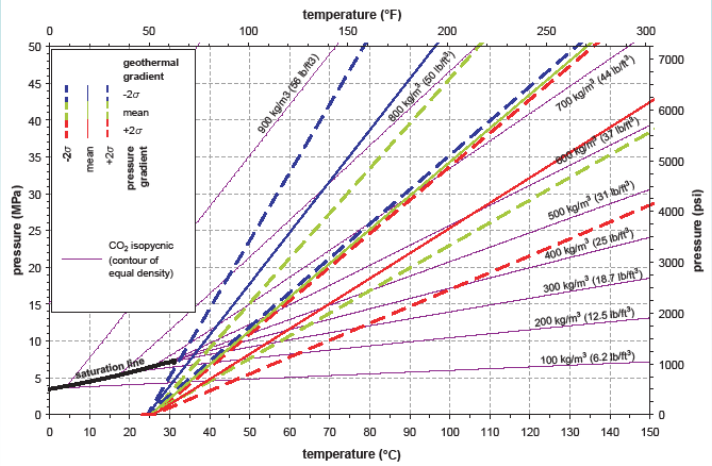
geothermal gradient: mean=21.7 °C/km (11.9 °F/1,000 ft)
pressure gradient: mean=101% hydrostatic

Pressure-Temperature Probability



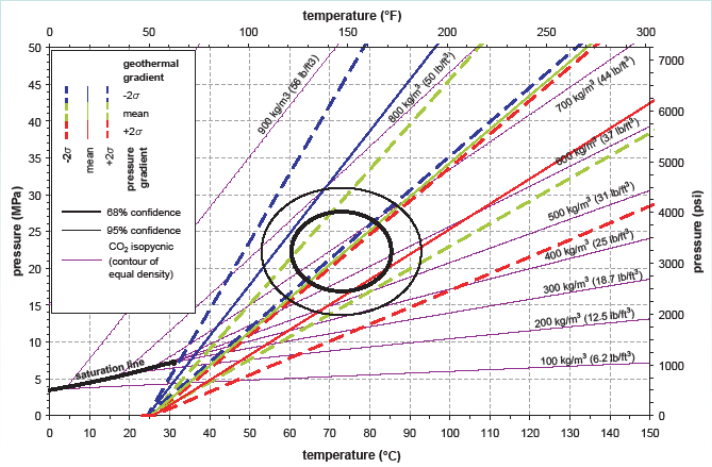
geothermal gradient: mean=21.7 °C/km (11.9 °F/1,000 ft), σ=3.7 °C (2.0 °F)
pressure gradient: mean=101% hydrostatic

Pressure-Temperature Probability



geothermal gradient: mean=21.7 °C/km (11.9 °F/1,000 ft), σ=3.7 °C (2.0 °F)
pressure gradient: mean=101% hydrostatic, σ=17% hydrostatic

Pressure-Temperature Probability



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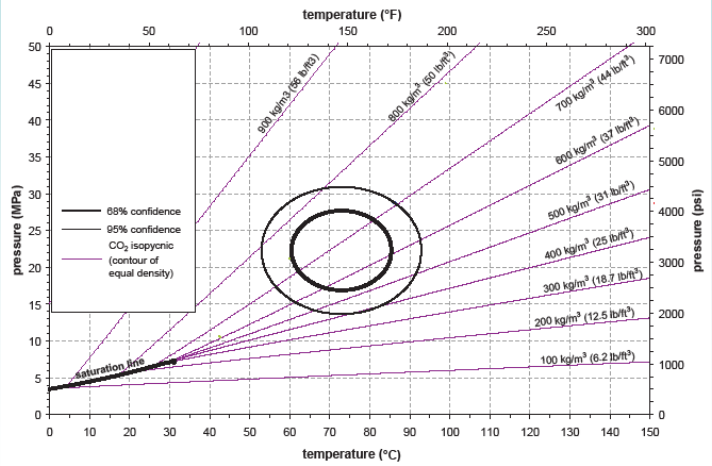
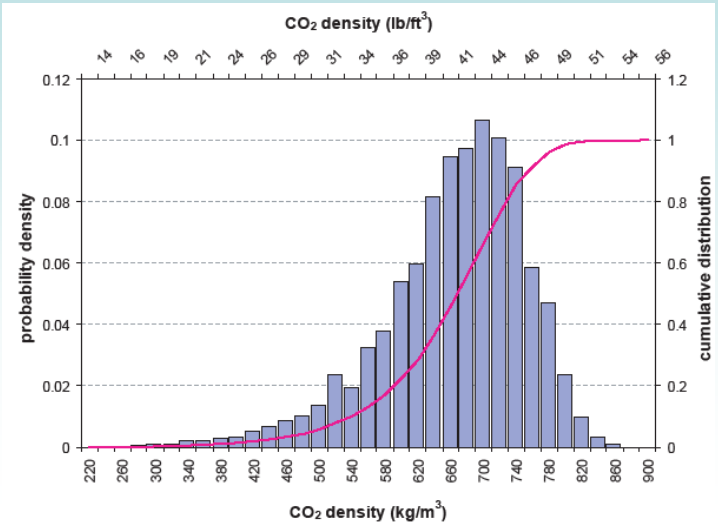
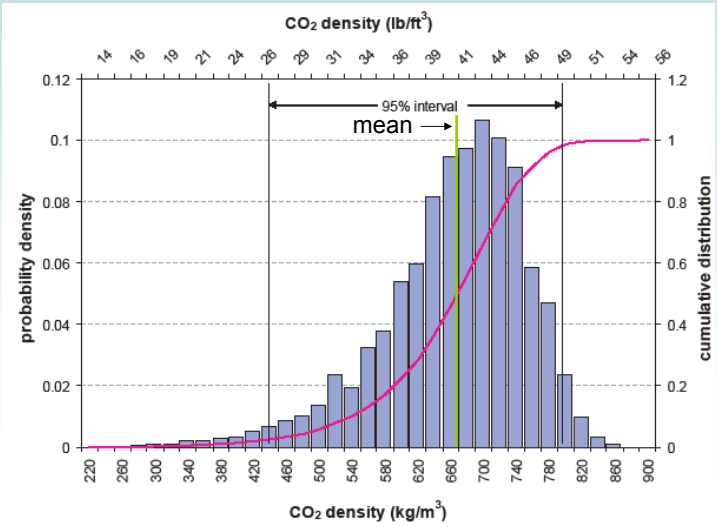


geothermal gradient: mean=21.7 °C/km (11.9 °F/1,000 ft), σ=3.7 °C (2.0 °F)
pressure gradient: mean=101% hydrostatic, σ=17% hydrostatic

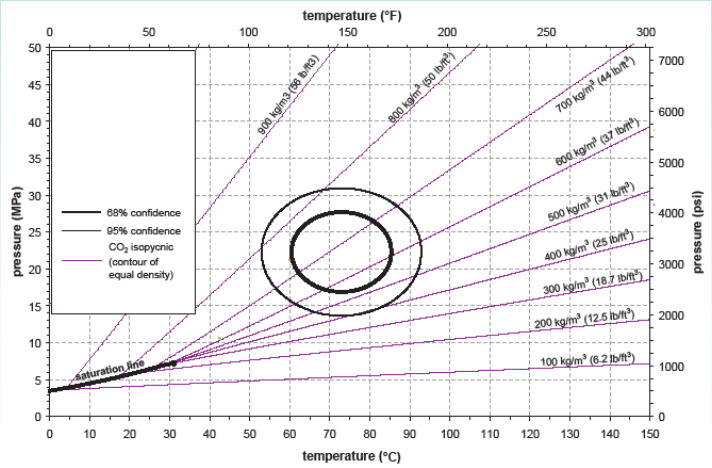
CO_2 Density Probability Distribution



CO_2 Density Probability Distribution



Pressure-Temperature Probability



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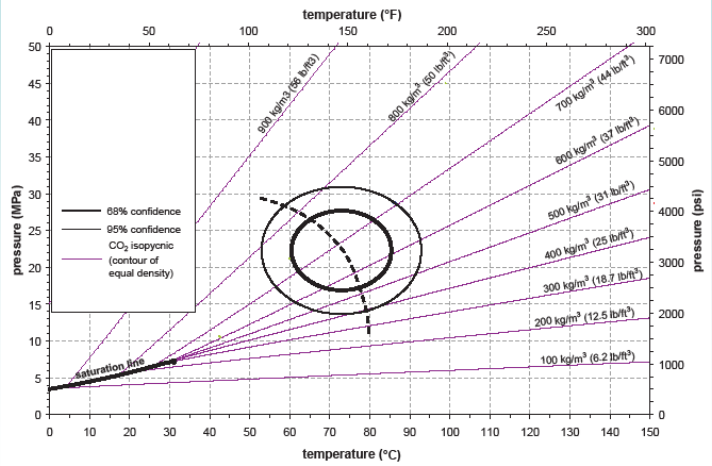
Pressure-Temperature Probability



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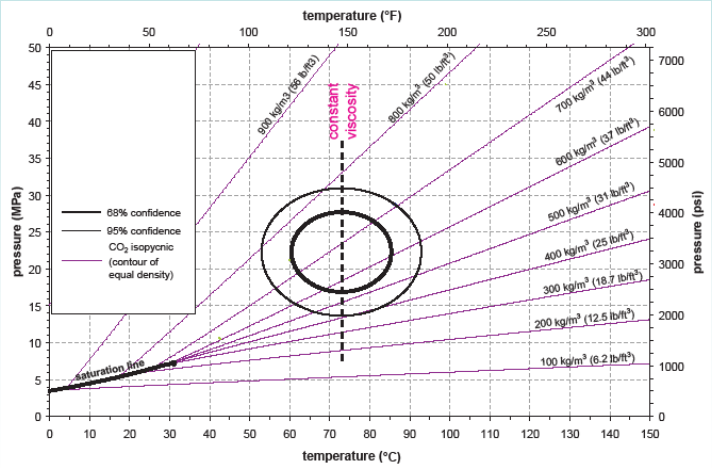
Pressure-Temperature Probability



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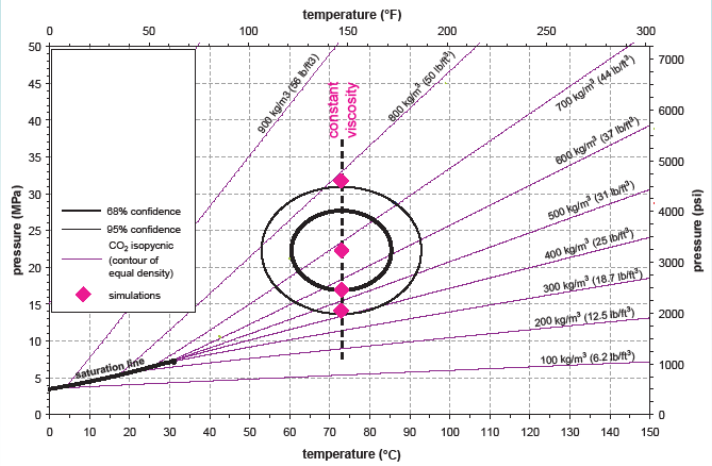
Pressure-Temperature Probability



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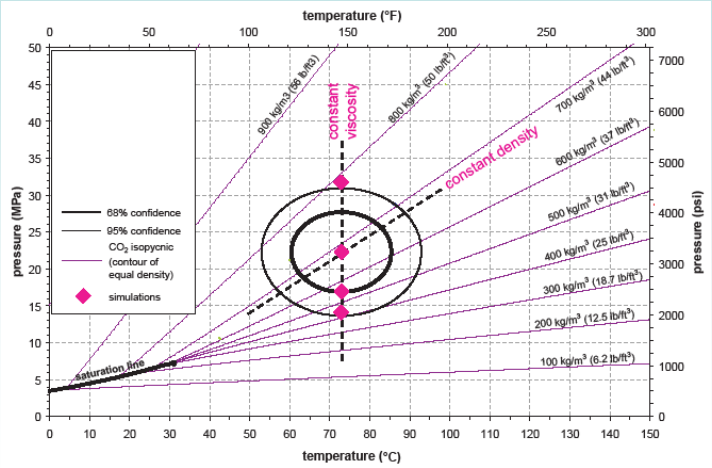
Pressure-Temperature Probability



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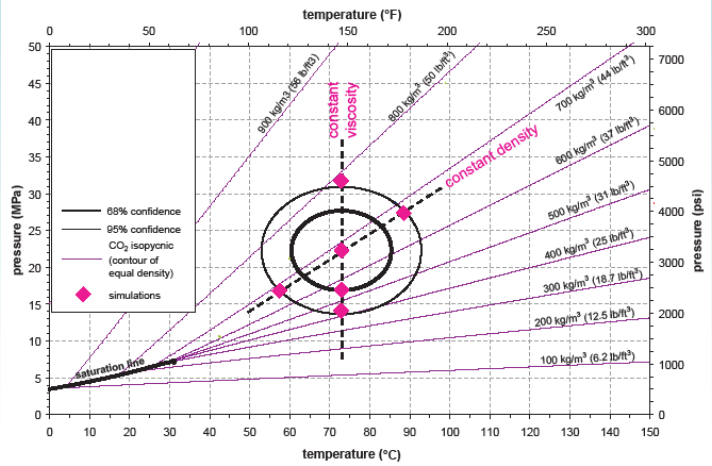
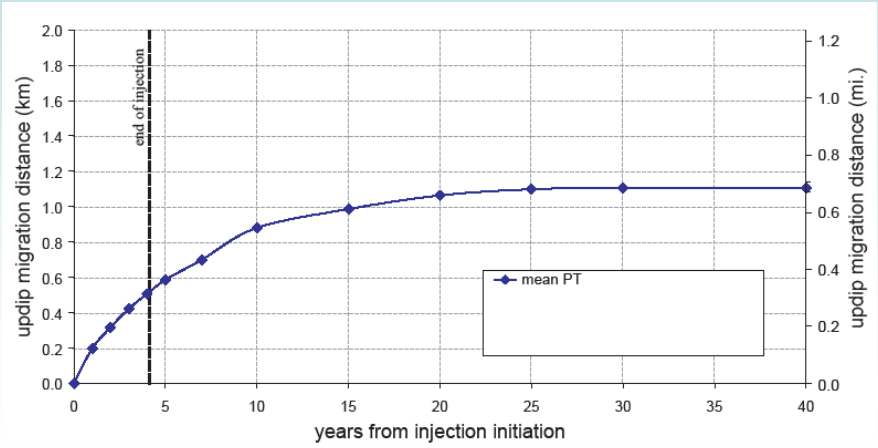
Pressure-Temperature Probability

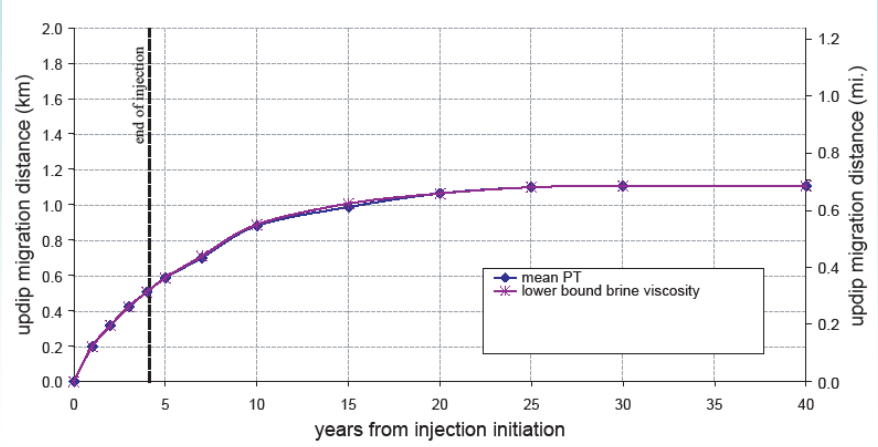


geothermal gradient: mean=21.7 °C/km (11.9 °F/1,000 ft), σ=3.7 °C (2.0 °F)
pressure gradient: mean=101% hydrostatic, σ=17% hydrostatic

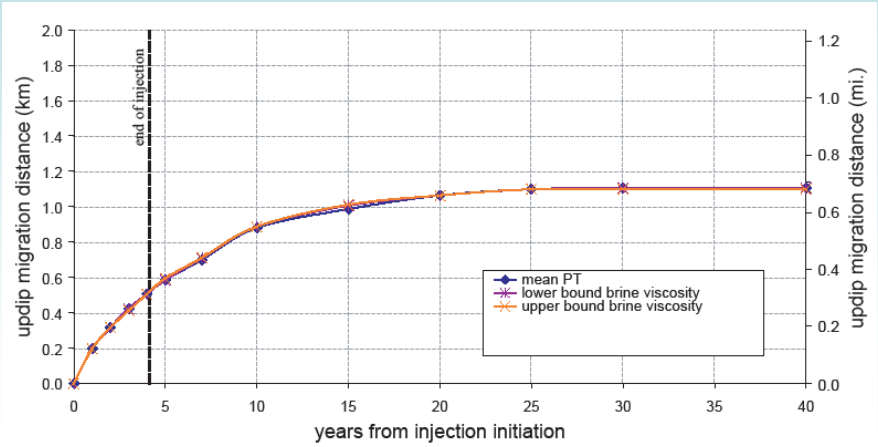
Kimberlina Plume Migration – Dipping Case



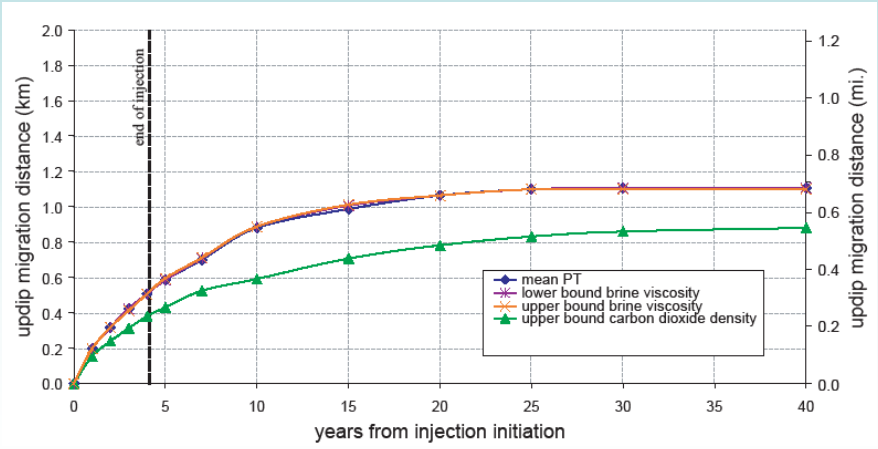
Kimberlina Plume Migration – Dipping Case



Kimberlina Plume Migration – Dipping Case



Kimberlina Plume Migration – Dipping Case



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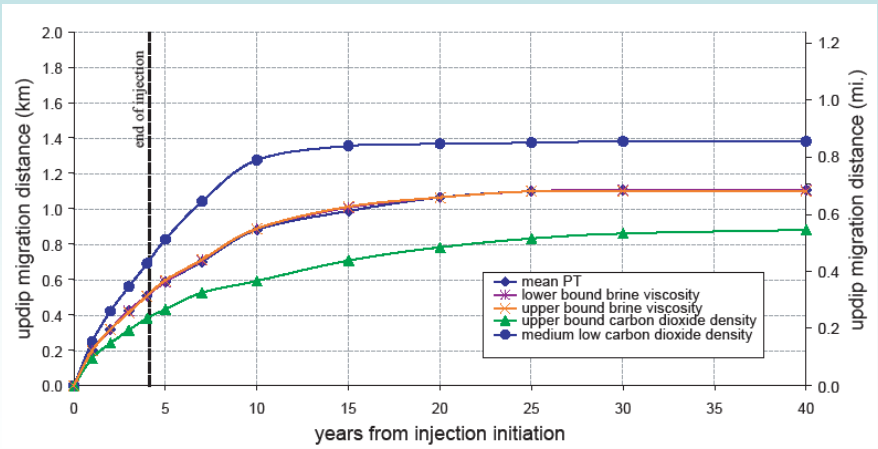
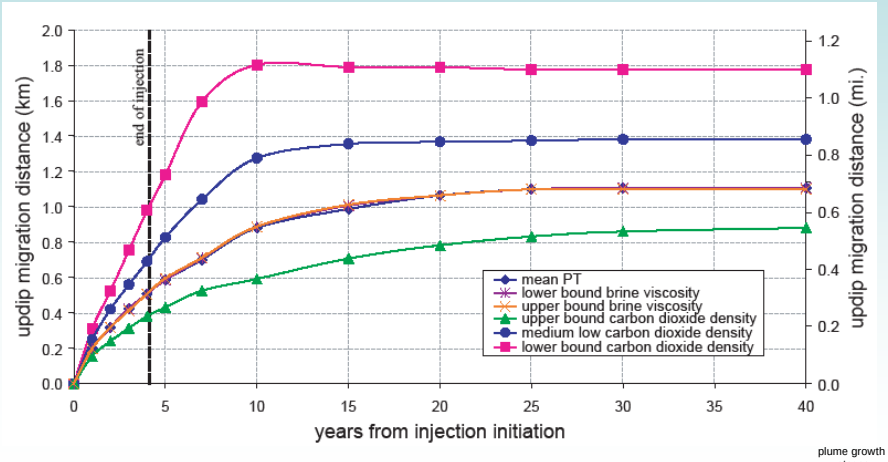


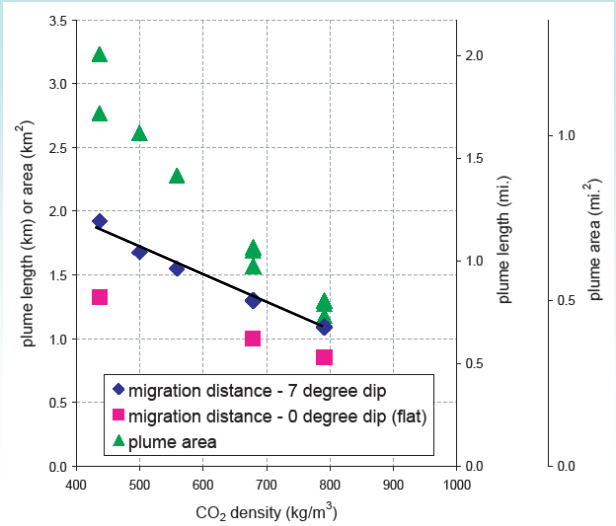
Kimberlina Plume Migration – Dipping Case



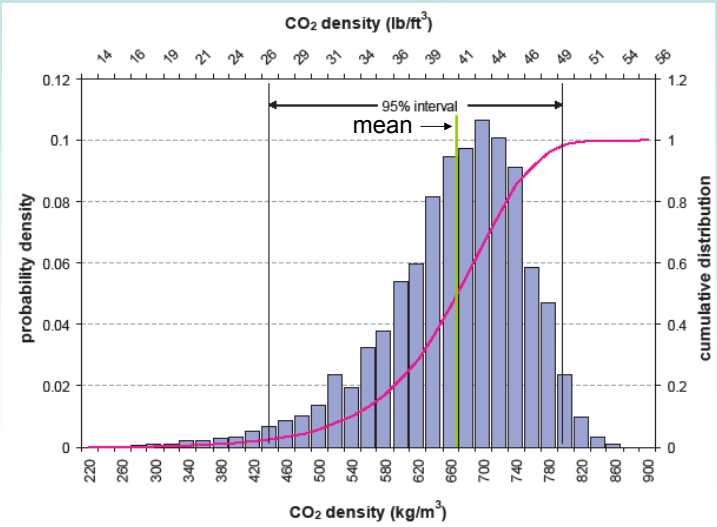
plume growth stages

horizontal plume

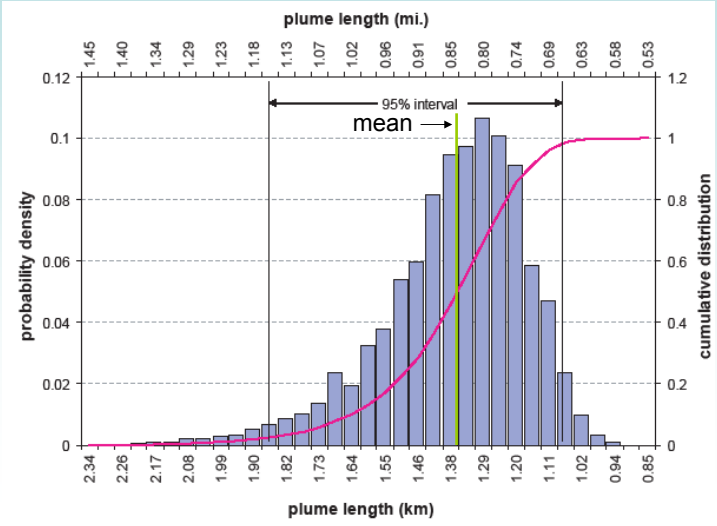
CO_2 Migration Versus Density



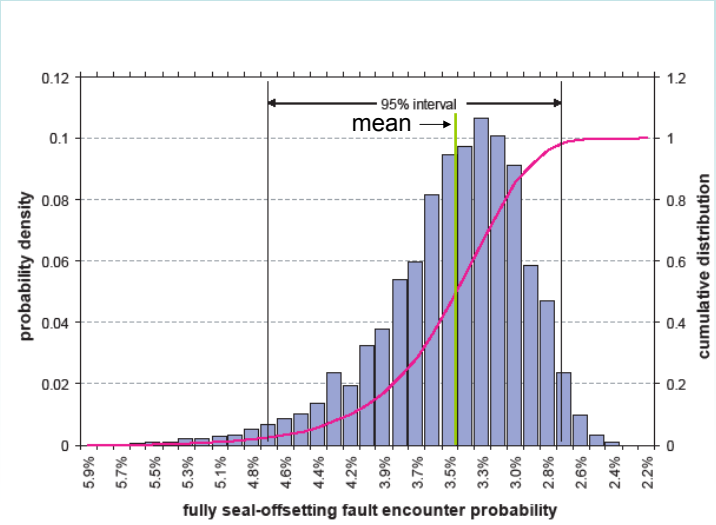
CO_2 Density Probability Distribution



Plume Length Probability Distribution



Containment Zone Offsetting Fault Encounter Probability Distribution



Acknowledgments

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CO_2 Capture Project

westcarb.org
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NETL
National Energy Technology Laboratory